THE DEVELOPMENT OF THE URANIUM AND NUCLEAR INDUSTRY IN SOUTH AFRICA, 1945 - 1970: A HISTORICAL STUDY

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Dissertation presented for the Degree of Doctor of Philosophy (History) at the University of Stellenbosch

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December 1995

Declaration

I, the undersigned, hereby declare that the work contained in this dissertation is my own original work and has not previously in its entirety or in part been submitted at any university for a degree.

21 · 11 · 1995

Date

SUMMARY

The story of South African uranium begins in the late 1880's when it was observed that the green fluorescence of minute crystals found in gold-bearing ore from South Africa was due to radioactivity. These were first indications that the ore contained uranium. The urgency of the Allied Nations to obtain uranium during the Second World War for the production of nuclear weapons, brought to the notice of the Combined development Trust a paper by the South African mineralogist, RA Cooper, that indicated that the South African gold reefs carried a mineral, uraninite, nearly half of which contained a compound of uranium.

In a combined effort metallurgists in South Africa, the United States, the United Kingdom and Canada discovered the most economical method to extract uranium from the gold ores of the Witwatersrand. These investigations were of great value for the advancement of chemistry and metallurgy relating to the refining of uranium for nuclear research. It was therefore realised that scientific research in South Africa should be co-ordinated and facilities be established for the training of nuclear physicists. The result was the founding of the National Physical Laboratory and the construction of the Pretoria cyclotron.

The construction of seventeen uranium extraction plants during the 1950's formed a very important part of the country's industrial activity. By 1957, twenty-six mines were producing uranium resulting in a rapid increase in uranium production. The importance of the uranium industry to the industrial and economic development of the country indicated the need to assure its future as far as possible.

The transportation of large quantities of coal from the Transvaal and Natal to the Cape indicated that a nuclear power plant could be

economical in the Western Cape area. The prospect of using South African uranium for nuclear power production set in motion investigations into nuclear energy production in South Africa. Dr AJA Roux's Atomic Energy Research and Development Programme provided for laboratories for the refining of uranium for nuclear fuel, the establishment of a nuclear research centre at Pelindaba, the acquisition of a research reactor, and facilities for nuclear reactor research and uranium enrichment experimentation.

The two major projects that were initiated in the 1960's were the Pelinduna nuclear reactor project and experimentation on Dr WL Grant's vortex tube method uranium enrichment (the Gas Cooling Project). By 1966 the vortex tube method had been proved in the laboratory. Simultaneously the Gas Cooling project as well as the Pelinduna Project required as a next step a large demonstration or pilot plant. South Africa could not afford both. A decision was taken to go ahead with the Gas Cooling Project and to shelve Pelinduna.

An Investigation Committee was appointed by the Government to assess the viability of a pilot uranium enrichment plant. Having reviewed the findings of the Committee, the Government came out in favour of the project. In July 1970, the Prime Minister announced to Parliament and foreign representatives that South Africa had mastered the complex technology of uranium enrichment and discovered a unique process. The process was a combination of the separating element using uranium hexafluoride in hydrogen as the process fluid and a new cascade technique. This was the culmination of years of experimental work by nuclear scientists and engineers.

South Africa's outstanding achievement would inevitably bring about international reaction for South Africa had not signed the 1968 Non-Proliferation Treaty.

OPSOMMING

Die verhaal van uraan in Suid-Afrika begin in die laat tagtigerjare van die neëntiende eeu toe groen fluoressensie van uiters klein kristalle waargeneem is in gouderts afkomstig uit Suid-Afrikaanse myne en dit verder bewys is dat dit deur radioaktiwiteit veroorsaak is. Dit was die eerste aanduiding dat die Suid-Afrikaanse gronderts uraan bevat.

Tydens die Tweede Wêreldoorlog het die Geallieerde Nasies dringend 'n uraanvoorraad benodig om kernwapens te vervaardig. Die aanwesigheid van uraan het onder die aandag van die Gekombineerde Ontwikkelingstrust gekom deur 'n referaat van die Suid-Afrikaanse mineraloog, RA Cooper, wat daarop gewys het dat Suid-Afrikaanse goudriwwe 'n mineraal, uraniniet, bevat waarvan amper die helfte 'n verbinding van uraan was.

In 'n gesamentlike poging het metaalkundiges in Suid-Afrika, die Verenigde State, die Verenigde Koninkryk en Kanada die mees ekonomiese metode ontdek om uraan uit gouderts van die Witwatersrand te ekstraheer. Hierdie besondere tegniese navorsing was van groot waarde vir die chemie en metaalkunde in verband met die affinering van uraan vir kernnavorsing. Daar is dus besef dat wetenskaplike navorsing in Suid-Afrika gekoördineer moes word en instellings tot stand gebring moes word vir die opleiding van kernwetenskaplikes. Die gevolg was die stigting van die Nasionale Fisiese Laboratorium en die oprigting van die Pretoria Siklotron.

Die oprigting van sewentien uraan herwinningsaanlegte gedurende die jare vyftig het 'n baie belangrike deel uitgemaak van die land se industriële werksaamhede. Teen 1957 het ses-en-twintig myne uraan geproduseer wat tot 'n indrukwekkende toename in die totale uraanproduksie gelei het. Die belangrikheid van die uraanbedryf en die

ekonomiese ontwikkeling wat dit meegebring het, het dit wenslik gemaak dat die toekoms van die bedryf waar moontlik verseker moes word.

Die groot hoeveelhede steenkool wat vanaf die Transvaal en Natal na die Kaap vervoer moes word, het aangedui dat 'n kernkragsentrale in die Wes-Kaapgebied waarskynlik ekonomies gevestig kan word. Die moontlikheid dat Suid-Afrikaanse uraan vir kernreaktor kragopwekking gebruik kan word het ondersoeke na kernenergie produksie in Suid-Afrika aan die gang gesit. Dr AJA Roux se Atoomenergie Navorsing- en Ontwikkelingsprogram het voorsiening gemaak vir laboratoriums vir die affinering van uraan vir kernbrandstof, die daarstellling van 'n kernnavorsingssentrum by Pelindaba, die aankoop van 'n navorsingsreaktor en fasiliteite vir kernreaktor- en uraanverrykingsnavorsing.

Die twee belangrikste projekte wat in die sestigerjare onderneem is, was die Pelinduna kernreaktor en proefnemings volgens dr WL Grant se draaikolkbuismetode van uraanverryking (die Gasverkoelingsprojek). Teen 1966 is die draaikolkbuismetode in die laboratorium bewys. Hierdie genoemde projekte het as 'n volgende fase die aanbou van 'n loodsaanleg om die projekte op nywerheidsskaal te bewys, benodig. Suid-Afrika kon nie albei aanlegte bekostig nie en 'n besluit is geneem om die Pelinduna-projek te staak en voorkeur te gee aan die voortsetting van die Gasverkoelingsprojek.

'n Komitee van Ondersoek is deur die regering aangestel om die lewensvatbaarheid van 'n uraanverrykingsloodsaanleg te ondersoek. Nadat die bevindinge van die Komitee oorweeg is, het die regering die oprigting van die loodsaanleg goedgekeur. In Julie 1970 het die Suid-Afrikaanse Eerste Minister in die Parlement en aan die buiteland aangekondig dat Suid-Afrika die ingewikkelde tegnologie van uraanverryking bemeester het en 'n unieke proses ontdek het. Die proses was 'n kombinasie van die skeidingselement, met die gebruik van uraanheksafluoried en waterstof as die draergas en 'n nuwe kaskade metode. Dit was die hoogtepunt van jarelange proefneming deur kernwetenskaplikes en ingenieurs.

Suid-Afrika se merkwaardige prestasie sou noodwendig internasionale reaksie uitlok, want Suid-Afrika het nie die Kernsperverdrag in 1968 onderteken nie.

ACKNOWLEDGEMENTS

I would like to thank the following persons who contributed to the accomplishment of this dissertation:

- Dr WE Stumpf, Chief Executive of the Atomic Energy Corporation, for making available certain documents (classified in 1991) at the Atomic Energy Corporation and the AEC Library, for historical dissertation purposes.

- Dr WL Grant for his historical informative interviews and for giving me the opportunity to research such a significant aspect of South African contemporary history.

- Dr DM Kemp, who was given the arduous task of reviewing the documentation for declassification at the Atomic Energy Corporation. Without his endeavours this history would not have been so comprehensive.

- for their interviews:

  Mr IFA de Villiers
  The late Dr JWL de Villiers
  Dr SJ du Toit
  The late Professor PC Haarhoff
  Dr RS Loubser
  Mr DB Sole
  Dr JJ Wannenburg

- for their interviews/correspondence as well as literature from their personal libraries:

  Dr PJ Hugo
  Dr DM Kemp
  Mr J Levin

Dr D Reitmann
Dr DP Toens
Dr JW von Backström

- Former Prime Minister, Mr PW Botha, (though not directly involved with the history up to 1970), for comments on a few general aspects of the history.

- Professor DJ van Zyl, the promotor of this dissertation for his advice and counsel throughout the investigations and writing of the script.

- Dr D Reitmann for accepting the position of co-promotor of this thesis and for checking the technical aspects of the text.

- Prof PH Kapp for having thoroughly reviewed the dissertation and providing constructive criticism.

- Professor DG Kröger for suggesting that this history be written as well as his informative comments on aspects of the subject.

- Personnel of the South African Library, Cape Town; Mr A Kok (Library, Atomic Energy Corporation); Mr Charles Scorer (NUFCOR); Mr LS Snyders (Atomic Energy Corporation); Mr U Kröger (Industrial Development Corporation); Mrs P Hayward (Library, MINTEK); the late Mrs I Viljoen (typist) and Mrs M Brown (word processor).

- My husband, Dr PMC Janson and sons, Johann, Karl, Jacques and Michael for their love and support throughout the many years of study.

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CONTENTS

PREFACE

The dramatic disclosure by President FW de Klerk in Parliament on March 25, 1993 revealed that South Africa had manufactured six powerful nuclear devices at a cost of R800 million. These were capable of being speedily converted into airborne bombs or missile warheads. The decision to go nuclear and to develop this limited capability was taken in 1974 against the background of a Soviet expansionist threat in Southern Africa. The build-up of the Cuban forces in Angola from 1975 onwards reinforced the perception that a deterrent was necessary in the context of South Africa's growing international isolation. The South African uranium enrichment project to enrich uranium to two and four percent would provide fuel for South Africa's nuclear programme. The President made known that the Government was prepared to throw open all facilities and records relating to its decommissioned nuclear deterrent programme to inspection by the International Atomic Energy Agency.[1]

These disclosures by President De Klerk brought into focus a ramification of the development of South African nuclear science that up to now has not been researched historically. This history, because of its sensitive nature, has virtually remained a closed book to the public except for a few persons directly involved with the history and some with a special interest in the subject.

The purpose of this dissertation was to trace the inception of South African nuclear development and particularly to establish its relationship to the South African uranium history. In order to discover the fundamentals of nuclear energy the early history of the atom and uranium was reviewed and constitutes an introduction to the history of South African nuclear development. Progress made in science created

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1 **The Argus**: 25 March 1993, "How South Africa's N-secrets were Unveiled. FW de Klerk's speech: The Full Text".

new demands for metals which were once mere laboratory curiosities. Uranium, for example, was a relatively useless metal until nuclear fission was discovered in 1938. In order to determine the destructive power of uranium during the Second World War the development of the atomic bomb was traced. During the middle forties, minds, materials, machines and money were organised into an Allied nations assembly line to transform the laboratory discovery of uranium fission in 1938 into the atomic bomb of 1945. The destructive power of uranium brought man face to face with the reality that his endeavour to progress could lead to his own destruction. The extent of international nuclear cognisance during the 1940's was looked into in order to discover exactly how far nuclear research had progressed before the discovery of South African uranium.

In this way the strategic importance of uranium was determined and indicated the urgency for obtaining uranium. This would have direct bearing on the USA and Britain jointly sponsoring worldwide prospecting programmes; the discovery and extracting of uranium from low-grade ores of the Witwatersrand during the post Second World War years and the development of the South African uranium industry.

To determine the forces leading to the establishment of the uranium and nuclear industries in South Africa the dissertation commences with the explosion of the first atomic bombs in 1945 and the first radiometric examination of the Witwatersrand uranium ores by Professor George W Bain of Amherst College, Massachusetts. Because of these events and the growing international interest in the development of the uranium and nuclear industries, South Africans were becoming increasingly aware of the nuclear advancements that had taken place overseas and it was realised that South African scientific research should be coordinated. As a result efforts were made to establish facilities for the training of nuclear scientists and engineers, an aspect that is investigated in this dissertation.

In order to establish to what degree the uranium industry was linked to the development of nuclear science in South Africa the following themes were researched: To what degree did the Second World War and the development of the atomic bomb lead to the discovery that South African gold ores hosted uranium; what role did the urgent need of foreign countries to obtain uranium internationally result in South Africa developing an imposing uranium industry; and, what was the foreign trade value of South African uranium and how would this effect nuclear development. Themes that formed the basis of this research were the establishment of the National Physical Laboratory, the construction of the Pretoria cyclotron by South African physicists and industry and the planning of a South African Atomic Energy Research and Development Programme.

The uranium industry in South Africa remained closely linked to the development of nuclear science. The following themes which have been studied will illustrate this: The Second World War and the development of the atomic bomb led directly to the discovery that South African gold ores hosted uranium and the geological investigations that followed revealed South Africa's extensive uranium reserves. The exploitation of South African uranium brought about that by 1957 twenty-six gold mines were producing uranium. In 1958 the foreign trade value of uranium reached the £50 million mark and the production of uranium oxide rose to 5 813 906 kg in 1960. South Africa's established uranium industry and large reserves instigated nuclear scientists to develop the industry further and to refine uranium for nuclear fuel and nuclear reactor research. The execution of the Programme for Research and Development at Pelindaba brought into being facilities for the refining of uranium and laboratories for nuclear reactor research and nuclear fuel experimentation.

In order to determine the dimensions of the South African nuclear research and development programme and the extent of the research done at Pelindaba during the 1960's the accomplishments were investigated; also the refining of uranium and the setting up of SAFARI I research reactor. Nuclear power reactor experimentation and the PELINDUNA critical assembly reaching criticality was significant. It was however, the separation of the isotopes of uranium by a method developed by South African nuclear scientists and engineers that constitutes the point of highest attainment of the research featured in this dissertation. This was a tremendous scientific achievement for a country like South Africa with limited industrial capabilities. In 1970, only the USA, Britain and France had mastered the sophisticated and highly complex technology of uranium enrichment.

The detailed history is concluded in 1970 when South Africa's uranium enrichment process had been proved in the laboratory and a pilot plant was to be constructed to test the process on a larger scale. Significant developments in the period 1970-1995 that were the direct result of this history, are mentioned in the final chapter.

In the dissertation attention is also given to the cardinal roles played by specific institutions and persons, including the Government Metallurgical Laboratory; the National Physics Laboratory (a research laboratory of the CSIR) and later the National Centre for Fundamental Nuclear Physics Research and Education; the Chamber of Mines, the gold mines producing uranium and particularly the mines that were the pioneers of uranium production, namely Blyvooruitzicht, Daggafontein, Western Deep and West Rand Consolidated, the South African Atomic Energy Board and ESCOM. The cardinal role played by prominent people in the establishment and development of the uranium and nuclear industries were investigated. These persons included General JC Smuts, Dr SJ du Toit, Dr AJA Roux, Dr HJ van Eck, Dr WL Grant and the leaders of government connected with South African nuclear development decision making, particularly Dr DF Malan, Dr HF Verwoerd and BJ Vorster.

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In 1989 when I embarked on this research all documentation on uranium enrichment was classified. Dr WL Grant was of the opinion that the work "Uraanverryking in die Republiek van Suid-Afrika" that he personally commissioned Professor HL de Waal to write (based directly on Grant's personal diary) should be declassified and made available for research purposes. It was only in 1991 that this document that was locked in Dr Grant's study at Valindaba was declassified and could be reviewed. Chapter 8 is largely based on information taken from this source as well as the informative interviews with nuclear scientists and engineers, who, according to Dr Grant, made significant contributions to the development of the South African enrichment process.

A number of articles on uranium and nuclear energy in South Africa have been published from time to time in journals, magazines and periodicals during the period 1948 to 1970. Of particular significance were articles written by persons directly concerned with the story of uranium. These include articles by Dr SJ du Toit, DAV Fischer, Dr RB Hagart, CS McLean, Dr SM Naudé, Dr AJA Roux, Dr BF Schonland, DB Sole, Prof L Taverner, Dr PD Toens and Dr JW von Backström.

Information in Government publications such as Assembly Debates, 1945-1970, Acts of Parliament 1948-1970 and Reports of Committees on nuclear power production in South Africa revealed significant historical information on the subject and large sections of the dissertation have been based on these primary sources.

AR Newby-Fraser's book, **Chain Reaction**, which deals with sections of this history was an important source. The book may be regarded as a primary source as Newby-Fraser was directly involved with heavy-water production in South Africa and with selecting a location for the nuclear centre Pelindaba.

Because of the sensitive nature of this subject all primary documents relating to this history could not be examined. However, Dr WE Stumpf, Chief Executive of the Atomic Energy Corporation made available certain documents in the AEC archives. The dissertation has therefore been based mainly on these documents and unclassified documents available at the Atomic Energy Corporation at Pelindaba.

Little is known of the laborious effort of hundreds of nuclear scientists, nuclear engineers, mathematicians, technicians and construction engineers at Pelindaba and Valindaba. Because of security precautions scientists could not publish their discoveries in scientific journals. This dissertation can only acknowledge the accomplishments of a few prominent people.

Interviews with prominent scientists that participated in the establishment of the South African uranium and nuclear industries during the period concerned contributed largely to filling in the information unavailable in documentation and enabling the writer to produce a clearer account of the history of uranium in South Africa.

Certain sections of the text were reviewed by persons directly involved with that particular part of the history. These were: AR Newby-Fraser (heavy water production on South Africa); Dr D Reitmann (particularly the history of the National Physical Laboratory and the Pretoria Cyclotron, but also the history in its entirety as co-promotor of the dissertation); Dr JW von Backström (geological background to the uranium industry); and Dr JJ Wannenburg (X-project).

The history of uranium, because of the refined mineral's high strategic value is also political history. This history has therefore been placed in political and international perspective. South Africa's position in world politics and the realisation that it would have to protect its vital national interests against an increasingly hostile world, would also determine the course of nuclear energy development in South Africa. International relations linked to the South African uranium and nuclear industries have largely been based on works by DB Sole and AR Newby-Fraser and interviews with Drs RS Loubser and WL Grant, DB Sole and IFA de Villiers.

Strict security precautions were placed by the South African Government and the Atomic Energy authorities on all uranium research during the 1940's and the first half of the fifties because of the material's strategic value. These precautions were intensified after 1960. Certain documents relating to aspects mentioned in the dissertation could not be examined. This refers specifically to the minutes of the meetings of the Uranium Research Committee which could not be located. The minutes of the meetings of the Research Advisory Committee (a sub-committee of the Atomic Energy Board) could not be made available by the Atomic Energy Corporation. The highly classified Report of the Investigation Committee on Uranium Enrichment could not be obtained from the Department of Internal Affairs. Statistics on the foreign trade value of uranium after 1965 are classified.

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Certain problems relating to technical information in the text should be mentioned. Firstly, in the period 1945-1970 South Africa changed currency. In the 1950's the monetary unit in South Africa was the South African pound sterling. The value of South African natural uranium (sold as uranium oxide) prior to 1960 is given in this unit. However, during 1960 South Africa adopted a decimal currency. Therefore, values of uranium in the 1960's are given in rand. The nominal international uranium market price is generally quoted in dollars. According to Dr RB Hagart (a former Joint Deputy Chairman, Anglo American Corporation) in 1957 the value of uranium in dollars compared to the South African pound was a follows: The international price of uranium taken at $10 or $11 per pound of uranium would be 70 shillings or 80 shillings respectively. The price that the Combined Development Agency was prepared to pay for uranium in the early sixties was $8 a pound (approximately 56 South African shillings or R5.60 in the new currency). The rate of conversion from pound to rand in the sixties was approximately £1 = R2.

Secondly, scientific and technical words, concepts, formulas and processes in the dissertation would be unfamiliar to the average reader. Therefore, where possible, these words, concepts, formulas and processes have been reduced in the text. Scientific and technical terms etc. that are mentioned have been tabulated in the "Technical Addendum" and an explanation of these is given in nonspecialists words and idiom. In the text scientific and technical terms used for the first time are indicated with an asterisk (*).

Abbreviations for organizations and institutions are frequently used. However, where these organizations and institutions are mentioned for the first time the names are given fully. In order to make it easier for the reader a full list of abbreviations is given at the beginning of the dissertation.

According to McGraw-Hill: **Dictionary of Scientific and Technical Terms**, "nuclear" and "atomic" are synonyms. In the dissertation these words are used as alternative forms. "Atomic" is historically the oldest form as used in "Atomic Energy Board" and "Proposed Atomic Energy Research and Development Programme". In the course of time the word "nuclear" has nationally and internationally become the new and most commonly used form.

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ABBREVIATIONS

AEB	Atomic Energy Board (South Africa)
AEC	Atomic Energy Commission (United States) (USAEC)
AEC	Atomic Energy Corporation (South Africa)
AECL	Atomic Energy of Canada Limited
AERE	Atomic Energy Research Establishment (Harwell, Berkshire, United Kingdom)
ADU	Ammonium diuranate
BWR	Boiling water reactor
CCDA	Conference of the Committee of Disarmament
CDA	Combined Development Agency
CEA	Commissariat a'l'Energie Atomique (France)
CSIR	Council for Scientific and Industrial Research
EBR	Experimental Breeder Reactor
EEC	European Economic Community
ENDO	Eighteen Nation Disarmament Committee
ERP	European Recovery Programme
ESCOM	Electricity Supply Commission
ESKOM	Electricity Supply Commission
EURATOM	European Atomic Energy Community
ex libris	from the library of
FCI	Federated Chamber of Industries
FOSCOR	Phosphate Development Corporation
GCP	Gas Cooling Project
GML	Government Metallurgical Laboratory (April 1944-March 1966 - formerly the Minerals Research Laboratory)
GVP	Gasverkoelingsprojek
H-bomb	hydrogen bomb
IAEA	International Atomic Energy Agency
IDC	Industrial Development Corporation
IFA	(Norwegian) Institute for Atomic Energy
ISCOR	(South African) Iron and Steel Corporation
ISNSE	International School of Nuclear Science and Engineering (United States)
JCMMS	Journal of the Chemical, Metallurgical and Mining Society (South Africa)
JENER	Joint Netherlands-Norwegian Research Institute
JSAIMM	Journal of the South African Institute fir Mining and Metallurgy
JSAIE	Journal of the South African Institution of Engineers
kWh	kilowatt-hour
kW	kilowatt
kV, KeV	kilovolt
lb	pound
Ma	million years
MeV	megavolt
MINTEK	Council for Mineral Technology (November 1981 - formerly the National Institute for Metallurgy)
MIT	Massachusetts Institute of Technology
MRL	Minerals Research Laboratory (July 1934 - March 1944)

MV	megavolt
MW	megawatt
NAC	National Accelerator Centre
NASA	National Aeronautics and Space Administration
NIM	National Institute for Metallurgy (April 1966 - Oct 1981 - formerly the Government Metallurgical Laboratory)
NP	National Party
NPL	National Physical Laboratory
NPT	Nuclear Non-Proliferation Treaty
NTBT	Nuclear Test Ban Treaty
NUFCOR	Nuclear Fuels Corporation of South Africa
NVS	Nasionale Versnellersentrum
OEEC	Organization for European Economic Co-operation
OPEC	Organization of Petroleum Exporting Countries
ORR	Oak Ridge (National Laboratory, USA) Research Reactor
PELINDUNA	South African Power Reactor Concept
PWR	Pressurised Water Reactor
RCN	Reactor Centrum Nederland
SAFARI I	South African Fundamental Atomic Reactor Installation ("1" indicates that it was the first research reactor)
SALT	Strategic Arms Limitation Talks
SAMEJ	South African Mining and Engineering Journal
SASOL	South African Coal, Oil and Gas Corporation
SUNI	Southern Universities Nuclear Institute
T	tesla (the international magnetic field unit of measurement)
tU	tonnes uranium
U	uranium metal
U-234	uranium isotope 234
U-235	uranium isotope 235
U-238	uranium isotope 238
U_3O_8	uranium oxide
UO_4	uranium tetrafluoride
UF_6	uranium hexafluoride
UCOR	Uranium Enrichment Corporation of South Africa
UKAEA	United Kingdom Atomic Energy Association
UNAEC	United Nations Atomic Energy Commission
UNO	United Nations Organization
URENCO	Combined (Commercial) Uranium Enrichment Company (United Kingdom, Germany and Holland)
USAEC	United States Atomic Energy Commission
USSR	United Soviet Socialist Republic
VECOR	Van der Byl Engineering Corporation
WNNR	Wetenskaplike en Nywerheids Navorsingsraad
X-project	Code name for the experimental phase of the South African uranium enrichment project
XYZ-project	Code name for the whole South African uranium enrichment project (Gas Cooling Project)
Y project or Project Y	Code name for group that was to design the actual atomic weapon in the Manhattan Project
Y-project	Code name for the pilot enrichment plant development of the South African uranium enrichment project
Z-project	Code name for the semi-commercial plant development of the South African uranium enrichment project.

ILLUSTRATIONS

CHAPTER ONE

THE EARLY HISTORY OF URANIUM AND THE ATOM

Like all the uranium deposits of the globe, South African uranium is distinctly time-bound. It would be the discovery of the radioactivity* of uranium at the close of the nineteenth century that would urge physicists to question the indestructibility of the atom.* While momentous achievements were being made in early nuclear science in Europe, the gold mines of the Witwatersrand were developing and yielding a wealth of gold - also unknowingly - preparing the way for the South African uranium industry.*

Uranium deposits and their time bound characteristics

Uranium is extremely widespread in small quantities (a few parts per million) in most of the igneous rocks particularly those of granitic composition, and in some sedimentary rocks.[1] The sea also contains minute quantities of uranium uneconomic to recover. Granites do not normally exhibit economic concentrations of uranium. The study of uranium occurrences suggests that the ultimate origin of uranium is associated with depths where magmas* originated. Further evidence in support of a deep ultimate origin are thermal springs,* geysers* and volcanic emanations with uranium content. There are certain well-defined uranium provinces.*[2]

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1 Igneous rocks: produced by solidification of the earth's internal molten magma. Granite: a coarse-grained igneous crystalline rock composed mainly of quartz, felspar and mica. Sedimentary rocks: rocks formed by accumulation and deposition of fragmentary materials derived from pre-existing rocks.

2 BB Brock, LT Nel and DJL Visser: "The Geological Background of the Uranium Industry", **Uranium in South Africa, 1946-1956**, p. 276.

The United Nations Symposium on "Peaceful Uses of Atomic Energy", Vol. VI (1955) recognizes seven principal uranium provinces: The Rim of the Canadian Shield, the Colorado Plateau (USA), Urgeirica (Portugal), Le Massif Central (France), Joachimstal (Czechoslovakia), Ferghana (Pan African Belt) and Southern Africa. India and the east coast of Brazil are classed as thorium provinces* containing uranium. Occurrences of uranium in Brazil, Argentine and Australia and others may qualify as provinces. Observations done in uranium provinces show that uranium deposits of varied types, tend to appear over an immense range of geological time.[3]

The distribution of the uranium provinces has more meaning when considered in relation to "shield" and "table" areas of the earth's surface. A shield is the ancient nucleus of a continent and uranium deposits are not likely to be found in the heart of a shield area. A table area is also a rigid sector of the earth's crust. Uranium sources are to some extent localised. For example, the Colorado Plateau uranium province lies on the edge of the North American Table. Joachimstal lies on the edge of the buried Russian Table. The Massif Central in France and Urgeirica (Portugal) constitute "outliers" of ancient rocks in rather disturbed areas of the earth's surface. All of Africa, south of the Atlas, is regarded as a shield area. Here the generalisation that uranium cannot be found in the heart of a shield must be modified. The African Shield has been subdivided into units, and along the "sutures" between units conditions may be found equivalent to the edge of smaller continental shields or tables. Chinkolobwe in the Belgian Congo[4] and Mindola in Zambia occupy one such "suture".[5]

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3 BB Brock, LT Nel and DJL Visser: "The Geological Background of the Uranium Industry", **Uranium in South Africa, 1946-1956,** p. 276; PD Toens: "Uranium Deposits and their Time Bound Characteristics", **Transactions of the Geological Society of South Africa**, 84, 1981, p. 299.

4 The name of the Belgian Congo changed to Zaire after independence on 30 June 1960.

5 **Ibid.,** pp. 276-277.

Uranium is estimated to be present in the Earth's crust to the extent of about four parts per 1 000 000. It is thus considerably more abundant than gold and silver. It never occurs uncombined in Nature. It is distributed in minute quantities nearly everywhere on land and sea. Compounds of uranium are present in rocks of varying composition and origin. The actual concentration of uranium in most of these ores is low, however, and ore bodies suitable for economic mining are rare. Concentrations of suitable ores may have occurred when uranium-rich compounds were exuded into rock faults after the molten uranium silicates* in the Earth's crust had crystallized. Later the rock weathered, leaving deposits of the more chemically unreactive uranium minerals. Other uranium minerals may have been taken into aqueous solution, transported, and subsequently precipitated as oxides* after reacting with other minerals.[6]

The two main categories of uranium are primary and secondary. Primary, relatively unoxidized uranium minerals of particular importance are uraninite* (a crystalline uranium form that is 45 - 48 % uranium) and its friable or massive variety, pitchblende*; coffinite* (60 % uranium); brannerite* (30 - 40 % uranium) and davidite* (7 - 10 % uranium). Important secondary, oxidized uranium minerals are carnotite,* autunite* and torbernite*. More than a hundred uranium-bearing minerals have been described, but the majority of these occur so sparsely that they are of little or of no economic importance. Uranium is a dense, hard, but malleable metallic element. It is radioactive, nickel-white with the heaviest atomic weight of any naturally occurring element.

6 PD Toens: "Uranium Deposits and their Time Bound Characteristics", **Transactions of the Geological Society of South Africa,** 84, 1981, pp. 295-297.

Pegmatite* deposits form a third category. None of the known pegmatite occurrences of uranium-bearing minerals are of any importance as a source of uranium.[7]

Primary deposits are recognised by the form in which they occur: (1) vein deposits (typified by Great Bear lake, Joachimstal and Chinkolobwe); (2) pegmatite dykes (primary uranium minerals, sparsely distributed as isolated crystals or in small nests or pockets scattered throughout the rock); (3) in migmatites and shear zones (as at Radium Hill, Australia). Vein deposits such as Joachimstal, Chinkolobwe and Great Bear Lake were responsible for the earliest production. Vein deposits, unless unusually rich or large, do not constitute a large portion of the world's resources. In fact they can hardly compete with the large lower grade bodies represented by the sedimentary deposits. True vein deposits carrying uranium are unknown in South Africa. Secondary or sedimentary deposits such as Colorado Plateau (USA), Blind River (Canada) and the Witwatersrand more than make up for their lower grade by cheaper, large scale exploitations. South Africa is particularly fortunate in that her uranium is to a large extent a by-product of gold.[8]

Uranium mineralization is present in rocks which encompass almost the whole of the geological history of South Africa.[9]

The Atom

For 2 400 years, from the fifth century BC to the end of the nineteenth century, science believed that all matter was composed of stable and

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7 JW von Backström: "Uranium", **Mineral Resources of the Republic of South Africa**, p. 238.

8 BB Brock, LT Nel and DJL Visser: "The Geological Background of the Uranium industry", **Uranium in South Africa, 1946-1956**, p. 279.

9 HJ Brynard et al: **Uranium in South Africa**, p. 7.

indestructible particles called atoms. The atomic theory of matter, unsupported by any evidence, was first propounded by the Greek philosopher, Democritus (c 460 BC - 370 BC). To account for the world's changing physical phenomena, he asserted that space (or the Void) had an equal right with Being (i.e. the physical world) to be considered existent. The Void, Democritus conceived as a vacuum, an infinite space in which moved an infinite number of atoms that made up Being. These atoms are eternal and indivisible. They are absolutely small, so small that their size cannot be diminished. Hence the name "atomon" or "indivisible".[10] The Greek philosopher Epicurius (c 300 BC) supported this theory. However it was not accepted by many other important philosophers. Aristotle (384 BC - 322 BC) rejected Democritus' theory in favour of the view that all matter was composed of different combinations of the four elements - earth, water, air and fire. This concept displaced the atomic theories and formed the basis of alchemy*, the study of matter that dominated science until the seventeenth century.

Alchemy was widely practised in Arabia, China and Renaissance Europe. Two of its main objectives were to find a way of turning a base metal, such as lead, into gold and to find an "elixir of life". Alchemy was supported by religious leaders of the time, whereas atomic theories with their applied atheism were suppressed by Jewish and Christian teachers. Many earlier texts survived however, including the **De Rerum Natura** (On the Nature of Things) written in the first century BC by the Roman poet Lucretius. In the first half of this six-volume poem, Lucretius described and defended the theories of Epicurius.

De Rerum Natura was used as a source of reference by several seventeenth and eighteenth century philosophers.[11] At the beginning of

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10 TI Williams (ed): **A Biographical Dictionary of Scientists,** pp. 165-166.

11 **The Marshall Cavendish Illustrated Encyclopaedia of Science and Technology**, 1979 edition, pp. 12-13.

the nineteenth century John Dalton (1766-1844) produced the first atomic theory. From his study of gases he came to the conclusion that elements* are made up of smaller particles called atoms and that chemical compounds of the elements are formed by the union of these atoms in simple numerical proportion.[12]

Uranium and the Advancement of Nuclear Science 1895 - 1939

The discovery of the element uranium is usually attributed to the German, Martin Heinrich Klaproth (1743-1817), a Berlin apothecary and an outstanding analytical chemist. He described it in a lecture to the Royal Prussian Academy of Science in 1789. Klaproth found the uranium in pitchblende, which he obtained from the cobalt-silver* mines at Joachimstal in Bohemia (now Jáchymov, Czechoslovakia). Pitchblende was a by-product of the cobalt-silver workings. Mineralogists of his time had tended to classify the mineral pitchblende as an ore of zinc.* Klaproth processed the mineral. He found that by dissolving pitchblende in aqua regia and then adding an alkali* to the cold solution, a yellow oxide was obtained. This was an oxide or mixture of oxides of a hitherto unidentified element. He named the substance uranit. A year later Klaproth changed the name from uranit to uranium after the planet Uranus which had been discovered by Sir Frederick William Herschel (1738-1822), an English astronomer, eight years earlier (1781). It was the eighteenth element to be identified out of the ninety-two known to-day to exist in their natural state. It was not until about half a century later that uranium metal was isolated from its salts.* This was achieved by the French chemist Eugène-Melchior Peligot in 1841. He passed chlorine over heated "uranium", studied the products of the reaction, and found that the "uranium" he used was an oxide. Peligot then heated uranium chloride with metallic sodium and dry potassium chloride in a platinum crucible. The potassium

12 TI Williams (ed): **A Biographical Dictionary of Scientists,** pp.127-129.

chloride dissolved away, leaving a black powder that was truly the element uranium. This method, with modifications, has been used since that time.[13]

Uranium was known for a hundred-and-fifty years before any serious application could be found for it. It is estimated that over the period 1850-1900 the world's annual production of uranium oxide was about three tons, derived mainly as a by-product from cobalt-silver workings at Joachimstal in Bohemia. Because of the canary-yellow colour of the oxide, its main use during this period was in the ceramic industry.[14]

The discovery of radioactivity and particularly the radioactivity of uranium made physicists question the indestructibility of the atom. In December 1895 Wilhelm Konrad von Röntgen (1845-1923), a German physicist, discovered that when an electric current passed through a vacuum tube, the tube emitted rays which could penetrate bodies opaque to ordinary light.[15] Henry Becquerel (1852-1908) of the University of Paris undertook a systematic investigation to ascertain whether fluorescent* substances emitted invisible rays similar to Röntgen rays*. The results were negative until he placed uranium compounds* on a photographic plate. The uranium compounds would fog the photographic plate, even though it had not been exposed to light. Becquerel believed that the uranium compound produced rays that could penetrate the wrapping of the plate. He had discovered the phenomenon of radioactivity in uranium (1896).

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13 TI Williams (ed): **A Biographical Dictionary of Scientists,** pp. 292-293; CS McClean: "The Uranium Industry of South Africa", **JCMMS,** 54, April 1954, p. 345; Norman Moss: **The Politics of Uranium**, p. 5.

14 "Story of Uranium Production in South Africa", **Mining Survey**, 4(3) March 1953, p. 11; SH Haughton: "Uranium in South Africa", **Coal**, 2(7) Sept. 1954, p. 47.

15 TI Williams (ed): **A Biographical Dictionary of Scientists,** pp. 448-449; More particularly they could pass through the flesh of a human body and throw a shadow of the bones on a suitable screen; JW Kane and MM Sternheim: **Physics**, p. 745.

Marie Curie (1867-1934) and Pierre Curie (1859-1906) were two French physicists who began to study this new phenomenon. Marie Curie made a thorough study of Bequerel's experiments. She wanted to know whether other metals produced rays. She found that the radioactivity of a sample of pitchblende was particularly marked.[16] From sackfuls of pitchblende, and after many years of investigation, they obtained a small amount of radium* (1898). Radium was found to be extremely radioactive.

Ernest Rutherford (1871-1937) and Frederick Soddy (1877-1956), British physicists, investigated three groups of radioactive elements at the turn of the century. The elements were radium, thorium and actinium.* They concluded in 1902 that radioactivity was a process in which atoms of one element spontaneously disintegrated into atoms of an entirely different element, which also remained radioactive. This could also apply to the element uranium. Following the Curies' isolation of radium from pitchblende in 1898, production of uranium ores rose somewhat during the next twenty years (1900-1920) to an annual average of about one hundred tons.[17] Radium and Röntgen rays held the world stage then and the uranium ores, after giving up their pittances of radium, were discarded in the waste piles. Uranium retained some value as it was necessary for the production of chemicals and it was still used by the ceramic industry.

Among physicists, the discovery of radioactivity opened the way to the exploration of the nucleus of the atom. The stage was now set for new developments that were to shatter the age-old theory of indestructible atoms. This interpretation was opposed by many chemists who held firmly to the concept of the indestructibility of matter, the suggestion that some atoms could tear themselves apart to form entirely different

16 TI Williams (ed): **A Biographical Dictionary of Scientists,** pp. 122-123, p. 41; JW Kane and MM Sternheim: **Physics**, p. 745.

17 TI Williams (ed): **A Biographical Dictionary of Scientists,** pp. 455-456, 482; SH Haughton: "Uranium in South Africa", **Coal**, 2(7) Sept. 1954, p. 47; JW Kane and MM Sternheim: **Physics**, p. 746.

kinds of matter was to them a remnant of medieval alchemy. Investigations of the structure of atoms themselves began in the late nineteenth century. In 1904 a Japanese physicist, Hautaro Nagaota, proposed the nuclear theory that each atom consisted of a central nucleus* surrounded by electrons.*[18] Experiments by Rutherford had shown unexpectedly that alpha particles* (positive particles) are scattered through large angles when fired through gold foil. Rutherford reasoned that a positive nucleus within the gold atoms deflects the particles. He concluded that the atom has a positive nucleus. In 1911 Rutherford put forward the modern theory of the atom. His atom consists of a small heavy nucleus with a positive charge, surrounded by a diffuse cloud of light negative electrons.[19] Soddy concluded in 1912 that certain elements might exist in forms that differ in atomic weight* while indistinguishable and inseparable chemically. The atoms of these elements are called isotopes.* Uranium is one of these elements. Uranium is radioactive in all its isotopes. The nuclei of uranium are unstable and break apart easily.[20]

The way radioactive elements change into other elements prompted scientists to try and change elements themselves.[21] Lord Rutherford was the first to attempt this in 1919. He succeeded in changing nitrogen* into oxygen* by bombarding nitrogen gas with a stream of alpha particles (two protons* and two neutrons*) from uranium. In their study of atoms scientists progressed to nuclear bombardment with accelerated particles. They developed machines called accelerators* - 'atom-smashers' - to do this. The general principle behind these

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18 **Encyclopaedia Britannica,** vol. 26, 15th edition, 1987, pp. 1023-1024.

19 **The Marshall Cavendish Illustrated Encyclopaedia of Science and Technology**, 1979, pp. 13-14;; JW Kane and MM Sternheim: **Physics**, p. 666.

20 TI Williams (ed): **A Biographical Dictionary of Scientists,** p. 482.

21 See Technical Addendum: "transmutation".

machines is that charged particles are accelerated by applying a powerful electric field to them so that they are strongly repelled.

In 1932 Sir John Douglas Cockroft (1897-1967), an English physicist, succeeded in bombarding the light element lithium* with protons and splitting the atom.[22] These experiments led to the accumulation of a great deal of valuable information and a clearer restatement of the structure of the nucleus. In the same year, 1932, Sir James Chadwick, an English physicist, discovered the existence of a new atomic particle. It was neither positive nor negative, but neutral, and was therefore named "neutron".[23] He bombarded beryllium* with alpha particles and obtained a "radiation"* which could knock protons out of wax (which contains a large amount of hydrogen*) with high energy. He showed that this radiation must consist of neutrons, electrically neutral particles with about the same mass as a proton. This immediately solved a long standing problem about what a nucleus is made of. Because they have no charge, neutrons are not repelled by a nucleus and can get inside quite easily even at low energies. They were therefore very useful for probing nuclei*.[24]

Physical chemists Frédéric Joliot-Curie (1900-1958) and his wife Irene (1897-1956), daughter of Marie Curie found that bombardment of elements with beta-rays* (electrons) and neutrons would produce artificial radioactive elements* not found in nature (1935). It was an extension of the method used by Frédéric Joliot-Curie and his wife Irene that led to the splitting of the atom.[25]

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22 TI Williams (ed): **A Biographical Dictionary of Scientists,** p. 109; "Story of Uranium Production in South Africa", **Mining Survey**, 4(3) March 1953, pp. 11-12.

23 JW Kane and MM Sternheim: **Physics**, p. 752.

24 TI Williams (ed): **A Biographical Dictionary of Scientists,** p. 280; **Readers' Digest Library of Modern Knowledge**, vol. 1, 1981, p. 186.

25 Using neutrons instead of alpha particles for the bombardment of nuclei. TI Williams (ed): **A Biographical Dictionary of Scientists,** pp. 279-281.

Uranium in South Africa, c. 1880-1939

While significant developments were taking place in Europe regarding uranium and nuclear energy, it became known that some gold-bearing ores of the Witwatersrand in South Africa contained uranium. Initially metallurgical investigations in South Africa were carried out by metallurgists of the early laboratories of the Witwatersrand gold mines and by the department of Metallurgy and Assaying at the University of the Witwatersrand. Uranium investigations in South Africa were done independently of those in Europe and elsewhere and it was only when the importance of uranium was discovered during the course of the Second World War that South African uranium deposits were implicated in international developments of uranium and atomic energy.

In the late 1880's Sir William Crookes (1832-1919), then Chairman of the Royal Society in London, noted the green fluorescence of minute crystals found in gold-bearing ore from South Africa. Laboratory tests subsequently showed that the fluorescence was due to radioactivity. These were the first indications that the gold deposits of the Witwatersrand hosted uranium.[26]

In the gold-mining industry of the Witwatersrand, since the very early years of its existence, there was a continuous need for research to improve its techniques. The industry had coped successfully with the major changes of technology, the most radical being the introduction of the cyanidation process* into an industry that had previously depended on physical methods for the extraction of gold. Numerous problems of a chemical and physicochemical nature had arisen, and it had become necessary to rely on chemists or metallurgists with a good training in chemistry, to cope with the problems experienced in operating the extraction plants. A considerable amount of experimental work was done on the various operating mines and, where a number of mines

26 **Uranium: South Africa's Mineral Wealth**, Public Relations Department of the Chamber of Mines and the Atomic energy Board of South Africa, p. 1.

were operated by a so-called group, it became necessary that a group laboratory be established. In the early years the main purpose of the group laboratories was to analyse incoming stores, especially coal and lime, and at some date they came to be called "group research laboratories".

Laboratories that were referred to as Consolidated Gold Fields Laboratory and the Rand Mines Laboratory were in existence in 1905, the Gold Fields Laboratory having just been established, and the Rand Mines Laboratory some time earlier. The Rand Mines Metallurgical Laboratory was for many years the most prominent of the group research laboratories.[27]

The first South African notification that the Rand gold ores contained radio-active substances dates from 1915, and is attributed to Dr AW Rogers, then Director of the Geological Survey of the Union of South Africa. On April 19, 1915, Dr Rogers delivered a paper "Notes on the Occurrence of Radio Active Minerals in South Africa", to the members of the Geological Society of South Africa. Minerals long known to mineralogists and chemists, but regarded as being of no commercial interest, were being scrutinized in South Africa once more, following the discovery of radioactive elements. One of the first hints of what was to become South Africa's multi-million rand uranium industry was a remarkable prophecy made in 1915. On July 5, 1915, commenting on this paper, the Government Mining Engineer, RN Kotze, later Sir Robert Kotze, predicted that the results obtained from radioactive elements "appear likely in the course of time to revolutionise chemistry, as well as the production of energy and, indeed, possibly the whole fabric of our present day civilization."[28]

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27 The Rand Mines Laboratory was closed down in 1973, and this brought to an end the history of the oldest metallurgical laboratory on the Witwatersrand. Jack Levin: **The Story of Mintek, 1934-1984**, pp. 8-12.

28 "How Uranium was Discovered in South Africa", **Mining Survey**, 69, Sept. 1971, p. 12.

In 1923 F Wartenweiler, then Assistant Consulting Metallurgist to the Central Mining Group of Companies, initiated an investigation into the mineral constituents of the corduroy concentrates.* This Mining Group had then decided to change from the plate amalgamation method* to the corduroy concentration method for the recovery of gold. That was a then recent innovation in the Witwatersrand metallurgical practice. The result was that the amount of concentrate collected was in excess of amalgamation barrel capacity. The concentrate obtained from the corduroys was being retreated on tables, and it was the detailed examination of these table concentrates which revealed the presence of relatively large amounts of osmiridium,* together with a radioactive mineral later identified by RA Cooper as a variety of uraninite.[29]

RA Cooper delivered his significant paper entitled "Mineral Constituents of Rand Concentrates" to the Chemical Metallurgical and Mining Society of South Africa on 20 October 1923, and it was published in the same month in the **Journal of the Chemical, Metallurgical and Mining Society of South Africa**. RA Cooper announced that a group of mines in South Africa, from the Boksburg fault, west to the Central Rand, carried a mineral known as uraninite nearly half of which consisted of a compound of uranium.[30]

Although Cooper did not foresee the possibility for the extraction of radium in future, GH Stanley[31] believed that the concentrates had potential commercial value. Cooper's identification of a heavy black mineral (uraninite) was not, as far as it has been possible to ascertain, accompanied by any attempt to determine the amount of uranium present in the original ore. According to Professor L Taverner,

29 L Taverner: "An Historical Review of the Events and Developments culminating in the construction of Plants for the Recovery of uranium from Gold Ore Residues", **JSAIMM**, 57, November 1956, p. 125.

30 "The Search for Uranium, South Africa's Position", **SAMEJ**, 58(2), 7 February 1948, p. 603; Jack Levin: **The Story of Mintek, 1934-1984**, p. 89.

31 GH Stanley was Professor of Metallurgy at the University of the Witwatersrand.

Director of the Government Metallurgical Laboratory (January 1940 - December 1958), this is understandable since the occurrence of uranium in such minute quantities could not, at that time, have been of any economic significance.[32] The paper described uraninite as having a black colour and brilliant lustre of polished jet. Cooper gave a detailed account of the composition of the concentrate. He suggested that it would be interesting to purify the uraninite by mechanical means. Probably the flotation method* would separate sulphides, arsenides and metals from the oxide - and ascertain the true constituent of the pure mineral and its radioactive value. An estimate of the value of the radium was given by Cooper.[33]

Since 1923 the gold-bearing ores of the gold mines on the Witwatersrand have been known to be a potential source of the radioactive minerals. No active steps were taken to develop these resources, because the commercial application of the radioactive minerals was then limited, and the occurrences in South Africa were generally of low grade.

During the 1920's, the State's Mines Department was concerned with the development of South Africa's mineral resources, particularly the base minerals. There was an interdepartmental committee, the Base Mineral Development Committee, which studied and advised the Mines Department on mineral resources. There were frequent suggestions from the government Mining Engineer's Department that facilities for research and experiments should be instituted to promote the exploitation of the known extensive, but low grade South African mineral deposits.[34]

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32 L. Taverner: "An Historical Review of the Events and Developments culminating in the construction of Plants for the Recovery of uranium from Gold Ore Residues", **JSAIMM**, 57, November 1956, p. 125.

33 "The Search for Uranium. South Africa's Position", **SAMEJ**, 58(2), 7 February 1948, p. 603.

34 J Levin: **The Story of Mintek, 1934-1984**, p. 6.

George Hardy Stanley believed that the State should establish such laboratory facilities and was persistent in his efforts to accomplish this. He came to South Africa having studied at London's Royal School of Mines. He joined the Transvaal Technical Institute. From 1905 he was Professor of Metallurgy and Assaying at the University of the Witwatersrand. In 1909 Stanley and Sir Robert Kotze, the Government Mining Engineer, negotiated an agreement by which Stanley received a grant of £2 200. The grant was for the equipping of an ore-testing laboratory in the new building of what was then known as the Transvaal University College. In the 1920's and 1930's Stanley submitted memoranda to the Mines Department in which he pointed out the mutual benefits of a research laboratory financed by the State, administered by the University as a component of the university.

The State wished to promote the exploitation of South Africa's base minerals. Dr Hans Pirow, the Government Mining Engineer, and HR Raikes, Principal of the University of the Witwatersrand (and a research scientist), supported the efforts of Professor Stanley, and three research institutes were established by the State and linked to the University of the Witwatersrand, but functioned independently of it. The Minerals Research Laboratory (MRL) was the first established by the government in 1934.[35]

Jack Levin, author of **The Story of Mintek**, was one of the two graduates who constituted the professional staff of the Minerals Research Laboratory when it was established in 1934. During the first two and a half years a wide range of investigations were undertaken, for example, the treatment of refractory gold ores and the recovery of vermiculite*, but as a result of the Second World War and the

35 Followed by the Bureau of Archaeology in 1935 and the Bernard Price Institute of Geophysical Research in 1937; Jack Levin: **The Story of Mintek, 1934-1984**, pp. 6-7; 16-19.

discovery of nuclear fission,* uranium research would only commence during the 1940's.[36]

36 Jack Levin: **The Story of Mintek, 1934-1984**, pp. 46-59.

CHAPTER TWO

URANIUM BECOMES A FACTOR IN INTERNATIONAL POWER POLITICS

Certain leading international physicists and chemists who were experimenting with uranium during the 1930's realised its potential destructive power. In the hands of political aggressors it could be extremely dangerous. This led to an exodus of leading scientists from pre-war Europe to the United Kingdom and the United States. During the war the Western Allies were never exactly sure how far the enemy had advanced in creating an explosive nuclear device. The result was an urgent and concerted effort on the part of the Allies to construct an implosive assembly (the Manhattan Project) and to assess the world's uranium resources. During the war the USA, Britain and the Soviet Union began formulating the principles for an organization for collective security. This led to a joint declaration after the war by the USA, Britain and Canada on the control of nuclear energy. Because the known uranium deposits at that time were few, uranium was of great strategic importance. General JC Smuts, Prime Minister of South Africa, was aware of the Manhattan Project in 1943. He would take a keen interest in the advancement of nuclear science and South Africa's uranium potential.

The Destructive Power of Uranium

The destructive power of the metal uranium can be understood by beginning with Albert Einstein's theory of relativity.*[1] In the nuclear

1 See Technical Addendum: "Einsteins's theory of Relativity". International fame came to Einstein in November 1919, when the Royal Society of London announced that a scientific expedition had completed calculations that verified the predictions made in Einstein's general theory of relativity. He was acclaimed the greatest genius on earth. In 1933, soon after Adolf Hitler became Chancellor of Germany, he renounced his German citizenship and left the country. He later accepted a full-time position as a foundation member of the School of Mathematics at the new Institute for Advanced Study at Princeton, New Jersey, USA. Einstein was so convinced that Nazi Germany was preparing for war that, to the horror of his pacifist friends, he violated his pacifist ideals and waged free Europe to arm and recruit for

fission process a nucleus of uranium breaks up into fragments and energy is released. In addition to fragments and energy, fission produces two or three neutrons which, under suitable conditions, can cause fission in other uranium atoms. If that happens, an ever-increasing number of fissions will occur as more and more neutrons are released and cause more fissions in turn. This process, called a chain reaction*, releases vast amounts of energy. In other words, uranium could be used to make an atomic bomb. However, as will be illustrated, the uranium chain reaction would only be discovered after much experimentation.[2]

In the history of uranium the developments in international relations after World War I were significant. World War I proved so destructive that it was felt that after 1919 a more effective method of solving international problems should be found. The result was collective security.[3] The concept of collective security would later form the basis for the control of uranium and other nuclear fuels.* It was a method devised by the League of Nations to maintain world peace.[4]

By 1936 the League of Nations as an agency of collective action was proved ineffective. In September 1931 Japan, still a member of the League, attacked China, which was also a member of the League. On 3 October 1935 Benito Mussolini (1883-1945), Fascist dictator of Italy, attacked a fellow-member of the League, Abyssinia. The following year, on 7 March 1936 Adolf Hitler (1889-1945), Nazi leader of

defence. TI Williams (ed): **A Biographical Dictionary of Scientists**, pp. 161-163.

2 JW Kane and MM Sternheim: **Physics**, pp. 766-767.

3 Collective security: For example, the use of sanctions by world organizations such as the League of Nations or United Nations.

4 The League of Nations: A scheme sponsored by American President Woodrow Wilson. Created to promote international co-operation, member states could meet to discuss common problems and matters liable to endanger world peace. A Le Roy Bennet: **International Organizations, Principles and Issues**, pp. 24-25 and 34-35; Michael Akehurst: **A modern Introduction to International Law**, p. 219.

Germany, sent his troops dramatically into the demilitarized zone of the Rhineland. These violent repudiations of the peace settlements, the Locarno Treaty and Kellogg-Briand Pact went unpunished by the League of Nations.[5] The countries of Europe found themselves at the mercy of aggressors, their security at risk. Belgium asked to be released from the Locarno commitments and declared a policy of neutrality. In July 1936 the civil war broke out in Spain. Italy and Germany jointly supported General Francisco Franco (1892-1975) against the (Loyalist) government, which was aided by Russia. In November 1936 Germany and Japan signed an Anti-Comintern Pact, a month after the formation of the Rome-Berlin Axis. In July 1937 Japan renewed its advance in China. The following year the Council of the League advised individual member states to apply separate sanctions against Japan, but they took no action. On 12 March 1938 German troops marched into Austria and occupied Vienna. France and Britain, harassed by a new war in China, felt unable to move.[6]

European affairs between March 1938 and March 1939 were dominated by the British Prime Minister, Neville Chamberlain's (1869-1940) policy of appeasement. In the study of the history of uranium, this was an important aspect. The policy of appeasement left no shadow of doubt in the world about the peaceful intentions of Britain and France, and their extreme reluctance to contemplate war. When war did begin (September 3, 1939) every moral advantage lay on the side of the democracies.[7]

Physicists and chemists, who were at that time experimenting with the unique metal uranium had during this time realized its potential

5 Locarno: Peace treaty made in 1925; Kellogg-Briand Pact: Pact for renunciation of war (1928). A Le Roy Bennet: **International Organizations, Principles and Issues**, pp. 36-38; David Thomson: **Europe Since Napoleon**, pp. 731-736.

6 FH Hartmann: **The Relations of Nations**, p. 369; David Thomson: **Europe since Napoleon**, pp. 731-738.

7 David Thomson: **Europe Since Napoleon**, pp. 735-739.

destructive power. This knowledge would be extremely dangerous in the hands of aggressors with motives of large scale domination. The sympathies of a number of prominent nuclear physicists lay with the Western Alliance.[8]

In 1934 Enrico Fermi (1901-1954), a young Italian physicist, began a series of experiments in which he systematically "bombarded"[9] a variety of targets with neutrons. Soon he discovered that placing water or a hydrocarbon* between the source and the target increased the production of artificial radioactivity.* Fermi realised that the light atoms had absorbed some of the kinetic energy* of the neutrons in a series of collisions and that the resulting slow neutrons were more readily captured by the target nuclei. Hoping to make new discoveries Fermi and his colleagues bombarded uranium with neutrons. Their experiment produced puzzling radioactive substances that could not be identified. At the time it was not realized that a different process of disintegration might occur in uranium than in any other element. Fermi and his colleagues had in fact caused uranium nuclei to fission.[10]

Enrico Fermi and his family fled the Fascist regime in Italy in 1938 by travelling to Stockholm where he accepted the Nobel Prize for Physics They then proceeded to New York and arrived on January 9, 1939. He was given a post at Columbia University.[11] There he would continue

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8 RG Hewlett and OE Anderson: **A History of the United States Atomic Energy Commission,** vol. I, p. 10; (Dr D Reitmann: Private Collection) DJR Bruckner: "The Day the Nuclear Age was Born", Science Times, **The New York Times**, 30 November 1982, p. c2; SE Morrison, HS Commager and WE Leuchtenberg: **The Growth of the American Republic**, vol. 2, p. 614.

9 Physicists "bombard" elements with neutrons hoping to discover new elements.

10 (SAL) J Daintith et al: **Biographical Encyclopedia of Scientists,** vol. 1, pp. 283-284; JW Kane and MM Sternheim: **Physics**, p. 760; (Dr D Reitmann: Private Collection) DJR Bruckner: "The Day the Nuclear Age was Born", Science Times, **The New York Times**, 30 November 1982, p. c2.

11 (SAL) J Daintith et al: **Biographical Encyclopedia of Scientists,** vol. 1, pp. 283-284; (Dr D Reitmann: Private Collection) DJR Bruckner: "The Day

with research to control nuclear energy.* This history will be related later in this chapter.

Between 1939 and 1942 nuclear scientists would discover how to use uranium to make a controlled nuclear chain reactor.

The bombardment of elements by physicists is done with minute quantities of matter and the immediate effects take place in a microcosm so small as to be far beyond the reach of human observation. In 1938 two German chemists, Otto Hahn (1879-1968) and Fritz Strassmann (1902-1980), working at the Kaiser Wilhelm Institute in Berlin, analyzed the results of Fermi's bombardment of uranium, and announced that they had found traces of the radioactive isotope barium.* This was baffling[12] as the atomic weight of barium is a little more than half that of uranium and it could hardly be produced by knocking one or two particles out of uranium atoms. Hahn published his discovery in a scientific journal. He also wrote an account of his findings in a letter to a former colleague, Lise Meitner (1878-1968), an Austrian physicist, who had been forced to leave Nazi Germany because she was Jewish and was then working at the Nobel Institute in Stockholm, Sweden. Lise Meitner suggested to her nephew, Otto Frisch (1904-1979), a German refugee scientist, then working at the Niels Bohr Institute in Copenhagen, what might have taken place in the experiment done by Hahn and Strassmann.[13] Some heavy atoms (like uranium) might be unstable in an usual way, so that one could be roughly split into two equal parts, by the injection of a neutron, and this could be how barium had resulted from the neutron bombardment of uranium. Meitner and Frisch journeyed to

the Nuclear Age was Born", Science Times, **The New York Times**, 30 November 1982, p. c2.

12 What happens after the bombardment of elements must be worked out or guessed at from analysis of the observed effects.

13 (JLUCT) Norman Moss: **The Politics of Uranium**, pp. 7-8; (SAL) J Daintith et al: **Biographical Encyclopedia of Scientists**, vol. 1, pp. 318-319; vol. 2, pp. 601-602.

Copenhagen, Denmark, to inform the Danish physicist, Niels Henrik Bohr (1885-1962), of this phenomenal discovery. They also published their theory in the English scientific report, **Nature**, on 16 January 1939. As soon as this paper appeared nuclear physicists in other centres repeated Fermi's experiment.[14] What had happened was that low-velocity neutrons caused the uranium nucleus to fission, or break apart, into two smaller pieces: the combined atomic number of the two pieces - for example barium and krypton* - equalled that of the uranium nucleus. Much energy was released in the process.[15]

As it happened Niels Bohr visited the United States in January 1939. He carried with him the explanation given by Lise Meitner and Otto Frisch. Bohr embarked on this journey because he was concerned about the impending war in Western Europe and the revolutionary discovery made by Hahn and Strassmann. Shortly after he reached the States, he received a cablegram from Frisch who informed him that laboratory results had confirmed his theory.[16] Niels Bohr and JA Wheeler published a paper in 1939, "The Mechanism of Nuclear Fission", in which Bohr showed how one may understand the role of neutrons in causing the uranium nucleus to break apart. Research by Niels Bohr and JA Wheeler of the USA suggested that the fission observed in uranium involved uranium-235,* an isotope comprising only one part in 140 of natural uranium, rather than the much more abundant uranium-238* species. The latter does not fission as readily as uranium-235, because it absorbs most of the neutrons that strike it. It was discovered that neutrons were produced during the fission process. On the average each fissioning atom produced more than two

14 (Dr D Reitmann: Private Collection) DJR Bruckner: "The Day the Nuclear Age was Born", Science Times, **The New York Times**, 30 November 1982, p. c2.

15 (AECA) AJA Roux: "Uraanverryking", 19 March 1971, pp. 4-5; RG Hewlett and OE Anderson: **A History of the United States Atomic Energy Commission**, vol. 1, p. 10.

16 (AECA) AJA Roux: "Uraanverryking", 19 March 1971, pp. 6-7; (SAL) DB Sole: **This Above All** (Unpublished manuscript), p. 86; (SAL) J Daintith et al: **Biographical Encyclopedia of Scientists**, vol. 1, pp. 318-319.

neutrons. This work was fundamental in the process that ultimately led to the nuclear chain reaction.[17]

When an uranium nucleus is split by the impact of a neutron, then other neutrons from this atom are sent shooting off, and these in turn may split other atoms (a chain reaction). This was spotted by the Hungarian-born physicist, Leo Szilard (1898-1964), who was then at the Columbia University in New York.[18] In February 1939 he wrote to Frédéric Joliot-Curie at the Collège de France and told him of his discovery. He mentioned that it may be used in the construction of explosives and bombs and that it could be extremely dangerous in the hands of certain governments.[19] When the nucleus of an uranium atom is split, the binding energy is released. The amount of energy is miniscule, but if a chain reaction takes place so that a lot of atoms undergo fission, the cumulative amount of energy released is enormous.

At the beginning of 1939 it was natural for Szilard to see this in terms of an explosive and danger. Germany had annexed Austria and had designs on Czechoslovakia. Every major power was rearming. Like many others, Szilard feared that Germany might develop a fission explosive before anyone else. He and Eugene Wigner, a fellow Hungarian, who shared his anxieties, went to see Albert Einstein, to ask him to lend his uniquely distinguished name to a letter to the United States President, Franklin D Roosevelt.[20] Albert Einstein, Enrico

17 RG Hewlett and OE Anderson: **A History of the United States Atomic Energy Commission,** vol. I, p. 13; (SAL) J Daintith et al: **Biographical Encyclopedia of Scientists,** vol. 2, pp. 942-943 and vol. 1 pp. 95-96; JW Kane and MM Sternheim: **Physics**, p. 674.

18 In 1932 Szilard joined the staff of the Institute of Theoretical Physics at the University of Berlin. When the Nazis came into power in 1933 he went to Vienna and in 1934 to London. In 1937 he settled in the USA. **Encyclopaedia Britannica**, 15th edition, 1987, vol. 11, p. 475.

19 (JLUCT) Norman Moss: **The Politics of Uranium**, p. 9.

20 RG Hewlett and OE Anderson: **A History of the United States Atomic Energy Commission,** vol. I, pp. 14-17.

Fermi and Leo Szilard warned President Roosevelt of the danger of Germany's obtaining a lead in uranium fission.[21]

The President was alerted to the military significance of nuclear fission. Roosevelt set up a Committee on Uranium to look into this. It was headed by Lyman J Briggs, the Director of the National Bureau of Standards.[22] This marked the beginning of what was later to become known as the Manhattan Project which was the wartime nuclear energy programme involving the designing and building of the first atomic bomb.

Otto Frisch, who left Germany to live in Denmark, went to England in 1939 to teach at Birmingham University. There, he and Rudolf Peierls, another refugee from Nazism, pondered the question of an uranium explosion. At first Frisch said that an uranium explosion would be impossible. This was because most uranium does not fission when hit by a neutron, only an isotope (uranium-235*) which makes up less than 1% (0,71%) of it.[23] If one could separate the uranium-235 from the rest, five kilograms of it could create an explosion equivalent to several thousand tons of TNT*.[24] Frisch and Peierls believed that this could be done. What Frisch and Peierls were saying was that uranium could be "enriched".*[25] Frisch and Peierls sent a memorandum reporting these

21 RG Hewlett and OE Anderson: **A History of the United States Atomic Energy Commission**, vol. I.

22 (JLUCT) Norman Moss: **The Politics of Uranium**, p. 10.

23 TG Moore: **Uranium Enrichment and the Public Policy**, p. 3; JW Kane and MM Sternheim: **Physics**, pp. 766-767; (SAL) J Daintith et al: **Biographical Encyclopedia of Scientists**, vol. 1, pp. 318-319.

24 (JLUCT) Norman Moss: **The Politics of Uranium**, pp. 10-11.

25 The term "enrich" is actually erroneous. It gives a false impression of what actually happens. The proportion of uranium-235 in the element uranium is 0,71% of the total. The proportion of uranium-235 is increased not by addition, but by subtraction, by removing some of the uranium-238. Matter is taken away, not added. To reduce 100 kilograms of uranium so that it is 3,5% uranium-235 instead of 0,71%, you will separate out 80 kilograms of the uranium-238. (JLUCT) Norman Moss: **The Politics of Uranium**, p. 21; (AECA) H de Waal: **Uraanverryking in die Republiek van Suid-Afrika**, Deel I, p. 4.

conclusions to the British War Cabinet's scientific office in March 1940. The following month, the government set up the Maud Committee to examine the prospects. In his memoirs, published posthumously in 1979, Szilard gives credit to the British for being the first to recognize that it would be possible to separate sufficient quantity of uranium-235 to make a bomb and for alerting the American authorities to this crucial fact.[26]

In April 1940 a short paper by Professors Frisch and Peierls, expanding on the idea of critical* wars, estimated that a super weapon could be built using several pounds of pure uranium-235 and that this amount of material might be obtainable from a chain of diffusion tubes. Meanwhile, in the USA, the Advisory Committee on Uranium reported that a chain reaction in uranium was possible, though unproved.[27]

Dr Fermi, Dr Herbert Anderson and Dr John Dunning physicists who had made Columbia University in Manhattan, New York City a centre of neutron research were conducting fission experiments in their laboratory on Morningside Heights. Chain reaction experiments with carbon and uranium were started in New York City at Columbia University, and in March 1940 it was confirmed that the isotope uranium-235 was responsible for low-velocity neutron* fission in uranium. The Advisory Committee in Uranium increased its support of the Columbia experiments and arranged for a study of possible methods for enriching uranium. The centrifuge process*, in which the heavier isotope is spun to the outside, as in a cream separator, at first seemed to be the most useful, but at Columbia a rival process was proposed. In that process, the gaseous diffusion* method, gaseous uranium hexafluoride* is diffused through barriers or filters.[28]

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26 (JLUCT) Norman Moss: **The Politics of Uranium**, p. 11.

27 RG Hewlett and OE Anderson: **A History of the United States Atomic Energy Commission**, vol. I, pp. 22-23, 40-41.

28 (Dr D Reitmann: Private Collection) DJR Bruckner: "The Day the Nuclear Age was Born", Science Times, **The New York Times**, 30 November 1982.

In the summer of 1940, Fermi began to build an atomic pile.*[29] Dr Fermi experimented with exponential piles*. Uranium and graphite* were arranged in latticed structures in an attempt to increase atomic fission in the piles. If enough uranium of the proper kind was packed into the proper shape and area, an energetic neutron escaping from an atomic nucleus might strike another atom, splitting it into two lighter atoms, in the process releasing more neutrons to strike more atoms. Since each fission or splitting would release several neutrons, the chance for increased fission would rise exponentially.[30] The neutrons bounce off the atoms of the moderator,* losing energy and slowing down as they do so.

Meanwhile in the same year (1940) Edwin McMillan and Philip Abelson of the University of California at Berkeley USA discovered element 93, named neptunium*; they inferred that this element would decay into element 94.* The Bohr and Wheeler fission theory suggested that one of the isotopes, mass number 239 of this new element might also fission under low-velocity neutron bombardment. The cyclotron* at the University of California at Berkeley was put to work to make enough element 94 for experiments. By mid-1941, element 94 had been firmly identified and named plutonium* and its fission characteristics had been established. Low-velocity neutrons did cause it to undergo fission, and at a rate much higher than that of uranium-235.[31]

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p. c2; RG Hewlett and OE Anderson: **A History of the United States Atomic Energy Commission,** vol. I, pp. 13-14, 96-101.

29 RG Hewlett and OE Anderson: **A History of the United States Atomic Energy Commission,** vol. I, pp. 27-28.

30 (SAL) J Daintith et al: **Biographical Encyclopedia of Scientists,** vol. 1, pp. 284-285. (Dr D Reitmann: Private Collection) DJR Bruckner: "The Day the Nuclear Age was Born", Science Times, **The New York Times**, 30 November 1982, p. c2.

31 (SAL) J Daintith et al: **Biographical Encyclopedia of Scientists,** vol. 1, p. 3; vol. 2, pp. 599-600; JW Kane and MM Sternheim: **Physics**, p. 577.

The Berkeley group, under Ernest Lawrence, was also considering producing large quantities of uranium-235 by turning one of their cyclotrons into a super mass spectrograph,* later called a calutron.*[32] Thus, by 1941 in the USA at least three possible methods of enrichments had already been considered; the centrifuge process, the gaseous diffusion process and the calutron system.[33]

In June 1941 President Roosevelt established the Office of Scientific Research and Development under the direction of the United States scientists, Vannevar Bush and James B Conant. The responsibility for further developments in nuclear research was assigned to the newly created office of Scientific Research and Development. In Britain the Maud Committee would look into the production of uranium-235. This committee's feasibility report in July 1941 caused the USA to propose a joint production effort of uranium-235, using the gaseous diffusion method, but nothing came of this. At Berkeley the calutron was exceeding expectations in separating uranium-235. It was enlarged to a 10-calutron system. It was capable of producing about three grams of enriched uranium per day.[34]

The Manhattan Project and the Atomic Bomb

The United States' entry into World War II on 8 December 1941 was significant for developments regarding uranium. It resulted in the rapid advancement of nuclear science and the establishment of the tremendous strategic value of uranium. It provided the funds for a massive research and production effort for obtaining fissionable

32 (SAL) J Daintith et al: **Biographical Encyclopedia of Scientists**, vol. 2, pp. 522-523; RG Hewlett and OE Anderson: **A History of the United States Atomic Energy Commission**, vol. I, p. 12.

33 McGraw Hill: **Encyclopaedia of Science and Technology**, vol. 19, p. 85.

34 RG Hewlett and OE Anderson: **A History of the United States Atomic Energy Commission**, vol. I, pp. 40-44, 51-52.

materials. This would be of particular importance to the Union of South Africa as a potential uranium producer.

In May 1942 the momentous decision was made to proceed simultaneously on all promising production methods (enriched uranium, plutonium, etc). Vannevar Bush decided that the army should be brought into the production plant construction activities. Army engineers under General Leslie Groves then took over. The Corps of the Engineers opened an office in New York City and named it the Manhattan Engineer District Office. (The name "Manhattan" was chosen because the initial scientific and engineering experimentation had taken place at Columbia University, Manhattan, New York). After considerable argument over priorities, a workable arrangement was achieved with the formation of a three-man policy board chaired by Bush and the appointment of General Leslie Groves as head of the Manhattan Engineer District. Under the code name "Manhattan District" Groves built small cities at Oak Ridge, Tennessee and Hanford, Washington, to make plutonium.[35]

Groves arranged contracts for a gaseous diffusion separation plant, a plutonium production facility, and a calutron pilot plant which could be expanded at a later stage. These projects involved millions of dollars. It stresses the fact that the USA was anxious to be ahead of the Axis powers in the construction of a fission bomb. Many problems in the enrichment process of uranium were still unsolved. The diffusion barrier (in the gaseous diffusion method) had not yet been demonstrated as practical. Berkeley had been successful with its empirically designed calutron, but the envisaged Oak Ridge uranium enrichment pilot plant contractors were understandably uneasy about the rough specifications available for the proposed massive enrichment of uranium

35 RG Hewlett and OE Anderson: **A History of the United States Atomic Energy Commission,** vol. I, pp. [illegible]4-85, [illegible]1-82; SE Morrison, HS Commager and WE Leuchtenberg: **The Growth of the American Republic,** vol. 2, pp. 614-615; Michael Wright (ed): "The World at Arms", **The Reader's Digest Illustrated History of World War II,** p. 44[illegible].

construction.[36] The Oak Ridge enrichment project was given the code name Y-12.

Julius Robert Oppenheimer (1904-1967) was appointed Director of Project Y, the group that was to design the actual weapon. The Manhattan Project involved teams of scientists working on separate problems at several locations throughout the United States. Oppenheimer and General Groves chose the former Los Alamos Ranch School some 140 kilometers north of Albuquerque, New Mexico as the site for the Los Alamos Scientific Laboratory. Prominent scientists, including a number of British scientists, joined the weapon design effort at Los Alamos. Considering that Britain was under close bombing attack and constant air reconnaissance, it seemed impossible to erect in the British Isles the vast and conspicuous factories that were needed. With their war economy stretched to its limits, the British could not make available the vast physical resources required for manufacturing the bomb.[37] By July 1942 two essential and encouraging pieces of experimental data had been obtained: plutonium did give off neutrons in fission, more than uranium-235; the neutrons were emitted in a

36 RG Hewlett and OE Anderson: **A History of the United States Atomic Energy Commission,** vol. I, pp. 88-102; Oak Ridge was the site selected in 1942 as headquarters for the United States wartime atomic energy programme, the Manhattan Project. Originally called Clinton Engineer Works, it was chosen because it was isolated yet accessible to power, water and transportation. It was situated in eastern Tennessee, USA, in a high valley along the southern slope of Black Oak Ridge between Cumberland and the Great Smoky Mountain. **Encyclopaedia Britannica**, 15th edition, 1987, vol. 8, p. 846; vol. 29, p. 578.

37 WK Hancock: **Smuts**, vol. 2, **The Fields of Force 1919 - 1950**, p. 434; Scientists that worked at Los Alamos were amongst others Cyril Stanley Smith (English metallurgist); Hans Albrecht Bethe (German physicist); and Edward Teller (Hungarian physicist). (SAL) J Daintith et al: **Biographical Encyclopedia of Scientists,** vol. 1, pp. 81-82, vol. 2, p. 869; **Encyclopaedia Britannica**, 15th edition, 1987, vol. 10, p. 893; SE Morrison, HS Commager and WE Leuchtenberg: **The Growth of the American Republic**, vol. 2, p. 615.

short time compared to that needed to bring the weapon's materials into supercritical assembly.[38]

A number of foreign scientists (several of whom had fled from Fascist regimes in Europe shortly before World War II) were working in separate smaller groups - Princeton, Chicago, New York and California - to control nuclear energy. They had been brought together by the Government as part of the Manhattan Project and they had embarked upon an all-out effort to create a controlled nuclear reaction. Until they knew they could do that, they would have no idea whether they could make an atomic bomb.[39]

On 2 December 1942, forty-two scientists, working under the direction of Enrico Fermi, gathered in an indoor squash court under the west grandstands of Stagg Field, the football stadium at the University of Chicago. An atomic pile had been set up and what they achieved that afternoon was the world's first controlled self-sustaining nuclear reaction made by man.[40]

Fermi's reactor or atomic pile consisted of a pile of graphite blocks, throughout which lumps of uranium were dispersed. Strips of neutron-absorbing cadmium* were provided as control rods,* regulating the speed at which the chain reaction could proceed by absorbing some of the free neutrons, while counters and foils were used to measure the rate at which neutrons were being produced. At criticality - that is when enough fuel had been assembled for a chain reaction to take place

38 JW Kane and MM Sternheim: **Physics**, p. 771; **Encyclopaedia Britannica**, 15th edition, 1987, vol. 29, pp. 578-579.

39 (Dr D Reitmann: Private Collection) DJR Bruckner: "The Day the Nuclear Age was Born", Science Times, **The New York Times**, 30 November 1982, p. c1.

40 (SAL) J Daintith et al: **Biographical Encyclopedia of Scientists**, vol. 1, pp. 284-285; (Dr D Reitmann: Private Collection) DJR Bruckner: "The Day the Nuclear Age was Born", Science Times, **New York Times**, 30 November 1982, pp. C1-C2; JW Kane and MM Sternheim: **Physics**, p. 760; SE Morrison, HS Commager and WE Leuchtenberg: **The Growth of the American Republic**, vol. 2, p. 614.

- the pile was about 7,8 meters across and 6,2 meters high.[41] Eugene Wigner, the eminent Princeton physicist, who worked with the Fermi group, recalls that within two weeks after they produced their chain reaction they received a telegram from a German scientist working in Switzerland which read "Hurry up. People here are working on it too."[42]

By July 1944 it became clear that the only way to use plutonium in a weapon was by the implosion method. As far as enrichment was concerned, the first Y-12 calutrons, after running for three months, were operating at less than 50 percent efficiency. The gaseous diffusion plant was far from completion, the production of satisfactory barriers remaining the major problem. The first reactor at Hanford, Washington, had been turned on in September, but it had promptly turned itself off. Solving this problem, which proved to be caused by the absorption of neutrons by one of the fission products, took several months. These delays meant almost certainly that war in Europe would be over before the weapon could be ready.[43]

By early April 1945 General Eisenhower's army was across the Rhine and thrusting deep into Germany and central Europe. On the 25th of April the United States First Army from Leipzig met the Russian army near Torgau on the river Elbe. Germany was cut in two and the German army was disintegrating. On the 30th of April Adolf Hitler died. On May 2nd Italy surrendered and on May 9th, 1945, the German High Command signed the formal ratification of unconditional surrender.[44]

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41 **The Marshall Cavendish Illustrated Encyclopaedia of Science and Technology**, p. 66.

42 (Dr D Reitmann: Private Collection) DJR Bruckner: "The Day the Nuclear Age was Born", Science Times, **New York Times**, 30 November 19[illegible], p. C1.

43 **Encyclopaedia Britannica**, 15th edition, 1987, vol. 29, p. 578.

44 Winston S Churchill: **The Second World War**, pp. 915-927.

It was estimated that by April 1945 enough plutonium would be available for an implosion assembly to be tested in early July. A second would be ready in August. Researchers at Los Alamos tested the first plutonium weapon at dawn on July 16, 1945. The test was named "Trinity" and done at Alamogordo, New Mexico. The theorists' predictions of the energy released, ranged from the equivalent of 1 000-5 000 tons of TNT. Instead the test produced an energy equivalent of 20 000 tons of TNT.[45]

On July 17, 1945, the British Prime Minister, Sir Winston Churchill (1874-1965) was informed that the Alamogordo experiment had succeeded. At the time both he and President Harry S Truman (1884-1972) were inspecting the devastated city of Berlin. Up till that date they had contemplated a joint American and British assault on the homeland of Japan by terrific air bombing and an invasion of very large armies. They were fully aware of the desperate Japanese resistance fighting to the death. To quell the Japanese man by man, and conquering the country yard by yard, might well have required the loss of millions of American and British soldiers. For Churchill, the success of the plutonium weapon erased that nightmare picture. Possibly the war could be ended with one or two shocks.[46]

President Truman's Committee of high officials and top nuclear scientists recommended that atomic bombs be exploded over Japan and without warning. On 25 July 1945 the President issued the necessary order to prepare to drop the bombs on the first favourable moment after 3 August 1945. On 6 August at 9:15 a single B-29 bomber flew over Hiroshima, the second most important military centre in Japan. An untested uranium-235 gun assembly* was air burst 600 meters above the city. Two-thirds (10 km^2) of the city area was destroyed in the blast. The second weapon, a duplicate of the plutonium 239

45 RG Hewlett and OE Anderson: **A History of the United States Atomic Energy Commission,** vol. I, pp. 389-390; SE Morrison, HS Commager and WE Leuchtenberg: **The Growth of the American Republic**, vol. 2, p. 615.

46 Winston S Churchill: **The Second Worl[illegible]**, pp. 9[illegible]9-940.

implosion assembly tested in "Trinity", was to be dropped on Kokura on August 11. To avoid bad weather, the schedule was moved up two days to August 9. The B-29 spent 45 minutes over Kokura without sighting its aim point. It then proceeded to the secondary target of Nagasaki. About 50 percent (4 x 2 km) of that city's area was destroyed.[47]

International nuclear cognisance

There was an astonishing amount of communication among American scientists in the war years. There was some secrecy, but not as much as General Leslie Groves, and the United States Army would have liked.[48] Dr Szilard had urged Frederic Joliot-Curie and his colleagues in France, who were working on fission, to suppress their reports and they refused. However, he persuaded Mr Anderson and Columbia University not to publish Dr Anderson's doctoral thesis on problems in atomic energy. According to Dr Fermi, it was the scientists who decided to maintain secrecy long before the Government knew what their work was about. He said that it was an unfortunate necessity and an affront to the tradition of science.[49] John A Simpson, a University of Chicago physics professor who worked on the Manhattan project, recalls that as scientists working in different areas became aware of the whole picture, many discussions and seminars on moral and philosophical problems were held. Eventually, several scientists in the

47 RG Hewlett and OE Anderson: **A History of the United States Atomic Energy Commission**, vol. 1, pp. 401-404; SE Morrison, HS Commager and WE Leuchtenberg: **The Growth of the American Republic**, vol. 2, pp. 615-616; Michael Wright (ed): "The World at Arms", **The Reader's Digest Illustrated History of World War II**, pp. 438-442; FR Dulles: **The United States since 1865**, pp. 467-468.

48 In January 1943, the American nuclear authorities imposed a security clamp on nuclear papers and progress reports in the USA. WK Hancock: **Smuts**, vol. 2, **The Fields of Force 1919 - 1950**, p. 434.

49 (Dr D Reitmann: Private Collection) DJR Bruckner: "The Day the Nuclear Age was Born", Science Times, **The New York Times**, 30 November 1982, p. c2.

Manhattan project, as well as members of the University of Chicago faculty of Social Sciences, Law and the Humanities formed the Association of Atomic Scientists. The group ultimately sent an appeal to the White House, urging that there be an international demonstration of the bomb rather than any use of it on an actual target in the war.[50]

Scientists in several countries performed experiments in connection with nuclear reactors and fission weapons during World War II, but no country other than the USA carried its projects as far as enriching uranium or manufacturing plutonium 239.[51] In Paris Frédéric Joliot-Curie and his colleagues concluded that a chain reaction was possible. With the fall of France in June 1940, two colleagues of Joliot-Curie reached England with the world's entire supply of heavy water (180 kilograms) and continued their chain reaction experiments at Cambridge University.[52]

During the war an Uranium Institute with a few physicists was established in Moscow. The USSR's military and industrial nuclear research in Moscow was under the control of Igor V Kurchatov (1903 - 1960). Under his direction the Soviet nuclear programme was remarkably successful. Studies were started on nuclear reactors, and on uranium enrichment by means of the gaseous diffusion method. The first Soviet chain reaction experiment went critical on Christmas day 1946. Their first nuclear weapon was tested on September 29, 1949.[53]

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50 (Dr D Reitmann: Private Collection) DJR Bruckner: "The Day the Nuclear Age was Born", Science Times, **The New York Times**, 30 November 1982, p. c2.

51 AJA Roux: "Uraanverryking", p. 9; SE Morrison, HS Commager and W E Leuchtenberg **The Growth of the American Republic**, vol. 2, p. 651.

52 (SAL) J Daintith et al: **Biographical Encyclopedia of Scientists**, vol. 1, p. 464; **Encyclopaedia Britannica**, 15th edition, 1987, vol. 29, p. 579.

53 (SAL) J Daintith et al: **Biographical Encyclopedia of Scientists**, vol 1, p. 505; **Encyclopaedia Britannica**, 15th edition, 1987, vol. 29, p. 579.

As mentioned British scientists took part in the Manhattan Project. After the war Britain continued with its own nuclear fission programme.[54]

By the time war started, Germany had a special office for the military application of nuclear fission. The War Office in Germany was advised to commence nuclear weapon development. Werner Heisenberg was called upon to come to Berlin to direct the programme to construct the atom bomb. He has claimed that he never had any real intention of making such a bomb, let alone giving it to Hitler. Chain reaction experiments with uranium and carbon* were being planned. Uranium enrichment was under study. German nuclear experiments never progressed beyond the laboratory stage. Several times these prototypes were destroyed in bombing attacks. The fission weapon itself was a rather distant goal.[55] There were no "secrets" about the atomic bomb, physicists everywhere in the world knew how to make the bomb. it was certain that within a few years after the war any country that cared to spend the money and effort could have bigger and more devastating bombs.[56]

The French and Chinese nuclear weapon projects were post-war efforts. Some French scientists had worked in exile during the war in Britain and Canada and returned to work for the Commissariat á l' Energie Atomique. This French undertaking, which was founded by General de Gaulle in 1945, was aimed at energy production. The first French plutonium production reactor went on line in 1956. The first nuclear

54 WK Hancock: **Smuts**, vol. 2, **The Fields of Force 1919 - 1950**, p. 434; CR Taylor (ed): **The Inventions that changed the World**, pp. 188-189.

55 (SAL) J Daintith et al: **Biographical Encyclopedia of Scientists**, vol. 1, pp. 400-401.

56 SE Morrison, HS Commager and WE Leuchtenberg: **The Growth of the American Republic**, vol. 2, p. 651.

weapon was tested in 1960. The Chinese nuclear fission programme started in 1958.[57]

The Hunt for Uranium

It has been illustrated to what extent research in nuclear physics was intensified during the Second World War. Uranium was brought into prominence and became the chief object of investigation. The explosion of the atom bomb brought home the fact to every nation of the world that nuclear energy was to be one of the major forces at the future disposal of the world. Uranium had become a vital strategic mineral.

A most important factor was that the American authorities were well aware of an ensuing shortage of uranium in the United States. In August 1943, General Groves, Director of the Manhattan Project, commissioned an evaluation of the world's uranium resources. The conclusion was that there was enough uranium available for the Manhattan Project, but after that there would be hardly any left in North America, and the only source of supply would be the Belgian Congo. This evaluation was presented to President Roosevelt.[58]

Nuclear co-operation between Britain and the USA had reached a low ebb in 1943.[59] An improvement of relations was indicated by the signing of the Quebec Agreement and the establishment of the Combined Policy Committee in which Britain, the USA and Canada were supposed to decide policy on atomic energy. This Committee was dissolved after the war, but the Combined Development Trust, which it

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57 (AECA) AJA Roux: **Atomic Energy Research and Development**, Part III, **Continent of Europe**, p. 3; **Encyclopaedia Britannica**, 15th edition, 1987, vol. 29, p. 589.

58 Norman Moss: **The Politics of Uranium**, pp. 13-14.

59 **Encyclopaedia Britannica**, 15th edition, 1987, vol. 29, p. 579.

had established to acquire raw materials, was kept in being. The establishment of the Trust was aimed at acquiring control of uranium ore deposits, not only within the boundaries of the three countries party to the agreement, but also in other countries.

At this point the question may well be asked: Where did the United States obtain its uranium for the Manhattan Project? As mentioned previously, prior to the development of the atomic weapon, world demand for uranium was small. This demand was more than satisfied from several rich mines of limited extent, notably Joachimstal (Czechoslovakia), Chinkolobwe (Belgian Congo) and the Great Bear Lake deposits in North Canada. Until the commencement of the Second World War these deposits were operated primarily for the extraction of radium and uranium residues from these and other operations which were accumulating since amounts available were in excess of world requirements. From 1920 to 1940 the pitchblende deposits of the Belgian Congo and of Canada gave an average annual production of uranium oxide estimated at 350 tons. Much the same position existed at the vanadium plants situated on the Colorado Plateau in the United States where uranium was recovered as a by-product.[60]

With the advent of atomic energy and the war the whole position changed.[61] Joachimstal was in the hands of the Nazi Government; Canadian uranium that had accumulated was available for the war project, but after the war Britain would compete with the USA for new supplies. The mines at Chinkolobwe were run by the Union Minière Company. When the Germans conquered Belgium in 1940, the Chairman of the Company, Edgar Sengier, was afraid that the Nazi's would somehow gain control of the Belgian Congo also. He took it upon himself to remove the 1 200 tons of uranium ore that had piled up at the mine, and had it shipped to America. Sengier also removed

60 SH Haughton: "Uranium in South Africa", **Coal and Base Minerals**, 2(7) Sept 1954, p. 47.

61 L Taverner: "An Historical Review ...", **JSAIMM**, 57, Nov 1956, pp. 125-126.

himself to America and established himself in Union Minière's New York office. When the Manhattan Project was under way this whole consignment of uranium was assigned to the United States. After the war the United States would have to compete with France and other nations for Chinkolobwe uranium. The Union Minière Company had previously negotiated an uranium contract with Frédéric Joliot, representing the French Government.[62]

Governments of the world set out on an uranium hunt. In the United States, in the USSR and throughout the British Empire intensive efforts were made to locate and develop all available resources of material that had suddenly become of paramount importance. Most countries immediately adopted measures to control their production, supply and use.[63] Today it is known that uranium is abundant. In the 1940's uranium was seen as a scarce commodity and this would have a major effect on internal and foreign policies of many nations. This initial scarcity would prove to be a great economic advantage to South Africa.

Failure to control Nuclear Energy Development

The United Nations Organization began as a grand alliance for fighting Germany, Italy and Japan. The principles of the Atlantic Charter were reaffirmed by the twenty-six allied states on January 1942 in the "Declaration by the United Nations". Draft proposals for the new organization were prepared under the auspices of the four "sponsoring powers" (the United Kingdom, United States, Soviet Union and China) at conferences held at Dumbarton Oaks near Washington in 1944. At the Yalta Conference in February 1945, Britain, the USA and the

62 Norman Moss: **The Politics of Uranium**, p. 14; RG Hewlett and OE Anderson: **A History of the United States Atomic Energy Commission,** vol. I, pp. 85-86; T Borstelmann: **Apartheid's Reluctant Uncle,** pp. 43-55.

63 "The Search for Uranium, South Africa's Position", **SAMEJ**, 58(2) Feb 1948, p. 603.

Soviet Union agreed on the voting procedure in the new organization. The draft Charter was then discussed, modified and improved, and finally signed by representatives of fifty states (including the Union of South Africa), at the San Francisco Conference in April - June 1945. They changed the United Nations from a wartime alliance to peace-time organization for collective security. It came into force on 24 October 1945.[64]

As Britain and Canada had been associated with the United States in the programme which led to the manufacture of the two atomic bombs used in the war, these three countries possessed the knowledge essential to the use of nuclear energy.

The heads of the three governments of the United States, Britain and Canada met in Washington on 15 November 1945 and issued a joint declaration of policy on the future development of nuclear energy. This declaration was to have profound influence on subsequent discussions of controls over nuclear energy. Some of the main points were namely: Nuclear energy had placed an unknown means of destruction at man's disposal in war for which there was no defence and no nation could have the monopoly. Such measures constituted the greatest threat to civilization. There was a need for international action and the responsibility of such action on the whole society of nations of the world.[65]

The declaration and its proposals were discussed between the foreign ministers of Britain, the Soviet Union and the United States in Moscow in December 1945.[66]

Following the Anglo/Canadian/United States and Anglo/Russian/United States discussions of 1945, and anticipating the first United Nations

64 A De Conde: **A History of American Foreign Policy**, pp. 633-640.

65 (SAL) A McKnight: **Atomic Safeguards: A Study in International Verification,** p. 3.

66 **Ibid.,** p. 4.

resolution, the United States Secretary of State appointed a committee of five to advise on the problem of nuclear energy and particularly on the aspects of controls and safeguards. The committee was chaired by Dean Acheson.[67] The committee appointed a board of consultants chaired by David E Lilienthal, and the two groups prepared a "Report on the International Control of Atomic Energy", which became known as the "Acheson - Lilienthal Report".[68] This Report, essentially the work of the board of consultants,[69] was the United States proposals for the control of nuclear energy.

On 24 January 1946 under pressure from the major powers the United Nations General Assembly adopted its first resolution, in which it resolved to establish a United Nations Atomic Energy Commission (UNAEC). The advent of nuclear weapons in the closing days of World War II created a need for collective security regarding nuclear power and a new urgency for introducing some form of arms control. The Commission was to inquire into all phases of the problem of nuclear energy and in particular to make proposals on the aspects defined in the Anglo/Canadian/United States declaration namely, exchange of information, control to ensure only peaceful use of nuclear energy, elimination of atomic weapons and other weapons of mass destruction and effective safeguards.[70]

The UNAEC first met on 12 June 1946. Bernard Baruch (the American representative at the UNAEC) presented a set of proposals

67 (SAL) A McKnight: **Atomic Safeguards: A Study in International Verification,** p. 6. Other members were General JJ McCloy, Prof Vannevar Bush, Prof JB Conant (scientists) and General LR Groves; RG Hewlett and OE Anderson: **A History of the United States Atomic Energy Commission,** vol. I, pp. 531--553.

68 **Ibid.**

69 CI Barnard (Bell Telephone Co); Robert Oppenheimer; CA Thomas (Monsanto Chemical Co); HA Winne (General Electric Co) and David Lilienthal (Chairman of Tennessee Valley Authority).

70 **Ibid.,** pp. 4-5; FH Hartmann: **The Relations of Nations,** pp. 287-289; A Le Roy Bennet: **International Organizations, Principles and Issues,** p. 210.

(based essentially on the Acheson - Lilienthal Report) to UNAEC on 14 June 1946. This set of proposals later became known as the "Baruch Plan".[71] It proposed the establishment of an International Atomic Development Authority (under the United Nations Security Council) to which would be entrusted all phases of the development and use of nuclear energy from raw materials to the management and ownership of all potentially dangerous nuclear energy activities, as well as power to control, inspect and licence such activities.[72]

The authority would be allowed free inspection throughout the territories of the United Nations members in order to assure itself that no clandestine operations were being carried on. Moreover, when and if the illegal manufacture of nuclear devices were made known to the Security Council, the vote in that body would not be subject to veto. By stages, as inspection and control became effective, the United States would reveal its atomic information, and when the process of control was complete, it would destroy its stockpile of atomic bombs.[73]

After the Second World War an increasing bitterness had begun to mark American-Russian relations. This grew initially out of disagreement over the future of the Balkans and later developed into the "cold war".[74] The USA was unsure of exactly how far the Soviet Union had progressed in nuclear research.

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71 The United States proposal consisted of two memoranda: the first was general and dealt with the problems of atomic energy; the second was particular and addressed the control aspects. (SAL) A McKnight: **Atomic Safeguards: A Study in International Verification,** p. 7.

72 **IAEA Safeguards Aims Limitation Achievements**, p. 15; (SAL) A McKnight: **Atomic Safeguards: A Study in International Verification,** pp. 287-289.

73 FH Hartmann: **The Relations of Nations**, pp. 287-289

74 WI Cohen: **The Cambridge History of American Foreign Relations**, pp. 21-57; George F Kennan: **The Nuclear Delusion,** pp. 27-32; Alexander De Conde: **A History of American Foreign Policy,** pp. 670-671; FH Hartmann: **The New Age of American Foreign Policy,** pp. 175-181.

According to George Kennan, the American foreign service officer who emerged as the leading American specialist on the Soviet Union, found his government slow to understand Soviet objectives and the need to be firm with Stalin. He said single sporadic efforts to counteract Soviet policy were not enough. American policy should be firm and vigilant containment of Russian expansive tendencies.[75]

The matter of international control of nuclear energy and nuclear weapons, served to undermine the ability of the two nations to cooperate. International control of nuclear weapons was seen by Truman and his advisors as feasible and could be managed without the risk of the security of the United States.[76]

The Baruch plan was based upon two assumptions. One, the United States nuclear monopoly could be only temporary. Two, the United States could not trust the mere word of the Soviets and destroy the nuclear stockpile before international control and inspection had become a reality. This control, which was to come by stages, marked by an increasing exchange of confidential information, had to be established first, then the bombs would be destroyed.[77]

Despite the majority approval that the Baruch plan quickly received, the Soviet Union rejected it.[78] On 19 June 1946, Andrei A Gromyko, the Soviet representative on the Security Council, put forward Soviet proposals for International control. He proposed an international convention prohibiting the production and use of atomic weapons. In addition to this he suggested a plan for organizing the work of the

75 WI Cohen: **The Cambridge History of American Foreign Relations**, p. 32; Alexander De Conde: **A History of American Foreign Policy**, p. 671.

76 WI Cohen: **The Cambridge History of American Foreign Relations**, p. 31.

77 FH Hartmann: **The Relations of Nations**, p. 228.

78 The Baruch Plan was accepted in the General Assembly by forty votes to six, with four members abstaining. But it was vetoed in the Security Council by the Soviet Union. David Thomson: **Europe Since Napoleon**, p. 858.

Atomic Energy Commission.[79] The Soviet Union, therefore, wanted to stop the production and use of the bomb first, followed by the destruction of nuclear stockpiles. The Soviets would then be prepared to permit limited inspection of certain plants at certain times, but to unlimited inspection, let alone monopoly ownership and operation of facilities by an international authority, the USSR would not agree to. The Soviet argument was that the safeguards function of international control would lead to interference in the functions of the State.[80] Deliberations in the Security Council on reported violations would, under the Soviet plan, remain subject to veto.[81]

The United States feared that if the bombs were destroyed first, as the USSR insisted, control might never really come.[82] The Soviets might delay it indefinitely. The Soviets in turn were afraid that control would be established and Soviet secrets laid bare, but that the United States would find reasons for postponing indefinitely the destruction of the nuclear stockpile. If the first situation came to pass and the Soviets had a secret stockpile, the United States would have placed itself in severe jeopardy. If the second situation occurred, the Soviets, assuming the United States would continually find reasons for delays, would have exposed themselves to the same danger.[83]

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79 RG Hewlett and OE Anderson: **A History of the United States Atomic Energy Commission,** vol. I, p. 583.

80 (SAL) A McKnight: **Atomic Safeguards: A Study in International Verification,** p. 24.

81 The permanent members of the UNO Security Council were China, France, United Kingdom, the USA and the USSR. The effect of Article 27(3) of the Charter of the UNO is that each permanent member of the Security Council has a "veto" on non-procedural questions. Michael Akehurst: **A modern Introduction to International Law,** p. 212; FH Hartmann: **The Relations of Nations,** p. 288.

82 RG Hewlett and OE Anderson: **A History of the United States Atomic Energy Commission,** vol. I, p. 583.

83 Michael Akehurst: **A modern Introduction to International Law,** p. 212; FH Hartmann: **The Relations of Nations,** p. 288.

The Soviet Union believed that the United Nations' control would be that of the United States and not of an international body. The history of voting in the United Nations at that time proved that the Russians assumed correctly. The Atomic Control Commission, voting by majority vote and a Security Council, weighing nuclear security matters without vetoes, would be in the favour of the USA.

The United States and Soviet positions are explicable in terms of their respective international positions. While the Baruch Plan seemed on its face a generous offer by a state with a nuclear monopoly, it preserved that monopoly of basic knowledge by restricting the freedom of any other state to develop and test a nuclear weapon. The United States insisted on maintaining its monopoly until a secure system was established, insuring against nuclear energy development by any other state and providing a method of taking effective action against violators of the agreements.[84]

The Soviet Union wished to escape from the disadvantaged position of bargaining in which it found itself by developing its own nuclear capability.[85] In September 1949 the Soviet Union detonated an atomic device and the USA a few months later, announced plans for a hydrogen bomb, a thousand-fold more powerful than the atomic bomb. This was the stalemate situation that existed between the major powers in 1949.[86]

In 1951, Secretary of State, Dean Acheson in the General Assembly supported the Anglo-French-United States view that the reduction of all weapons (including nuclear weapons) must be by stages, with arms

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84 A Le Roy Bennet: **International Organizations, Principles and Issues,** p. 211.

85 **Ibid.**

86 RG Hewlett and OE Anderson: **A History of the United States Atomic Energy Commission,** vol. II, pp. 362-363.

inventories verified by an international count and the completion of each stage fully certified before the next began.[87]

To this the Soviets replied that the transition from one stage to the next would be directly dependent on whether those states possessing the most powerful, dangerous and threatening weapons, on which information had to be published and made known at succeeding stages, would be prepared to accept as satisfactory the results of submitting the required information at the first stage. This could only mean that the fate of the whole plan for collecting data on armaments would reside in the hands of the possessors of the most powerful and dangerous weapons. This, finally would mean that the decision as regards the transition from one stage to the next would be entirely up to those same powers, which would decide in accordance with their interest.[88]

The efforts of the United Nations Atomic Energy Commission revealed fundamental differences between the East and the West in the approach to the control of nuclear energy. Differences which were a reflection of fundamental political differences. The Commission did not meet after 1949.[89] It was dissolved by the General Assembly on 11 January 1952.[90]

America's loss of the nuclear monopoly foreshadowed a shift in the world balance of power; a shift that would aid Soviet diplomacy and constrain American action.

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87 FH Hartmann: **The Relations of Nations,** p. 288.

88 **Ibid.,** p. 289.

89 The consultations between the United States, the United Kingdom, the Soviet Union and Canada ceased in 1949, ostensibly over the issue of which government should be seated as the Government in China.

90 The United Nations merged the Atomic Energy Commission and the Commission for Conventional Armaments into a new Disarmament Commission.

Early South African Involvement

General JC Smuts was most likely the first South African to be aware of the developments of uranium and nuclear energy abroad and the Manhattan Project. As mentioned, General Groves had commissioned an evaluation of the world's uranium resources in August 1943. According to DB Sole, General Smuts knew of the Manhattan Project during his second visit to London, which began in September 1943.[91] DB Sole was at that time the Senior South African Affairs representative and Political Secretary in London, and handled all the arrangements of General Smuts' visit, as well as official appointments which involved relations with the British Government, that had to be channelled through South Africa House, London.[92]

The immediate reason for Smuts' visit was the Conference of Commonwealth Prime Ministers. At the end of the Conference, he stayed on as a member of the War Cabinet. As British Prime Minister, Winston Churchill was to be away from England, attending the Teheran Conference, where he met Allied leaders Joseph Stalin and President Franklin D Roosevelt (November and December 1943). During Churchill's absence, in effect - although not officially - Smuts presided over the War Cabinet.[93]

It was during Smuts's second visit to London (September 1943) that DB Sole observed that one paper among a number of certain Cabinet papers that had been routinely selected for Smuts' special attention, dealt with the planned atomic bomb. As far as he could recollect it was not named as such, in that particular paper. The fact that Smuts learned about the Manhattan Project during his second visit to London is of significance, considering that on his return journey to South Africa,

91 In October, 1942, Smuts paid his first visit to London since the outbreak of the war; Interview with DB Sole, 12.12.1990.

92 (SAL) DB Sole: **This Above All** (Unpublished manuscript), p. 81.

93 **Ibid.**, pp. 81 and 83, Clement Attlee, later Prime Minister.

Smuts met with President Roosevelt in Cairo. Roosevelt was on his way back from Teheran. This was the first and only meeting between Roosevelt and Smuts during the war.[94] Only a few months previously (August 1943) General Groves had commissioned an evaluation of the world's uranium resources. Considering that Roosevelt was on his way back from the Teheran Conference (where the Combined Development Trust had been established to search for uranium deposits) one can assume that early in 1944 General Smuts was aware of the value of uranium in the war and international politics.

General Smuts attended the Commonwealth Prime Minister's Conference in London in May 1944. The main issue on the agenda was the conduct of the war. It was during this visit to London in the summer of 1944 that a meeting was set up between General Smuts and Niels Bohr, the Danish nuclear physicist.[95]

Niels Bohr, like many scientists involved with nuclear research during the Second World War, was deeply concerned about the effects of nuclear fission on mankind. As a physicist he looked beyond the atom bomb to the development of the hydrogen bomb. The purpose of Niels Bohr's visit to London in the summer of 1944 was to try and persuade the Churchill government that the time had come for it and the American Government to share their nuclear secrets with the Russians. He believed the bomb should not be used in competition for power by the great nations. If this happened, humanity would be putting its survival into jeopardy. He realised that the Russians possessed sufficient resources of science and technology to produce a bomb at some stage in future.[96]

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94 (SAL) DB Sole: **This Above All** (Unpublished manuscript), p. 85.

95 **Ibid.**, pp. 85-86; Donald B Sole, at the time in the South African Diplomatic Service in London (later South Africa's representative on the Board of Governors of the IAEA) arranged the first meeting between General Smuts and Dr Niels Bohr. Interview with DB Sole, 23.10.1989.

96 WK Hancock: **Smuts**, vol. 2, **The Fields of Force 1919 - 1950**, p. 435.

Sir John Anderson, the Chancellor of the British Exchequer, who had been entrusted by Churchill with special responsibilities in connection with the development of nuclear energy and Lord Cherwell (who was in charge of the statistical department in the Churchill government) insisted that Niels Bohr's proposals be taken seriously. Churchill invited Smuts to examine Bohr's proposals.[97] According to DB Sole, "the meeting took place because Smuts had been most intrigued by the information concerning the Manhattan Project, and Smuts had further discussions with Churchill."[98]

General Smuts had for many years pondered the problem of the maintenance of world peace.[99] There was a convergence between the ideas of Bohr and those of Smuts. Bohr believed that cooperation was the antithesis of competition and that the sharing of scientific knowledge could form a basis for lasting cooperation between the leading nations. Smuts, in turn believed that the great powers of the world should form themselves together in a world society and be bound by common interests, common adversity and common danger.[100] Smuts believed that there would have to be international control of nuclear energy. He produced no answer to Bohr's proposal that the Soviet Union should be informed of the Manhattan Project. The British could not give an answer by themselves. In an agreement dated 18

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97 WK Hancock: **Smuts**, vol. 2, **The Fields of Force 1919 - 1950**, p. 436.

98 (SAL) DB Sole: **This Above All** (Unpublished manuscript), p. 86.

99 His memorandum of 1917, "The League of Nations: A Practical Suggestion" had a direct influence on the formulation of President Woodrow Wilson's plans for post-First World War settlement. Smuts was also a member of the commission (representing the British Empire) to prepare the draft proposal of the Covenant of the League of Nations. Smuts was also concerned about the danger of the new destructive power at man's disposal. WK Hancock: **Smuts**, vol. 2, **The Fields of Force 1919 - 1950**, p. 434; A Le Roy Bennet: **International Organizations, Principles and Issues**, p. 22; TRH Davenport, **South Africa**, p. 188.

100 WK Hancock: **Smuts**, vol. 2, **The Fields of Force 1919 - 1950**, p. 435; GD Scholtz: **Hertzog en Smuts en die Britse Ryk**, p. 134.

Sept 1944 President Roosevelt and Churchill opened the way to Hiroshima.[101]

While in London, Smuts had discussions with Sir John Anderson. Arising out of these discussions, some time later, when Smuts was back in South Africa, Anderson requested him to arrange an investigation into reported deposits of radium and pitchblende in South Africa and South West Africa.[102]

The urgency for obtaining an uranium supply resulted in the USA and Britain jointly sponsoring world-wide prospecting programmes for the discovery of new sources of the metal. (This was achieved by the Cairo and Teheran Conferences and the setting up of the Combined Development Trust.) The decision was taken that the USA, with the help of Britain and Canada, should look into all possible sources of uranium and procure, through the Combined Development Trust, as much as possible, as soon as possible, and all in the utmost secrecy.[103] As a part of this programme an intensive search of technical literature was undertaken in the United States under the direction of Joseph Sinclair. During this undertaking RA Cooper's paper, "Mineral Constituents of Rand Concentrates" came under review. As a result Weston Bourret, an American geologist, was, in May 1944, commissioned to visit South Africa for the purpose of studying and reporting on this occurrence.[104]

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101 WK Hancock: **Smuts**, vol. 2, **The Fields of Force 1919 - 1950**, p. 436.

102 (SAL) DB Sole: **This Above All** (Unpublished manuscript), p. 86; AR Newby-Fraser: **Chain Reaction**, pp. 20-21.

103 In the paper presented at the Geneva Conference (1956), Jesse Johnson (Director of Raw Materials of the United States Atomic Energy Commission) mentions an expenditure of some 46 million dollars for exploration and development of exploration methods. L Taverner: "A Historical Review:, **JSAIMM**, 57, Nov. 1956, p. 126; J Levin: **The Story of Mintek, 1934-1984**, p. 89.

104 According to Jack Levin, Acting Director of the Government Metallurgical Laboratory (from 1958 to 1961), it is probably fortunate that geologists were inclined to collect specimens rather than representative samples, because what was collected indicated favourable uranium concentrations, much higher than the overall concentrations in the ores. It has been suggested that, if the latter

It is interesting to note that General Smuts was informed of the investigation of possible deposits of pitchblende in South Africa at the same time that Weston Bourret was commissioned to visit the country in May 1944. Bourret paid an informal visit to the Witwatersrand on behalf of the British-American Atomic Energy Organization. In company with an assistant geologist, Frank West, he spent four months in the Union investigating and sampling operating properties on the Rand. Over 100 mill products and ore specimens are said to have been collected for a preliminary radiometric assay and this examination was supplemented by chemical analyses and mineralogical studies in the United States, the latter carried out by Dr D'Arcy George, a consulting mineralogist to the American Atomic Energy Programme.[105]

In May 1945 a preliminary report on the uraninite in amalgam barrel* residues was submitted to Professor George W Bain, of Amherst College, Massachusetts, then serving as consulting geologist on an Advisory Committee appointed by the American Atomic Energy Programme. This prompted Bain to make his first radiometric examination of Rand ore specimens in his possession. As early as 1941 Professor Bain had made an extensive tour of the Rand goldfields during which he had collected hand-picked specimens of geological interests. One of these came from Kimberley reef on the East Daggafontein mine. On his return to the United States he kept these specimens in his laboratory at Amherst College. After reading Bourret's report he then examined his samples for radioactivity and confirmed the presence of radioactive minerals in what he must have

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had been known by the authorities concerned, they would have abandoned interest in the Witwatersrand. As it was, it was decided that the Witwatersrand ores should be investigated intensively. Jack Levin: **The Story of Mintek, 1934-1984**, p. 89.

105 CS McLean: "The Uranium Industry of South Africa", **JCMMS**, 54, April 1954, p. 346; L Taverner: "A Historical Review ...", **JSAIMM**, 57, November 1956, p. 126.

regarded as appreciable and very significant amounts, bearing in mind the very large tonnage of ore treated on the Rand.[106]

It thus appears that the first chemical determinations of the uranium content in Rand gold ores were made on samples collected by Bourret. It is, however, not known what figures were obtained.[107] The results were regarded as sufficiently important to justify an urgent approach to the South African Government regarding the possibilities of extraction and recovery of uranium.

General Smuts, on his return from London in 1944, immediately had an estimate made of the uranium potential in South Africa. The areas that were specifically mentioned were the Gordonia district in the North Western Cape Province, and the Swakopmund district in South West Africa. Smuts brought the exploitation of uranium in South Africa and South West Africa under control by War Measure No. 70 of 1945. Under this regulation anyone who discovered uranium would have to notify the authorities, and no unauthorised person would be allowed to search, prospect or mine for uranium. The export of ores was prohibited and no substance would be allowed to be extracted from uranium ores.[108]

General Smuts had taken a keen interest in uranium. Historical accident had brought him into contact, and after a time into friendship, with the Danish nuclear physicist, Niels Bohr. Smuts's "unflagging interest" in the search for uranium in South Africa, his deep involvement in military decisions in South Africa, as well as in the British planning of the grand strategy of the Second world War, must

106 CS McLean: "The Uranium Industry of South Africa", **JCMMS**, 54, April 1954, p. 346; L Taverner: "A Historical Review ...", **JSAIMM**, 57, November 1956, p. 126.

107 L Taverner: "A Historical Review ...", **JSAIMM**, 57, November 1956, p. 126.

108 (CAP) Proclamation No 212 of 1945 (War Measure No 70 of 1945) signed by WJ de Wet and CF Stallard, Smuts Collection A1, File 171, no 44; AR Newby-Fraser: **Chain Reaction**, p. 21.

be taken into account in the history of uranium in South Africa. Although he had no advance knowledge of the decision to drop the atomic bomb, he endorsed that decision after the event.[109]

An important aspect to consider in this respect was Smuts's knowledge of the changing relationship between the United States and Britain on the one hand, and the Soviet Union on the other. The Yalta Declaration (February 1945) on Poland had provided that the then Provisional Government would be re-organized on a broader democratic base. By this the West meant a parliamentary regime based on free elections. The Soviets were determined to achieve a position of dominance in Eastern and Central Europe. Although the West was prepared to see the re-establishment of Russian pre-1914 boundaries in Europe, it was far less ready to acknowledge the Balkans as a Soviet sphere of influence, nor did it want Poland a puppet of Russia. Much less was it willing to tolerate an indefinite Red Army occupation in Germany. The cold war began over Poland and the Balkans because of the rapid introduction of soviet-type regimes there even before the end of the war.[110]

Both Churchill and Roosevelt had kept secret the fast progress made in the progress of nuclear science. At the Yalta Conference (February 1945) they had still been uncertain of the outcome of the nuclear experiments. At the Berlin Conference held at Potsdam (2 August 1945) President Truman told Stalin of a new secret weapon in American hands. Since it was still uncertain whether Japan could be

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109 WK Hancock: **Smuts**, vol. 2, **The Fields of Force**, pp. 434-439; CS McLean: "The Uranium Industry of South Africa", **JCMMS**, 54, April 1954, p. 346. Donald B Sole, at the time in the South African Diplomatic Service in London (later South Africa's representative on the Board of Governors of the IAEA) arranged the first meeting between General Smuts and Dr Niels Bohr. Interview with DB Sole, 23.10.1989.

110 FR Dulles: **The United States since 1865**, pp. 489; FH Hartmann: **The Relations of Nations**, p. 454.

beaten without Soviet help, the Western powers conceded to Stalin advantages which they would otherwise hardly have conceded.[111]

Stalin gave his word at the Teheran and Yalta Conferences that the Soviet Union would attack Japan as soon as the German army was defeated.[112] The Potsdam agreements between the USA, Britain and the Soviet Union appeared to reaffirm the unity of purpose at Teheran and Yalta, but there were already intimations that Soviet policy was swinging toward the harsh assertion of wholly Soviet interests and the broad extension of a communist sphere of interest.[113]

British Prime Minister, Clement Richard Attlee (1883-1967), wrote to Smuts 31 August 1945. He said that as a result of the atomic bomb most problems of foreign policy and defence would have to be considered from a new angle. Many principles that up to that time had been accepted as axiomatic would possibly have to be amended or discarded. Attlee suggested to Smuts that in order to maintain understanding and trust between the great powers a world organization should be established. World safety would lie in collective security. He was aware that during the Berlin Conference there were signs that the wartime alliance was falling apart.[114]

Considering that Smuts played a prominent role in international politics at the time, he must have had considerable insight into the vital necessity of uranium for those nations who wished to preserve the peace after the war. No matter how fearful the prospects of atomic warfare must have been, it was a factor that would have to be dealt

111 David Thomson: **Europe Since Napoleon**, pp. 800-801. At Potsdam the Allied leaders were President Truman, British Prime Minister Clement Attlee (Labour Party) and Stalin.

112 WS Churchill: **The Second World War**, p. 941.

113 FR Dulles: **The United States since 1865**, pp. 488-489.

114 J van der Poel (ed.): **Selections from the Smuts Papers**, vol. VII, p. 67, Letter 679 from CR Attlee to JC Smuts, 31 August 1945.

with in future international relations. Therefore, it is understandable that Smuts would have given much support for the post-war investigation into South African gold ores for the purpose of extracting uranium.

In 1945 General Smuts approached CS McLean, then President of the Transvaal Chamber of Mines, to discuss a matter which he described as being "of vital importance to the country."[115] At that interview in Pretoria McLean learned that there was a desperate need on the part of the United States and Britain to obtain uranium, and that the Prime Minister wished to know how the magnitude of the Witwatersrand deposits could be ascertained. McLean pledged the full co-operation and assistance of the Chamber of Mines. After that he reported the matter to his colleagues on the Gold Producers' Committee and events began to move rapidly.[116]

In collaboration with the Transvaal Chamber of Mines it was decided that research on the extraction of uranium would be carried out by the Minerals Research Laboratory, under the direction of Professor L Taverner. The name of the Laboratory, however, would change to "Government Metallurgical Laboratory" (GML) to give greater recognition to the fact that the Government was financing the laboratory, and that the laboratory was originally established to give special consideration to the investigations submitted by the Government Mines Department. According to J Levin, the name did not draw attention to the essential function of the organization which was to promote the exploitation of minerals.[117] It was the GML's

115 CS McLean: "The Uranium Industry of South Africa", **JCMMS**, 54, April 1954, p. 346. The Chamber of Mines deals with all questions, directly and indirectly concerning the mines: labour, taxation, laws dealing with mines, etc.

116 The Gold Producers Committee of the Chamber of Mines acted as the selling agency. CS McLean: "The Uranium Industry of South Africa", **JCMMS**, 54, April 1954, p. 346; CS McLean's reply to Dr AJA Roux, "Atomic Energy Research and Development Programme of South Africa", **SA Mechanical Engineer**, 9 December 1959, p. 116.

117 (MLA) J Levin: **The Story of Mintek**, pp. 6-7, 80-82.

responsibility to undertake an extensive research programme of South Africa's uranium ores in the following years.

Many employees of the gold mining industry were seconded to the GML to assist with the programme. It was important that the gold mining industry had, in the Chamber of Mines, an established organization which could quickly, effectively and efficiently adapt itself to uranium investigation. While the different Mining Groups were individually quite capable of developing their own plants, this co-operative effort, through the Chamber of Mines, assisted greatly to accelerate matters. McLean stressed the fact that the existence of a system of joint consultation and co-operation through the Chamber of Mines, which the many units of the gold mining industry - administrative, productive and exploratory - had for a long time enjoyed, was invaluable in dealing with the importance and urgency of the uranium investigation. It proved once more, as on so many occasions during the history of the gold mining industry, the importance of the Chamber of Mines, not only to the industry, but to the country as a whole.[118]

118 CS McLean: "The Uranium Industry of South Africa", **JCMMS**, 54, April 1954, p. 347.

Professor L Taverner, Director of the Minerals Research Laboratory and Government Metallurgical Laboratory (1940-1958).

(Source: J Levin: **The Story of Mintek, 1934-1984**)

CHAPTER THREE

THE ESTABLISHMENT OF THE SOUTH AFRICAN URANIUM INDUSTRY, 1945-1956

Between 1945 and 1956 the basis of the South African uranium industry was laid. Towards the end of 1945 samples of selected uranium-bearing gold ores from specific Witwatersrand mines were submitted for examination to the Government Metallurgical Laboratory as well as to laboratories in the United States, the United Kingdom and Canada. The combined effort of these laboratories to find the most economical method of extraction of uranium from the gold ores was of great value for the advancement of chemistry and metallurgy relating to nuclear energy research. Both General Smuts and later the National Party realised the urgency to introduce legislation to control uranium and nuclear energy development. It was essential that South African scientific research should be co-ordinated and research facilities be instituted where South African nuclear physicists and scientists could be trained. The result was the founding of the National Physical Laboratory and the construction of the Pretoria Cyclotron.

Combined Investigations in the Extraction of Uranium

When the Government Metallurgical Laboratory was established the name of the controlling committee was changed from Advisory Committee to Management Committee. The Management Committee did much more than "advise" the Minister of Mines on the running of the Laboratory. The change of name of the Committee was accompanied by a change of composition: the University of the Witwatersrand's representation was increased by two members and their alternates, and the Director appointed was professor Leonard Taverner, also a member of the University staff. Heads of the

Minerals Development Section and the Government Chemical Laboratory were excluded, whereas members of the Mines Department and Geological Survey were included.

The first meeting of the Management Committee took place in July 1944. Although the Management Committee was nominally responsible for all work done at the Laboratory, it had no control over the uranium project because the effective control of that work lay with other bodies. Initially it was the State itself that assumed responsibility for the project.[1]

The overall effect of the Second World War (1939-1945) on the Minerals Research Laboratory was largely predictable. Activities at the Laboratory were increasingly directed towards helping the country to find substitutes for materials and minerals that were in short supply or unavailable.[2] By 1945 mineral research was well established in the Union of South Africa.

In Spring 1945 Professor GW Bain and Dr CF Davidson, then Chief Geologist of the Atomic Energy Division of the Geological Survey of Great Britain, visited the Union. During this Government-sponsored visit arrangements were made through Dr LT Nel of the South African Geological Survey, for underground examination of several mines. This was done using a portable type of Geiger-Müller counter* supplied from the United States. It has always been assumed that this was the first occasion on which a Geiger counter was employed underground in South Africa, but some doubt arises as to whether Weston Bourret (in 1944) used a similar type of instrument for his earlier surveys.[3]

In order to asses the potentialities of the Rand mines, Professor Bain requested that the collection of ore samples be made by the Geological

1 (MLA) J Levin: **The Story of Mintek**, pp. 80-84.

2 **Ibid.**, p. 62.

3 L Taverner: "An Historical Review...", **JSAIMM**, 57, Nov. 1956, pp. 125-127.

Survey. These ore samples would be the initial step in a programme of chemical metallurgical investigation. A programme was undertaken jointly by the Massachusetts Institute of Technology Laboratory (MIT) in the United States of America, the Chemical Research Laboratory at Teddington, Great Britain, the Bureau of Mines Laboratory, Ottawa and the Government Metallurgical Laboratory in the Union with the ultimate aim of producing a uranium concentrate sufficiently pure as to be acceptable to future uranium refinery plants in South Africa.[4] It should be noted in connection with the roles of the Geological Survey, and particularly that of the GML, that the overall uranium project was conducted at the instigation and with the active co-operation of the Combined Development Agency. They would promote and encourage the developments of the South African uranium industry with financial and technical assistance.[5]

A collection of a series of 400 kg samples were made from each of the following mines, Blyvooruitzicht, Vogelstruisbult, Western Reefs and East Daggafontein. The samples from each mine were split into three portions: one portion of each was sent to the above laboratories involved in the research programme. After a short interval a further request was received for 5 000 kg samples from the four mines. The ores had to have a specified minimum content. These samples were all obtained by selective mining, in other words they had very high values for both gold and uranium. Professor Taverner stresses the fact that these samples were of particularly high grade. He believed that

4 The experimental work in the USA was done at the Watertown Arsenal, where security precautions could readily be maintained, under the guidance of Professor AM Gaudin of the Massachusetts Institute of Technology (MIT). The reports on the work came through Gaudin and the MIT and the work described is therefore generally, but incorrectly attributed to MIT itself. It was the Manhattan Engineer District that originally requested Gaudin to organize an investigation for the flotation recovery of uranium low-grade ores. Gaudin began work on South African ores in March 1946. J Levin: **The Story of Mintek, 1934-1984,** p. 96; RE Robinson and RG Velthuis: "The Ion Exchange Process as applied to Uranium Extraction", **Uranium in South Africa,** 1946-1956, vol. 1, p. 332.

5 (MLA) J Levin: **The Story of Mintek, 1934-1984,** p. 91; (SAB) J Levin: "Concentration Tests on the Gold-Uranium Ores of the Witwatersrand for the recovery of Uranium", **Uranium in South Africa**, vol. I 1946-1956, p. 345.

because of this the United States authorities at that time may have regarded the Rand deposits as of much higher grade that they actually were. The ores may not have attracted the serious and urgent interest they did, if the correct value of the ore, as mined, had been fully realised. It was difficult to assess accurately the uranium content of very low grade ores at the onset of the investigation. Underground determinations by radiometric methods could have been incorrect owing to contamination of stopes* with uranium-rich dust from previous blasting operations. Radiometric determinations that were made underground were appreciably higher than the duplicate determinations made on the same sample after it was brought to the surface. The Geiger counters available at that period were relatively insensitive instruments as compared with those available in later years.[6]

In his report to the Department of Scientific and Industrial Research in London, in October 1945, on his visit to South Africa, Dr Davidson said: "Present evidence appears to indicate that the Rand may be one of the largest low-grade uranium fields in the world."[7] It was to the advantage of South Africa that this conclusion was made, considering Professor Taverner's doubt of accurate initial calculations. In 1945-1946 uranium was a scarce commodity and low-grade deposits would have attracted attention if suitable methods could be found to extract the metal. It was of particular importance to the country that the laboratories of the USA, Britain and Canada were involved. This combined international research would be the first full-scale nuclear energy research programme in South Africa.

6 L Taverner: "An Historical Review...", **JSAIMM**, 57, Nov. 1956, pp. 127-129. Professor AM Gaudin was one of the world's most prominent persons in the development of mineral-processing science. He may be regarded as a contender for the title of the foremost mineral-processing scientist. Gaudin's laboratory at the Watertown Arsenal was staffed by prominent metallurgists and chemists. Gaudin made several visits to South Africa. J Levin: **The Story of Mintek, 1934-1984**, pp. 86-97.

7 CS McLean: "The Uranium Industry of South Africa", **JCMMS**, 54, April 1954, p. 346.

The most economical method for the extraction of uranium had to be found and an exchange of knowledge took place between the laboratories concerned. This combined effort was of particular significance to the South African uranium industry, and also for the advancement of chemistry and metallurgy relating to nuclear energy research. It stimulated interest in the metal and encouraged those involved to try and establish the most economic and successful method to extract the metal. This research would be a basis for further programmes in nuclear chemistry. When concentration tests were commenced in December 1945, the problem was to recover an unknown mineral in an invisible form and in extremely small proportion. It appeared evident that flotation would be the most likely method of concentration, and in the initial tests this was applied in an analytical manner, to fractionate the ore and determine the association of the uranium with the other components of the ore. The first series of the flotation tests was carried out on the high-grade material from Blyvooruitzicht which had the highest uranium content of the four samples submitted for the initial test-work. The results which indicated a total recovery of 60 percent, of the uranium in combined concentrates of 12.5 percent-weight, were considered promising and were according to J Levin "unexpected".[8]

In February 1946, the Prime Minister, General Smuts, appointed a Uranium Research Committee. This Committee took over the responsibility of the uranium project on behalf of the State. On it were represented the Gold Mining Industry, the Department of Mines, the Department of External Affairs and the Geological Survey. The Committee was under the chairmanship of Dr BFJ Schonland. Dr Schonland played an important role in advising the Prime Minster on matters relating to uranium. The Committee had to co-ordinate action between the various investigations concerning uranium that were in progress, and programmes for the future. It dealt with information

8 (SAB) J Levin: "Concentration Tests on the Gold-Uranium Ores of the Witwatersrand for the Recovery of uranium", **Uranium in South Africa, 1946-1956**, vol. I, pp. 345-346.

whether classified or of general interest. In this respect the Committee was in close association with the State Departments concerned with uranium extraction and research in the USA and Britain. This is of significance in estimating the extent of the co-operation between South Africa and the foreign powers. In order to execute its many tasks the Uranium Research Committee was assisted by various sub-committees.[9]

At the first meeting of the Uranium Research Committee on 8 March 1946, the results of the preliminary test work were reported. A recovery of over 40 percent of the total uranium content present in a rich Blyvooruitzicht sample was reported in a carbon and sulphide concentrate of approximately four percent of the original weight. It was at this meeting that the Technical Sub-committee of the GML was appointed under chairmanship of Professor Taverner, Director of the Laboratory.[10]

According to TK Prentice, the development of a metallurgical process for the production of uranium was carried out by the Technical Sub-Committee of the GML. In 1946 the Technical Sub-Committee comprised the Government Mining Engineer; the gold-mining industry which was represented by CS McLean of the Gold-Products Committee; by six senior consulting metallurgists (of which TK Prentice was one); and by R Craib (a mechanical engineer).[11] In this way dove-tailing of the efforts of industry with those of the State organizations involved in the uranium project was achieved.

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9 (MLA) L Taverner: "An Historical Review...", **JSAIMM**, 57, Nov. 1956, p. 129; CS McLean: "The Uranium Industry of South Africa", **JCMMS**, 54, April 1954, p. 346; J Levin: **The Story of Mintek, 1934-1984,** pp. 90-91; **Assembly Debates**, vol. 64, 6 August-10 September 1948, col. 725-726.

10 Dr OAE Jackson, TK Prentice and Y Wartenweiler were appointed to serve on this Committee, which held its first meeting in April 1946; (MLA) L Taverner: "An Historical Review...", **JSAIMM**, 57, Nov. 1956, p. 129.

11 (SAB) TK Prentice: "Discussion" in JJP Dolan: "Co-operative Construction of Uranium Plants", **Uranium in South Africa**, 1946-1956, vol. I, p. 408.

It seems that the "Technical" Sub-committee and the "Metallurgical" Sub-committee as described by L Taverner comprised the same people.[12] Later (in 1946 and 1947) men with technical expertise were seconded from predominantly the gold mining industry. African Explosives and Chemical Industries (AECI) was to assist in advancing the complicated uranium project and to increase the rate at which it was necessary to get through much experimental work.[13]

By April 1946, a recovery of 53 percent uranium oxide was obtained.[14] This was recovered from a Blyvooruitzicht sample. It is, therefore, understandable why it was decided to concentrate attention on the ore samples of this mine.[15]

The GML made significant progress, even during the early stages of investigation. Cooper's paper had indicated the presence of uraninite, but there was doubt whether uraninite was the only uranium-bearing mineral and mystification as to why no-one had seen uraninite in the rock. The particle size of uraninite is usually minute. The Laboratory commenced a detailed mineralogical examination of the Blyvooruitzicht ore and had ascertained that a considerable portion of the uranium content was locked as minute particles of uraninite in a hydrocarbon mineral called thucolite. Thucolite is an uranium-bearing variety of the so-called "carbon" which is well-known to Rand mines. All assay

12 L Taverner: "An Historical Review...", **JSAIMM**, 57, Nov. 1956, p. 133.

13 (MLA) J Levin: **The Story of Mintek, 1934-1984,** pp. 103-104.

14 Results obtained April 1946:

	Percent U_3O_8 recovery carbon and weight sulphide concentrate	Percent concentrate
Blyvooruitzicht	53	5
East Daggafontein	25.5	7,3
Vogelstruisbult	22.3	5
Western Reefs	36	5,25

L Taverner: "An Historical Review...", **JSAIMM**, 57, Nov. 1956, p. 130.

15 (SAB) J Levin: "Concentration Tests on the Gold-Uranium Ores of the Witwatersrand for the Recovery of uranium", **Uranium in South Africa,** 1946-1956, vol I, pp. 345-346.

samples at the Laboratory were, therefore, calcined* at a low temperature to remove the hydrocarbon (thucolite) and expose the uranium minerals before bringing them into solution for analysis. These initial samples were assayed by D Millin in the Metallurgy Department of the University of the Witwatersrand and, ultimately, the results he provided proved to be the most accurate.[16]

Uranium estimates were made with an electroscope* (loaned to the GML by the Bernard Price Institute for geophysical research) using chemical standards prepared by the GML, based on chemical assay values obtained by the method devised by Millin. Accurate physical determinations were being obtained in this manner. In addition, a B (beta) counter,* which Professor Bain had agreed to supply at the request of Professor Taverner, was brought to the Union by Dr SH Haughton (Vice-Chairman of the Uranium Research Committee, formerly Director of the Geological Survey) on his return by air from the United States, and was in use at the Laboratory. Dr Haughton also obtained the American methods of chemical analysis, which Professor Bain had previously agreed to provide, and handed them over to Professor Taverner. The American methods differed from those that the GML had developed from a study of analytical literature, and the Laboratory continued to use its own methods, as being more suitable for South African ores. Later they changed to other methods.[17]

As far as the work done at the GML was concerned, Professor Taverner played an important role. He was called upon to travel extensively. He was convinced that personal association with American

16 (MLA) Uranium never occurs in a pure form, but is to be found as a mixture of hydrocarbon and pitchblende or uraninite, or both. To this type of material the name "thucolite" was given by a Canadian mineralogist in 1928. The word "thucolite" is derived from the chemical symbols of the main constituents of the mixture, namely, thorium (Th), uranium (U), carbon (C), hydrogen (H), oxygen (O)-lite. "Uranium", **Industrial Review of Africa**, 4(7), Jan. 1953, p. 23; J Levin: **The Story of Mintek, 1934-1984,** p. 95. It was Dr WR Liebenberg at the GML who described the thucolite after the mineralogical examination of the products of the first tests.

17 L Taverner: "An Historical Review...", **JSAIMM**, 57, Nov. 1956, p. 130; J Levin: **The Story of Mintek, 1934-1984,** pp. 93-95.

and British scientists was invaluable. It certainly accelerated the rate of progress. Owing to secrecy stipulations, it was a requirement that all correspondence and reports should be conveyed through diplomatic channels. Normal airmail correspondence took several days at most, the transmission of reports occupied several weeks owing to the number of offices through which the documents passed.[18]

The Laboratories partaking in the search to find a method to extract the uranium started off by putting much time and effort into the flotation and gravity* methods of extraction. The uranium in the ore, that could not be recovered initially, was found to be present in minute particles, either free uraninite or uraninite associated with sericitic* minerals. Experiments were conducted with a fatty acid float,* but these proved most discouraging. The carbon sulphide flotation* technique showed greater promise. Later it was learned that at the same time a considerable amount of work was being undertaken at the MIT on the fatty acid flotation procedure, but on the basis of a limited concentration, the aim being to obtain maximum recovery. These tests were being made in the absence of lime* and using distilled water* for flotation. Both these conditions were later found to be essential for optimum recoveries.[19]

At this point in the course of the investigation in South Africa, there was an absence of knowledge regarding the grade and quantity of the product required and also its monetary value.[20] The British Authority concerned with Atomic Energy was prepared to discuss these aspects with representatives from the Union. Dr Schonland and Professor Taverner took advantage of this opportunity and travelled to Britain in July 1946. During this visit they had the privilege of visiting both

18 L. Taverner: "An Historical Review...", **JSAIMM**, 57, Nov. 1956, pp. 131, 132, 133 and 136.

19 **Ibid.**, pp. 130-131.

20 (SAB) Vid. J Levin, "Concentration Tests on the Gold-Uranium ores of the Witwatersrand for the Recovery of Uranium", **Uranium in South Africa, 1946- 1956**, vol. I, p. 344.

Harwell and Springfield. It was indicated to the visitors that the GML should aim at a product containing approximately 98 percent uranium oxide (U_3O_8) although material of much lower grade would be acceptable. At that stage quantities were not discussed, but it became evident that any anticipated output would be bought at a price based on cost of extraction plus a reasonable margin of profit. At that point recoveries of 65 percent had been made from rich ore, using carbon-sulphide flotation techniques. In the meantime flotation tests had been done on a run-of-mine* samples composed of a mixture of ball-mill feed* and crusher slimes.* The recoveries were disappointingly low as compared with the rich ore results.[21]

In December 1946, General Smuts in company with General Groves, Director of the Manhattan Project, had visited Professor Gaudin at MIT and had been informed of the progress made there with rich bulk ore* sample. Immediately after his return Professor Taverner was instructed to proceed to the USA for discussions with Professor Gaudin.[22]

According to Professor Taverner, operating with only rich ore, metallurgists had succeeded in obtaining 80-85 percent recovery of uranium and 96-99 percent recovery of gold in 20-25 percent weight of the original ore. They considered the investigation had progressed to the stage requiring pilot plant development. The policy to be followed in respect of pilot plant test work was fully discussed and the advantages of erecting any pilot plants required in South Africa, were accepted by the United States authorities. It was explained that steps had already been taken to construct a pilot flotation plant at Blyvooruitzicht mine. The MIT was undertaking investigations on South African samples on a much larger scale than the Government Metallurgical Laboratory in South Africa. A special laboratory had been provided and equipped, employing many more personnel than

21 L Taverner: "An Historical Review...", JSAIMM, 57, Nov. 1956, p. 131.

22 **Ibid.**, p. 131.

were available in South Africa, more particularly in the analytical section.

Professor Taverner was convinced that his and Dr Schonland's visit proved of the greatest value in hastening developments, and provided proof of the advantages derived from personal contacts, particularly where secrecy requirements were involved. Arrangements were made for more rapid and, where possible, more direct interchange of information. Future programmes of work were discussed and correlated and more suitable provision was made for the supply of representative ore samples. During their visit arrangements were made for Professor Gaudin to visit the Union. After discussions had taken place it was decided that Professor Gaudin's visit would be postponed for a couple of months, by which time his Laboratory would have completed tests on a run-of-mine sample by the flotation procedure they had so successfully developed.[23]

It is significant that the Government Metallurgical Laboratory concentrated its attention on run-of-mine ore. Even at this early stage it was realised that if the established gold mines could directly be involved and uranium could be extracted from run-of-mine ore, it would certainly minimise costs. A process for the concentration of uranium can be coupled with the gold extraction in one of three ways. Firstly, uranium concentration can precede cyanidation. Secondly, uranium concentration can follow cyanidation. Thirdly, uranium and gold can be concentrated simultaneously by flotation and extracted separately from the concentrate. The second method was favoured by the Canadian investigators of the problem. MIT favoured the third possibility. South Africa advocated extraction from cyanide residues*, but considered that the other possibilities should be explored to ensure

23 L Taverner: "An Historical Review...", JSAIMM, 57, Nov. 1956, pp. 128, 130-132.

that no promising economic process for the extraction of gold and uranium was disregarded.[24]

Before Dr Schonland and Professor Taverner returned to the Union they took the opportunity of visiting Parsons and members of his staff at the Canadian Bureau of Mines Laboratory in Ottawa. This laboratory had been supplied with rich ore samples from Vogelstruisbult and Western Reefs, and had carried out a series of flotation tests very similar in character and results to those made at the Government Metallurgical Laboratory. This laboratory, possibly as a result of its close association with the Canadian Government as a uranium producer, had made a very valuable contribution to the development of analytical chemical methods suitable for the determination of small quantities of uranium in the presence of interfering impurities. The application of the mercury cathode* is an excellent example. This method was subsequently adopted by the Government Metallurgical Laboratory.

By the time Dr Schonland and Professor Taverner returned to the Union it was evident that some integration of the gold extraction process and uranium recovery was a possibility. They reported to the Prime Minister and JH Hofmeyr, Minister of Finance, in person. By that time it had become evident that uranium could be extracted and the method selected would be determined by the quantity required and economic considerations. Bearing this in mind, the integration of the gold extraction process and uranium recovery would likely prove to be a necessity. The Prime Minister informed the Transvaal Chamber of Mines very fully as to the position as it then existed, and they, on behalf of the mining industry, offered to provide their fullest co-

24 J Levin: "Concentration Tests on the Gold-Uranium ores of the Witwatersrand for the Recovery of Uranium", **Uranium in South Africa,** vol. I, p. 344.

operation and to accept responsibility for the construction and operation of pilot plants.[25]

The Uranium Research Committee agreed to the installation of a pilot flotation plant at Blyvooruitzicht mine. Its main purpose was to provide sufficient carbon and sulphide concentrates to enable test work on the later stages of recovery to proceed. At the time there was also a small, continuous flotation unit available at the Government Metallurgical Laboratory.[26] A considerable amount of work was done at the MIT laboratories and GML on flotation methods of concentration, but owing to the relatively low recoveries obtainable and the need for maximum output, it was realised that the most economical and practical first step in the uranium recovery process would be the acid leaching* of the total cyanide residues.[27]

The acid leaching process is the method enabling the simultaneous extraction of both gold and uranium. The first leaching tests were made at the Government Metallurgical Laboratory in October 1946 from a carbon-sulphide concentrate.[28] These tests were done at this early stage because the process enabled simultaneous extraction of gold and uranium. Recoveries of 99 percent of the gold and 95 percent of the uranium were initially obtained, but the reagent requirements and

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25 L Taverner: "An Historical Review...", **JSAIMM**, 57, Nov. 1956, pp. 132-133.

26 **Ibid.**, p. 133; J Levin: "Concentration Tests on the Gold-Uranium ores of the Witwatersrand for the Recovery of Uranium", **Uranium in South Africa**, 1946-1956, vol. I, p. 347.

27 RE Robinson and RG Velthuis: "The Ion Exchange Process as applied to Uranium Extraction", **Uranium in South Africa**, 1946-1956, vol. 1, p. 332.

28 (SAB) PA Laxen and MG Atmore: "The Development of the Acid Leaching Process for the Extraction and Recovery of Uranium from Rand Cyanide Residues", **Uranium in South Africa**, vol. 1, 1946-1956, p. 315.

consumptions were found to be very excessive.[29] For this reason tests on flotation procedures were continued.

The Prime Minister invited Professor Gaudin, together with Professor Bain and Dr Davidson to visit the Union for the purpose of making a general survey of the local gold mining conditions, including the cyanide practice in the gold mines. This deputation arrived towards the end of March 1947, by which time Professor Gaudin had completed preliminary flotation tests by the MIT procedure on run-of-mine ore. The process required an exceptionally fine grind of ore and this would involve considerable capital expenditure. The conclusion of Professor Gaudin's visit became an appropriate moment to review the whole position and to decide on the future programme of investigation. It was decided that the MIT procedure would not be applicable to existing producers. The other alternatives were to leach the cyanide residues (from the gold mining process) as a whole or obtain a concentrate from the cyanide residues by carbon and sulphide flotation methods, and leach this product.[30]

The Government Metallurgical Laboratory was not in a position to undertake a comprehensive leaching investigation, mainly owing to lack of adequate personnel for the large number of routine chemical assays required, but also because of insufficient accommodation. Professor Gaudin's offer to be responsible for this aspect of the future programme, until such time as these deficiencies could be corrected, was gladly accepted. The design of the pilot flotation plant at Blyvooruitzicht had been modified to make it adaptable for all types of flotation procedures envisaged. There was a pilot flotation plant at Western Reefs which could be made available for experimentation.

By the end of 1947 it was essential that a pilot plant be put into full operation. This was necessary for further progress. Owing to delays in

29 L Taverner: "An Historical Review...", **JSAIMM**, 57, Nov. 1956, pp. 133-134.

30 **Ibid.**, p. 134.

the delivery of equipment for the Blyvooruitzicht pilot plant, the Western Reefs pilot plant was put into operation late in December 1947.[31]

The Metallurgical Committee (GML) was becoming more and more convinced that recovery by treatment of cyanide residues would be the most effective method and issued a directive that future investigation should proceed on this basis.[32] The pilot plants at Blyvooruitzicht and Western Reefs were enlarged to accommodate leaching sections and a third pilot plant was under construction at Sub Nigel Mine. A small pilot leach plant was also established at the Government Metallurgical Laboratory.[33]

Sulphuric* acid* plays as important a part in the recovery of uranium as that played by cyanide in gold production.[34]

In April 1948, the Governments of Great Britain and the United States offered their assistance in the provision of additional staff to hasten the process of investigation. Professor Taverner travelled to Britain, Canada and the USA in order to recruit personnel. (It was in mid 1948 that RR Porter, a metallurgist, then temporarily engaged by the MIT, was offered employment in South Africa. The MIT was concentrating on the leaching of the total gold residue and were obtaining excellent results. Professor Taverner paid a second visit to the Canadian Bureau of Mines Laboratory in Ottawa in 1948. Their own expanding

31 L Taverner: "An Historical Review...", **JSAIMM**, 57, Nov. 1956, pp. 132-135.

32 The "Metallurgical" and "Technical" Sub-Committees of the GML must be distinguished from the sub-committees established by the Gold Producers' Committee in November 1950. The Uranium Technical Sub-Committees: Metallurgical Committee and Mechanical Committee (of the Gold Producer's Committee) were appointed to investigate and advise on ways and means of achieving early uranium production. (SAB) DM Stuart: "The Supply of the Raw Materials Requirements of the Uranium Programme", **Uranium in South Africa**, 1946-1956, vol. 2, p. 14.

33 **Ibid.**, pp. 132-136.

34 See Technical Addendum: "Methods of Recovering gold and uranium."

programme of uranium investigation made it impossible for them to consider the release of any of their own personnel for service in the Union. This decision came as a disappointment, but not as a surprise. There were shortages of personnel in America and Britain. Professor Taverner visited the uranium refinery at Fort Hope and also, at the invitation of the United States Atomic Energy Commission, the vanadium plants recovering uranium in the Colorado plateau.[35]

The processes employed at these plants differed essentially from any process considered for the Rand. The main purpose of the visits was to examine the methods used in handling the products and to assess the health hazards to the operatives employed in the various operations. The health hazards had not been overlooked, since as early as 1946, it had received the attention of both the Uranium Research Committee and the Metallurgical Committee. Underground tests for the presence of radon had been conducted by Dr EC Halliday of the CSIR.[36] The quantities found were well below the minimum amount regarded as a health hazard. These results were anticipated in view of the very small concentration of uranium in South African ores, and no further underground testing was undertaken. The plants overseas had been dealing with a much richer ore for a number of years. They had not found it necessary to take any abnormal precautions. It was, therefore, decided that the pilot plants could be operated safely, provided that the usual precautions taken in the handling of poisonous materials were observed, together with the normal precautions in the use and handling of mineral acids.[37]

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35 L. Taverner: "An Historical Review...", **JSAIMM**, 57, Nov. 1956, p. 137.

36 Radon is a radioactive noble gas. It is produced as one step in a long chain of decays that starts with uranium-238 and terminates with lead-206. (See also radioactivity in Technical Addendum). As a result radon occurs in uranium mines. The inhalation of radon can lead to a form of lung cancer. TR Harrison et al (eds.): **Principles of Internal Medicine**, p. 144.

37 L. Taverner: "An Historical Review...", **JSAIMM**, 57, Nov. 1956, pp. 137-138.

In order to avoid duplication of effort, it was agreed by the Uranium Research Committee and the Combined Development Agency that Professor Gaudin's Laboratory at the MIT would concentrate its attention on the several alternative upgrading steps. The GML would meanwhile direct its efforts to the sulphuric acid-ferric sulphate leaching step on cyanide residues in the pilot leach units at the GML and on the mines.[38]

Acid-leaching produced a solution with large amounts of impurities and small amounts of uranium. The obvious way of separating uranium from the impurities seemed to be the precipitation* process. This method however, proved to be impossible and soon had to be replaced by the anion exchange* method. Research carried out at the Batelle Memorial Institute under the direction of HE Brosse and the Dow Chemical Company's Laboratories, California in 1949 indicated that anionic exchange would provide a complete and most satisfactory method for the recovery of uranium. Tests carried out by the MIT appeared very promising and a considerable amount of research was next devoted to the development of the anion exchange process.[39]

Research on the anion exchange project had progressed sufficiently for preliminary design work to be carried out in South Africa. This work related to the design and operation of the first complete leading pilot plants at the Western Reefs and Blyvooruitzicht gold mines. During the latter half of 1949 the GML pilot plant was closed down.) The Blyvooruitzicht pilot plant was the first in operation - this plant being commissioned on 31 October 1949. Many mechanical difficulties were experienced during the initial operating period. On 28 March 1950 the pilot plant at the Western Reefs Mine was commissioned and started up

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38 L Taverner: "An Historical Review...", **JSAIMM**, 57, Nov. 1956, p. 138; (MLA) J Levin: **The Story of Mintek, 1934-1984**, p. 91.

39 RE Robinson and RG Velthuis: "The Ion Exchange Process as applied to Uranium Extraction", **Uranium in South Africa**, 1946-1956, vol. 1, p. 336.

with little difficulty due to the experience gained at the Blyvooruitzicht pilot plant.[40]

The role of the GML in the co-operation work referred to above, was a special one. The Laboratory devoted a considerable proportion of its activities to the examination of reports received from the overseas institutions, duplicating the more promising tests reported, and determining the applicability of these tests, to the ores of the various prospective uranium producers. In addition the Laboratory initiated its own test-work, the results of which were conveyed to the overseas workers. Co-operation between the GML and overseas institutions was close, but this did not prevent the various problems being approached from different viewpoints.[41] The combined effort was, without doubt, of great advantage to South Africa.

Considering the effect of internal political policy on international relations in later years, it is significant that during the period 1946-1950 foreign countries were prepared to share their scientific endeavours in the field of uranium research with South Africa, even though it was a subject veiled in secrecy and guarded by stringent security precautions. During 1946-1948 Dr Malan's Reunited Nationalist Party was promoting a policy of apartheid among the White South African electorate. Racial segregation had a long history in South Africa, but in pre-war years external criticism of this policy was neither wide-spread nor sustained. Large parts of Africa and Asia were still Imperial domain and South Africa and the colonial powers had one feature in common: they felt responsible for the welfare of their non-white subject people. A number of Asian and African states pledged to

40 RE Robinson and RG Velthuis: "The Ion Exchange Process as applied to Uranium Extraction", and PA Laxen and MG Atmore: "The Development of the Acid Leaching Process for the Extraction and Recovery of Uranium from Rand Cyanide Residues", **Uranium in South Africa**, 1946-1956, vol. 1, pp. 325-326; and p. 336.

41 (SAB) J Levin: "Concentration Tests on the Gold-Uranium ores of the Witwatersrand for the Recovery of Uranium", **Uranium in South Africa,** vol. I, p. 343.

end racial discrimination within and beyond their borders. It was the elevation of apartheid by the Nationalist Government, that came to power in 1948, into an all-embracing political and social theory, and its implementation as a policy of large scale social engineering, that estranged foreign powers. South Africa found herself in a "cold war" situation and this would have far-reaching effects.[42] This would certainly apply also to nuclear energy research and, therefore, the extent of the combined programme of research, between the GML and foreign laboratories.

Atomic Energy Act

The South African Government thought it essential to introduce legislation to regulate the discovery of uranium and the scientific developments related to the extraction of uranium concentrated from South African gold ores. In 1945 the United Party Government introduced War Measure No 70 which exercised control over uranium. Under this Measure the sole right to search prospect and mine for, and to dispose of, uranium and thorium and to extract uranium and thorium from any substance, was vested in the State. War Measure No 11 of 1947 prohibited the grant of patents and the disclosure of information relating to the production of fissionable material and the production and use of nuclear energy.[43]

Towards the end of 1947, General Smuts and his United Party Government, realised that legislation had to be introduced to control uranium and nuclear energy activities in South Africa as War Measures

42 M Wilson and L Thompson: **The Oxford History of South Africa**, vol. II, pp. 478-479.

43 (CAP) Smuts Collection A1, File 171, no 44, Proclamation No 212 of 1945 (War Measure No 70 of 1945) signed by NJ de Wet and CF Stallard; Proclamation No 57 of 1947 (War Measure No 11 of 1947) signed by G Brand van Zyl and Sidney F Waterson; **Statutes of The Union of South Africa**, Act No 35 of 1948, section 32 (Repeal of War Measures No 70 of 1945 and No 11 of 1947).

No. 70 of 1945 and No. 11 of 1947, would expire on 30 June 1948. It was, therefore, necessary to have a comprehensive Bill to control all matters relating to uranium and the allied element thorium. General Smuts appointed a committee to discuss the prospective legislation. On the 23rd January 1948 the private secretary of the Minister of Mines, CF Stallard forwarded a copy of the Uranium Bill to General Smuts.[44] This Bill was to be discussed during a Cabinet meeting. However, the Bill was never introduced to Parliament by the United Party as the first parliamentary session in 1948 ended on 24 March of that year in preparation for the general election in May.

The salient features of the United Party draft Bill were the vesting in the State of the right of prospecting and mining for prescribed substances (uranium, thorium and other fissionable materials); the extraction, isolation, refining and purification of prescribed substances and the production and use of nuclear energy. The second feature was the establishing of an Atomic Energy Control Board under the chairmanship of the Minister of Mines. The Minister of Mines would be placed in control of prospecting and mining of prescribed substances. The Atomic Energy Control Board would be in charge of extracting and refining of prescribed substances. Patents and disclosure of information relating to the purification and use of prescribed substances for any purpose as well as the import, manufacture and use of radioactive isotopes would also fall under the charge of the Atomic Energy Control Board.[45]

The National Party Government that came to power in May 1948, regarded the legislation to control uranium and nuclear energy essential. At the Second Reading of the Bill, Eric Louw, the Minister of Mines, stressed the fact that in the interests of the state, as well as the public, nuclear power should be properly controlled. Not only the

44 (CAP) JC Smuts Collection A1, File 172, no 13, Letter from Private Secretary, Minister of Mines to Prime Minister JC Smuts dated 23rd January 1948: "Uranium Bill" to be introduced by Minister of Mines.

45 (CAP) JC Smuts Collection, A1, File 172, no 13, Draft Uranium Bill.

power, but the sources of that power. That he regarded as the main aim of the Bill. He mentioned that the Bill was substantially the same as the Bill which the Minister of Mines in the Smuts' Government had intended to introduce. The only additions that were made were payment of compensation to workers, male or female, who were injured, or who, in the course of their duties in connection with uranium, would contract some disease or other; provision was made for the Atomic Energy Board or Minister's representative to enter any land and to undertake certain work if the Minister had good reason to believe that that land contained uranium; and the Auditor General would have more control and power in connection with expenditure.[46]

During the Second Reading the Minister of Mines mentioned that the possibility of atomic energy for industrial purposes had been freely discussed, but its use as a terrifying weapon in the time of war, was the first consideration to be taken into account, particularly at that time of uncertainty in international relations. Uranium, the main mineral from which that energy could be manufactured, was found in South Africa. Because of its strategic importance and because it is regarded as a potentially dangerous mineral, it was essential, in the national interest, that it should be controlled.[47]

Uranium and thorium were described as "prescribed materials". The Act vested in the State the sole right to search, prospect and mine for prescribed material. The Minister of Mines was given power to authorise persons in companies to prospect and mine for prescribed material on his behalf.

The Act vested in the State the ownership of all prescribed material mined, extracted or isolated, just as it vested in the State the sole right to produce nuclear energy. The Act established an Atomic Energy Board, which was to comprise the Minister of Mines (who was to be

46 **Assembly Debates**, vol. 64, 6 Aug.-10 Sept. 1948, 23 August 1948, col. 722.

47 **Ibid.**

chairman), the Secretary of Mines (who was to be deputy chairman), the Secretary of External Affairs, the Secretary for Finance, the Government Mining Engineer, one person nominated by the CSIR, and, in addition, three persons appointed by the Minister, at least two of whom were to represent those engaged in mining operations in areas where prescribed material occur. Two representatives of the gold mining industry were thus nominated by the Minister to serve on the Board.[48]

The powers of the Atomic Energy Board were considerable, since it would act for the State in the ownership and disposal of all prescribed material. The Board also administered the provisions of the Act prohibiting the disclosure of any information relating to reserves of ore containing prescribed material, the annual output of such material, the price paid, and the extraction processes. The Board would derive its funds from moneys which would be voted annually by Parliament. The proceeds derived from the sale of uranium and radio-active elements would be paid into the Consolidated Revenue Fund. The Minister considered that the Consolidated Revenue Fund would be assured of an annual and by no means inconsiderable source of revenue.[49]

The Act made provisions with regard to inventions in connection with the production and use of atomic energy, and particularly with regard to the question of patents. This was to ensure that any research work done or inventions made in connection with prescribed materials, would remain the property of the State, and would not leak out to other countries. The Board had the right to sell the patent rights, subject to compensation. Any research worker in the sphere of nuclear energy would have to furnish full information with regard to his research work to the Atomic Energy Board. Any person obtaining such information, either from any person or as a result of his own research, would be

48 (GP) **Statutes of the Union of South Africa**, Act No 35 of 1948, Sections 1, 2, 3, 11 and 12.

49 **Ibid.**, Sections 13-17.

forbidden to communicate it to any person outside the Union. These provisions in connection with patents and the disclosure of information were essential in the interests of State security.[50]

After careful consideration and discussion with Dr Schonland, heads of departments, and chairman of the Public Service Commission, the Minister decided that the staff of the Atomic Energy Board and the staff required for its work would not be appointed from the ranks of offices in the Public Service. The work would be of a highly specialized nature and the country had at that time few, if any, such specialized persons. Highly qualified personnel would have to be imported.[51]

After the Second Reading of the Atomic Energy Bill, General Smuts addressed the House of Assembly. Smuts, having been in the fortunate position of being involved with uranium during the war, as well as the preliminary search for the metal, and having played a role in the drafting of the Bill, could give an informative speech on the subject. Smuts stressed the fact that uranium was a rare element. Within the first minutes of his address he actually repeated the fact no less than six times. He informed the Assembly that great progress had been made in the extracting of uranium from the gold ores of the Witwatersrand mines. Of particular significance was Smuts' knowledge at that early stage, of the progress that had been made in the utilization of nuclear power for industrial purposes. He said that the sources of energy in the world were being tapped to an unprecedented extent. Petroleum resources, as well as coal resources, although very much larger, were being consumed at a very great rate. Uranium and atomic energy were sources of energy infinitely more powerful than coal and oil. Nuclear energy would turn out to be of significant industrial importance. He commented on United Nations Organization having established the Atomic Energy Commission as a controlling authority and how that

50 (GP) **Statutes of the Union of South Africa**, Act No 35 of 1948, Sections 18-28.

51 **Assembly Debates**, vol. 64, 6 Aug.-10 Sept. 1948, 23 August 1948, col. 729.

Commission, as many others, had not been successful.[52] He believed that the whole question of peace and war and of world security would begin to revolve around the question of uranium. Because of this an immense responsibility was therefore being placed on South Africa.[53]

Of particular significance in the history of uranium and the development of nuclear power in South Africa, was the contribution to the debate made by MJ van den Berg, NP Member of Parliament for Krugersdorp. He wanted to know what was going to happen to South Africa's uranium. Was it going to be simply regarded as an article of commerce, because it was in world-wide demand. He suggested that the Minister of Mines inform the House as to its use in industrial development in South Africa. He believed that if this important mineral could be used in industrial development, the day would come when South Africa would be able to compete industrially with other countries of the world.[54] This address by Van den Berg was an early indication of what would later become more pronounced: South Africa should use its uranium and advancement in nuclear research to the benefit of the country's mining industry, industrial development, commerce and armaments programme.

The Atomic Energy Act (Act No 35 of 1948), came into operation on 1 January 1949. The stipulations laid down by the Atomic Energy Act and the Atomic Energy Board of South Africa being bound by the terms of the agreement with the Combined Development Agency, cast a blanket of secrecy over the production and sale of uranium. The Agency prohibited the release of information concerning the price paid for uranium from South African producers. This they believed would jeopardise security in the nuclear energy programme of the free nations

52 General Smuts was referring to the Atomic Energy Commission set up by the United Nations Organization in January 1946.

53 **Assembly Debates**, vol. 64, 6 Aug.-10 Sept. 1948, 23 August 1948, col. 731-734.

54 **Ibid.**, col. 735-736.

of the Western world. The gold mining industry, most closely associated with the production of uranium, found the question of secrecy an embarrassment. As plans for uranium plants were projected and construction later commenced, the embarrassment increased. The gold mining industry had always followed a policy of issuing to the public the fullest possible information concerning its operations. The industry felt that the Government should urge the overseas associates to allow the release of information, compatible with security requirements, so as to enable the shareholders of the uranium-producing companies to assess the value of their investments. The secrecy stipulations concerning the production of uranium were eased, to a certain degree, during the 1950's. The publication of articles on the subject was permitted.[55]

Furtherance of research facilities: The National Physical Laboratory

The combined research on South African uranium ores was only a beginning. If South Africa wished to secure contracts for the sale of uranium, provision would have to be made for the furtherance of research. South Africa would have to establish facilities where the scientific knowledge, so rapidly accumulated in the American war effort, could be practised by South African scientists.

The Manhattan Project, under which the United States Government built in a relatively short period, such facilities as large plants for the enrichment* of uranium* (using the gaseous diffusion method) for the extraction of plutonium and for the production of heavy water,* was evidence of the advancements made in nuclear physics, nuclear chemistry and engineering. Test and research reactors were established, as well as weapon production facilities. The Manhattan

55 (CAP) "Publication of Information Relating to Uranium", October 1952, Archives of the Secretary of Information, 1939-1966, Information 41, File 21/12/ vol. 1; CS McLean: "The Uranium Industry of South Africa", **JCMMS**, 54, April 1954, pp. 354-355.

Project was a monumental engineering feat. During the war, in the course of development of the atomic bomb, a large team of scientists and engineers had been assembled, who had gained considerable knowledge and developed many new techniques in the field of nuclear energy. Engineers in those early programmes had to learn about a host of nuclear-related subjects ranging from reactor theory and reactor control to radio-activity and the behaviour of material under irradiation.* During the Manhattan Project nuclear engineers were educated by senior and more experienced nuclear scientists and physicists, first through personal discussions and later through seminars, lectures and classes. Many of those who entered this new field were first educated in other engineering disciplines - mechanical, electrical, chemical, civil, etc. Nuclear engineering is a strongly interdisciplinary activity. Two schools of reactor technology were established, one in Tennessee at Oak Ridge National Laboratory and another in Illinois at Argonne National Laboratory.[56]

The explosion of the atomic bombs, overseas weapons production, as well as other factors such as the combined investigations into uranium done by the GML and the other laboratories overseas, made South Africans aware of the advancement that had taken place in all branches of engineering during the war. In the course of the joint research programme on South African uranium ores pilot plants had been established and the laboratories were provided with the necessary apparatus and equipment. It was also realised that South African scientific research should be co-ordinated. As a result of this awareness, and the fact that international relations demanded that a nation could not be ignorant in these fields of science and engineering, the United Party Government under General Smuts initiated the establishment of the South African Council for Scientific and Industrial Research (CSIR) in October 1945. The President of the Uranium

56 (AEC Archives) AJA Roux: **Atomic Energy Research and Development, Part I, United States**, 3. March 1958, pp. 84-89.

Dr BFJ Schonland.

(Source: Atomic Energy Corporation)

Research Committee, Dr BFJ Schonland, was appointed as the first President of the CSIR.

Dr Schonland was a scientist of considerable standing and, as a Brigadier in the war-time forces, was closely involved in the development of radar. He was in close contact with General Smuts at that time.

General Smuts stated in his address to the first meeting of the Council for Scientific and Industrial Research on 8 October 1945: "I am confident that this body will become one of the most important organizations of advancement in this country. The time has come when we must tackle our own job and the problems which lie before South Africa. We must develop our own scientific handling of these problems."[57]

Dr Schonland immediately set about setting up the research Laboratories of the CSIR: The National Physical Laboratory, The National Chemical Research Laboratory, The National Institute for Personnel Research and the National Building Research Institute.[58] Professor S Meiring Naudé from Stellenbosch was appointed head of the National Physical Laboratory. Dr WS Rapson from Cape Town took charge of the National Chemical Research Laboratory. Eariy in 1947 the Applied Radioactivity Division was created as part of the National Physical Laboratory (NPL). Although the National Physical Laboratory had nothing to do with the investigation programmes of the Metallurgical Laboratory, uranium studies and nuclear physics were, even at that early stage, moving in the same direction. Dr Schonland certainly realised that studies in nuclear physics would have to be

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57 "The Council for Scientific and Industrial Research, The First Five Years", **Lantern**, February 1951, p. 45.

58 **Ibid.**, p. 45.

Dr SJ du Toit.

(Source: Atomic Energy Corporation)

developed in countries such as South Africa, with a large uranium potential.[59]

The staffing of these laboratories presented a problem. The general world shortage of qualified scientists had been accentuated in South Africa. The training of research workers had been largely neglected and lack of careers and opportunities had driven the best brains to join large research organizations overseas.[60]

Atomic energy development incorporates the disciplines of mechanical, electrical and chemical engineering, but at the CSIR during 1945-1956 it was the National Physical Laboratory that was developed, specifically, for nuclear studies with a view to train scientists for future nuclear energy research and development.

Dr SJ du Toit who was, after the war, Senior Lecturer in Physics at the University of Potchefstroom had developed some knowledge of nuclear physics. He was accordingly appointed in 1947 by the CSIR, with the idea that nuclear physics studies should be developed there. Dr Du Toit joined the staff of the CSIR on March 1, 1947 and initially worked in an old building next to the Mint in Visagie Street, Pretoria. (This building housed the Applied Radio-activity Division which was created as part of the National Physical Laboratory.) Dr Du Toit recalls how Dr S Meiring Naudé showed him to his first laboratory. There were two rooms available, the one was to be used as an office and the other as a laboratory. The laboratory consisted of an electrical point, a wooden table and a chair, nothing else. The staff comprised Dr Du Toit and J van der Walt.[61]

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59 Interview with Dr SJ du Toit, 9.1.1992.

60 "The Council for Scientific and Industrial Research: The First Five Years", **Lantern**, Feb. 1951, p. 45.

61 (NAC Faure) NAC 84-01 (SR), SJ du Toit: 'Die vroeë geskiedenis van die Pretoria-Siklotron", Simposium ter viering van die 25 jaar diens van die Pretoria-siklotron, Junie 1983, WNNR, NVS-verslag, p. 5.

The leading mining companies of the Witwatersrand, concerned about the health of their workers, wished to determine the concentrations of uranium oxide and radon* in the gold mines. In other words, the amount of radio-activity in the air (being inhaled by mine workers) had to be established. Dr Du Toit had obtained his Doctor's degree by studying cosmic rays and researching Geiger-Müller counters. Geiger-Müller counters had to be built in South Africa, as they were not otherwise obtainable. With his experience he established the means of constructing counters that could be used to measure the radioactivity on the mines. The mining companies approached the newly-established National Physics Laboratory to investigate the problem. The monitoring of radioactivity and radon gas determination in the gold mines was the first investigation programme done by the Radioactivity Division which would later develop into the Division for Nuclear Physics of the National Physical Laboratory. In this way the Radioactivity Division became involved with the uranium investigations being done on the mines.[62]

There was at that time a world-wide interest in nuclear physics. In the Radioactivity Division there was a mutual feeling that that Division should be extended in order to accommodate a broader spectrum of nuclear physics, than solely radioactivity. The Applied Radioactivity Division had been created with the object of encouraging and promoting the use of radio isotopes.* There was a particularly heavy demand for the Applied Radioactivity Division's services in connection with the importation of radioactive isotopes, and the application of this new research tool in medical, biological and industrial research. The isotopes came to the Division in South Africa by air from atomic piles

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62 (NAC Faure) NAC 84-01 (SR), SJ du Toit: "Die vroeë geskiedenis van die Pretoria-Siklotron", p. 5; SJ Mills: "Oorsig van die Kernfisika-Navorsingsprogram", Simposium ter viering van die 25 jaar diens van die Pretoria-siklotron, Junie 1983, WNNR, NVS-verslag, p. 39. Interview with Dr SJ du Toit, 9.1.1992.

overseas.[63] Prominent in this activity was Dr EC Halliday who developed the wing-tip system of transporting radio isotopes by air.[64]

The Pretoria Cyclotron

Early in 1948 the CSIR had decided to acquire an accelerator. This was the first major step with regard to the advancement of nuclear physics in South Africa. An accelerator, a basic research instrument, had to be obtained in order to initiate a nuclear physics experimental programme. Nuclear physicists are interested in the reactions that take place between atomic nuclei. To bring atomic nuclei into such close contact that they can start reacting, it is necessary to shoot nuclei at other nuclei with velocities that correspond to temperatures of billions of degrees. For this purpose some form of accelerator was essential.

At the beginning of 1948, Dr Schonland informed Dr Du Toit that the Council had decided to send him to Europe to study nuclear physics and it would be expected of him, on his return to South Africa, to initiate a nuclear physics research programme at the CSIR. Dr SJ du Toit believed that a cyclotron should be the research instrument acquired for the National Physical Laboratory. A cyclotron is a type of accelerator used in nuclear research for investigating the character and behaviour of the basic components of matter. It is one of a class of devices known as particle accelerators, so called because they speed up the movement of electrically charged atomic particles. In a cyclotron charged

63 Atomic piles or atomic reactors were constructed for the purpose of generating power. The neutrons emitted in the process incidentally bombard atomic nuclei in the reactor core, giving rise to radio-active materials which find a widening applicability in many fields.

64 By this system the need for heavy lead containers to protect crew and passengers was obviated. At one time a gram of radio-active material had to be surrounded by lead weighing up to 30 lbs (13,64 kg). This weight made carriage expensive and increased the cost of using radio isotopes. By the new method the radio-active substance made its journey by air in a thin container weighing only a few ounces. AR Newby-Fraser: **Chain Reaction**, p. 26.

particles are kept moving in circles by electromagnets, and are given a small acceleration on every revolution. In this way they can be given the very high energies equivalent to millions of volts, needed to penetrate atomic nuclei. These particles are often protons, the nuclei of hydrogen atoms. Although these devices do not figure in a nuclear power plant, they are important for research and the production of radio-isotopes.

At the end of August 1948, Dr SJ du Toit left for the Nuffield Physics Institute at the University of Birmingham to study cyclotrons. There he would work under Professor Marcus Oliphant. Dr Schonland had decided on the Nuffield Physics Institute for, according to available information at the time, a cyclotron was under construction there. This project was near completion and much progress had been made on a second subject, the building of a proton synchrotron.[65]

The first cyclotron was built in 1930 by EO Lawrence (1901-1957) and MS Livingstone in Berkeley.[66] In various other laboratories in the United States and Europe cyclotrons of various capacities were constructed, but with varying degrees of success.[67]

Dr Du Toit soon ascertained that the cyclotron being built at Birmingham would not be completed within the two years that he

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65 (NAC Faure) NAC 84-01 (SR), SJ du Toit: "Die vroeë geskiedenis van die Pretoria-Siklotron", Simposium ter viering van die 25 jaar diens van die Pretoria-siklotron, Junie 1983, WNNR, NVS-verslag, pp. 5-6; Interview with Dr SJ du Toit, 9.1.1992; (Dr D Reitmann: Private Collection) Speech by Dr SM Naudé, at the official inauguration ceremony at the CSIR cyclotron, 26 Jan. 1956, p. 4 (ex libris, Dr D Reitmann).

66 The first cyclotron was erected on a laboratory table and could accelerate protons to an energy of 10keV. After the cyclotron principle had been tested in this way, further development followed quickly. By 1939, an enormous cyclotron with a pole diameter of 4,67 m was under construction at Berkeley. In 1939, that was the maximum size of a classic cyclotron, because the accelerated particles would then place near-intolerable demand on the radio frequency system.

67 (NAC Faure) SJ du Toit: "Die vroeë geskiedenis van die Pretoria-Siklotron", Simposium ter viering van die 25 jaar diens van die Pretoria-siklotron, Junie 1983, WNNR, NVS-verslag, p. 6.

would be there and research on the completed cyclotron was, therefore, out of the question. A study of the available nuclear physics literature of the time indicated that Kai Siegbahn at the Nobel Institute of Physics in Stockholm was working on a new development in nuclear physics, namely, nuclear spectroscopy*.[68] A small group of about 15 scientists there, were particularly productive and contributed about 40 publications annually. The Nobel Institute had acquired a cyclotron that could accelerate deuterons to 25 MeV. Dr Du Toit earnestly requested the CSIR transfer him to Stockholm. After Dr AJA Roux (then connected with the Building Research Institute of the CSIR) had paid a visit to the Nuffield Institute and ascertained the circumstances there, it was decided by the Council to transfer Dr Du Toit to Stockholm. While at Stockholm, Dr Du Toit visited laboratories (in order to observe the progress made in nuclear physics research) at the Collège de France in Paris, the University of Rome (where an earlier colleague of Enrico Fermi, Dr Amaldi, was in charge), Zurich and Copenhagen.[69]

At Stockholm Dr Du Toit was assigned to work with Professor Hilding Slätis on two research projects of Kai Siegbahn. These two projects would demand his attention for the duration of his stay in Stockholm. However, Dr Du Toit could also devote time to planning the Nuclear Physics Division that he was appointed to establish on his return to South Africa. He was assisted in this by two occurrences. Firstly, in August 1949, two international conferences on nuclear physics and cosmic rays were held in Basel, Switzerland, and Como, Italy. Dr Du Toit attended both these conferences and had the privilege of meeting leading physicists such as Pauli, Fermi, Heisenberg, Buchner and Bakker.[70] From their advice he could determine how he should set

68 Kai Siegbahn: Member of the Swedish Atomic Research Council; Member of the Nobel Institute Committee for Physics.

69 (NAC Faure) NAC 84-01(SR), SJ du Toit: "Die vroeë geskiedenis van die Pretoria-Siklotron", Simposium ter viering van die 25 jaar diens van die Pretoria-siklotron, Junie 1983, WNNR, NVS-verslag, p. 6.

70 The leading physicists were Dr Wolfgang Pauli, Technical University Zürich, Switzerland; Professor Enrico Fermi, University of Chicago, USA;

about establishing a Nuclear Physics Division in a country like South Africa, in which that field of science was completely new and their funds were limited. Secondly, the Director of the Nobel Institute of the time, Dr Manne Siegbahn, made a point of introducing Dr Du Toit to the many visiting physicists to the Nobel Institute. Two nuclear physicists that he knew well were Dr GT Seaborg and Dr EM MacMillan.[71]

Everyone with whom Dr Du Toit discussed the matter was of the opinion that nuclear spectroscopy was the advisable course to initiate studies in nuclear physics. The expenditure involved would not be unreasonably high and the variety of projects that could be researched was great. In order to commence a nuclear spectroscopy programme, the acquisition of an accelerator that could produce isotopes for research, was essential. A heavy particle accelerator with adequate energy, so that the charged particles could penetrate nuclei with the greatest nuclear charge, would be necessary. The beam intensity would have to be such that a reasonable production of radio-isotopes could be obtained. A classic cyclotron would meet these demands, and Dr Du Toit wrote to Dr Naudé and enquired whether it would be possible to acquire a cyclotron for the Nuclear Physics Division. Dr Du Toit's concept was that a national centre be established around the cyclotron at the CSIR, and that the facilities at the centre be put to the disposal of lecturers and doctoral students of all South African universities. In that way, South Africa could train its own nuclear physicists, and at the

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Professor Werner Karl Heisenberg, Director of the Max Planck Institute for Physics, Göttingen, Germany, 1946-1958; Professor Joachim Andreas Buchner, German physicist; and Professor CJ Bakker, Physics Laboratory, Philips, Amsterdam, Netherlands.

71 Dr Edwin Mattison MacMillan, Nobel Prize Winner 1949; Dr Glenn Theodore Seaborg; (NAC Faure) NAC 84-01(SR), SJ du Toit: "Die vroeë geskiedenis van die Pretoria-Siklotron", Simposium ter viering van die 25 jaar diens van die Pretoria-siklotron, Junie 1983, WNNR, NVS-verslag, p. 7.

same time could develop the discipline nuclear physics through research done at the centre.[72]

In November 1949 Dr Du Toit was shattered when he learned that he had not been consulted on a decision made by Dr Schonland concerning the acquisition of a linear electron accelerator from the United Kingdom. Dr Schonland had decided to act accordingly and acquire a linear accelerator. Dr Du Toit, having been overseas for fourteen months, and by that time having acquired much knowledge on cyclotrons, realised that no worthwhile nuclear physics research could be accomplish with an electron accelerator that would be unable to produce mono-energetic nucleons. Dr Du Toit sought the advice of certain physicists whom he had met at Basel and discussed the matter with MacMillan in Stockholm. They all agreed that for a country that could only afford to acquire one accelerator, a cyclotron was the best choice and that an electron accelerator would be a poor decision. All these testimonies that Dr Du Toit gathered together, he sent to Dr Naudé with the fervent request that a cyclotron be acquired (for accelerating protons). At the beginning of 1950, Dr Du Toit was informed that Dr Schonland had altered his decision to obtain an electron accelerator and that the Council of the CSIR had advised the Prime Minister that the CSIR should build its own cyclotron. The Prime Minister, Dr Malan, had given his consent with the prerequisite that, as far as possible, locally produced materials should be used, as well as a South African work force. Dr Du Toit was delighted by this turn of events.[73]

A CSIR electro-technical engineer, C Kritzinger, was appointed to be in charge of the construction of the Pretoria cyclotron. He joined Dr Du Toit at the Noble Institute in April 1950, and together they started

72 (NAC Faure) NAC 84-01(SR), SJ du Toit: "Die vroeë geskiedenis van die Pretoria-Siklotron", Simposium ter viering van die 25 jaar diens van die Pretoria-siklotron, Junie 1983, WNNR, NVS-verslag, pp. 7-8.

73 (NAC Faure) NAC 84-01(SR), SJ du Toit: "Die vroeë geskiedenis van die Pretoria-Siklotron", Simposium ter viering van die 25 jaar diens van die Pretoria-siklotron, Junie 1983, WNNR, NVS-verslag, p. 8.

on the design of the cyclotron for South Africa. In September 1950, Kritzinger proceeded to the United States where he worked with Professor Livingstone at MIT. The first decision that had to be taken in connection with the cyclotron on the design of the cyclotron for the NPL was to determine the energy of the accelerated particles and the beam intensity. Funds were limited, but it was essential that the cyclotron be adequate in order to fulfill its function as the core of the envisaged national nuclear physics centre. In the choice of the parameters of the cyclotron, Dr Du Toit and Kritzinger were strongly influenced by a thorough investigation of the cost of the classic cyclotron published by Professor Livingstone in the Journal of Applied Physics in 1944.[74]

The magnet is the most important part of the cyclotron. The magnet plus the generator system cost about 50% of the total price of the cyclotron. Dr Du Toit and Kritzinger were fortunate to be able to secure the consulting services of Dr Dreyfus, a South African, then employed by ASEA in Vasterås, Sweden. He was one of the world's best authorities on magnet design. His advice on the magnet was invaluable.[75]

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74 In choosing a design energy of 16 MeV for deuterons, nuclear reactions with good efficiency in the nuclei, up to the highest atomic numbers, could be obtained. If the magnet was manufactured in high quality steel, the magnetic flux density would be 1,6 T and the pole diameter 1,13 m. If the measurement of the gap between the poles of the magnet pieces had been established, the size of the accelerator can be determined. A larger gap gives a larger beam. In making the decision as to the size of the gap, Dr Du Toit could apply the knowledge that he had gained in overseas laboratories. The MIT cyclotron could produce as many as 1 m A deuterons with the gap of 140 mm. At 16 MeV, energy dissipation in the target would amount to 16 kW, and that was the maximum that could be employed with the then known techniques. It was, therefore, decided to make the gap 140 mm. (NAC Faure) NAC 84-01(SR) SJ du Toit: "Die vroeë geskiedenis van die Pretoria-Siklotron", Simposium ter viering van die 25 jaar diens van die Pretoria-siklotron, Junie 1983, WNNR, NVS-verslag, pp. 8-9.

75 Cutting away the inside corners of the vertical yoke bars, for example, enlarged the experimental area around the vacuum chamber. On his suggestion the mass of the proposed magnet was reduced to 80 tons. (NAC Faure) NAC 84-01(SR) SJ du Toit: "Die vroeë geskiedenis van die Pretoria-Siklotron", Simposium ter viering van die 25 jaar diens van die Pretoria-siklotron, Junie 1983, WNNR, NVS-verslag, p. 9.

Dr Du Toit returned to South Africa in August 1950, and Kritzinger in April 1951. The planning of the cyclotron for the NPL started in earnest in June 1951. More than 300 drawings were prepared. The design was a challenge to South African industry. The magnet was estimated to weigh 80 tons. (The actual weight of the CSIR cyclotron magnet is 84 tons). ISCOR was prepared to undertake the manufacture of the magnet. The steel that ISCOR delivered proved to what degree they had succeeded in their endeavour. It was even an improvement on the given specifications.[76] The steel was particularly difficult to machine, because of its softness. The Van der Byl Engineering Corporation (VECOR), to whom the task of manufacturing the magnet was assigned, were particularly successful in accomplishing this task.[77]

As far as the radio frequency system was concerned, the firm that undertook the construction of the dees (which have an unusual form), was instructed to use two tons of oxygen-free electrolytic copper.[78] This involved, amongst other things, that in the assembly of the dees, copper would have to be welded to the steel. It was specified that the completed copper dees would have to be totally air-tight.[79] This task was successfully accomplished. Pressures lower than one thousand-

76 The steel for the magnet had to be manufactured with specific magnetic properties, and amongst other specifications, a carbon content lower than 0,1 percent. Gauss: Unit of magnetic flux density. Origin: Karl Friedrich Gauss (1777-1855), German mathematician and physicist.

77 VECOR was obliged to construct pole pieces, flat and parallel to 0,001 inch. To attain such precision was a challenge. So successful was the manufacture, that on final assembly the gap of the magnet was accurate to within 0,6 thousandth of an inch. (Dr D Reitmann: Private Collection), Speech by Dr SM Naudé, President of the CSIR, at the official inauguration ceremony of the CSIR cyclotron, January 26, 1956, p. 5; AR Newby-Fraser: **Chain Reaction,** p. 27-29.

78 A cyclotron consists of two evacuated hollow metal dees in a uniform magnetic field perpendicular to their plane. Protons or other positive ions are injected near the centre. An electric generator reverses the potential difference between the dees at the orbital frequency of the ions, so they are accelerated each time they pass through the gap between the dees. JW Kane and MM Sternheim: **Physics**, p. 468.

79 This would amount to a leak rate so small that a thousand years would be required for the chamber to fill up with air.

Winding the first magnet of the CSIR's Cyclotron. In this picture one conductor layer is complete

(Source: SO Ecklund: "Nuclear Energy: A Current Review", **Industrial Review of Africa**) millionth of atmospheric pressure were achieved in the cyclotron. The coils of the cyclotron magnet were the largest coils made in South Africa up to that time.[80]

The above aspects were but a few of the problems that the nuclear physicists imposed on South African industry. They give some idea of the precision required in the manufacture of the various parts of the cyclotron, as well as the magnitude of the undertaking.[81] The design of the building that would house the cyclotron was a challenge to the engineers. The stability of the foundations of the hall in which the cyclotron would be assembled was a crucial feature. The consulting engineers were required to give this aspect special attention. It was stipulated by the concrete engineer, that the foundation of the cyclotron might not deform more than 0,005 inch, regardless of what the ground under the foundation might do.[82]

When the cyclotron magnet is switched on, the pole pieces are drawn together with a force of one hundred tons. It has happened that

80 In order to wind them a special machine had to be constructed. A hollow rod of aluminium, 1½ miles (approximately 2,4 km) long, and with a cross sectional area of one square inch, was wound under a tension of several tons. The windings had to be particularly secure in order that they did not spring loose under the extreme tension. The construction of the coils was successfully accomplished. (Dr D Reitmann: Private Collection), "Probleme in verband met die bou van die Siklotron", Opening address by Dr SM Naudé, President of the CSIR, at the official inauguration of the CSIR cyclotron, January 26, 1956, pp. 5-6.

81 (Dr D Reitmann: Private Collection), Speech by Dr SM Naudé, President of the CSIR, at the official inauguration ceremony of the CSIR cyclotron, January 26, pp. 5-6.

82 Considering that the normal allowance in the building industry is about one hundred times greater than this figure, it was an accomplishment that such accuracy was actually achieved. There were a number of other specifications that required special attention. Sufficient shielding had to be given to the cyclotron to ensure that sensitive experimental work being done in the nuclear physics building, would not be affected. The builder was required to cast the entire concrete roof of the main hall (44 X 34 X 3 feet or 13.42 x 10.37 x .91 meter), in one day. The architect was instructed to convey hundreds of electric wires and pipes for water, gas and compressed air to the main hall, but neutrons might not escape from the hall along the tubes and ducts that housed the wiring and pipe work. (Dr D Reitmann: Private Collection), Speech by Dr SM Naudé, President of the CSIR, at the official inauguration ceremony of the CSIR cyclotron, January 26, pp. 6-7.

accelerator magnets have collapsed under this tremendous force. It is, therefore, a tense moment when the power supply is activated for the first time and the deflections of the magnet have to be measured. The magnet of the Pretoria cyclotron functioned extremely well in this respect.[83] As far as it was known at the time, the Pretoria cyclotron was the first cyclotron in the world with a fully automatic target-removing* mechanism.[84]

All the large components were manufactured in South Africa, except the vacuum chamber, which was made in Sweden. Eventually, after numerous difficulties, the cyclotron was brought into operation. The first beams of 16 MeV deuterons were accelerated in 1955. The first beam, however, disappeared before full radius was reached.[85] The final cost of the cyclotron was approximately £59 000 (R116 000). The South African manufacturing industry had proved that it could undertake sophisticated scientific projects.[86]

Because of the absence of an accelerator, during the period 1947-1956, the Division Nuclear Physics of the National Physical Laboratory concentrated its activities on the study of radio* nuclides* and ionising radiation,* and the application thereof. However, from the beginning,

83 (Dr D Reitmann: Private Collection), Speech by Dr SM Naudé, President of the CSIR, at the official inauguration ceremony of the CSIR cyclotron, January 26, p. 7.

84 After irradiation, the target is intensely radio-active and dangerous to handle. The Pretoria cyclotron staff solved the problem by developing an interesting mechanism that, after radiation, turns off the water to the target, that serves as a coolant, and removes excess water. The target is then drawn from the cyclotron through a vacuum gate valve that automatically locks and prevents air from entering a vacuum system. After that the target is detached and transported through a tube to the physics laboratory. This whole action is done automatically. (Dr D Reitmann: Private Collection), Speech by Dr SM Naudé, President of the CSIR, at the official inauguration ceremony of the CSIR cyclotron, January 26, pp. 7-8.

85 By October 1958, beam intensity if 200 micro-amperes at 15 MeV was achieved.

86 (NAC Faure) NAC 84-01(SR) SJ du Toit, "Die Vroeë Geskiedenis van die Pretoria-Siklotron", Simposium ter viering van die 25 jaar diens van die Pretoria-siklotron, Junie 1983, WNNR, NVS-verslag, pp. 9-10.

the research programmes of the Division were strongly influenced by the prospect of the acquisition of an accelerator.[87]

No doubt, besides the intrinsic value of the cyclotron as the instrument on which the research programmes of the Laboratory would be based, it had value for all the building contractors that were involved in its construction. The experience gained would be of benefit in projects that the Atomic Energy Board would launch during the later fifties and sixties.

Training of Nuclear Scientists

During the years, before the Second World War, nuclear physics constituted but a small part of the study of physics. In 1939 few textbooks on the subject nuclear physics were obtainable. As was indicated in a previous chapter, the three main centres for research on nuclear fission were Rome, Paris and Berlin: Fermi's team in Rome, Frédérich and Irene Joliot-Curie and their colleagues in Paris and Hahn and Strassmann with their group in Berlin.

In South Africa, physics students heard little about the nuclear physics aspect. Dr SJ du Toit, who would later play a leading role in the establishment of nuclear physics studies in South Africa, stated in an interview that up to 1942, the year in which he obtained his M.Sc. degree, students were not lectured on the subject. The knowledge that he had acquired in the early 1940's, he had learned from the few text books available, and only because the subject was of particular interest to him.[88] During the war, for security reasons, no articles were allowed to be published on research in nuclear physics. It was, therefore, only after the explosions that ended the war, that the general

87 (NAC Faure) NAC 84-01(SR) SJ Mills, "Oorsig oor die Kernfisika-Navorsingsprogram", Simposium ter viering van die 25 jaar diens van die Pretoria-siklotron, Junie 1983, WNNR, NVS-verslag, p. 39.

88 Interview with Dr SJ du Toit, 9.1.1992.

public became aware that nuclear physics would be an essential aspect of the physics discipline. No country could in future afford to ignore the advancements that had taken place in that field of science.

Nuclear physics would form the basis of all knowledge concerning nuclear power production. It should be understood that at the Nuclear Physics Laboratory purely nuclear physics would be studied - not nuclear energy as such. Nuclear physics gives the scientists a basic knowledge of the principles of physics, but the implementation of those principles lies with the nuclear engineers. Dr SJ Du Toit believed that young South African physicists should do their basic training at a nuclear physics laboratory. They should continue their research work until they obtained a doctorate and then proceed for further study overseas. With a Master's Degree scientists would be appointed in foreign laboratories as assistants to the professors and heads of laboratories. With a doctorate, South Africans were accepted as fully qualified researchers with far more facilities at their disposal. They could immediately proceed to more advanced research (often unobtainable in scientific literature), and the time spent overseas would be of far greater value.[89]

By 1948 the USA was employing 137 000 men and women with university degrees on scientific research of all kinds. Of these 41 000 were research engineers and 30 000 research chemists. Large as the number of qualified research workers in the United States was, it was not considered large enough. A report to the President of the United States recommended that action should be taken to raise the number to 270 000 by the year 1957. In that year the USA was spending 200 million pounds a year on scientific research. Britain and the Soviet Union were spending 76 million pounds (R152 million) and 300 million pounds (R600 million) a year, respectively.[90] By 1948 these countries

89 Interview with Dr SJ du Toit, 9.1.1992.

90 BFJ Schonland: "Scientific and Industrial Research", **JSAIE**, September 1948, pp. 19-20.

were involved in extensive nuclear research programmes to acquire knowledge concerning the release, control and application of nuclear energy. As far as nuclear research was concerned, South Africa in comparison at the end of the 1940's had made but a humble start.

During the 1950's nuclear physics was a most popular and sought-after course of study. It received much publicity and many physicists wished to acquire a greater knowledge of nuclear physics.[91] At the National Physical Laboratory with the cyclotron as the basis of research, a number of other instruments were acquired. In 1950 the Division Nuclear Physics ordered a beta spectrometer from Sweden. This instrument would later be used to determine decay schemes. Uranium decays at a specific rate, and in this way geologists and physicists can establish the age of layers of the earth and the age of fossils present in the layers. In establishing a nuclear spectroscopy laboratory, an electromagnetic isotope separator was essential. This was constructed and operated with great success.[92]

The first meeting of the statutory Atomic Energy Board took place in Cape Town on 15 March 1949. For a number of years the Board concerned itself almost exclusively with uranium production and sales, and with its regulatory functions regarding all radio-active materials.[93] The issue of nuclear research was raised for the first time through a proposal submitted to the Board in 1953. It was suggested that scientists be trained in nuclear physics. An assessment of funds required for staff and the necessary facilities to be put at their disposal was included in the proposal. The Board approached a somewhat unsympathetic Treasury, which at first rejected the request, but was subsequently induced to reconsider its decision and finally agreed to

91 Interview with Dr SJ du Toit, 9.1.1992.

92 (NAC Faure) NAC 84-01(SR), SJ Mills, "Oorsig van die Kernfisika-Navorsingsprogram", Simposium ter viering van die 25 jaar diens van die Pretoria-siklotron, Junie 1983, WNNR, NVS-verslag, p. 43.

93 AR Newby-Fraser: **Chain Reaction**, p. 31.

make funds available. This was followed in mid-1954 by Cabinet approval for the Board to form its own Physics Unit. The proposal of a Physics Unit was specifically motivated on the basis of the need for research on uranium extraction and refining.[94]

This was the very beginning of an order of events to both promote studies in nuclear physics, and to refine South African uranium so that it could be used for the peaceful applications of atomic energy.

In January 1955 research was begun at the National Physical Laboratory on the decay schemes on certain decay products of uranium. The beta spectrometer was used to determine the decay schemes. It was later upgraded by Drs Jan Louw and JWL de Villiers. Later Dr De Villiers built a spectrometer for SASOL, that would be used in later heavy water analyses.[95]

It was with the establishment of the Physics Unit that the Atomic Energy Board instituted a bursary scheme for South African physicists. The National Physical Laboratory benefitted greatly from this scheme. A number of proficient scientists proceeded to research specific aspects of nuclear physics at the National Physical Laboratory.[96] On 1 April 1955 the National Centre for Fundamental Nuclear Physics Research and Education was officially established by the National Physical Laboratory. Two experienced overseas nuclear physicists joined the staff to assist with the training of advanced students. By the middle of 1956, five students were employed in the Division Nuclear Spectroscopy. These students obtained bursaries from the Atomic Energy Board. They were the forerunners of a line of South African nuclear physicists that would contribute to the establishment of nuclear studies at various universities and institutions throughout the country: Dr Erik Barnard, PD Hartzer, Professor RH Lemmer, Professor WL

94 AR Newby-Fraser: **Chain Reaction**, p. 31.

95 Interview with Dr JWL de Villiers, 10.1.1992.

96 Interview with Dr SJ du Toit, 9.1.1992.

Rautenbach and Dr D Reitmann.[97] The experimental research programme of this division was directed to beta and gamma spectroscopy of radio-active nuclei. As a result of these developments theoretical research on nuclear models and nuclear matter was begun.[98]

The initiative by the CSIR in establishing a nuclear group, realizing that knowledge of basic nuclear physics was essential for later nuclear research, produced a team of scientists that had received advanced training in nuclear physics. Some of the members of that team would make valuable contributions to South Africa's nuclear research and development programme. In the beginning the universities were not associated with the programme at the Laboratory - the reason for this was that the field was too new.

When Dr Du Toit studied physics at Potchefstroom University during the early 1940's, Afrikaans was the medium of instruction. According to Dr Du Toit at that time lectures in physics at the University of Stellenbosch were in English. Potchefstroom was the first university to teach nuclear physics through the Afrikaans medium. While at the university, Dr Du Toit referred to Dutch physics textbooks and the Dutch terminology gave him sentience for linguistic form. He became aware of how technical terms should be formed. Dr Du Toit and Dr SM Naudé both worked on the first Afrikaans physics glossary. They strove to create words that would be explicit of what the term actually implied.[99] The Afrikaans physics glossary was later published by the Suid-Afrikaanse Akademie vir Wetenskap en Kuns. When the cyclotron was being built, Dr Du Toit felt so strongly about the fact that the National Physics Laboratory was being established by Afrikaners, that the inscriptions on the Pretoria cyclotron (the control

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97 Interview with Dr SJ du Toit, 9.1.1992.

98 (NAC Faure) NAC 84-01(SR), SJ Mills: "Oorsig van die Kernfisika-Navorsingsprogram", Simposium ter viering van die 25 jaar diens van die Pretoria-siklotron, Junie 1983, WNNR, NVS-verslag, pp. 39-40.

99 Examples given by Dr Du Toit were: "kernklowing" for "fission" and "tiendeler" for "scale- of- ten".

panel and the various parts) are in Afrikaans. It was not a way of discriminating against English terminology or the language. It was a fact that, at the time, Afrikaans was spoken in his laboratory and, after all, the laboratory staff and scientists were the ones using the cyclotron.[100]

In the middle of 1955 the first beams of the Pretoria cyclotron were accelerated. Initially this had little effect on the basic nuclear physics programme of the Division, as external beams could not be achieved. However, internal irradiations with the cyclotron produced a number of short-lived isotopes that could be studied by means of nuclear spectroscopy. (It was only in 1962 that effective external beams were achieved.)[101]

It was decided by the CSIR that the inauguration of the cyclotron should take place on 26 January 1956. Representatives of the three countries which were most intimately connected with the research efforts of the cyclotron, namely the United Kingdom, Sweden and the United States of America, were invited to attend the ceremony. In his opening address the President of the CSIR, Dr SM Naudé, welcomed the representatives and said that he regretted that Dr Malan, under whose premiership the decision was taken to build a cyclotron in South Africa was unable to undertake the long journey from Cape Town to be present. The Minister of Economic Affairs and of Mines, Dr van Rhijn represented the government and performed the inauguration ceremony of the Pretoria Cyclotron.[102]

At the ceremony Dr van Rhijn stressed the fact the South Africa would in future require many nuclear scientists. The day would come that few

100 Interview with Dr SJ du Toit, 9.1.1992.

101 (NAC Faure) NAC 84-01(SR), SJ Mills: "Oorsig van die Kernfisika-Navorsingsprogram", Simposium ter viering van die 25 jaar diens van die Pretoria-siklotron, Junie 1983, WNNR, NVS-verslag, p. 40.

102 (Dr D Reitmann: Private Collection), Opening address by Dr SM Naudé, at the official inauguration of the CSIR cyclotron, January 26, 1956, pp. 1-2.

industries would be able to manage without nuclear physicists on their staff. It would be impossible to operate nuclear power stations without the assistance of nuclear physicists and engineers, just as it was then impossible to operate the conventional power station without electrical engineers. Scientists would be required in hospitals, agriculture and at universities. The Minister came to the conclusion that the Government had not spent too much on facilities for nuclear studies. Perhaps, he said, it had spent too little. He hoped that the facilities at the National Physical Laboratory would be the beginning of great developments in South Africa.[103]

In the history of uranium and nuclear energy in South Africa the co-ordination of research at the CSIR was of significance. The National Physical Laboratory and the Pretoria Cyclotron were established with the specific purpose to advance nuclear physics research. At the CSIR studies relating to mechanical engineering and chemical research were initiated in the 1940's. Work done at these research laboratories would have bearing on the development of nuclear energy technology in South Africa. At the National Physical Laboratory, the National Chemical Research Laboratory and the National Research Institute for Mechanical Engineering scientists and engineers could be made available for the uranium and nuclear industries. These research units laid the foundation for these industries and subsequently for nuclear research and development.

103 (Dr D Reitmann: Private Collection), Address by Dr van Rhijn, Minister of Mines and Economic Affairs at the official inauguration of the Pretoria Cyclotron on 26 January 1956, pp. 7-9.

CHAPTER FOUR

THE PRODUCTION AND MARKETING OF NATURAL URANIUM

By the middle of 1949 enough information was available concerning the extraction of uranium to begin negotiations for the sale thereof to the Combined Development Agency. After agreement between the South African Atomic Energy Board and the CDA the Transvaal Chamber of Mines set about the establishing of the uranium extraction plants. By 1958 the foreign trade value of South Africa's uranium reached the £50 million mark. However, there were circumstances that strongly indicated that South Africa could not be assured of an increasing demand for uranium. The world-wide discovery of new uranium deposits during the 1950's as well as the decline in the military requirements of the United States and the United Kingdom, resulted in a new agreement between the South African Atomic Energy Board and the Combined Development Agency (CDA). As the CDA no longer wished to purchase all South Africa's uranium new markets and contracts overseas had to be established. In the early sixties a further reduction was made in the purchases of uranium oxide by the United States Atomic Energy Commission and the United Kingdom Atomic Energy Authority. As a result of the "stretch out agreement" South African uranium production and foreign trade value reached an all time low in 1965. However, the upward trend of uranium production and foreign trade earnings in 1968 as well as the optimistic predictions for enriched uranium in nuclear power generation brought about a renewed search for uranium deposits in South Africa.

International discussions for the sale of South African uranium

By the middle of 1949 sufficient information had become available concerning the extraction or uranium to justify the beginning of negotiations for the sale of uranium. Dr RB Hagart, who, as Joint Deputy Chairman of Anglo American Corporation and member of the

Atomic Energy Board, was directly involved with the sale negotiations.[1]

With the establishment of the Atomic Energy Board under the Atomic Energy Act, the Uranium Research Committee was dissolved.[2] The Atomic Energy Board under the chairmanship of Eric Louw, Minister of Mines, assumed complete responsibility for all matters concerned with the potential production of uranium in the Union. The composition of the Board was such that it could co-ordinate the interests of the uranium industry and the Government in all matters dealing with the extraction and marketing of uranium, within the scope of the Atomic Energy Act. It had the additional function of rendering assistance with the formulation of Government policy during a time of very tense international relations.[3]

Towards the end of 1949 Eric Louw invited a joint mission from the United States and Britain to visit South Africa to discuss the possibility of purchasing uranium oxide.[4] The mission that visited the Union represented the Combined Development Agency. This Agency developed from the Combined Policy Committee which was instituted during the Second World War and in which Britain, the United States and Canada were represented. The Combined Policy Committee established an organization to find and acquire raw materials, namely the Combined Development Trust. This Trust was kept in being after the war and in 1948 its name was changed to the Combined Development Agency.[5] It was this Agency that sent representatives to South Africa in 1949 to negotiate the purchase of uranium. Its function

1 RB Hagart: "National Aspects of the Uranium Industry", **JSAIMM**, 57, April 1957, p. 565.

2 **Assembly Debates**, vol. 64, 6 August-10 September 1948, col. 725-726.

3 (PLA) **Annual Report of the South African Atomic Energy Board**, 1958, p. 3.

4 L Taverner: "An Historical Review...", **JSAIMM**, 57, Nov. 1956, p. 140.

5 (JLUCT) N Moss: **The Politics of Uranium**, pp. 27-28.

was to enter into contracts for the purchase of the greatly increased quantities of uranium needed for the expanding plants in America and Britain where nuclear weapons were being manufactured.[6] As the South African Atomic Energy Act prohibited the disclosure of any information relating to reserves of ore, negotiations for the sale of uranium oxide were done in the strictest secrecy.

At the onset of the discussions between the Atomic Energy Board and the joint mission, certain difficulties became apparent. The Chamber of Mines and the Atomic Energy Board had no experience in selling uranium oxide and there was no established market and thus no established price for uranium.[7] The Combined Development Agency was in effect the sole buyer (since the Soviet Union and her satellites were excluded). The negotiators in the Union of South Africa had hoped that the Agency would offer a fixed price for uranium oxide, and that the Atomic Energy Board could then determine which mines were able to supply the material profitably at that price. The Agency was not prepared to do this, because the official fixed prices in the United States and in Canada would be too low for South Africa. Those prices would not cover development costs of South African uranium plants and permit profitable South African uranium production. If South Africa were offered a higher fixed price there would have been repercussions elsewhere. Thus the Agency was prepared to negotiate only on the basis of a price determined primarily by the cost of production, the amortization of capital and a margin of profit. This meant a separate price for each individual producer. Moreover, the Agency was not willing to allow any mining costs to be included in the cost of production of uranium itself. The Agency's argument was that, since mining was in progress anyway for the production of gold, uranium would be a by-product. In calculating what would be a fair

6 RB Hagart: "National Aspects of the Uranium Industry", **JSAIMM**, 57, April 1957, p. 566.

7 (Government Printer) **Assembly Debates,** Volume 70, 20 January - 3 March 1952, 19 March 1952, col. 3106.

profit the Chamber of Mines had to take into account the taxation which would be payable on any profits the mines would make from producing uranium.[8]

It was, therefore, necessary for the Government to determine on what basis taxation would be levied on profits derived from the production of uranium. The gold mining industry contended that profits from uranium mining should be taxed at the ordinary company rate of taxation, as with other base metals. The Government would not agree. Legislation would be introduced to provide that there would be included with the taxable profits from gold any profits made from the simultaneous production of uranium, thus making uranium subject to the differentially higher rate of tax levied on gold mining.[9] Although this decision was unwelcome to the gold mining industry it had one particular result: it helped to clarify the position as far as the joint mission was concerned. The Agency was able, in those preliminary discussions, to get general information as to how much uranium South Africa might be able to supply on specific conditions. South Africa then became aware as to the type of contract the Agency was prepared to offer for the production of uranium. Useful contacts were also established between the technical experts on both sides.[10]

When the first discussions were held in 1949, South Africa's main motive had been a desire to assist the Western World in the aim of securing an adequate number of atomic weapons. It had been emphasized that South Africa would be contributing a great deal to this vital security need if she were to agree to produce uranium at prices showing only a moderate profit. South Africa was asked by the representatives of the Combined Development Agency not to take

8 RB Hagart: "National Aspects of the Uranium Industry", **JSAIMM**, 57, April 1957, pp. 566-567.

9 (Government Printer) **Statutes of the Union of South Africa**, 1951. No 56 of 1951, p. 410.

10 RB Hagart: "National Aspects of the Uranium Industry", **JSAIMM**, 57, April 1957, p. 567.

advantage of her strong position as an uranium supplier by holding out for unduly high prices. In 1949 South Africa could be reasonable on this issue. Two years later the position would change.[11]

During the next twelve months much progress was made towards finally determining the methods of uranium production and the probable costs of these operations. The money for the capital expenditure involved in the erection of the uranium extraction plants to produce uranium was advanced from overseas by arrangement with the British and United States Governments in the form of loans to the mining companies. Four companies would enter the field of uranium production, namely West Rand Consolidated Mines, Ltd; Daggafontein Mines Ltd; Blyvooruitzicht General Mining Co., Ltd and Western Reefs Exploration and Development Co., Ltd.[12] This method of finance made it unnecessary for the shareholders of the companies concerned to be called upon to supply any of the capital required. The total capital expenditure by those gold mining companies that had agreed to erect plants for the extraction of uranium and the production of sulphuric acid, was estimated at £40 000 000.[13]

In October 1950 representatives of the Combined Development Agency again arrived in South Africa to resume discussions.[14] Arrangements relating to uranium extraction between the Minister of Mines and the gold mining companies were concluded towards the end of 1950. The decision to produce uranium was made by the Gold Mining Industry in

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11 RB Hagart: "National Aspects of the Uranium Industry", **JSAIMM**, 57, April 1957, p. 567.

12 DN Stuart: "The Supply of Raw materials Requirements of the Uranium Programme", **Uranium in South Africa 1946-1956**, vol. 2, p. 2.

13 VH Osborn: "South Africa Becomes a Uranium Producer", **Optima**, (3)1, March 1953, p. 13; RB Hagart: "National Aspects of the Uranium Industry", **JSAIMM**, 57, April 1957, p. 567.

14 (Government Printer) **Assembly Debates,** vol. 70, 20 January - 3 March 1952, 19 March 1952, col.3106.

November 1950.[15] Before the end of that year a definite form of contract had been drawn up between the Agency and the Atomic Energy Board. This made provision that four mines enter the field of uranium production, namely Blyvooruitzicht, Daggafontein, Western Reefs and West Rand Consolidated. These four mines were to form the pioneers of uranium production in the Union.[16] The agreement was not signed until a much later date. It was decided that where the GML had (prior to the negotiations with the CDA) played the major role in extraction research and construction of experimental uranium pilot plants at the GML and certain mines (Rand Mines Laboratory, Western Reefs mine and Blyvooruitzicht) the mining industry would take full responsibility for the design and erection of the full-scale uranium extraction plants.

Personnel of the GML with experience in uranium extraction were seconded to the Chamber of Mines, for example, RR Porter, under whose supervision the pilot leach plants had been constructed and operated, was at the request of the Transvaal Chamber of Mines released from his contract with the GML to act as Metallurgical Consultant to the Chamber of Mines. Additional members of staff were engaged by the laboratory to replace those seconded members who were then operating the pilot plants for the Chamber of Mines. The actual transfer of the Blyvooruitzicht plant took place in November 1950, and Western Reefs plant on 1 December of the same year.[17]

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15 (SAB) JJP Dolan: "Co-operative Construction of Uranium Plants", **Uranium in South Africa 1946-1956**, vol. I, p. 408.

16 RB Hagart: "National Aspects of the Uranium Industry", **JSAIMM**, 57, April 1957, p. 567.

17 L Taverner: "An Historical Review...", **JSAIMM**, 57, Nov.; (SAB) Levin, "Concentration Tests on the Gold-Uranium ores of the Witwatersrand for the Recovery of Uranium", **Uranium in South Africa,** vol. I, 1946-1956, pp. 347-348.

At the end of October 1951, representatives from the Agency visited South Africa for further discussions.[18] They then asked for a much enlarged programme of uranium production. The United States and the United Kingdom had decided to extend very substantially their programme of nuclear weapons production, and for this it was essential that they should obtain considerably increased supplies of uranium. South African gold mines were the most likely source from which these additional supplies could be obtained. To secure these supplies, the Agency was prepared to offer a new and more favourable contract acceptable to all mines able to enter the production scheme. This created a new situation. Where South Africa had been reasonable in her bargaining in 1949, in 1951 the position was somewhat changed. South Africa had to take stock of the internal position in the country and of the effect a vast programme of uranium production would have on the general economy of the country. South Africa was short of steel, power, cement and labour. Even though the government was aware that priority would have to be given to the uranium industry as far as for example power, railway transport and labour, was concerned the Cabinet gave their approval and details of the new contract were thereafter discussed and finality was reached.[19]

On very broad lines the contracts then negotiated provided as follows: Each contract was for a period of a few years from what was called "the date of full production". That was the date upon which each individual mine was capable of treating slimes to the extent of its normal plant capacity. Under these contracts, some mines commenced full production on 1 January 1954, and their contracts would expire on 31 December 1963. Other mines entered the scheme at later dates, but

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18 (Government Printer) **Assembly Debates,** vol. 70, 29 January - 3 March 1952, 19 March 1952, col 3106.

19 RB Hagart: "National Aspects of the Uranium Industry", **JSAIMM**, 57, April 1957, pp. 567-568.

the date of expiry of the latest contracts accepted at that point, was 31 December 1966.[20]

The loans provided by the CDA for the building of the extraction plants were repayable over a period of ten years. The loans were from American and British sources. Part of that capital would be spent in the Union which would mean a very considerable gain in foreign exchange for South Africa.[21]

The uranium produced by certain gold mines would then become the property of the Atomic Energy Board. The Board would sell the uranium at a price which had previously been agreed upon (by the CDA and the AEB) and with the funds obtained by the Board it would pay the mines concerned for the uranium which they produced. The price payable for the uranium oxide was based on a formula related to the cost of production of each mine. The price covered the working costs in respect of the production of uranium oxide, repayment of the loans, plus interest, and profit. The formula also provided an incentive to keep costs as low as possible by increasing the margin of profit when a reduction in costs was made. At the end of the ten year period the plants would have been paid for out of the price obtained, and would be the property of the mines concerned.[22]

The contract also provided for a guarantee by the Agency in regard to any unpaid balance of the loans in the event of a mine being unable to continue to produce uranium below a ceiling price. This guarantee was necessary, since the industry was asked to erect plants for producing

20 RB Hagart: "National Aspects of the Uranium Industry", **JSAIMM**, 57, April 1957, p. 568.

21 (Government Printer) **Assembly Debates,** vol. 70, 20 January - 3 March 1952, 19 March 1952, col 3106 - 3107. Speech by JH Viljoen, Minister of Mines on the Agreement between the CDA and the AEB.

22 (Government Printer) **Assembly Debates,** vol. 70, 20 January - 3 March 1952, 19 March 1952, col 3106 - 3107. Speech by JH Viljoen, Minister of Mines on the Agreement between the CDA and the AEB; RB Hagart: "National Aspects of the Uranium Industry", **JSAIMM**, 57, April 1957, p. 568.

uranium on certain mines which had done only a limited amount of development, and on which that probable grade of uranium in the ore could not be determined with any degree of accuracy. It was not possible to make accurate assessments of the uranium grade in 1950-1951. Provision was made in the contracts for an adjustment of the price of uranium when there was an increase or decrease in costs, arising out of circumstances beyond control. The contracts set an overall target of production for the Union of South Africa. Each mine was expected to produce at any time to the maximum of its plant capacity.[23]

Finally, the Agency was given the first refusal of any additional supplies of uranium the Union might be able to produce, subject only to the Union's being allowed to produce any quantity it might require for internal consumption. The Union could therefore, under the contracts, retain as much uranium as it needed for its own purposes.[24]

Immediately after the signing of the agreement with the Combined Development Agency in October 1950, the Transvaal Chamber of Mines took control of the establishment of the uranium extraction plants at certain gold mines. On 2 November 1950, RB Hagart, WHA Lawrence, CS McLean and WM Frames, acting for the Gold Producers' Committee, appointed a sub-committee of Consulting Mechanical and Electrical Engineers and a sub-committee of Consulting Metallurgists to consider the establishment of the extraction plants. The Uranium Technical Sub-Committee of the Transvaal and Orange Free State Chamber of Mines was appointed to design the basic features of the uranium plants.[25] These Sub-Committees were required to make

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23 RB Hagart: "National Aspects of the Uranium Industry", **JSAIMM**, 57, April 1957, p. 568.

24 **Ibid.**, p. 569.

25 (SAB) S Craib and DG Maxwell: "Basic Principles of Uranium Plant Design" and JJP Dolan "Co-operative Construction of Uranium Plants', **Uranium in South Africa**, 1946-1956, vol. 1, pp. 388 and 413.

The Monarch shaft of the West Rand Consolidated Gold Mine near Krugersdorp - the first to be sunk to exploit the uranium of the gold-bearing reef

(Source: AR Newby-Fraser: **Chain Reaction**)

recommendations for the earliest production date of uranium by the Transvaal gold mines.

On October 8, 1952, the then Prime Minister, Dr DF Malan, opened the country's first uranium production plant at West Rand Consolidated Mine, 30 km west of Johannesburg. The opening ceremony took place under strict security. On the platform were the Prime Minister accompanied by the Minister of Mines, JH Viljoen; JGN Strauss, the leader of the Opposition; Sir John le Bougetel, the United Kingdom's High Commissioner; Dr T Glennan, a member of the United States Atomic Energy Commission; FC How of the British Ministry of Supply; Sir George Albu, Chairman of West Rand Consolidated Mines and CS McLean, President of the Transvaal Chamber of Mines. There were no women at the ceremony. Guards were posted along the roads and inside the property of the West Rand Consolidated Mine. Only the 400 invited guests were allowed inside and many people were turned away by the officials on duty.[26]

Dr Malan stated at the opening of the plant that the capital cost of the programme of construction of plants for the production of uranium was likely to exceed £40 million. Thirteen mines would proceed with the construction of plants and at least nine other mines, including Vogelstruisbult, would later be added. Constructional facilities of the engineering industry had been stretched to the limit in order to accelerate construction to the maximum. The initial stages of the uranium production would impose strain on manpower, transport, power supplies, water and other resources. The uranium undertaking would however create new spheres of skilled and professional employment.[27]

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26 **Cape Times,** 9.10.1952: "Uranium "Ban" on Women"; "Malan on the Prospects for Uranium".

27 **Cape Times,** 9.10.1952: **Ibid.**; **Die Burger**, 26.9.1952: "Miljoene ponde vir uraanfabrieke".

It was Malan's opinion that to equip mines with the required plants would strain the Union of South Africa's resources to a great extent. Plants would only be constructed after careful deliberation. The output of the mines erecting uranium plants at that tim. would yield almost £30 million a year. That amount would cover running expenses and the redemption of £40 million of loans during the following ten years. The amounts payable as remuneration to the mines on a cost-plus basis had not been disclosed. It was believed that the amount would vary at each mine. It was estimated that after taxation the profits of the mines might rise by one third of the amounts earned at that point in time.[28]

According to Dr Malan the Union of South Africa had shown that it was determined to make a contribution to the cause of the western powers as illustrated by the country's contribution to the struggle in the war in Korea.[29] South Africa's contribution to that cause was the production of uranium on a large scale for the Combined Development Agency and therefore the arsenals of the Western powers.[30]

By 1954, the following mines were approved by the gold mining industry and the AEB for uranium production. Their location and relationship to the uranium treatment and extraction plants were as follows: On the West Rand: four mines were listed: West Rand Consolidated was in the second year of production; Randfontein Estates and East Champ d'Or had a short time before started production (both in February 1954); Luipaardsvlei was due to produce in the near future (November 1954). The Randfontein Estates plant was treating East Champ d'Or residues. Three mines had been approved as uranium producers on the "West Wits Line": Blyvooruitzicht, which was in operation, West Driefontein and Doornfontein (these two mines

28 **Cape Times**, 9.10.1952: **Ibid.**; **Die Burger**, 26.9.1952: "Miljoene ponde vir uraanfabrieke".

29 The war in Korea took place from June 1950 - July 1953. D Thomson: **Europe since Napoleon**, pp. 844-846.

30 **Cape Times**, 9.10.1952: "Malan on the Prospects for Uranium".

commenced production in March 1956). The slime residue from Doornfontein would be treated at the West Driefontein extraction plant.

In the Klerksdorp area three uranium plants were located: at Stilfontein and Western Reefs (both started production in September 1953); and Dominion Reefs (June 1955). The Stilfontein plant would treat, in addition to its own, ore material from Afrikander Lease, Babrosco, Ellerton and New Klerksdorp Gold Estates. The plants at Stilfontein and Western Reefs were then operating. In the Orange Free State, uranium plants at Welkom and President Steyn (both commenced production January 1955), would treat material from Welkom, President Steyn, President Brand, Western Holdings and Free State Geduld mines. Further uranium plants would operate at Virginia and Harmony (production commenced in 1955).[31]

By 1954, seven sulphuric acid plants had been approved to be erected at strategic points to supply sulphuric[32] acid to the uranium industry. The sulphuric acid was produced from the Witwatersrand pyrite*.[33] The guiding principles were the desire to keep down as far as possible the costs of transport of pyrite to the acid plants, and the resultant sulphuric acid from them to the uranium plants. Six of the acid plants would consume pyrite, while the seventh would use elemental sulphur. It was

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31 DN Stuart: "The Supply of the Raw Materials Requirements of the Uranium Programme", **Uranium in South Africa,** vol. II, 1946-1956, p. 2; SH Haughton: "Uranium in South Africa", **Coal and Base Minerals**, September 1954, p. 54.

32 See Technical Addendum: "Methods of recovering gold and uranium" and "sulphuric acid".

33 The material used for producing sulphuric acid is Witwatersrand pyrite, which is obtained from the residues of the uranium and gold plants. The pyrite is first concentrated by flotation. The concentrate is then roasted to liberate sulphur dioxide gas. This gas is, in turn, converted to sulphur trioxide by raising it to a high temperature in the presence of vanadium pectoxide. The sulphur trioxide is then absorbed in water to make sulphuric acid. VH Osborn: "South Africa Becomes a Uranium Producer", **Optima**, (31)1, March 1953, p. 14; MS Solomon and A Beal: "Sulphuric Acid Production in the Uranium Industry", **Uranium in South Africa**, vol. 2, pp. 341-376.

estimated that the seven acid plants would produce approximately 40 000 tons of sulphuric acid a month.

The first acid plant to go into production was that at West Rand Consolidated in 1952. It was the first plant in the world to combine the fluo-solids roasting of pyrite with a contact sulphuric acid plant. It is interesting to note that for more than a quarter of a century pyrite had been extracted from the gold ores on this mine and had been sold to African Explosives and Chemical Industries. No additional plant for the extraction of pyrite was necessary when it was decided to locate an acid-producing plant on West Rand Consolidated Mine.[34]

The significance of the early development of the uranium industry

In 1952 the Minister of Mines, JH Viljoen gave an early indication at a Nationalist Party Congress at the Strand, Cape Town of the importance of the Union's uranium contracts. According to the Minister the contracts were so valuable that when fully developed, uranium would mean as much for the country as the gold production. At that early stage he assured South Africa that enough uranium would be kept back to ensure scope for nuclear research in the Union and its use in the nuclear power industry, when the country reached that stage of development.[35]

Possible future developments in the field of nuclear energy in the Union were thus not overlooked when the agreement between the Atomic

34 CS McLean: "The Uranium Industry of South Africa", **JCMMS**, 54, April 1954, pp. 352-354; MS Solomon and A Beal: "Sulphuric Acid Production in the Uranium Industry", **Uranium in South Africa**, vol. 2 p. 348.

35 "Uranium Production Commences", **Mining Magazine**, 42, Sept. 1952, p. 425; Issues such as the constitutional crisis that arose as a result of the separate representation of voters; the incorporation of the Protectorates; and the extension of votes to 18 year olds that were on the agenda of the National Party Congress at the Strand Cape Town 15-19 September 1952 were given priority in Cape Town newspapers 15-19 September 1952. The Hon. JH Viljoen's statement concerning the contracts was not reported in **The Cape Argus** and **Die Burger** in the period 13-20 September 1952.

Energy Board and British and American nuclear energy authorities was negotiated.[36]

The co-operation between South Africa, Britain, the United States and Canada resulted in a combined total of 528 reports on the subject of uranium extraction during the period 1945-1952.[37] The CDA would finance the calcining plant (that would process the uranium delivered by the extraction plants) as well as the sulphuric acid plants.[38] This collaboration led to the rapid emergence of South Africa as a major producer of uranium. The construction of no fewer than 17 uranium extraction plants, formed a major part of the country's industrial activity since the building began in January 1951. By the time the programme was completed in 1957 a total sum of over £66 000 000 had been invested in them. All this expenditure, with the exception of the cost of the equipment purchased overseas, represented new money injected into the South African economy. By far the greater part would have been spent in South Africa. This benefit to the country would be permanent.[39]

The involvement of the USA and Britain enabled South Africa to purchase equipment from overseas. The vital question of the supply of the necessary materials for fabrication of the plants on the mines was thoroughly investigated. When the plant erection programme was started, structural steel, steel plant and reinforcing steel were in very short supply in South Africa, and much of these requirements that were of necessity were imported from overseas. Bulk orders were placed by

36 "Atomic Energy Board. Uranium in South Africa", **South African Journal of Economics**, 21(1), March 1953, p. 14.

37 (MLA) J Levin: **The Story of Mintek, 1934-1984,** p. 92; L Taverner: "An Historical Review...", **JSAIMM**, 57, Nov. 1956, p. 142.

38 (SAB) JJP Dolan: "Co-operative Construction of Uranium Plants", **Uranium in South Africa** 1946-1956, vol. I, pp. 390 and 199.

39 RB Hagart: "National Aspects of the Uranium Industry", **JSAIMM**, 57, April 1957, p. 569; ND Stuart: "The Supply of Raw materials Requirements of the Uranium Programme", **Uranium in South Africa**, vol. II, 1946-1956, p. 2.

the Transvaal Chamber of Mines for approximately 64 000 tons of steel. One instance of speed and vigour illustrated the speed with which the programme progressed: Four months after placing the initial orders, not only had the first consignment of steel arrived, but the first tanks were being erected on the site of one of the mines. The delivery of large tonnages of steel and other raw materials was made possible by the co-operation and assistance of the British and American Governments.[40]

Although the ownership of the uranium produced by the several mines was vested in the Atomic Energy Board, the proceeds which accrued to the Board from the sale of the uranium was paid over to the producers, and the State participated in the profits through the operation of applicable lease and income tax formulae. Sections 4 and 5 of the Finance Act, 1951, stated that in the case of a leased mine the costs and revenue from the mining would be merged in the other mining costs and revenue for the purpose of determining the State's share of profits under the lease. The interest payable on monies borrowed for the purpose of producing uranium would be deducted from the revenue in the determination of such share of profits.[41]

One of the consequences of the Government's decision to tax the profits from the uranium at the same rate as gold, had been to limit temporarily the amount of taxation drawn from this source. The mines producing uranium were allowed to amortize the capital expenditure on their uranium plants against their profits from gold even before the uranium plants started operating. Thus the Government suffered a considerable reduction in revenue from gold mining taxation in the years from 1951 onwards. The Government would in the long run, however, recover this temporary loss of revenue through the added

40 CS McLean: "The Uranium Industry of South Africa", **JCMMS**, 54, April 1954, p. 348.

41 (Government Printer) **Statutes of the Union of South Africa**, 1951, Act No 56 of 1951, Sections 4 and 5, p. 410; "Atomic Energy Board. Uranium in South Africa", **South African Journal of Economics**, 21 (1), March 1953, p. 14.

yields from taxation of gold and uranium profits when the uranium plants had been amortized. The gold mining industry regarded the Government's decision on the tax issue as one of expediency. Had uranium not been associated with gold, there would not have been such a heavy rate of taxation. Later the Government agreed that a mine producing only uranium, would pay taxation in accordance with the ordinary Company rates.[42]

In the fifties uranium was no longer as scarce a commodity as it may have seemed to be during 1942-1945. Deposits throughout the world were rapidly being developed and exploited. In the United States by 1954 there were 200 active uranium mines ranging from small one-man operations to mines employing 100 men or more. Nine extraction plants were in operation and at least two more planned. By then uranium was also produced in the United States as a by-product from phosphate manufacture. This operation on large tonnages of ore of low grade was then the closest analogy overseas to uranium production in South Africa.[43] Therefore, by the time South Africa commenced production in the early fifties, she did not monopolise the international uranium market.

In addition to the metallurgical intricacies, the construction of the uranium plants presented many engineering problems new to the gold mining industry, and called for increased production by outside manufacturing organizations. The launching of the programme brought considerable benefit to local engineering firms. Not only was it a stimulus to business, but it also presented new engineering problems to stimulate their ingenuity.

As a sulphuric acid process is employed in the uranium extraction process, a means of protecting the plant from corrosion had to be

42 **Statutes of the Republic of South Africa**, Income Tax Act 58 of 1962, Section 1.

43 CS McLean: "The Uranium Industry of South Africa", **JCMMS**, 54, April 1954, p. 355.

devised. Also stainless steel and other acid-resisting alloys and plastics were widely used. Stainless steel fabrication in South Africa was a new development which had grown primarily from the requirements of uranium extraction plants. Uranium plant instrumentation was another highly important feature of the extraction operations, and the installations that were made then were more elaborate than anything that had been used in South Africa up to that time.[44]

Another aspect of the benefits accruing from the new uranium industry had been the sharp increase in demand for power and certain chemical reagents such as manganese dioxide and lime. The experience gained in the construction of these plants would later be of value in the construction of nuclear power plants and facilities for the enrichment of uranium. A number of the building and engineering companies involved with the extraction plants were later approached for these undertakings, for example Roberts Construction Company.

The Electricity Supply Commission had done well in helping to meet the extraordinary demand for power created by the rapidly expanding uranium production programme.[45] When the Combined Development Agency representatives discussed the programme this subject was given attention. The uranium industry would place an ever-increasing strain on the Witwatersrand power resources. It was decided that as little as

44 (SAB) KW Findlay: "The Application of Stainless Steel in the Uranium Industry", **Uranium in South Africa**, 1946-1956, vol. II, p. 519; BJ Olivier, "Uranium", **Industrial Review of Africa**, 4(7), Jan. 1953, pp. 29-33; CS McLean: "The Uranium Industry of South Africa", **JCMMS**, 54, April 1954, pp. 348-354.

45 The Electricity Supply Commission was established early in the 1920's. See the Electricity Supply Act. (No 42 of 1922). It was stipulated that without profit or loss, the Commission, an independent body, would provide sufficient and cheap electric power to industries. During the Second World War, large projects undertaken by ESCOM were hampered by the disruption of commercial shipping as result of the war. An ocean liner carrying a turbo-generator system for Congella, for example, was sunk by a torpedo from a German submarine. A number of projects were indefinitely postponed. However, by 1945 the Vaal power station started supplying electricity and the following year ESCOM managed to increase its sales to over the 5000 million units mark. ESCOM **Een Honderd Jaar Elektrisiteit in Suid-Afrika,** (1882-1982), pp. 12-13.

possible dislocation of local needs for power should be aimed at. A number of schemes for power supply were considered but eventually the Electricity Supply Commission took the long range view that Wilge station should be developed to feed into the Rand Undertaking network and part of this credited to uranium power supply. Two 30 MW and two 60 MW turbo generators were planned. The Combined Development Agency agreed to contribute to the financing of Wilge power station. A loan from the CDA of £7 000 000 was arranged for the uranium power supply. The first 30 MW set came into service on 16 July 1954 and a 60 MW set in March 1955. The uranium power requirements were met before these dates by stringent control of power on the gold mines.[46]

The market for uranium during the fifties

The construction of seventeen extraction plants after January 1951 formed a very important part of the country's industrial activity. In 1953, the first full year of production, the total output of uranium oxide of South Africa was 514 923 kg. Between 1952 and 1957 there was a steady increase in the number of mines producing uranium. By 1957 the number totalled twenty-six. No new mines started production after 1959. This resulted in a rapid increase in uranium production during the fifties, as is indicated in the following table[47]:

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46 (SAB) JJP Dolan: "Co-operative Construction of Uranium Plants", **Uranium in South Africa** 1946-1956, vol. I, p. 388.

47 (Nuclear Fuels Corporation of South Africa Ltd) Production Statistics, NUFCOR: nominal price from United States Atomic Energy Commission purchases, **Statistical Summary of the Uranium Industry**, Energy Research and Development Administration, (ERDA), United States of America, Grand Junction, Colorado, 1976; (AECA, Pelindaba) **Annual Report, Atomic Energy Board. 1960**; "Uranium in South Africa", **SA Panorama,** 3(11), November 1958, p. 5; EF Jeal: "The Uranium Industry in South Africa", **South African Bankers Journal**, 55, Aug. 1958, p. 152.

Table 1 Uranium oxide production and value 1953-1959

	Mines Producing	Production Uranium oxide (kg)	Nominal Price International Uranium Market Price US $ per pound (0,454 kg) uranium oxide	Value of uranium uranium oxide £ (millions)
1952	1	40 177	11.28	
1953	5	514 923	12.35	3.3
1954	12	1 466 118	12.27	14.2
1955	19	2 998 025	12.25	29.1
1956	24	3 962 590	11.51	38.0
1957	26	5 174 476	10.49	49.3
1958	26	5 668 718	9.45	50.0
1959	26	5 846 229	9.12	50.0

The table indicates a dramatic rise in uranium production, namely from 40177 kg in 1952 to 5,8 million kg in 1959 - a rise of 14336%. Despite a decrease in the nominal international market price for uranium oxide, from $12,35 to $9,12 in 1959, the value in that period increased from £3,3 million in 1953 to £50 million in 1959 - an increase of 1415%.

The establishment of the uranium industry resulted in a sharp increase in demand for power, sulphuric acid and chemical reagents. The engineering industry in South Africa had been stimulated by the new challenges and in the construction of the uranium plants. These factors indicated the importance of the uranium industry to the industrial and economic development of the country, and the need to assure its future as far as possible.[48]

By 1958, there were circumstances that strongly indicated that South Africa could not be assured of an increasing demand for uranium. A delegation of the Combined Development Agency visited South Africa toward the end of April 1958, under the leadership of Mr Jesse

48 (AECA) AJA Roux: Proposed Atomic Energy Research and Development Programme for South Africa, p. 15.

Johnson, Director of Raw Materials of the United States Atomic Energy Commission, to discuss with representatives of the Board matters relating to the Heads of Agreement in terms of which the Board supplied uranium oxide to the Agency. The South African Atomic Energy Board was informed that America and England were no longer requiring the amount of uranium for the production of armaments as they had during previous years. Uranium was required more and more for industrial purposes. Therefore, the stockpiling requirements of Britain and America, from 1960, would not exceed 40 000 tons per year.[49]

It was thus necessary for the immediate future for the CDA to impose a ceiling as far as what the Combined Development Agency was prepared to undertake to purchase.[50] During the discussions that took place in April and May 1958 between Dr AJR van Rhijn, the Minister of Mines, and representatives of the Combined Development Agency, the Minister stressed the need for measures that would protect the South African uranium industry from price undercutting. His recommendations were well received by the delegation.[51]

The discussions resulted in a memorandum of understanding between the Agency and the Board, whereby the quantity of uranium oxide to be purchased by the Agency, was fixed at 3 100 short tons for the period 1 July 1958 to December 1958, and thereafter 6 200 short tons per annum until 31 December 1963.[52] The ten-year contracts[53] with the

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49 (AEC Archives, Pelindaba) **Annual Report of the Atomic Energy Board**, 1958, p. 1.

50 **Ibid.**

51 **Die Burger**, 29.4.1958: "Toekoms van Uraan Bespreek": The British representatives were W Starth and EJS Clark and the American representatives: Jesse Johnson, T Upchurch, HES Springarn and CF Shank.

52 A short ton = 2000 lb (1000 kg) USA. **Chamber's Twentieth Century Dictionary**, p. 1159.

53 The various mines producing uranium oxide, each had a ten-year contract to sell its uranium oxide to the CDA. These contracts all had varying dates of

various producers of uranium oxide would commence to lapse from the last-mentioned date. Consequently the Agency's annual purchases from South Africa would gradually decrease until all the ten-year contracts had terminated. The last contract would terminate on 30 June 1967, but the Agency had an option to terminate it on 31 December 1966. It also agreed that the Board might dispose elsewhere of all production in excess of that purchased by the Agency. Previously the full production had to be offered to the Agency. The Union of South Africa agreed to accept a ceiling over the then current production of 6 200 tons of uranium oxide a year. The balance of uranium still outstanding in the existing contracts was stretched out over a longer period.[54]

The question is, how would these developments affect the country? In 1958 it was estimated that South Africa would produce not much less than the fixed maximum. That year South Africa would have no surplus and would collect over £50 million for uranium. The total revenue in that year was second only to gold. Because of the ceiling placed on production, potential development of the uranium industry was curbed. The Buffelsfontein mine, for example, had requested to increase its crushing capacity to 35 000 tons of ore per month, but was refused. Had the mine been allowed to do this, its profit would have increased by £600 000 a year. This was the position in one mine - an indication of the great loss of potential revenue to the country.[55]

Prospects of finding new markets for uranium were not optimistic. Klerksdorp Consolidated Goldfields, that had no contract with the Combined Development Agency, had been unable to find buyers for its uranium.[56] The Combined Development Agency had agreed to

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commencement depending on when each mine started production. Consequently these ten-year contracts all had varying dates of termination.

54 **(AECLP) Annual Report of the Atomic Energy Board**, 1958, p. 1; **Assembly Debates**, vol. 97, 4 July - 25 August 1958, 20 August 1958, col. 2571 - 2572.

55 **Die Burger**, 10.5.1958: "SA 'verloor' groot potensiële inkomste uit uraan".

56 **Ibid.**

facilitate sale of any surplus to other governments of the West, conducted through the AEB at Pretoria. In 1958 a number of other governments, including those of Japan and France, were making enquiries at the South Africa Atomic Energy Board. According to Dr van Rhijn South Africa would be trading in uranium with Japan, Israel, Germany and other countries. (In 1957 South Africa had sold 6,5 tons of uranium oxide to the Atomic Energy Fuel Corporation of Japan.) Although these arrangements seemed favourable to some, others realized that South Africa would no longer be able to depend on uranium as a stabilizing factor in her economy. By that year the world price of uranium was dropping. The American Energy Commission had predicted in 1954 that 10 dollars a pound (0,45 kg), would be a likely price in the long term. In 1958, the Commission could only guarantee a price of 8 dollars a pound after 1962.[57]

A second negative factor for South African uranium dioxide production was the improving world uranium supply. The two most important sources of nuclear fuel, uranium and thorium, were being discovered in many parts of the world. Vast amounts of money were spent in the search for and development of new resources, and on research to improve methods of extraction.

In 1956 the production of uranium oxide of the three main producers, United States of America, Canada and the Union of South Africa, was somewhat less than 15 000 tons of uranium oxide per annum. Indicated reserves of these three countries (on the basis of known information) were in 1957 as follows: United States of America: 150 000 tons;

57 **Assembly Debates**, vol. 97, 4 July - 25 August 1958, 20 August 1958, col. 2572; EF Jeal: "The uranium industry in South Africa", **South African Bankers Journal**, 55, Aug. 1958, pp. 152-154; **Die Burger**, 10.5.1958, "SA 'verloor' groot potensiële inkomste uit uraan"; (AEC Archives, Pelindaba) **Annual Report, South African Atomic Energy Board**, 1958, Introduction.

Canada: 237 000 tons; Union of South Africa: 370 000 tons.[58] According to RB Hagart these figures were on the low side.[59]

During discussions with Dr WF Libby, one of the Commissioners of the United States Atomic Energy Commission, Dr Roux was told that with the new uranium reserves that had been discovered in New Mexico in 1958, the United States had larger uranium reserves than the rest of the free world. Other countries that had started producing uranium in the fifties were France, Australia and Portugal, all of which had important reserves. The production of the Belgian Congo would also have to be taken into account.[60] This was an indication of great uncertainty as to the future market for uranium.

According to Rafford L Faulkner, Deputy Director of the Division of Raw Materials of the United States Atomic Energy Commission, the production of the free world was estimated to reach 30 000 tons per annum by the end of 1958, and 40 000 tons per annum by the end of 1959 or early 1960's. There was little doubt that this rate of production could be maintained and could be increased.[61]

It was to be expected that every country in the world would do its utmost to determine whether it had workable deposits of uranium and thorium, and would develop such deposits. Both France and Sweden

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58 (AEC Archives, Pelindaba) AJA Roux: Proposed Atomic Energy Research and Development Programme for South Africa, p. 16.

59 RB Hagart: "National Aspects of the Uranium Industry", **JSAIMM**, 57, April 1957, p. 571.

60 (AECA, Pelindaba) AJA Roux: Proposed Atomic Energy Research and Development Programme for South Africa, pp. 16-17.

61 (AECA, Pelindaba) AJA Roux: Proposed Atomic Energy Research and Development Programme for South Africa, pp. 17-18; (AECA, Pelindaba) RB Hagart: "National Aspects of the Uranium Industry", **JSAIMM**, 57, April 1957, p. 571.

were refining their uranium and were planning to increase their uranium metal production.[62]

A third negative trend with regard to South African uranium oxide production was the fact that progress in commercial nuclear power programmes was much slower than expected.

In 1957/58 nuclear authorities in the USA all agreed with the view that there was likely to be a period between 1965 and 1975, when the supply of uranium would exceed the demand. The main reasons for this condition setting in during the late fifties was the rapid rate at which uranium production in the Western World was increasing and slower progress in nuclear power programmes than was anticipated earlier in the fifties.[63]

It was clear that South Africa would have to do everything in its power to produce its uranium as cheaply as possible.[64] In anticipation of the reduction in demand for uranium, the South African Government and the Chamber of Mines decided during the first half of 1959 to despatch what was called a uranium supply mission to Europe to investigate all aspects of nuclear energy that could assist in decision-making with respect to the further development of South Africa's uranium resources. The mission was to comprise a representative of the Chamber of Mines (H Koch of Anglo American), the Head of the Mineralogical Institute (Professor Taverner) and DB Sole. The mission's assignment began in Vienna with discussions with the IAEA. Centres visited were Stuttgart, Frankfurt, Brussels, Paris, Milan, Düsseldorf, Cologne, Zurich, Berne, Stresa and Stockholm. The itinerary included a seminar on the industrial prospects of nuclear energy at Stresa, discussions with the atomic energy authorities in Stockholm, visits to various atomic energy

62 (AECA, Pelindaba) AJA Roux: Proposed Atomic Energy Research and Development Programme for South Africa, p. 17.

63 (AECA, Pelindaba) AJA Roux: Atomic Energy Research and Development, Part I, United States, pp. 50-51.

64 **Ibid.**

and uranium plants and installations in France, as well as an uranium mine. According to DB Sole the results achieved by the mission were "negligible except in the sense that invaluable contacts were established".[65]

The foreign trade value of uranium oxide increased dramatically during the fifties. In 1953 the total value was £3 873 029 and in 1958 it earned £53 661 840. In 1958 and 1959 it earned respectively 15 percent and 12 percent of the Union of South Africa's total foreign trade value. The following table illustrates the phenomenal increase.

Table 2 Foreign trade value of uranium oxide 1953-1959[66]

Year	uranium oxide produced kg	Value uranium oxide[67] £	Value of total exports £	Percentage of total exports %
1953	514 923	3 873 029	340 018 656	1.14
1954	1 466 118	14 835 344	321 747 153	1.61
1955	29 98[illegible] 25	29 159 589	369 047 639	7.90
1956	3 962 590	38 695 080	369 834 063	10.46
1957	5 174 475	49 988 63[illegible]	402 662 214	12.41
1958	5 668 718	53 661 840	357 362 755	15.02
1959	5 846 229	49 232 449	386 184 689	12.70

65 (SAL) DB Sole: **This Above All** (Unpublished manuscript), pp. 213 and 214.

66 (NUFCOR) Production statistics NUFCOR; (SAL) Government Printer, Union of South Africa: **Annual Statement of the Trade and Shipping of the Union of South Africa,** 1953, 1954 and 1955; **Foreign Trade Statistics** 1956, vol. II, pp. 100 and 170; 1957, vol. II, pp. 98 and 168; 1958, vol. II, pp. 98 and 168; 1959, vol. II, p. 106; **Supplementary Trade Statements**, 1959, vol. III, p. 17.

67 In official statistics uranium oxide is included in "prescribed materials". "Prescribed materials" figures included the value exports of thorium and "rare earths". As thorium and "rare earths" were only a small percentage, uranium oxide, therefore made up virtually the total value of "prescribed materials". (Figures for uranium oxide can not be isolated from the other products).

The exceptional increase in the foreign trade value of uranium oxide brought about that uranium oxide became one of South Africa's most important export commodities in the 1950's. In 1958 and 1959 it was South Africa's second most important export product - second only to gold. Its foreign trade value surpassed both that of wool and diamonds (uncut). This is illustrated in the following table. The value of only the major export products is given.

Table 3 Importance of uranium as export product during 1953-1959[68]

Year	Gold	uranium oxide	Wool	Diamonds (uncut)	Total Value of export
	(£1000)	(£1000)	(£1000)	(£1000)	(£1000)
1953	98 253	3 873	65 933	8 253	340 019
1954	155 848	14 835	61 437	7 141	321 747
1955	178 141	29 160	58 936	23 824	369 048
1956	193 205	38 695	62 001	23 361	369 834
1957	216 893	49 989	67 125	24 686	402 662
1958	221 869	53 662	42 506	20 572	357 363
1959	250 136	49 232	42 566	26 273	386 185

The market for uranium during the sixties and early seventies

In the light of the imminent overproduction of uranium, the future demand and the future market for uranium was a subject of much speculation during the late fifties. No one knew exactly what the future demands for military purposes would be. There was uncertainty about

68 (SAL) Government Printer, Union of South Africa: **Union Statistics for Fifty Years, Jubilee issue 1910-1960,** compiled by the Bureau of Census and Statistics, Pretoria, March 1960, p. N-2; Foreign Trade Statistics, vol. IV, **Standard International Trade Classification and Supplementary Tables,** 1959, 1958 and 1057, p. 6; **Foreign Trade Statistics,** 1956-1959; **Annual Statement of Trade and Shipping in the Union of South Africa,** 1953-1955.

the rate at which breeder reactors would be developed, the extent to which plutonium would be employed as a nuclear fuel, and the rate at which reactor technology would advance.[69]

The future of uranium production in South Africa was thus debatable. On the one hand South Africa, as a result of the factors mentioned, could not be assured of an increasing international demand for uranium. Statistics indicated that unquestionably. On the other hand Dr Roux and uranium authorities were confident that South Africa's uranium industry, despite the uncertainties for the short term, would be of even greater value in the long term and, therefore, it was imperative that everything should be done to ensure its future.[70]

During his visit to South Africa, Jesse Johnson stated that South Africa had a sound uranium industry, and that the long-term prospects were very bright.[71] CS McLean and Dr RB Hagart (Joint Deputy Chairman of the Anglo American Corporation), the two prominent men in the gold mining industry, best versed in the subject, had always looked upon uranium as likely to loom large in the country's destiny. This view was amply vindicated by events.

In the late fifties South Africa had received a better price than had, on the average, been paid elsewhere, but prices had hardened. The Canadian distributing company reported sales in 1957 at an average of $10 (70 shillings) per pound. The average for the Union for South

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69 AJA Roux: Proposed Atomic Energy Research and Development Programme for South Africa, p. 18; RB Hagart: "National Aspects of the Uranium Industry", **JSAIMM**, 57, April 1957, p. 576.

70 AJA Roux: "Nuclear Energy": The Impact on South Africa", **Commercial Opinion**, 35(415), Aug. 1957, pp. 28-29.

71 EF Jeal: "The Uranium Industry in South Africa", **South African Bankers Journal**, 55, Aug. 1958, p. 152.

Africa was over $12 (85 shillings). The lowest South African contract price was about $10 (70 shillings).[72]

Dr RB Hagart set out certain factors that indicated that there would be a future market for South Africa's uranium after the contracts with America and Britain expired. He stated in an address at a joint symposium on uranium of the South African Institute of Mining and Metallurgy and the University of the Witwatersrand in 1957 that South Africa would hold its position in the field of uranium production, and would be of paramount importance for the world of the future. Though not the largest individual producer in the world, South Africa's position was assured until at least the end of the century. At the annual rate of production of 6 000 tons of uranium oxide, South Africa had some 60 years of continuous production ahead. Because the uranium industry was linked to gold mining in South Africa, there were distinct advantages according to Dr Hagart. Although South Africa's grade was lower than that of America and Canada, most of South Africa's mines had the great advantage that they were producing uranium oxide as a by-product of gold. No mining or crushing costs had to be charged to uranium production, and only actual treatment costs in uranium plants were charged. In America and Canada however, all mining and crushing costs, as well as treatment costs, had to be charged against revenue from the sale of uranium.[73]

By 1964-1966 the entire cost of the then established uranium plants would have been paid for out of the revenue under the existing contracts. No capital costs, other than for the renewal and replacements to plants, would thereafter be necessary. With assured reserves of ore, far in excess of the milling capacities, South Africa would be able, if necessary, to offer long-term contracts and assurances

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72 EF Jeal: "The Uranium Industry in South Africa", **South African Bankers Journal**, 55, Aug. 1958, p. 153.

73 RB Hagart: "National Aspects of the Uranium Industry", **JSAIMM**, 57, April 1957, p. 578.

of delivery. According to Dr Hagart, South Africa was, therefore, in a highly competitive position.[74]

As regards the price of uranium oxide, there was every reason for confidence. The 1957 price could be taken roughly as between $10 (70 shillings) and $11 (80 shillings) per pound of uranium oxide. For forward contracts the United States were offering local producers a price of $8 or 56 shillings per pound. After the then existing contracts had expired South Africa was not obliged to offer its uranium to the Combined Development Agency and might well find other buyers. Many new private companies had been formed on both sides of the Atlantic to exploit the nuclear power market throughout the world.[75] Private American (and British) firms were at that stage already competing in a race to obtain export markets for nuclear power application. Much of the necessary technical information in regard to nuclear reactors had been freely published in both those countries. Acceleration of nuclear developments would be the result.[76]

In the uranium debate the international conflict situation that was the result of the Suez Crisis of 1956 was of significance. In that year Colonel Nasser of Egypt nationalized the Suez Canal Company which resulted in Anglo-French military action against the United Arab Republic. The threat of closing the world waterway emphasized the factors of transport and freight charges and facilities in favour of the use of uranium as against the conventional fuels.[77] A pending

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74 RB Hagart: "National Aspects of the Uranium Industry", **JSAIMM**, 57, April 1957, pp. 577-578.

75 **Ibid.**, p. 575.

76 SO Ecklund, "Nuclear Energy: A Current Review", **Industrial Review of Africa**, 8(1), July 1956, p. 69.

77 David Thomson: **Europe Since Napoleon**, p. 869; RB Hagart: "National Aspects of the Uranium Industry", **JSAIMM**, 57, April 1957, p. 575.

international conflict would necessarily focus attention on the application of nuclear energy in the military sphere.[78]

Enriched uranium would increasingly be used in reactors for the generation of electricity[79] and for ship propulsion. This would mean new markets for enriched uranium in future. Countries such as the UK, France, Norway, Sweden and Switzerland were very seriously considering nuclear power as an alternative power source. In countries where there was a shortage of conventional fuels, where hydro-electric power sources were frozen in winter, and in areas where nuclear power stations would minimise both the transport of conventional fuels and freight expenditure, nuclear power would be introduced in industrialised countries to meet the increase in the demand for power.[80]

In an interview with Dr Roux, W Perine, President of the Vitro Engineering Co. in New York, said that the United States Navy was building most of its new naval vessels with nuclear propulsion, and that it was a very large programme.[81]

It was thus of the utmost importance that South Africa should pursue the programme of research and development in order to improve methods of mining, extraction and processing of uranium with the view to export a more refined uranium product. In this work the United Kingdom was prepared to assist South Africa with the supply of information. Dr Roux, in discussion with authorities including Sir Edwin Plowden (Chairman of the UKAEA, London), Sir Christopher Hinton (Managing Director, Industrial Group of the Atomic Energy

78 FH Hartmann: **The Relations of Nations,** pp. 243-245.

79 By 1957, in the USA, the three main types of reactors that held promise, the Pressurized Water Reactor,* the Boiling Water Reactor* and the Sodium-graphite Reactor,* all employed enriched uranium as fuel.

80 (AECA Pelindaba) AJA Roux: Atomic Energy Research and Development, Part II, United Kingdom and Canada, 31.3.1958, pp. 45 and 5-25; Part III Continent of Europe, pp. 1-3, 26, 38-39 and 78-79.

81 (AECA, Pelindaba) AJA Roux: Atomic Energy Research and Development, Part I, United States, p. 43.

Authority, Risley) and Dr Schonland considered the refining of uranium as vital for the future South African uranium export market.[82]

Therefore, in the uranium debate, the factors mentioned such as cheaper South African uranium as compared to other countries and the application of enriched fuel in reactors for power generation and ship propulsion outweighed the arguments that there would be no future demand for uranium. There were also definite indications that South Africa would have to produce its uranium in a more refined form.

During the sixties and early seventies the short-term demand for uranium was uncertain. Canada's contracts with the Combined Development Agency expired between 1962 and 1963; those of the Union of South Africa between 1964 and 1966 and those of Australia in 1965. Producers were concerned about what would happen after that year. South Africa would, however, be able to compete as refining plants at the mines would have been paid for, and especially the fact that uranium was mined as a by-product of gold. Even though the prospects after 1965 were unsure, PH Anderson, Chairman of the Transvaal Chamber of Mines, remained optimistic about the long-term prospects of uranium.[83]

As a result of the decline in the military requirements of the USA and the UK and also to accommodate the problem of surplus uranium, a new agreement between the South African Atomic Energy Board and the United Kingdom Atomic Energy Authority and the United States Atomic Energy Commission was issued in January 1961. The new agreement became known as the "stretch-out agreement". The terms of this agreement, which came into operation on January 1, 1961, were that the 28 350 tons of uranium oxide which had to be delivered over the period 1 January, 1961 to 31 December, 1966, would be delivered over a longer period, ending on 31 December, 1970. The annual

82 Annual Report of the South African Atomic Energy Board, 1961, p. 5.

83 **Die Burger**, 30.6.1959: "SA soek plan met oorskot-uraan".

Dr TEW Schumann, Deputy Chairman of the Atomic Energy Board signed the "stretch out" Agreement with the Combined Development Agency on behalf of the Board
(left: AJ Brink, AEB's Secretary and JHA Nel, AEB's Legal Advisor)

(Source: Annual Report of the South African Atomic Energy Board, 1961) quantity bought by the USA and UK was reduced to approximately 2 835 tons over the period of ten years, January, 1961, to December, 1970. This was a considerable reduction, considering that the CDA had (according to the previous agreement) acceded to buying 6200 tons of South African uranium per annum between 1959 and 1963.[84]

The Deputy Minister of Mines, M Viljoen, said in Parliament that the "stretch-out agreement" which had been reached by the Atomic Energy Board with the assistance of representatives of the mining industry, was a most complicated agreement. Complicated negotiations had to be carried out which called for the utmost tact and perseverance. Arrangements were entered into which were to the advantage of South Africa and to the whole uranium industry.[85]

The "stretch-out agreement" with the Combined Development Agency had a profound effect on South Africa's uranium production. Although the agreements implied a reduction in the tonnage to be delivered each year it ensured that reduced uranium production in the country could proceed at least to the end of the 1960's. This was of great importance as it was hoped that the Republic could remain in production until the use of nuclear power had assumed the dimensions where there would be a steady world demand for nuclear material. The "stretch-out agreement" gave the opportunity to keep mine workers employed. Adaptations could be made over a long period and with much less disruption than would have been the case if the delivery of uranium oxide were to have been completed over the period 1964 to 1966 in accordance with the previous contracts.[86]

Instead of the former type of the cost-plus contract with the CDA, the South African producers would, under the new contract, receive fixed

84 (Government Printer) **Assembly Debates,** vol. 108, 1 May - 20 May, 23 May 1961, col 7-16.

85 **Ibid.,** col. 7016.

86 **Ibid.**

prices which were in line with the prices received at the termination of the previous contracts. Repayments of loans granted by the partners in the Combined Development Agency, through the Import-Export Bank for the erection of the uranium installations, would not be affected in view of the fact that certain payments would be made in advance to the Board for the purpose of enabling the producers to comply with their loan obligations within the original loan period. According to Section 16 (4) (a) of the Atomic Energy Act (No 44 of 1961) the Atomic Energy Board would retain such advance payments and invest the money until it became necessary to repay the loans, and also to repay such advance payments when the money was no longer required. According to section 16 (4) (a), sub-paragraph (vi), any surplus earned from interest on the investment of such advanced payments, would be paid into the Consolidated Revenue Fund, whilst any shortage would be paid from funds voted by Parliament for that object.[87]

Provision was also made in section 16 (4) (b) in terms of which the Minister of Finance, on behalf of the Government, could guarantee the repayment of advance payments. The furnishing of such a guarantee formed part of the agreement between the AEB and the Atomic Energy Authority of the United Kingdom.[88]

As a result of the new agreements continued production for uranium by some high-cost mines became unprofitable. Treatment plants were closed and ore was selectively dumped for possible future processing. In some cases this practice was economically unattractive and the uranium in the gold ore was simply discarded. The cost-plus figure of $12 per pound (R22,9 per kg) - which in the early fifties determined that the industry would be viable - plummeted to half of that by 1970.[89]

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87 **Assembly Debates**, vol. 108, 1 May-26 May, 1961, 23 May 1961, col. 7016-7017.

88 **Ibid.**

89 AR Newby-Fraser: **Chain Reaction**, pp. 65-66.

The "stretch-out" agreement opened the way for producers such as the Randfontein Mines to rationalise their output by transferring all or part of their quotas to other companies in exchange for suitable royalties. For example, towards the end of 1960 Randfontein invited tenders for the transfer of 880 tons of the 4 880 tons that the mines was committed to produce for the CDA. In January 1961 the Atomic Energy Board accepted the offer and uranium was transferred to Rand Mines on behalf of its operations at Harmony and Blyvooruitzicht Mines. In March 1962 the Board agreed to transfer a further 800 tons to West Rand Consolidated at the rate of 200 tons per year over four years. That left Randfontein responsible for producing no more than 2 200 tons by the end of 1965.[90]

There seems little doubt that the "stretch-out agreement" would be beneficial to the uranium industry during difficult times. This view was endorsed by members of the South African parliament. According to JC Greyling, Member of Parliament for Ventersdorp, uranium in 1961 no longer had the expected commercial value. Consequently, changes had to be made to the agreement which existed between the South African Government, the Atomic Energy Board and the Combined Development Agency. By the agreement South Africa would benefit financially, certain mines would as a result enjoy the continuity of sales, would remain in operation for a longer period and employment for workers would be ensured. He regarded it as significant that the old cost-plus system under which uranium was sold, would be replaced by a stable price. That was the best method that could be adopted under the circumstances. It was possible for mines that had uranium extraction installations to make arrangements that gold mines with the lowest costs of production, could concentrate on the production of uranium.[91]

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90 A Hocking: **The Randfontein Estates, The First Hundred Years,** pp. 186-187.

91 **Assembly Debates,** vol. 108, 1 May - 26 May 1961, 23 May 1961, col. 7021-7023.

In the following table the effects of the "stretch-out agreement" on uranium marketing are illustrated:

Table 4 Foreign trade value of uranium oxide 1960-1970.[92]

Year	Uranium oxide produced kg	Nominal price International uranium market price US dollars per pound (0,454kg) uranium oxide	Value of total SA exports R1000	Calculated foreign trade value uranium oxide $1000	Value uranium oxide R1000	percentage of total exports
1960	5 813 906	8,75	1 419 964	111 918	108 533	7.64
1961	4 960 750	8,50	1 527 199	92 766	79 372	5.00
1962	4 557 874	7,82	1 585 658	78 431	74 391	4.69
1963	4 111 677	8.00	1 684 742	72 366	66 954	3.97
1964	4 032 638	8.00	1 771 995	70 974	uranium ore concentrates 58 068	3.28
1965	2 669 230	8.00	1 825 602	46 978	33 308	1.82
1966	2 981 138	8.00	1 982 324	52 468	classified information	± 2.00 (calculated)
1967	3 048 815	8.00	2 126 984	53 659	-	less than ± 2.00
1968	3 513 591	6,50	2 275 263	50 244	-	-
1969	3 615 435	6,25	2 323 897	49 712	-	-
1970	3 742 201	6.30	2 373 611	51 867	-	-

The following deductions can be made from the table: Uranium oxide production reached a peak of 5 813 906 kg in 1960.[93] Production

92 (SAL) Central Statistical Service, Pretoria: **South African Statistics, 1993**, Dec 1993, p. 164; (NUFCOR) Production Statistics 1960-1965, NUFCOR annual reports 1966-1970; (NUFCOR) Nominal price from United States Atomic Energy Commission purchases, **Statistical Summary of the Uranium Industry**, Energy Research and Development Administration (ERDA), USA, Grand Junction, Colorado, 1976; (SAL) **Foreign Trade Statistics**: 1960: pp. 114 and 115; 1961, p. 81, 1962, p. 79; 1963, p. 190; 1964, p. 165; 1965, p. 187.

93 According to the Annual Report of the Atomic Energy Board, in 1961, in terms of the new agreements, 5 002 tons of uranium oxide (which was produced either as the main product or as a by-product from the gold extraction slimes by seventeen uranium producers) was delivered under the contracts. A total of 5 014,6 short tons of uranium oxide was marketed in 1961. This figure was 1 422,5 short tons less than the quantity marketed in

figures decreased every year until 1965 when an all time low of 2 669 230 kg was recorded. The nominal international uranium market price dropped steadily from 8,75 dollars in 1960 to 6,05 dollars in 1971. The South African foreign exchange value of uranium oxide dropped from R108 533 000 in 1960 to R33 308 000 in 1965. Although the nominal price for uranium oxide dropped from 1966 to 1971 production figures increased and the calculated value of South African uranium oxide on the international market remained fairly steady. The highest and the lowest values recorded for 1967 and 1969 are namely $53 659 000 and $49 712 000 respectively.

In 1960 uranium oxide contributed 7.64% of the total of South African foreign trade value. In 1965 this percentage for uranium ore and concentrates decreased to 1.82%. Between 1966 and 1970 the calculated foreign trade value of South African production of uranium oxide remained fairly steady at an average of $51 411 500. Therefore, with the increased total value of South African exports between 1966 and 1970 from R1982 324 000 to R2373 611 000, the value of uranium oxide as a percentage of the total value of exports decreased every year. The figure in 1966 calculated at approximately 2% of the total exports and declined further between 1967 and 1970.

The importance of uranium as an export product is illustrated in the following table. It is compared to gold, wool and diamonds (rough and uncut).

Table 5 Importance of uranium as an export product during 1960-1970[94]

1960. **Annual Report of the South African Atomic Energy Board,** 1961, p. 5.

94 (SAL) Central Statistical Service Pretoria (compiler): **South African Statistics, 1993,** Dec. 1993, p. 164; (Central Statistical Service Pretoria) **Maandbulletin van Statistiek,** Buro van Statistiek, Pretoria, Desember 1962, p. 59; Desember 1964, p. 54; Maart 1967, p. 97; **Bulletin van Statistiek,** Departement van Statistiek Pretoria, Maart 1970, p. 113; Desember 1973, pp. 9·5, 9·6; (SAL) **Foreign Trade Statistics, Exports,** 1960, pp. 114 and 115; 1961, p. 81; 1962, p. 79; 1963, p. 190; 1964, p. 195; 1965, p. 187. Where the values of wool and diamonds (rough and

Value of major export products					
Year	gold (R1000)	uranium oxide (R1000)	wool (R1000)	diamonds (rough and uncut) (R1000)	total value of exports (R1000)
1960	536 009	108 533	96 625	46 717	1 419 964
1961	574 909	79 372	109 935	59 247	1 527 199
1962	636 516	74 391	115,300	50,400	1 585 658
1963	685 675	66 954	115,900	68,000	1 684 742
1964	730 511	uranium ore and concentrates 58 068	132,300	74,100	1 771 995
1965	766 492	33 308	123,500	28,800	1 825 602
1966	776 064	classified information	128,200	121,700	1 982 324
1967	762 893	"	106,500	116,600	2 126 984
1968	768 964	"	115,400	140,600	2 275 263
1969	788 754	"	116,500	152,400	2 322 897
1970	837 088	"	79,800	110,000	2 373 611

The foreign trade value of gold and rough and uncut diamonds increased considerably between 1960 and 1970. The value of wool increased to a maximum of R132,5 million in 1964 and then dropped to R79,8 million in 1970. In comparison the importance of uranium oxide as a export product dropped steadily between 1960 and 1965. Taking into account the calculated foreign trade value of uranium oxide as indicated in Table 5, gold, wool and rough and uncut diamonds were more important export products for South Africa between 1966 and 1970.

uncut) are given in R million, figures have been adjusted in the table for uniformity and given in R1000.

As indicated in Tables 4, 5 and 6 there was a steady increase in the production of uranium oxide between 1966 and 1970. With the increasing development and utilization of nuclear energy, particularly for the generation of electricity, the demand for uranium by 1967 also indicated an upward trend.[95] There was some evidence that the predictions of Dr Hagart and others in the late fifties (though doubted when the price of uranium dropped in the sixties) could prove to be correct, in the long term. They believed that there would be a future export market for South Africa's uranium after the contracts with America and Britain had expired.[96]

Consequences of the stability in uranium foreign trade value 1966-1970

Even though the value of uranium oxide dropped in comparison to other major South African export products, the stability in South Africa's uranium foreign trade value between 1966 and 1970 was adequate to restore confidence in uranium. In addition the worldwide projected increase in nuclear generating capacity and the furtherance of processing uranium oxide for South Africa's nuclear programme and for foreign trade brought about the following:

In the first instance a renewed search for uranium deposits was undertaken. According to Dr JW von Backström, head of the Atomic Energy Board's Geology Division in 1967, known deposits were unlikely to guarantee output sufficient to meet persistently increasing demand for a low-cost product after 1975.[97] Less uranium was

95 JW von Backström, Correspondence, November, 1991; JW von Backström: "Uranium", **Mineral Resources of the Republic of South Africa**, p. 239.

96 **Die Burger**, 25.5.1967: "Oppenheimer is optimisties oor Uraan".

97 The task of the Division was to discover and assess natural deposits in South Africa of materials required for the construction and fuelling of nuclear reactors and associated equipment. Exploration was not done by the Board's staff, but was carried out on behalf of the Board by the Geological Survey Division of the Department of Mines. The Geology Division of the Atomic Energy Board coordinated this work, maintaining its relationship with the overall programme, and also kept an eye on world trends and requirements in

discovered world-wide in the late sixties than had been mined. Many areas throughout South Africa had yet to be intensively explored.[98]

In 1966 radiometric surveys in various parts of the Republic were undertaken.[99] The following year studies were done by Palabora Mining Company into possible methods of extracting uranium from urano-thorianite at Phalaborwa in the northeastern Transvaal. Towards the end of 1969, following the development of novel and successful gravity concentration and chemical extraction techniques feasibility studies were completed and the construction of a full-scale plant commenced. This was completed in mid-1970 and production of uranium oxide began in August of that year. Prospecting resulted in extensions to known South African uranium reserves from 1966 to 1972.[100]

Secondly, as it was in the country's interest to locate additional sources and to extend and develop South Africa's uranium industry, a new Act was introduced to Parliament which would delete or amend certain of the hampering provisions of the old Atomic Energy Act of 1948.[101]

By the new Atomic Energy Act of 1967, the ownership of the mined uranium was transferred from the State to the person or mining company which had mined such material. (These measures had also been adopted by countries such as the United States of America and

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the field of nuclear raw materials. HJ Brynard et al: **Uranium in South Africa**, publication of the Atomic Energy Corporation, June 1988, p. 12; JW von Backström: "Uranium", **South Africa's Mineral Wealth**, p. 13.

98 "Search for Uranium Urged. Resumption of Uranium Prospecting is Needed", **SAMEJ**, (78), No (3), August, 1976; JW von Backström, Correspondence, November 1991.

99 **Assembly Debates**, vol. 21, 1 May-14 June 1967, 26 May 1967, col. 6755.

100 HJ Brynard et al: **Uranium in South Africa**, pp. 10-11; FAGM Camisani Calzolari and PD Toens: "South African Uranium Resource and Production Capability Estimates", AEB, PER - 51 - 3, September 1980, Introduction; AR Newby-Fraser, **Chain Reaction**, p. 70.

101 **Statutes of the Republic of South Africa**, Act No 90 of 1967, pp. 1428-1476. Assented to 19 June 1967.

Canada.) Permission still had to be obtained from the Minister to prospect for uranium but might only be withheld if the Minister considered that the security of the State would be endangered. In this way the essential control was retained because the uranium and other source materials still were regarded as of strategic importance. Written authority by the Minister, which he might only grant after consultation with the Atomic Energy Board, was required for the possession, disposal, enrichment, re-processing and export of uranium.[102]

Finally, by 1970 South Africa had increased its uranium reserves. The increase had resulted from new discoveries in both the Republic and South West Africa, as well as from the achievement of higher extraction efficiencies coupled with the development of improved extraction processes.[103]

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102 **Assembly Debates**, vol. 21 1 May-15 June 1967, 26 May 1967, col. 6[illegible]-6746.

103 AJA Roux: Talk on the Radio programme, "Top Level", 27.6.1970.

CHAPTER FIVE

ATOMS FOR PEACE

South Africa's position as a leading uranium producer contracted to the Combined Development Agency gave the country status in developing international atomic energy relations. By early 1954 it was becoming essential that some form of agreement be attained between the nuclear nations on nuclear proliferation. President Eisenhower's Atoms for Peace initiative would lead to the First International Conference on the Peaceful Uses of Atomic Energy in Geneva in 1955, fissionable material being made available to developing countries and the founding of a new international agency to control nuclear energy. South Africa sent a delegation to the conference at Geneva. Even though the Minister of External Affairs, Eric Louw, had by 1957 embarked on a policy of confrontation with the United Nations Organization, South Africa's representatives could participate in the formation of the International Atomic Energy Agency (IAEA). South Africa's favourable position led to formal agreements with both the United States Government and the United Kingdom Atomic Energy Authority. Nuclear science had unlocked a vast new source of energy.

Eisenhower's Atoms for Peace Programme

The development of the uranium industry opened the way for nuclear energy production in South Africa. The importance of the established uranium industry in this regard cannot be overemphasized. Although uranium deposits throughout the world were rapidly being developed, South Africa in the early fifties had the largest known reserves of uranium in the world.[1] Major uranium deposits in the United States, Britain and elsewhere still remained to be discovered. In terms of the contracts with the Combined Development Agency, South Africa provided the United States and Britain from 1953 with huge amounts of

1 RB Hagart: "National Aspects of the Uranium Industry", **JSAIMM**, 57, April 1957, p. 577; Interview with DB Sole, 12.12.1990.

uranium for employment in various military programmes. There is little doubt that the South African uranium supplies were essential to the United States military programme.[2] This situation would change after 1958. It was therefore of importance that South Africa utilize its paramount position in world uranium production. The South African Atomic Energy Board seized the moment, and made the most of its direct involvement with atomic energy authorities in both the United States and Britain. Developments in international politics will illustrate how it came to be that South Africa was to play a role in international nuclear energy affairs in the fifties.

In 1950 America could not disregard the importance of nuclear armaments as the Soviet Union would not partake in the United Nations' proposals on disarmament. The Western powers were following a policy to contain Communist influence in Europe and Asia and deepening international conflict had led to a cold war situation with the Soviet Union.[3]

As has been discussed earlier, the Baruch Plan (1946) was unacceptable to the Soviet Union. They had objected to the system of inspection and insisted upon keeping the power of veto in the United Nations Organization. Without these two provisions the Western powers felt that there could be no security against the secret manufacture of nuclear bombs and therefore no value in the plan. In 1948 the Soviet Union proposed a one third reduction of armed forces by the great powers. To adopt it would have meant a much greater reduction for the Western forces, each of which would have had to be reduced one third. Instead the United States urged in mid-1952 that absolute figures be sent for the armed forces. The Soviet Union opposed this. In America work had been pressed forward on the hydrogen bomb. It was successfully tested

2 DB Sole: "The Rise of Nuclear Sanctions against South Africa", **American Review**, Jan. 1986, p. 3.

3 GF Kennan: **The Nuclear Delusion**, pp. 59-60; WI Cohen: **The Cambridge History of American Foreign Relations**, pp. 37-42; FH Hartman: **The New Age of American Foreign Policy**, pp. 126-128.

in the Pacific proving ground in 1952. On August 12, 1953, the United States announced that their monopoly of the H-bomb, had been broken by the Soviet explosion of a hydrogen device. In that same year a series of United States announcements revealed that tactical nuclear weapons had become a reality. By early 1954 Russia, the USA and Britain had nuclear weapons. These rapid advances in destructive capacity made disarmament by agreement more urgently essential.[4]

In the years 1949-1953 there was no single decision or resolution in the United Nations on disarmament that enjoyed unanimous support of the nuclear nations.[5]

Between 1949 and 1954 the problem on nuclear disarmament changed in two important respects: nuclear weapons were no longer confined to a single nation and nuclear weapons were proliferating in kind and number. Where "the bomb" had received all the attention, the interrelation of all weapons systems were now reasserted. The United Nations merged the UN Atomic Energy Commission and the Commission for Conventional Armaments into a new Disarmament Commission on 11 January 1952 giving it power to survey the entire programme. Both the United States and the Soviet Union brought their proposals for disarmament of conventional forces before the new commission.[6]

The development of the atomic and hydrogen bombs as well as tactical weapons could only be controlled by some form of collective security. An accumulation of atomic weapons and nuclear devices was in a sense a form of "external aggression". The USA, Britain and Russia needed a mutual insurance plan, which could be a guarantee that these most

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4 D Thomson: **Europe Since Napoleon**, pp. 884-885; FH Hartmann: **The Relations of Nations**, pp. 289-290.

5 A McKnight: **Atomic Safeguards: A Study in International Verification**, p. 19.

6 FH Hartmann: **The Relations of Nations**, p. 290

destructive nuclear devices would be kept in check for the preservation of all mankind.

In the early 1950's a committee of scientists headed by Julius Robert Oppenheimer (Director of the Y Project of the Manhattan Project) submitted a report to President Eisenhower on the destructive effect of thermonuclear (i.e. hydrogen) weapons. The report recommended some new approach to Russia on preventing war, in view of the new potential for destruction and recommended that the public be informed of the danger of such weapons.[7] President Eisenhower accepted this. On 8 December 1953 he addressed the General Assembly of the United Nations Organization. In preparing his speech two approaches appear to have been considered by his advisors. The first was to stress the increased destructive potential of nuclear weapons and the second was to propose an international effort to use nuclear energy for the welfare of man. The President chose the second approach.[8]

The theme of his speech developed from the fact that in 1953 world supplies of special fissionable materials (plutonium and enriched uranium) were almost wholly used for weapons programmes. Almost the entire world production of natural uranium fed the reactors and isotope separation plants in the nuclear weapons countries. The question the President posed was whether the time had not come for a concerted world effort to devote some part of the nuclear energy effort to the peaceful applications of nuclear energy. This proposal became known as Eisenhower's Atoms for Peace Programme. He believed that the nuclear military build-up could be reversed. This could be done if the governments principally involved would make contributions from their stockpiles of natural uranium and special fissionable materials to a new international agency for nuclear energy. This agency would allocate its materials in order to serve the peaceful pursuits of mankind,

7 N Moss: **The Politics of Uranium**, pp. 41-42.

8 A McKnight: **Atomic Safeguards: A Study in International Verification,** p. 19.

such as the production of electric power. There were also subsidiary uses of radioactivity in agriculture, medicine and other fields. Assistance provided by the agency would be accompanied by some form of verification that the nuclear energy would not be used for destructive ends. Such an agency would be set up under the aegis of the United Nations Organization.[9]

The speech was received with tremendous acclaim. For many years nuclear energy had appeared to be only destructive. At last there was hope that the new science would be beneficial. President Eisenhower's speech provided something positive and hopeful. In the middle fifties expectations of what nuclear power could do were somewhat inflated.[10]

The United States was swift to follow up the President's proposals and the US Secretary of State made his first approach to the Soviet Ambassador on 11 January 1954. The negotiations which followed occupied nearly four years.[11]

With Eisenhower's Atoms for Peace Programme, the Russians departed from their negative attitude in the 1940's and were prepared to discuss proposals. The progress of negotiations was not encouraging, however, the USA persisted with its initiative. These new efforts were not aimed directly at disarmament, but rather at decreasing the tensions implicit in the existence of threatening large United States and Soviet military forces. The new approach admitted by implication that a method had not been found actually to disarm; but if tension could be reduced, the way might be prepared for voluntary scaling down of armaments on a significant scale.

Two important proposals were made. President Eisenhower proposed a reciprocal aerial ("open skies") inspection of security installations by

9 N Moss: **The Politics of Uranium**, pp. 41-43.

10 A McKnight: **Atomic Safeguards: A Study in International Verification**, p. 20.

11 **Ibid.**

the United States and the Soviet Union, together with a complete exchange of blueprints and pinpointed data on such installations. The Russian reaction was unenthusiastic. They, in turn, proposed an alternative "cross roads" inspection plan. They suggested that foreign commissioners inspect transportation and communication facilities vital to war preparation, so that there would be warning if mobilization was being attempted secretly for a surprise attack. The USA was equally unenthusiastic about this proposal. As before, neither the USA nor the Soviet Union trusted each other sufficiently to institute nuclear or conventional disarmament on a basis of good faith, without guarantees.[12]

However, the United States went ahead with Eisenhower's plan. There was substantial development of bilateral arrangements for co-operation in nuclear energy. In 1954 Eisenhower took steps to clear away domestic impediments to the carrying out of his plan. He authorized Congress to amend the 1946 Atomic Energy Act so as to permit the transfer of fissile materials to other countries and private industry. As things turned out, action did not wait upon Soviet agreement. Underdeveloped countries pressed at the United Nations for some follow-up to Eisenhower's bold words. In November 1954, eleven months after Eisenhower's speech, the United States announced in the General Assembly that it was willing to give away 100 kilograms of fissile material for peaceful uses. However, the United Nations Agency did not yet exist to receive it. So this material was to be given bilaterally to individual countries. Agreements were made not only with the United States. The United Kingdom and Canada also negotiated their own bilateral agreements.[13]

Meanwhile talks went ahead on the setting up of the new international agency. The Soviet Union maintained that the renunciation of nuclear

12 FH Hartmann: **The Relations of Nations**, p. 291.

13 A McKnight: **Atomic Safeguards: A Study in International Verification**, pp. 20-21; N Moss: **The Politics of Uranium**, pp. 41-45.

weapons must be a precondition to any international plan for peaceful uses. Eisenhower announced that the new agency would be set up without the Soviet Union, if necessary. When it became clear that an agency was going to be brought into being anyway, the Soviet Union switched its tune and agreed to take part in the negotiations. The Geneva Conference of 1955 was, therefore, a turning point in USA and Soviet relations and the latter was willing to participate in the creation of the proposed agency.[14]

The International Conference on the Peaceful Uses of Nuclear Energy

1955 marked the tenth anniversary of the date on which nuclear energy was released on a practical scale. In 1945 the explosions of nuclear bombs that destroyed large areas of Hiroshima and Nagasaki announced the advent of a new epoch in the history of mankind. The military use of nuclear energy left its mark in all future developments in science, technology, economics and politics. Work in nuclear armaments and all related research, even that connected only indirectly with the development of such weapons, was carried out in the strictest secrecy, which made professional contacts between scientists not merely difficult but actually impossible in many fields of science and technology. This isolation was broken by the initiative of the United Nations when the First International Conference on the Peaceful Uses of Atomic Energy was convened (in Geneva, 8-20 August 1955). The advent of the production of electricity by nuclear fission and the designing of a successful reactor fueled with natural uranium in the United Kingdom (1953) gave practical demonstration of the non-military application of nuclear processes.[15]

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14 N Moss: **The Politics of Uranium**, p. 45; A McKnight: **Atomic Safeguards: A Study in International Verification**, pp. 21-22.

15 As early as 1950, a plutonium producing experimental reactor at Windscale on the north-west coast of Britain went critical. In February 1953 a natural uranium reactor design was produced by the Harwell Atomic Energy Research Establishment (Berkshire). It was suitable for the production of

The International Conference in 1955, which was a direct result of Eisenhower's Atoms for Peace Programme initiative, saw the restoration of the scientific contacts that had been interrupted by the Second World War and the conditions of strict secrecy that followed it.[16] The conference proved that the major powers wished to make a fresh and direct approach to the nuclear problem.

Even though South Africa in 1955 had no urgent immediate need for a new electric power source, the Atomic Energy Board and the Government were determined that South Africa should share in the benefits of the peaceful uses of nuclear power. A government mission, consisting of Dr HJ van Eck, the industrialist and chairman of the Industrial Development Corporation (IDC), Dr JT Hattingh (the then chairman of ESCOM), and Dr S Meiring Naudé, chairman of the CSIR, visited Britain and Europe in 1955, specifically to investigate the industrial uses of nuclear energy and to compose the South African delegation to the First International Conference on the Peaceful Uses of Atomic Energy.[17]

As Dr HJ van Eck would be called upon to play a particular significant role in nuclear energy decision-making during the 1950's and 1960's, his accomplishments, prior to 1950, should be reviewed. Dr Van Eck had obtained his doctorate in chemical engineering from the University of Leipzig. During the 1930's he played a significant role in the development of ISCOR and the Anglo-Transvaal Consolidated Investment Company's oil from coal project. He was appointed Chairman of the Industrial and Agricultural Requirements Commission

military plutonium and for the generation of electric power. (AECA) AJA Roux: **Atomic Energy Research and Development**, Part II, **United Kingdom and Canada**, p. 10.

16 (AECL) Address by VS Emalyanov, President of the Third International Conference on the Peaceful Uses of Atomic Energy: **Proceedings of the Third International Conference on the Peaceful Uses of Atomic Energy, 31 Aug - 9 Sept 1964**, vol. I, p. 27.

17 (AECA-P) AJA Roux: Proposed Atomic Energy Research and Development Programme for South Africa, pp. 66-67.

in 1939. The Commission produced the renowned Van Eck Report. It revealed that South Africa was rich in minerals, but inefficient in its use of the available natural resources. Dr Van Eck thought it a matter of utmost urgency that South African industries should be encouraged. He believed that South Africa was one of the least self-sufficient countries of the world and vitally dependent on the outside world for its own economic activity. Far too high a proportion of manufactured goods was being imported from overseas (machinery, timber, textiles) while there was unemployment and a "poor white" problem in the land. When the IDC was established in 1940 Van Eck was appointed managing director. It would be through the IDC that he would make the greatest contribution to a greatly expanded and more balanced economy. The IDC financed private enterprises, but became also the medium of finance for large Government-sponsored undertakings such as SASOL and FOSKOR (both established in 1955). Therefore, when it came to nuclear energy decision-making during the 1950's and 1960's, Dr Van Eck's knowledge of South Africa's industrial capabilities, fuel requirements and its economic potential would be called upon.[18]

DB Sole (who was from September 1955 to March 1957 in charge of South Africa's Permanent Mission to the United Nations) believed that South Africa sent a top-level team to the First Conference and exhibition on the scientific and industrial uses of nuclear energy held in Geneva in 1955. They were particularly proficient for the mission. The attendance of Dr HJ van Eck and Dr S Meiring Naudé at this Conference would play an important role in influencing the South African Government to set in motion the South African Atomic Energy

18 (IDC Library, Johannesburg) "Pioneer in Industry - Architect of a Remarkable Revolution", **FCI Viewpoint**, May 1970, p. 11; (IDC Library, Johannesburg) **1940-1970 Thirty Years on the Industrial Development Corporation of South Africa Limited**, p. 7; GD Scholtz: **Die Ontwikkeling van die Politieke Denke van die Afrikaner**, Deel VIII, 1939-1948, pp. 27-28.

Research and Development Programme, that will be discussed in detail in a following chapter.[19]

South Africa's participation in the First International Conference is historically significant for a number of reasons. South Africa's nuclear collaboration with the Federal Republic of Germany probably took its origins from the contact made between the South African and German delegations at this Conference.[20]

The attendance of a South African delegation at the First International Conference was of importance as the papers that were submitted to the Conference gave a broad international and worldwide spectrum of development in nuclear power. Papers on the following subjects were submitted: The World's Requirements for Energy; The Role of Nuclear Power; Physics; Research Reactors; Power Reactors; Cross Sections Important to Reactor Design; Physics of Reactor Design; Geology of Uranium and Thorium; Nuclear Chemistry and the Effects of Irradiation; Production Technology of the Materials used for Nuclear Energy; Reactor Technology and Chemical Processing; Radioactive Isotopes and Nuclear Radiation in Medicine; Biological Effects of Radiation, Radioactive Isotopes and Ionizing Radiation in Agriculture; Physiology and Biochemistry; Legal, Administrative, Health and Safety Aspects of Large-scale Use of Nuclear Energy; General Aspects of the Use of Radioactive isotopes; Dosimetry; Applications of Radioactive Isotopes and Fission Products in Research and Industry.[21]

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19 (SAL) DB Sole: **This Above All** (Unpublished manuscript), p. 201; Interview with DB Sole, 12.12.1990.

20 DB Sole: "The Rise of Nuclear Sanctions against South Africa", **American Review**, Jan. 1986, p. 5.

21 (Atomic Energy Corporation Library) **Proceedings of the International Conference on the Peaceful Uses of Atomic Energy**, vol. 1, Preface, p. VII.

This first International Conference on the Peaceful Uses of Atomic Energy included such a wide range of subjects pertaining to peaceful uses of nuclear power at a time when the world was still very much aware of the destructive power of nuclear energy. The horrors of Hiroshima and Nagasaki were partially forgotten in the increasing interest in nuclear power and the many possibilities of radioisotope applications. The peaceful use of atoms and the First International Conference played a major role in promoting nuclear power for peaceful purposes and stressed the need for collective security on such an important issue.

Dr BFJ Schonland delivered a paper on nuclear energy in South Africa at the Geneva Conference. The rapid technological achievement of extracting uranium from gold ores would mean a great deal to South Africa in future. He said in his paper that in spite of its advantages as an uranium producer, the Union of South Africa was not likely to be a rapid user of nuclear power on a large scale, for it has abundant supplies of good and cheap coal in concentrated areas of the Transvaal and Natal. Those were highly localized deposits and the more distant industrial areas such as Cape Town and Port Elizabeth have to rely for their coal on rail transportation over nearly a thousand miles (approximately 1609 km). This not only adds greatly to the cost of electrical power at those places, but also makes industrial development difficult. Dr Schonland stated that South Africa might well, within ten years, be "calling out for nuclear power stations". There were two other areas in the Union which were still in a worse position for coal supplies, and in which fairly large amounts of power could be profitably employed. The first was the highly mineralized region of the North West Cape and Namaqualand; the second, also served by a tenuous rail system, was the territory of South West Africa.[22]

22 BFJ Schonland: "Nuclear Energy and Southern Africa", **Proceedings of the International Conference on the Peaceful Uses of Atomic Energy**, 8 August - 20 August 1955, vol. I, pp. 411-412

It is of significance in the development of uranium and nuclear energy in South Africa that it was established at the Geneva Conference in 1955 that nuclear power gave every promise of supplementing the world's dwindling resources of conventional energy. Were South Africa to decide to embark on a nuclear energy research and development programme in the 19..'s it would involve millions of rands. It is therefore relevant to give some idea of the advantages and statistics relating to nuclear energy that were expounded by representatives from various countries at the Conference. These statistics would in the 1960's have bearing on decision-making concerning a possible market for South Africa's enriched uranium.

According to WL Cisler from the Detroit Edison Company USA the basic sources of energy in the early 1950's were firstly the heat energy released by the combustion of fossil fuels - coal, oil and gas - and secondly the energy of falling water. Although the fossil fuel and hydro-electric power resources of the world were collectively great indeed, they were not evenly distributed geographically. In many areas of the world where energy had been extensively utilized power requirements had increased to such an extent that complete exploitation or exhaustion of conventional resources were already becoming apparent. Everywhere there were foreseeable limits which, taking history into account, gave cause for concern.[23] Therefore, countries with inadequate natural fuel resources would at some future date be dependent on a foreign source for nuclear fuel.

In a paper by AEG Robinson and GH Daniel from the United Kingdom, in the years 1860-1954 man's use of energy had been multiplied many times by the use of the commercial fuels coal, oil, natural gas and water power.[24] A striking feature was the

23 WL Cisler: "The Role which Nuclear Energy can Play as an Energy Source in the next 25-50 Years", **Proceedings of the International Conference on the Peaceful Uses of Atomic Energy**, 8 August - 20 August 1955, vol. I, pp. 436-437.

24 This paper was jointly written by AEG Robinson (University of Cambridge) and GH Daniel (Ministry of Fuel and Power, UK). The former contributed primarily to the analysis of the growth of future demand for power; the latter

comparatively steady upward trend over the whole period in total energy consumption, including wood and farm wastes. This trend had been about two percent per annum compound.[25] During the second half of the nineteenth century the use of wood was declining, and that of coal increasing rapidly. During the first half of the twentieth century the total consumption of the conventional fuels had increased at a fairly steady two percent per annum, but the increase in coal utilization had slowed down and the main burden of meeting the increase in requirements had been carried by oil, natural gas and hydro-electricity. The rates of increase of these averaged five or six percent per annum.[26]

According to EAG Robinson and GH Daniel the world's natural resources were not inexhaustible. If total demand for the primary fuels continued its long-term growth of two percent per annum, and no relief was available from nuclear or other new sources of energy, the reserves of solid fuel, liquid fuels and natural gas would have been reduced by the year 2025 to about 300 years' life at the existing rate of consumption.[27] With increasing industrialisation in the second half of

was chiefly responsible for the sections concerned with the reserves of fuel and future supplies.

25 "Compound" meaning that the calculation of energy consumption includes the accumulative two percent per annum increase each year between 1860-1954.

26 EAG Robinson and GH Daniel: The World's Need for a New Source of Energy", pp. 38-39, **Proceedings of the International Conference on the Peaceful Uses of Atomic Energy**, vol. 1, 1955.

27 **Possible demand for the Conventional Sources of Energy in the Absence of a New Source according to Robinson and Daniel**

(Milliard tons of coal equivalent)

	Total energy	Coal	Hydro-electricity	Oil and Natural Gas
1950	2,8	1,6	0,2	1,0
2000	7,4	2,0	0,9	4,5
2025	12,1	2,3	2,2	7,6

EAG Robinson and GH Daniel: "The World's Need for a New Source of Energy", **Proceedings of the International Conference on the Peaceful** the twentieth century long-term growth would increase. At a rate of growth of three percent per annum, they would have been reduced to about 120 years' life at the then current rate of use. If expansion continued at two percent a year to 2050 (implying a total consumption per head of about four times that of 1950) the remaining reserves would fall to about 150 years, with a three percent rate of growth reserves would be depleted within 40 years. In many countries a decline in consumption would have been enforced by then. However, the need to supplement the existing sources of energy during the fifties was considerably more urgent than was implied by a calculation of possible overall demands and reserves.[28] In the absence of a new source, scarcity of fuel would begin to create serious problems. In addition there was, however, the danger of underestimating world requirements and diminishing resources.[29]

In his "Summary of the Conference", Glenn T Seaborg, Chairman of the United States Atomic Energy Commission, said that by the year 2000 more than half the world's electricity would be generated by nuclear energy.[30] Nuclear energy would be the answer to a future scarcity of fuel. South Africa would therefore have to prepare for the new situation in global fuel requirements.

Uses of Atomic Energy, vol. I, 1955, p. 46. See also Department of Economic and Social Affairs, United Nations, "World Energy Requirements in 1975 and 2000", pp. 3-15. **Proceedings of the International Conference on the Peaceful Uses of Atomic Energy**, vol. I, 1955.

28 EAG Robinson and GH Daniel: "The World's Need for a New Source of Energy", **Proceedings of the International Conference on the Peaceful Uses of Atomic Energy**, vol. I, 1955, pp. 46-47.

29 ES Mason and Staff of the Peacetime Atomic Energy Project, USA, "Energy Requirements and Economic growth", pp. 64-65; Department of Economic and Social Affairs, United Nations, "World Energy Requirements in 1975-2000", **Proceedings of the International Conference on the Peaceful Uses of Atomic Energy**, vol. I, 1955, p. 15.

30 GT Seaborg: "Summary of the Conference", **Proceedings of the International Conference on the Peaceful Uses of Atomic Energy**, vol. I, 1955, p. 394.

It was stated at the Conference that nuclear energy has one advantage that would have far-reaching impact. From a weight standpoint it is the most portable of energy sources. Hydro-electric resources are absolutely fixed geographically. As for coal, oil and gas, there are economic limits to the distances over which these conventional fuels might be transported.[31] Dr S Meiring Naudé had said previously in an address to a group of Johannesburg businessmen, early in 1954 that it seemed likely that nuclear power could compete with coal in the Western province, because of the increasing costs of the transport of coal from the Witwatersrand to Cape Town.[32]

Formation of the International Atomic Energy Agency

The idea of an international authority that would control all phases of nuclear energy production and use goes back to 15 November 1945. However, as discussed in a previous chapter a stalemate situation existed between the major powers on nuclear weapons control in 1949. Although reports by the United Nations Atomic Energy Commission were passed by the Security Council and the General Assembly, the Commission reached an impasse and was dissolved by the General Assembly in 1952.[33]

After these failures the ideals of an international authority were incorporated under Eisenhower's Atoms for Peace policy. In his address to the United Nations (December 1953) President Eisenhower proposed the establishment of such an authority. From January until September 1954, the United Nations and the Soviet Union exchanged views on the Eisenhower proposal. These were kept confidential until

31 WL Cisler: "The Role which Nuclear Energy can Play as an Energy Source in the next 25-50 Years", **Proceedings of the International Conference on the Peaceful Uses of Atomic Energy**, vol. I, 1955, p. 437.

32 SM Naudé: "Atomic Energy in South Africa", **Coal**, 2(2) April 1954, p. 34.

33 (SAL) **20 Years, International Atomic Energy Agency, 1957-1977**, IAEA Publication, Austria, 1977.

publication of the main documents by mutual consent on 25 September largely for the information of the General Assembly. In June 1954 the United States, after notifying the USSR, began discussing the proposal for an international atomic energy agency with a group of states comprising the United Kingdom, Canada, France, South Africa, Belgium, Australia and Portugal. This became known as the eight nation group. Membership was based on being advanced in the technology of atomic energy or being a producer, actual or potential of uranium for the American and United Kingdom military programmes. States in either category would be the prime source of contributions of know-how and materials to the new agency. Discussions in the eight nation group appear to have been preliminary in 1954.[34]

By 1955 South Africa was supplying a fair share of the uranium for the US nuclear weapons programme.[35] As a leading uranium producer and having commenced developments for the furtherance of nuclear science, South Africa was one of the original eight states which initiated the establishment of the International Atomic Energy Agency.[36]

The United States, as a result of Eisenhower's Atoms for Peace initiative, and without waiting for the creation of the international agency, was prepared to share its advanced nuclear technology with countries it regarded as friendly. It offered each of them a research reactor and a grant of $350 000 towards its installation costs. The main elements of the safeguards of the Baruch Plan were incorporated in these bilateral agreements for supplying material to other countries.

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34 A McKnight: **Atomic Safeguards, A Study in International Verification**, p. 21.

35 See Chapter 5, p. 141; DAV Fischer: "Slowing the spread of nuclear weapons - The Role of International Safeguards", **Optima**, vol. 33, no 3, September 1985, p. 100.

36 (AECA) Annual Report of the South African Atomic Energy Board 1958, p. 1.

These agreements gave the USA the right to examine design information, call for reports and carry out inspections.[37]

During 1955 the eight nation group considered the proposal for the new agency while the United States continued bilateral dialogue with the USSR. On 29 March 1955, the United States circulated to the group a first draft of a statute for consideration. A second draft was handed confidentially to the USSR on 29 July.[38]

The impact of the Conference on the Peaceful Uses of Atomic Energy (1955) sharpened the demand for the early creation of the international agency and broadened the desire for participation in the task of its establishment.[39] At the end of the Conference, the United States distributed the second draft of the statute to eighty four States and requested their comments. Discussion in the General Assembly that followed in the last quarter of 1955 was cordial. There was some dissonance, but no negative vote was cast against the concluding resolution, by which, in effect, the eight nation group, became the twelve nation group, with the addition of Brazil, Czechoslovakia, India and the USSR. This twelve nation group was to prepare a draft statute for the establishment of the International Atomic Energy Agency taking account of views expressed either in the General Assembly debate or by individual States. This draft would be submitted to a final conference to which would be invited all Members of the United Nations and of the specialized agencies of UNO.[40]

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37 DAV Fischer: "Slowing the spread of nuclear weapons - The Role of International Safeguards", **Optima**, vol. 33, no 3, September 1985, p. 100; **IAEA Safeguards, Aims, Limitations, Achievements**, IAEA Publication, 1983, p. 15; A McKnight: **Atomic Safeguards, A study in International Verification**, pp. 20-21.

38 A McKnight: **Atomic Safeguards, A study in International Verification**, p. 22.

39 **20 Years, International Atomic Energy Agency, 1957-1977**, IAEA Publication, Austria, 1977, p. 5

40 **20 Years, International Atomic Energy Agency, 1957-1977**, IAEA Publication, Austria, 1977, p. 5; A McKnight: **Atomic Safeguards, A**

During the formation of the IAEA, South Africa's international relations were deteriorating. South Africa was recognised as a leading uranium producer and supplier to the West, but South Africa's situation in the United Nations Organization changed after 1955.

In the early 1950's the government passed a number of Acts enforcing complete social and residential segregation.[41] A number of Asian and Middle East states including India took the matter to the United Nations Organization. Opposition to the Union of South Africa began playing an important part in the deliberations of the United Nations.[42]

WC du Plessis, South Africa's High Commissioner in Ottawa, led the South African delegation to the 1955 General Assembly of the United Nations Organization, which commenced on 20 September of that year. The South African Minister of External Affairs, Eric Louw, had decided to embark on a policy of confrontation with the United Nations, so it came about that on 24 October 1955, acting on instructions from the South African Government, the South African delegation withdrew from the discussion on apartheid. This was followed about two weeks later by the withdrawal of the South African delegation from the General Assembly as a whole.[43]

In September 1956, the Indian delegation to the United Nations had requested once again the inclusion in the General Assembly agenda of the United Nations the item dealing with apartheid. That session of the United Nations would see the biggest drive up to that time against the so-called colonial powers, which included South Africa. It would also be against Britain and France over the Suez Canal; against France over Algeria and Togaland; against Britain over Cyprus and against Holland

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study in International Verification, p. 22; (AECA) **Annual Report of the South African Atomic Energy Board 1958**, p. 1.

41 Population Registration Act (1950); Group Areas Act (1950); Separate Representation of Voters Act (1951).

42 Amry VandenBosch: **South Africa and the World**, pp. 229-233.

43 (SAL) DB Sole: **This Above All** (Unpublished manuscript), pp. 171-172.

over New Guinea. The anti-colonialist drive was becoming more than a drive against countries with colonial empires. It was a drive against all people of the white race.[44] Sole believed that South Africa's isolation in late 1956 was not only because of apartheid, but South Africa's decision for neutral detachment in the Suez crisis and its abstention on a General Assembly resolution condemning British and American aggression in Suez.[45]

In December 1956, the South African Government took the decision to partially withdraw from the United Nations Organization. At this time isolation did not affect South Africa's position as a leading uranium producer. Despite South Africa's situation in the United Nations, South African representatives could participate in the formation of the International Atomic Energy Agency (IAEA). The negotiations for the establishment of the Agency took place in three stages: the twelve nations Washington Conference (February 1956); the Statute Conference (September - October 1956); and the IAEA Preparatory Commission meetings (January to March 1957).

The twelve nations group met in Washington DC early in 1956 to complete the draft of the statute. This conference became known as the Twelve Nations Conference.[46]

The second stage was the Statute Conference (September - October 1956) which convened at the United Nations headquarters in New York, to approve in final definitive form the draft constitution and terms of reference of the International Atomic Energy Agency drawn up by the representatives of the twelve powers who had met in Washington earlier in 1956. The Statute Conference was open to all members of the United Nations Organization and specialized agencies,

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44 (SAL) DB Sole: **This Above All** (Unpublished manuscript), p. 180.

45 **Ibid.**, pp. 181-182.

46 **20 Years, International Atomic Energy Agency, 1957-1977,** IAEA publication Austria, p. 5.

and over 60 states participated. At the Statute Conference there was a natural tendency for the twelve States to say that the draft before the conference represented the maximum consensus obtainable among any group of States. However, there was a countervailing tendency for others to resent the fact that they had not been associated with the negotiations among the twelve and to seek new discussion on many provisions of the draft. As a result there were some eighty amendments tabled to the draft; about sixty were voted upon and about thirty adopted. Some of the main points of arguments were disarmament; the "sovereignty" argument[47]; discrimination between nuclear-weapon states and near-nuclear weapons states; relations with other organs of the United Nations, constitutional provisions in the IAEA Statute; the composition of the Board of Governors; powers of the Board of Governors and the General Conference; Finance; and sanctions. The statute was finally approved on 23 October and signed on 26 October 1956.[48]

The Statute Conference appointed a Preparatory Commission of eighteen States.[49] South Africa was one of the eighteen nations forming the Preparatory Commission. This Commission was the forerunner of the Board of Governors which would later control the functioning of the IAEA. In January and February 1957, the IAEA Preparatory Commission continued its work in New York. Its tasks were to make arrangements for the first session of the Agency's General Conference and for the first meetings of the Board of Governors of the Agency and to carry out other preparatory work

47 The "sovereignty" argument that safeguards would lead to interference in the most varied fields of the life of a State. Safeguards should not place a State in a position of political, economic or military dependence on other States. (SAL) A McKnight: **Atomic Safeguards: A Study in International Verification,** p. 24.

48 A McKnight: **Atomic Safeguards, A study in International Verification,** pp. 22-33.

49 The eighteen states were: Argentina, Australia, Belgium, Brazil, Canada, Czechoslovakia, Egypt, France, India, Indonesia, Japan, Pakistan, Peru, Portugal, Union of South Africa, USSR, United Kingdom, United States of America.

needed to bring the Agency into operation. In particular the Preparatory Commission was given a mandate to recommend an initial programme of the activities for the Agency as well as its initial staff structure, budget and the location of the permanent headquarters of the Agency.[50]

The Preparatory Commission elected Carlos Bernades (Brazil) as its President. It met until 20 August 1957, when it transferred its seat to Vienna to supervise preparations for the first session of the General Conference and the first meetings of the Board of Governors.[51]

The IAEA's first General Conference was held in Vienna from 1-23 October 1957. At the beginning of the Conference, the Agency had fifty-four Member States, by the end there were fifty-nine. The Conference elected ten Member States to the Board of Governors, who joined the thirteen States already designated by the Preparatory Commission. The Conference and Board jointly approved the initial working programme for the Agency that had been drafted by the Preparatory Commission and voted $4.1 million to carry it out. With the establishment of the first Board of Governors, the mandate for the Preparatory Commission was discharged and it ceased to exist. The Conference unanimously decided that Vienna be chosen as the site for the permanent headquarters of the IAEA and approved an agreement between the Agency and the host government, Austria. A draft agreement for the relationship between the United Nations and the IAEA was adopted by the General Conference. The General Conference approved the appointment of W Sterling Cole of the USA as Director General of the IAEA for a term of four years.[52]

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50 **20 Years, International Atomic Energy Agency, 1957-1977**, IAEA publication Austria, 1977, p. 5.

51 **Ibid.**

52 **Ibid.**, pp. 6-9.

The Objectives of the IAEA were to accelerate and enlarge the contribution of nuclear energy to peace, health and prosperity throughout the world. The Agency would ensure that nuclear energy would not be used in such a way as to further any military purpose.[53]

Although the idea of the Agency acting as a nuclear fuel bank was discarded in the course of the initiating negotiations, the original concept of an organization to control nuclear materials and equipment and ensure their peaceful utilization, was entrenched in the Statute. The main functions of the IAEA were briefly: to encourage and assist research on, and the development and practical application of nuclear energy for peaceful uses throughout the world; to make provision for materials, services, equipment and facilities for these purposes, including the production of electric power; to foster the exchange of scientific and technical information on the peaceful uses of nuclear energy; to encourage the exchange and training of scientists and experts in this field; to establish and administer safeguards to ensure that special fissionable materials and sources were not used in such a way as to further any military purpose; to establish standards of safety for the protection of health and minimization of danger to life and property in the operations making use of fissionable materials; finally to conduct its activities in accordance with the purposes and principles of the United Nations, to promote peace and international cooperation and, in conformity with the policies of the United Nations, to further the establishment of safe-guarded world-wide disarmament.[54]

53 Article II, Statute of the International Atomic Energy Agency, Annex 4 in A McKnight: **Atomic Safeguards, A study in International Verification**, p. 205.

54 Article III, Statute of the International Atomic Energy Agency, Annex 4 in A McKnight: **Atomic Safeguards, A study in International Verification**, p. 205-207; RB Hagart: "National Aspects of the Uranium Industry", **JSAIMM**, 57, April 1957, pp. 571-572.

DB Sole

(Source: Atomic Energy Corporation)

Throughout all three stages of the long-drawn negotiations South Africa made important contributions.[55] South Africa's representative, Donald B Sole, played a significant role in promoting compromises and achieving an essential measure of compatibility between opposing views. His moderating influence and the high esteem in which all the other governors held him are acknowledged as having had a very significant and progressive influence on the development of the IAEA.[56]

DB Sole gives an account of what happened behind the scenes at all three stages of negotiations for the establishment of the IAEA. According to Sole, from February 1956 (when the Twelve Nations Conference took place in Washington) the South African delegation, including Jack Holloway, South African Ambassador in Washington, DB Sole and Brand Fourie (later, from 1958, South African representative at the United Nations Organization) had to do a considerable amount of lobbying.[57]

Even at this early stage in the establishment of the IAEA, it can be deduced from Sole's account that the behind the scenes activities among IAEA representatives followed much the same pattern as at the United Nations itself. Lobbying of United Nations Representatives takes place in the delegates' lounge of the United Nations headquarters, at receptions and even at the offices of Missions to the United Nations Organization.[58] Sole, as a South African representative at the United Nations, had some experience in these tactics and, as indicated above,

55 (AECA) RB Hagart: "National Aspects of the Uranium Industry", **JSAIMM**, 57, April 1957, p. 172; **Annual Report of the South African Atomic Energy Board**, 1958, p. 1.

56 AR Newby-Fraser: **Chain Reaction**, p. 10.

57 DB Sole: **This Above All** (Unpublished manuscript), pp. 171-175; DAV Fischer: "Slowing the spread of nuclear weapons - The Role of International Safeguards", **Optima**, vol. 33, no 3, September 1985, p. 100; Brand Fourie: **Brandpunte**, p. 38.

58 DB Sole: **This Above All** (Unpublished manuscript), p. 177

played a role in swaying certain decisions in South Africa's favour. It should however be borne in mind that the United Nations Organization is under the sway of the leader nations (the USA, Britain, the Soviet Union and France) - countries that determine major decision making. South Africa's involvement with the Combined Development Agency at the time would undoubtedly have carried weight in the Twelve Nations Conference and in the appointment of a South African representative to the Board of Governors.

The ambassadorial duties of the leader of the South African delegation to the twelve nations Washington Conference, Jack Holloway, took up a great deal of his time, therefore most of the lobbying, the wheeling and dealing with other delegations, was delegated to the deputy leader DB Sole. Sole was obliged to develop his own nuclear expertise by intensive reading.[59]

According to Sole, the American delegation at the Washington Conference seemed to regard the South African delegation as expendable. However, Sole believed that the good personal relationship he was able to establish with Dr Homi Bhaba, the leading Indian nuclear scientist, was of much consequence during the proceedings of the Conference, as well as the final composition of the Board of Governors. At one stage during the Washington Conference Sole feared that South Africa would be sold down the road. His good relationship with Dr Bhaba saved the day. This relationship was facilitated by the fact that the deputy leader of the Indian delegation was Arthur Lall, head of the Indian Mission to the United Nations, whom Sole knew personally from their association as regular participants in the meetings of the Commonwealth United Nations group in New York. Sole was favoured by an additional factor, the leader of the French delegation to the Conference, was Ambassador Couve de Murville, whom he had known during World War II when he

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59 DB Sole: **This Above All** (Unpublished manuscript), p. 173.

was a leading member of the Free French administration established in London by De Gaulle.[60]

Another member of the French delegation was nuclear scientist Dr Bertrand Goldschmidt, in charge of the external liaison division of the French Atomic Energy Commissariat, with whom he became firm friends - a friendship which remained constant for many years. Goldschmidt was a great help in teaching Sole, a diplomat, to understand Bhaba, his fellow nuclear scientist.[61]

The formula finally adopted for establishing the composition of the Board of Governors of the proposed IAEA was largely the product of Bhaba's initiative, based on a prior understanding and tentative agreement reached with the South African delegation. It in effect guaranteed both countries, India and South Africa, a permanent seat on the Board of Governors. However, with the proviso that each country (India and South Africa) continued to be the member of the IAEA in a specific region most advanced in the technology of nuclear energy, including the production of source materials. That meant, India in the region of South Asia, and South Africa in the region of Africa and the Middle East.[62] The phrase "including the production of source materials" was Sole's addition, designed to strengthen South Africa's claims arising from her position as a major producer of uranium. Sole regretted that he failed to foresee and make provision against unconstitutional action that would later deprive South Africa of its position in the IAEA.[63]

The twelve nation Washington Conference launched Sole on his long association with IAEA and with nuclear energy generally, an

60 DB Sole. **This Above All** (Unpublished manuscript), p. 173.

61 **Ibid.**

62 (AECA) **Annual Report of the South Africa Atomic Energy Board**, 1958, p. 1.

63 DB Sole: **This Above All** (Unpublished manuscript), pp. 173-174.

association which was to last until his retirement from the Board of the South African Atomic Energy Corporation in June 1985, nearly thirty years later. It was this conference which also launched DAV Fischer, Second Secretary in the South African Washington Embassy into his career in the IAEA. He took an active part in this Conference, and later in the Statute Conference in New York.[64] The twelve nations Conference was a tremendous triumph for South Africa, in contrast to the role the South African representatives were assigned at UNO at the time.[65]

WC du Plessis, the South African ambassador in Washington, was appointed leader of the South African delegation to the Statute Conference (September 1956). He delivered the opening speech, but had little time to attend to the duties of the Statute Conference as he had to assist the South African Minister of Finance who was then in Washington, conducting financial discussions with bankers in New York. Sole, as deputy leader of the delegation, had to deliver most of the speeches and nearly all the lobbying was his responsibility. He achieved success in this despite the pressures against South Africa as a pariah state in the United Nations Organization at the time. Of importance is that South Africa was able to retain without diminution or amendment, its prestigious position in the IAEA which had been achieved at the twelve nation conference in Washington, and was acknowledged a leading world producer or uranium.[66]

DB Sole believed that he accomplished much and was able to make a notable contribution as South Africa's representative on the 18 nations Preparatory Commission. (The third stage of the establishment of the IAEA, January and February 1957). The IAEA headquarters would be

64 DAV Fischer was seconded to the IAEA Secretariat in Vienna in 1956. He later joined the IAEA as an international civil servant and rose steadily in the IAEA hierarchy. He was later head of the Agency's Division of External Liaison. DB Sole: **This Above All** (Unpublished manuscript), p. 174.

65 DB Sole: **This Above All** (Unpublished manuscript), pp. 171-175.

66 **Ibid.**, p. 179.

in Vienna. Sole was transferred from New York to the Austrian capital where he would be South Africa's representative at the IAEA. Sole was appointed governor on the Agency's Board of Governors for ten years, leading the Union's (after 1961, the Republic) delegation to each of the annual General Conferences of the newly established IAEA.[67]

South Africa's Collaboration Agreements with the United States and United Kingdom

South Africa's favourable position as a leading uranium producer led to close relations with the United States and Britain in the nuclear field despite the country's diminishing status in the United Nations' General Assembly. Relations were such that on July 8, 1957, a formal Cooperation Agreement was signed in Washington between the United States and South Africa, covering the civil uses of nuclear energy. The United States had agreements with many nations as part of the Atoms for Peace Programme. South Africa's Cooperation Agreement was therefore a result of Eisenhower's Programme.[68]

The Agreement for Cooperation between the Government of the Republic of South Africa and the Government of the United States concerning the civil uses of nuclear energy, should be reviewed in some detail. The Agreement was entered into on 8 July 1957, and would remain in force for a period of ten years.[69] Although political and ideological differences would develop between the two countries in later years, for the period 1957 to 1970 this Agreement was of paramount importance in the development of nuclear energy in South Africa. It permitted the exchange of unclassified information on the

67 (AECA) AR Newby-Fraser: **Chain Reaction**, p. 10; (AECA) **Annual Report of the South African Atomic Energy Board**, 1958, p. 1.

68 Interview with DB Sole, 12.12.1990.

69 (AECA) Agreement for Cooperation between the Government of the Union of South Africa and the Government of the United States of America concerning the civil uses of nuclear energy, Article II, p. 3.

development, design, construction, operation and use of research, experimental power, demonstration power and power reactors, as well as information on geology, chemistry, technology of extracting uranium, health and safety problems and the use of radio isotopes.[70]

Of particular importance was the approval of the exchange of research materials for specific research projects relating to the peaceful uses of nuclear energy. Furthermore, that research facilities and reactor material testing facilities were made available to the two parties (the Union of South Africa and the United States of America) in the agreement. South Africa was thereby in a position to acquire a research reactor*, to send South African scientists and engineers to the USA for specialized training and obtain uranium enriched up to twenty percent in the isotope U-235*.[71] The enriched uranium would not be in excess of the amount of material necessary for the full loading of each specific reactor. Should the materials testing reactor*, research reactor and reactor experiments require special nuclear material, the United States Commission would, upon request, make a portion of the material enriched* (up to 90%) available. Each reactor would not operate with a load that would exceed eight kilograms of contained U-235 in uranium. All conditions and safety precautions (that would have to be undertaken by both parties in the Agreement) in the transferring, storage and use of the enriched uranium were set out in detail in the Agreement. This included special nuclear materials produced as a result of irradiation processes.*

Both parties gave their assurance that all material and equipment would be used for civil purposes only. According to Paragraph B of Article X, the International Atomic Energy Agency could, if it regarded it necessary, replace certain safeguards provided in the Agreement (by agreement of the parties). The United States Government also

70 (AECA) Agreement for Cooperation between the Government of the Union of South Africa and the Government of the United States of America concerning the civil uses of nuclear energy, Article IV, p. 4.

71 **Ibid.**, Articles VI, VII, VIII, X, pp. 4-7.

maintained the right to review the design of any reactor or other equipment that the United States Energy Commission might determine to be relevant to the effective application of safeguards. South Africa agreed that these safeguards would be maintained.[72]

The parties would consult with each other, the extent to which they would desire to arrange for the administration by the IAEA of those conditions, controls and safeguards, including those relating to health and safety standards, required by the IAEA. If the parties found that it was necessary to arrange for administration of safeguards by the IAEA on material and equipment transferred under the Agreement for Cooperation, arrangements for such administration could be effected without the necessity of modifying the terms of Agreement. In the event that the parties did not reach mutual agreement on this issue, either party could by notification terminate the Agreement.[73]

In the same month that the Cooperative Agreement with the United States of America was signed, on July 18, 1957, an inter-agency collaborative agreement was signed between the United Kingdom Atomic Energy Authority (UKAEA) and the South Africa Atomic Energy Board (AEB), spelling out certain aspects of nuclear development in which the United Kingdom would assist the Union of South Africa. The UKAEA and AEB (the parties in the agreement) would assist each other in procuring materials required for the respective nuclear energy programmes. The UKAEA was prepared to make available to the AEB information for the promotion and development of the peaceful uses of nuclear energy. This information could be used freely by the AEB, except if the information related to an invention owned by the UKAEA. The AEB could make application for patents and own any patents for inventions within the field of collaboration. However, the AEB was not entitled to patents on

72 (AECA) Agreement for Cooperation between the Government of the Union of South Africa and the Government of the United States of America concerning the civil uses of nuclear energy, Article XI, p. 7.

73 **Ibid.**, Article XII, pp. 9-10.

communicated information alone. All information would be transmitted in confidence and could not be communicated to a third party unless agreed upon by both the UKAEA and the AEB.[74]

The UKAEA was prepared to supply reactor fuel elements to the AEB and to process spent fuel elements. The AEB undertook to employ the fissile material wholly in the mutually agreed research and development programme, and not to divert it to any other uses without prior agreement with the Authority. The AEB would agree to the arrangements made by the UKAEA for chemical processing of any fuel elements, which might from time to time require replacement. No alteration would be made to the form or content of fuel elements, after their removal from the reactor and prior to their return to the UKAEA.[75]

The UKAEA would, as far as it was in their power, assist the AEB in its negotiations with industrial firms in the United Kingdom, and provide training facilities for South African scientists and engineers.[76]

The Agreement would be for a period of ten years, after which it could be renewed for such periods as the parties might agree upon.[77]

The signatories were VH Osborn, Deputy Chairman of the Atomic Energy Board, and Sir Edwin Plowden, Chairman of the United Kingdom Atomic Energy Authority.[78]

The Agreement had a First and Second Annex. The First Annex set out the basis of exchange of information concerning the design,

74 (AECA) Agreement between the United Kingdom Atomic Energy Authority and the South Africa Atomic Energy Board, pp. 1-2.

75 **Ibid.**, pp. 1 and 3.

76 **Ibid.**, p. 1

77 **Ibid.**, p. 3.

78 **Ibid.**, p. 4.

construction and operation of nuclear reactors. Each party would convey to the other general information on the overall progress and economics of their respective power reactor programmes. Should the Board intend at some future date to construct a reactor the UKAEA would supply information on reactor materials (e.g. heavy water, uranium, pile grade graphite and zirconium*), properties of reactor materials, reactor components, reactor physics technology, reactor engineering technology and environmental safety considerations.

The Second Annex dealt specifically with the collaboration on methods of producing heavy water. The AEB having declared its interest in carrying out research on methods of producing heavy water, the UKAEA agreed to provide facilities for two workers employed by the Board to do research on heavy water at the Atomic Energy Research Establishment, Harwell.[79]

(The Agreement between the UKAEA and the South African AEB was renewed after ten years expired in July 1967. It was extended for a further period of five years, until July 1972, after an exchange of letters between Dr AJA Roux (Director-General of the AEB) and Lord William Penney (UK) in February - March 1967. During discussions between Dr JM Hill (Chairman, UKAEA) and Dr AJA Roux (Chairman, AEB), Dr Hill declared that the Authority was prepared to extend the existing Collaboration Agreement until July 17, 1977.[80])

As shall be seen in the following chapter, these two agreements of July 1957, between the United States and South Africa and the UKAEA and the AEB, enabled South Africa to acquire much nuclear information from both the United States and the United Kingdom. South Africa could formulate a nuclear energy research and development programme

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79 (AECA) Agreement between the United Kingdom Atomic Energy Authority and the South African Atomic Energy Board, pp. 1-4, First Annex and Second Annex.

80 (AECA) Letter from Dr JM Hill to Dr AJA Roux, 19.9.1968; Letter from Dr AJA Roux to Dr JM Hill, 11.10.1968.

in the knowledge that it would receive assistance from both those countries. Throughout the years that the two agreements were in active operation much was achieved, in particular the basic training essential for the ultimate realisation of a nuclear industry in the Republic. Dr WL Grant, (during the 1950's a mechanical engineer to the staff of the CSIR) is in agreement with the above statement and believed that although political pressures were mounting towards South Africa in the fifties and early sixties, there was much cooperation between South Africa and both the United States and British nuclear energy authorities.[81]

The provisions spelt out in the Agreement of Cooperation with the United States were to have significant bearing on the history of South African nuclear energy, as a result of political developments both internationally and internally. This was largely brought about by the international movement in 1958, that began to focus attention on proposals for achieving a nuclear test ban*. Considerable world opinion feared the ever-rising radio-activity in the atmosphere resulting from tests. Moreover the nuclear powers had a certain mutual interest in encouraging the cessation of nuclear testing before such devices became more widespread among nations. Although those countries that did not have nuclear weapons, would by such an agreement be prohibited from testing, it would make any testing programme more difficult to defend. The idea had obvious merit in preventing further pollution of the atmosphere and some potential for preventing further nuclear proliferation. Despite their political differences, the Russians on the one side, and America and Britain on the other, agreed on unilateral suspension of tests in 1958, following a technical conference in Geneva on the detection of nuclear blasts. This conference having concluded that an effective control system should be devised to police a test ban, a political conference began setting about preparing a treaty on 31 October 1958.[82] These events would have a direct influence on

81 Interview with Dr WL Grant, 28.7.1989; AR Newby-Fraser, **Chain Reaction**, pp. 8-9.

82 FH Hartmann: **The Relations of Nations**, pp. 291-292.

South Africa's uranium industry and nuclear energy research developments.

In the IAEA, the need for collective security and an understanding on essential issues on the part of the two super-powers, the United States and the Soviet Union, enabled the Agency to surmount petty problems such as, for example, personality prejudices.[83] (Sole believed that Sterling Cole "was one of those Americans who believed that anyone or anything Russian (was) basically suspect".)[84] According to Sole it was an extremely important achievement on the part of the Agency that essential nuclear issues prevailed over other differences between the Soviet Union and the United States.

The latter would, in its function of establishing and administering safeguards to ensure that special fissionable materials and sources were used for peaceful purposes and not applied in any way as to further any military purpose, acquire paramount international status. Inspections of this nature would involve a derogation from sovereignty. In other words, the Agency would be involved with a state or nation's most classified and independent decision making: its nuclear potential and armaments. This made the whole issue of inspection very highly political. The political factors were compounded by the fact that the four nuclear powers (USA, UK, USSR and France) insisted that no safeguards should be applied to their own nuclear installations, while pressing for the most rigid application of safeguards to the installations of the non-nuclear powers.[85]

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83 Collective security: all nations could be secure if all were guaranteed their territorial integrity and existing political independence against external aggression by any state or states - it is a mutual insurance plan. FH Hartmann: **The Relations of Nations**, p. 15; DB Sole: **This Above All** (Unpublished manuscript), p. 198.

84 Sterling Cole was the first Director General of the IAEA. See DB Sole: **This Above All** (Unpublished manuscript), p. 198.

85 DB Sole: **This Above All** (Unpublished manuscript), p. 201.

The USA, with Soviet backing, for a long time argued that source material, even in the form of uranium-bearing ore, should be subject to safeguards. If this proposal was to have been carried to its logical conclusion, it would have involved making South Africa's gold mines subject to international safeguards, since South Africa's uranium production was essentially a by-product of the Witwatersrand Gold Mines. Sole fought this proposition and like proposals in every way. Ultimately the concept of such proposals was dropped entirely. In the process, however, Sole was seen as the leader of those members of the IAEA, the non-nuclear countries, represented on the Board of Governors (namely, South Africa, India, Pakistan, Argentine and Brazil) which had the most reservations about the rigidity of the safeguards system which the IAEA, under United States directions and with Soviet support, sought to apply. Sole emphasised that there was never any objection on the part of South Africa to the application of health and safety measures by the IAEA.[86]

South Africa took a stand against the imposition of excessive safeguards against diversion to military purposes. There existed inherent discrimination in this respect against those non-nuclear powers seeking to develop their own nuclear programmes. It is interesting to note, in this regard, that at that time Canada gave full support in the IAEA for the application of the most stringent safeguards, but it was that country that was at least partly responsible for the transfer to India of materials and technology that enabled India at a much later date (February 1974) to explode a nuclear bomb. In his position as Governor on the Board of Governors, Sole became the South African expert on safeguards, and could advise the AEB and the Government on those and related issues.[87]

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86 DB Sole: **This Above All** (Unpublished manuscript), pp. 201 and 202.

87 **Ibid.,** p. 202; N Moss: **The Politics of Uranium**, pp. 79-88.

South Africa would, therefore, have to be supplied from abroad with enriched fuel for an essential part of the research programme. The functioning of South Africa's research reactor would be dependent on an overseas supply of enriched fuel. As early as 1959, South Africa's international status indicated that problems might arise from such a dependence.

On United States and British initiative an organization known as the "London Suppliers Group" was set up. This group comprised representatives of Western countries who were in a position to supply nuclear materials (including enriched fuel). The group normally met in London - hence the name - but also in Paris and Washington. Its object was to reach agreement on what quantity of materials and what type of equipment would bear a risk of nuclear proliferation. The supply sent to a specific country would be subject to the application of the effective safeguards. The group initially comprised representatives of the United States, Britain, France (as nuclear powers) plus Australia, Belgium, Canada and South Africa. Later the group would be enlarged.

DB Sole represented South Africa at the meetings of the London Suppliers Group. He was subjected to a lot of pressure because of his insistence on preserving a certain freedom of action for South Africa. It was only the French representative who occasionally gave him support in this, because France was also concerned to retain her freedom of action, although as a nuclear power she was not so constrained as South Africa was. Sole found that he had to make independent decisions at the meetings of the group, as Pretoria, while he was involved with the IAEA, did not have the expertise to supply proper directives.[88]

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88 DB Sole: **This Above All** (Unpublished manuscript), p. 202.

It would be through this group that South Africa could collaborate with the United States concerning a supply of enriched fuel for her research reactor (that would be acquired in the 1960's).

CHAPTER SIX

INVESTIGATIONS INTO AND PLANNING OF A NUCLEAR ENERGY INDUSTRY FOR SOUTH AFRICA

In the 1950's it was evident that economically nuclear power could not compete with coal in the Pretoria-Witwatersrand-Vereeniging area in this century. However, an abundance of coal was no reason why a country should not consider nuclear development. Where coal was to be transported for great distances nuclear power could be a proposition. The possibility of a nuclear power plant in the Western Cape as well as the prospect of using South African uranium for nuclear power production set in motion investigations into nuclear energy production in South Africa. In 1956 a Commission of Enquiry was appointed to study the possibility of nuclear power in South Africa and shortly after the Atomic Energy Board appointed the Research Advisory Committee to investigate the question of research in the nuclear energy field. Later that year Dr AJA Roux was appointed Director of the Board's Atomic Energy Research programme. In 1957, Dr Roux undertook an extensive overseas tour to inquire into the nuclear research and development programmes abroad as well as possible markets for South African uranium. He acquired extensive knowledge of types of nuclear reactors functioning overseas and learned which centres for advanced nuclear studies would be prepared to accept South African graduates who could be trained to initiate reactor development in South Africa. On his return Dr Roux set about the formulation of an Atomic Energy Research and Development Programme for South Africa.

The Commission of Enquiry (1956)

In an address early in 1954 to a group of Johannesburg businessmen, Dr SM Naudé stated that there was wide diversity of opinion as to when South Africa would start to use nuclear power.[1] There was no doubt, however, that it was going to happen in spite of the difficulties involved. At this early stage a number of aspects regarding nuclear power production were being considered. Cost was an important factor. The only way to estimate the expenditure involved in a nuclear power plant was to build a full-scale nuclear power station. Taking into account an overall thermodynamical efficiency*, the amount of uranium needed to fuel a natural uranium reactor*, and the cost of electricity production in South Africa, there was little chance that nuclear power could compete with coal in Pretoria, on the Rand or in Vereeniging.[2]

As early as 1954, Dr Bronowski, an outstanding British expert on the effects of nuclear power, believed that Southern Africa could play a leading part in the new industrial revolution based on nuclear energy.[3] Expansion in South Africa was hampered by the limitations set by railway transport. According to Dr Bronowski uranium was not a rival for coal in South Africa. Both coal and uranium could be sources of power, especially in the expanding economy of Southern Africa. Any addition to power resources was a gain. Where coal had to be transported for great distances, and in the mining industry, Dr Bronowski saw advantages for nuclear power in Southern Africa.[4]

Both Dr Naudé and Dr Bronowski made mention of the conservation of fossil fuels. In the fifties there was an awareness that in years to come man would be compelled to discover a new power source and that he would not be able to rely on non-renewable natural resources indefinitely. Of significance was the realization in most countries of

1 A meeting under the auspices of the National Development Foundation of South Africa, S Meiring Naudé: "Atomic Energy in South Africa", **Coal and Base Minerals**, 2(2) April 1954, p. 34.

2 **Ibid.**, pp. 34 and 36.

3 J Bronowski: "Nuclear Power, A Great Opportunity for South Africa", **Optima**, 4(4) Dec 1954, pp. 11 and 12.

4 **Ibid.**, p. 13.

the world of the need to establish the extent of their own natural reserves in order to be assured of an ever increasing source of power in the future. A great optimism for nuclear power prevailed at that time. With the advent of Eisenhower's Atoms for Peace Programme, the American public was treated to a stream of optimistic forecasts about the benefits that nuclear power would bring. Nuclear power would be science's gift to the ordinary citizen. It would produce electricity too cheap to meter. Totally unfounded predictions were made as to the uses of nuclear reactors. It was even said that nuclear reactors could be installed in amongst others nuclear powered cars and vacuum cleaners.[5]

The knowledge acquired by the South African mission to Europe and the Geneva Conference in 1955 led by Drs HJ van Eck, JT Hattingh and SM Naudé, placed leading South African industrialists, scientists and engineers in a position to estimate the potential of nuclear power in South Africa. They advised the South African Government on the feasibility of the application of nuclear power in the country. In their report the mission recommended that a nuclear power station should be constructed in Cape Town. It might be the most economic way of overcoming the transport problem between the Witwatersrand and Cape Town, which was to some extent aggravated by the large amount of coal which had to be conveyed for the purpose of power generation.[6] Drs Van Eck and Naudé set in motion the start of the South African uranium development plan, i.e. the refining of uranium so that it could be used as nuclear fuel.[7]

The delegation to the Geneva Conference also recommended that scientists should be trained in South Africa for a period of two years, after which the team members representing the various disciplines involved in nuclear research, should receive further specialist training

5 N Moss: **The Politics of Uranium**, p. 47.

6 (AECA) PRE.PEL 2 AJA Roux: **Proposed Atomic Energy Research and Development Programme for South Africa**, 15 April 1958.

7 Interview with DB Sole, 23.10.1989.

overseas, aimed at enabling them to operate an experimental reactor on their return to South Africa. Their recommendations led directly to the appointment of a Government Commission by the Governor-General of South Africa, Dr EG Jansen, and the responsible Cabinet Minister, Dr AJR van Rhijn, to study the application of nuclear power on South Africa and to commence investigations for an Atomic Energy Research and Development Programme for South Africa.[8]

Dr RB Hagart, Dr JH van Eck, Dr SM Naudé and CS McLean were members of the Atomic Energy Board Committee that drafted the terms of reference of the National Commission of Enquiry, appointed by the Government in 1956, that would investigate the application of nuclear power in South Africa. Chairman of the Commission was DD Forsythe, then Secretary of Foreign Affairs.[9] The Electricity Supply Commission, the mining industry, the South African Railways, commerce and the CSIR were all represented.[10]

The terms of reference set out for the Commission for Enquiry included the possibility of nuclear power in the Western Cape. In order to establish this, investigations would be carried out concerning (a) the possible future demand for electrical power in the Western Cape including demands resulting from possible future extensions to the electrification of the South African Railways; (b) the estimated comparative capital and operating costs of a nuclear power station and a

8 Appointment of the Commission of Enquiry by EG Jansen and the Governor-General-in-Council AJR van Rhijn, 7.12.1956, document as preface to RP 23/6, **Commission of Enquiry into the Application of Nuclear Power in South Africa**, (under the chairmanship of DD Forsyth), 21 April 1961, p. iii; AJA Roux: **Proposed Atomic Energy Research and Development Programme for South Africa**, pp. 66-67; Interview with DB Sole, 12.12.1990; AR Newby-Fraser: **Chain Reaction**, pp. 32-33.

9 Appointment of the Commission of Enquiry by EG Jansen and the Governor-General-in-Council AJR van Rhijn, 7.12.1956, document as preface to RP 23/61 **Commission of Enquiry into the Application of Nuclear Power in South Africa**, p. iii, 7.12.1956.

10 The members of the Commission of Enquiry were DD Forsyth, SM Naudé, T Coulter, JA Kruger, IMK de Villiers, MD Marais and AJA Roux. Dr Roux was co-opted to the Commission as Dr Naudé would not be able to attend all the meetings of the Commission on behalf of the CSIR.

comparative capital and operating costs of a nuclear power station and a conventional power station; (c) the possible effect on the Railways in their efforts to meet the full transport requirements of the country and their planning for the future, if they were relieved, wholly or partially of the transport of coal for power production; (d) the possible effect on the economic structure of the country of substituting nuclear power for conventional power in the Western Cape and other areas remote from the coalfields; and (e) the distribution of extra costs, if any, of producing power from nuclear energy against conventional methods of power production.[11]

Secondly, the Commission would investigate the possible effect on the coal mining industry if nuclear energy was used for power production in the Western Cape instead of coal.

Thirdly, ownership, installation, operation and control of a nuclear power station would have to be considered. Finally (as this was of particular importance to the uranium industry) in which fields industry might be further advanced by the utilization of nuclear power.[12]

Therefore one of the main areas of investigation of the Commission was whether South Africa should embark on nuclear power production even though large reserves of coal were available in the country.

The Commission only published its findings on 21 April 1961. While investigations were being done between 1956 and 1961 the Atomic Energy Board went ahead with preparations for nuclear power production in South Africa.

In the light of the evidence that had been laid before the Commission, the following conclusions on the terms of reference were reached: The

11 Appointment of the Commission of Enquiry by EG Jansen and the Governor-General-in-Council AJR van Rhijn, 7.12.1956, document as preface to RP 23/61 **Commission of Enquiry into the Application of Nuclear Power in South Africa,** 21 April 1961, p. iii.

12 **Ibid.**

demand for electrical power in the Western Cape area, would be adequately met until at least 1968/69 by the existing conventional power stations, augmented when and where necessary by a few additional generating sets and by the large new conventional power station at Athlone in Cape Town. The needs at other areas remote from the large coal fields had been, or would be, similarly catered for. No reliable estimate of the capital and operating costs of a nuclear power station in South Africa was at that time possible. Such an estimate then could only be based on the known costs of the diverse types of nuclear reactors in the United Kingdom, USA, Canada and elsewhere, which in themselves were largely in the experimental stage and whose ultimate costs were still largely a matter of conjecture. All that could be said in that regard was that in South Africa the overall cost of power generated in a nuclear station would, at that time, substantially exceed the cost of power generated in a conventional station of like capacity, and the capital cost of a station of the former type would be rather more than twice that of the latter.[13]

The Commission found that the Railways could adequately cope with the transportation of coal until at least 1968/69. There was no reason to doubt that the needs of the country thereafter could safely be left to the system of continuous advanced planning in operation by the Administration.[14] According to the Commission the total substitution of nuclear power for conventional power in the Western Cape would have a serious effect on the coal mining industry and the country's economy. When the production of electrical power by the use of nuclear heat became competitive and desirable in South Africa, the introduction of nuclear reactors would be a gradual process, for conventional power stations would have to be permitted to exhaust their useful lives. Ownership, installation, operation and control of all

13 Appointment of the Commission of Enquiry by EG Jansen and the Governor-General-in-Council AJR van Rhijn, 7.12.1956, document as preface to RP 23/61 **Commission of Enquiry into the Application of Nuclear Power in South Africa,** 21 April 1961, p. iii.

14 **Ibid.**

future nuclear power stations should repose in the Electricity Supply Commission. Finally, according to the Commission, there would be no economic advantage for the substitution of nuclear power in the Cape Western area or elsewhere in the Union, but there could be no doubt that the advent of nuclear power in South Africa on an appreciable scale at some future date would provide a stimulus not only to the expansion of existing industries, but to the establishment of new industries. It might facilitate the establishment of industries in remote areas.[15]

About a month after the appointment of the Commission of Enquiry, the Atomic Energy Board took a first step in nuclear investigation. In January 1956, the Research Advisory Committee was appointed to investigate the question of research in the nuclear energy field.[16] Members of the committee were Dr HJ van Eck (Chairman), Dr SM Naudé (with Dr SJ du Toit as his alternate), Dr EJ Marais (Director of the National Physical Laboratory), VH Osborn (Secretary for Mines) and Dr AJA Roux (member of the AEB Physics Committee and Director of the National Mechanical Engineering Research Institute).[17]

This Committee made certain recommendations to the AEB. General exploration work about markets for uranium and a search for other minerals potentially important in an nuclear programme were to be carried out. The installation of an experimental reactor was recommended. The Research Committee was under no illusions. It believed South Africa could not adopt a "wait and see" policy. Developments overseas were taking place at a tremendous tempo and

15 Appointment of the Commission of Enquiry by EG Jansen and the Governor-General-in-Council AJR van Rhijn, 7.12.1956, document as preface to RP 23/61 **Commission of Enquiry into the Application of Nuclear Power in South Africa,** 21 April 1961, pp. 40-41.

16 The Research Committee was one of a number of sub-committees appointed by the Atomic Energy Board. According to Dr DM Kemp the minutes of the meetings of this Sub-Committee could not be made available for research, 24.4.1991.

17 AR Newby-Fraser: **Chain Reaction**, p. 32.

great changes, especially in the field of the economics of nuclear power for electricity could be expected in the following decade. It was essential that South Africa remained abreast of developments taking place overseas in that field.[18]

It was the responsibility of the Research Advisory Committee to advise the AEB and make certain recommendation. The production of nuclear power in South Africa at some future date was one of the main considerations.

The fact that one of the items on the minutes of the first meeting of the Research Advisory Committee, in April 1956, was a report by Dr AJA Roux, "Heavy Water Production in South Africa", indicates that a nuclear reactor* using natural uranium and heavy water as a moderator was being considered.[19] (The report by Dr Roux revealed the results of the preliminary survey done by suggesting that the heavy water project warranted further investigation.)

Heavy water production was an expensive undertaking and it was regarded as uneconomical in nuclear power production. When the methods of producing heavy water were analysed, South Africa had two very important conditions in its favour in the economic production of heavy water. These were the availability of cheap power in the country, and SASOL was one of the largest producers of hydrogen in the world. It was in view of these conditions, in the latter half of 1956, that it was suggested by Dr HJ van Eck that South Africa might

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18 RB Hagart: "National Aspects of the Uranium Industry", **JSAIMM**, 57, April 1957, p. 578.

19 The physical properties of heavy water (or deuterium oxide) rendered it an excellent moderator for the slowing down of fast neutrons in natural uranium reactors. It is four times as effective as graphite in this respect. The critical size of a natural uranium fueled heavy water moderated reactor is much smaller than a graphite-moderated reactor, the ratio being 5:2. (AECA) AJA Roux: **Proposed Atomic Energy Research and Development Programme for South Africa,** p. 56-58.

consider large-scale heavy water production at a price that compared favourably with production in the USA and the UK.[20]

Taking into account South Africa's large reserves of uranium, a natural uranium reactor was strongly favoured in the middle fifties. The range of materials as moderators, in reactors using natural uranium, is limited and the best of these is heavy water. Consequently the capital cost of a heavy water-moderated reactor would be substantially less than that of a graphite-moderated counterpart, an advantage which, however, was off-set by the much higher price of heavy water as compared with graphite.[21] Consequently it was recommended that two engineers be appointed for the specific purpose of carrying out technical and economic investigations to the stage at which the AEB could make a decision on the future of such a potential industry. The AEB approved these appointments and from the beginning of 1957, AR Newby-Fraser (chemical engineer) and JR Colley (mechanical engineer) were engaged full-time in heavy water research in South Africa. From July 1957, in collaboration with the Heavy Water Group at the United Kingdom Atomic Energy Research establishment, Harwell they continued investigations in England. They also visited heavy water plants in West Germany. This was the first applied research undertaken by the staff of the AEB.[22]

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20 AR Newby-Fraser: **Chain Reaction**, pp. 32-34; In 1955 the price of coal was two shillings and two pence per ton and that of electricity 0,39 pence per kWh.

21 (AECA) AJA Roux: **Proposed Atomic Energy Research and Development Programme for South Africa**, p. 56-58.

22 Early investigations into heavy water production: AJA Roux and AR Newby-Fraser: **A Survey of Processes for the Production of Heavy Water in the Union of South Africa**, 29 March 1957, CSIR Pretoria; (AEC Archives, Pelindaba) AJA Roux: **Investigation of a Possible New Process for Deuterium Separation**, AEB, September 1958. (AEC Archives, Pelindaba) **Annual Report of the South African Atomic Energy Board**, 1958, pp. 8-9.

Dr AJA Roux.

(Source: Atomic Energy Corporation)

Dr Roux's Overseas Mission

By the end of 1956 the Atomic Energy Board was contemplating a natural uranium heavy water moderated nuclear reactor as a type of reactor most likely to be suitable for South Africa. However, the next step was to determine how far overseas countries had developed nuclear reactors, and also how all the branches of uranium and nuclear research were incorporated in an organised research programme.

At a meeting held on November 20, 1956, the Atomic Energy Board constituted a Permanent Research and Advisory Committee, representing all sectors which could be concerned with nuclear development. Dr AJA Roux, then Director of the Mechanical Engineering Research Institute of the CSIR, was appointed for a period of eighteen months in a part-time capacity as Director of the Board's Atomic Energy Research Programme. This appointment, which took effect on December 1, 1956, was made with the approval of Dr S Meiring Naudé, President of the Council for Industrial Research (CSIR), on the specific understanding that Dr Roux accepted the task of formulating and planning the research programme.[23]

Dr Roux had received his doctorate in Mechanical Engineering and had obtained a B.Sc. (Hons) in Applied Mathematics, cum laude at the University of the Witwatersrand.[24] In 1945 he was appointed senior lecturer in mechanical engineering at the University of Stellenbosch where he contributed to developing new engineering terms and expressions which had not existed in the Afrikaans language.[25] He was promoted to Vice-President of the CSIR and later full-time Director of the Atomic Research Programme. He would take a leading role and

23 Comment by tape-recording, AR Newby-Fraser, July 1991.

24 At the University of the Witwatersrand (1932-1944) he was instrumental in establishing the Society for Science and Philosophy, and became the first editor of that association's publication, *Die Suid-Afrikaanse Denker*, which had as its objective the promotion of the Afrikaans language as related to science.

25 AR Newby-Fraser: **Chain Reaction**, p. 37.

became known as one of South Africa's leaders in science. He had a strong personal interest in nuclear energy, which led him to read deeply on the subject. He was aware that in his position as Director of the Atomic Research Programme, he was given an opportunity and responsibility. It would depend in a very large measure on his judgment and recommendations whether such a programme could be implemented and whether South Africa could achieve world stature in the field of nuclear science. Eventually Dr Roux, the scientist, built up the reputation as a diplomat of unique ability. He could, in any company, political or intellectual, put across that which he firmly believed in, in a way that would bring his listeners to consider his proposals. In this regard, the promotion of nuclear energy in South Africa found in Dr Roux an advocate and diplomat without equal. This ability and reputation which Dr Roux developed in the 1950's would, with the later discovery of South Africa's uranium enrichment process, be of even greater significance.[26]

During the period of approximately four months, from 17 August to 9 December, 1957, Dr AJA Roux undertook an overseas tour on behalf of the South African Atomic Energy Board with the following objects in view: To ascertain the nature and trends of developments in the field of nuclear energy; to discuss with overseas authorities the tentative research and development programme for South Africa, which the author had drafted and submitted to the Board before his departure, and to obtain the views and comments of those authorities in regard to the programme; to determine the extent to which the tentative programme required modification in the light of the information obtained and discussions conducted; to determine whether it would be advisable for South Africa to link up the programme that it should decide to undertake with the programme(s) of one or more overseas countries and if so, how and to what extent it should be done; to establish the size of staff and the extent of facilities required for the execution of a

26 Interview with Professor PC Haarhoff, 29.7.1989 and Dr RS Loubser, 28.7.1989.

conservative but realistic programme for South Africa, and thus the approximate cost of the programme; to examine schemes and facilities which were offered by overseas laboratories for training and study in the field of nuclear energy and to discuss the conditions under which South African trainees would be accepted for further training and study; to ascertain the nature of any requirements in regard to the implementation and execution of the programme and to obtain, for the Commission of Enquiry into the Application of Nuclear Power in South Africa (of which Dr Roux was a member), as much information as possible on the then status of nuclear power and its development.[27]

Information from abroad, regarding a country's natural energy resources and advancements in nuclear research, was not easily available or publicised. Dr Roux's visits in 1957 to nuclear establishments, and to conduct conversations with many authorities in all fields on nuclear science, were invaluable in nuclear decision-making in South Africa. Considering how many important nuclear research centres he visited as well as the number of nuclear authorities with whom he conducted discussions, Dr Roux was well-informed at the time he formulated a nuclear research and development programme for the Union of South Africa.[28]

On his return to South Africa Dr Roux compiled a report which he called Atomic Energy Research and Development. The three parts were: United States; United Kingdom and Canada; and Continent of Europe (France, Norway, Sweden, Holland, Belgium, Switzerland and Western Germany). In the three volumes covering his mission, Dr Roux gives a detailed description of each country's research and development programme and the natural resources available to that country for power production; nuclear reactor development; heavy

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27 (AECA) AJA Roux: **Atomic Energy Research and Development, Part I, United States,** 31 March 1958, pp. 1-2.

28 (AECA) AJA Roux: **Atomic Energy Research and Development, Part III, Continent of Europe,** pp. 94-107.

water production and facilities available for the training of South African scientists.

Dr Roux's fact-finding mission in 1957, was of great significance in the history of uranium and nuclear power in the Republic of South Africa. He observed that research and development programmes of the various countries differed in the way they incorporated the various divisions of nuclear development, eg. natural resources, research, reactor development. The United Kingdom Atomic Energy Authority (UKAEA), for example, was established in July 1954. It operated initially through three main groups: A Research group of which the Atomic Energy Research Establishment (AERE) at Harwell, Berkshire, was the main establishment; an Industrial group at Risley, Lancashire, and a Weapons group.[29] The United States, in 1957, had by far the most extensive research and development programme in the field of nuclear energy.[30]

Like Canada, France had its own uranium deposits. France was the only other non-Communist country which had a nuclear research and development programme comparable with those of the United States of America, the United Kingdom and Canada.[31]

In 1957 South African nuclear authorities were contemplating a natural uranium reactor. For this reason Dr Roux's observations on nuclear reactor development in particularly the United Kingdom and Canada was of significance. Costs estimated in Britain for the production of electricity from nuclear power stations were used in an attempt to assess

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29 (AECA) AJA Roux: **Atomic Energy Research and Development, Part II, United Kingdom and Canada**, pp. 1 - 2.

30 (AECA) AJA Roux: **Atomic Energy Research and Development, Part I, United States,** p. 4.

31 (AECA) AJA Roux: **Atomic Energy Research and Development, Part II, United Kingdom and Canada**, pp. 77-79; AJA Roux **Atomic Energy Research and Development Part III, Continent of Europe**, pp. 3-6.

costs involved in the proposed nuclear power station in the Western Cape.[32]

By the time Dr Roux visited Britain in the second half of 1957, the natural uranium Calder Hall "A" reactors had been in operation for more than 18 months and, technically, very little difficulty had up to then been experienced. Technical advancement in the United Kingdom was more rapid than expected, and the programme was radically revised on two occasions.

By the end of 1957 nuclear power costs in the United Kingdom were almost competitive with those of thermal power, and it was estimated that costs would decrease in the period 1960-1990. The British had embarked on an extensive nuclear power programme and proved by 1957 that the natural uranium, gas-cooled, graphite-moderated reactor could successfully be utilized for nuclear power production.[33]

In the United States only the Pressurized Water* and Boiling Water* reactor types had, in 1957, reached the stage of development in which they could be considered with reasonable confidence for full-scale commercial power plants. This view was confirmed by all the leading authorities in the field of nuclear power in the United States, with whom Dr Roux discussed the matter. Both these reactors would, in the case of large-scale plants, operate on enriched uranium fuel.[34]

The French power reactor programme was very similar to that of Britain. The early developments were almost entirely concentrated on the natural uranium-fueled, graphite-moderated, gas-cooled reactors,

32 (AECA) AJA Roux: "Nuclear Energy: The Impact on South Africa", **Commercial Opinion**, August, 1957, p. 19.

33 (AECA) AJA Roux **Atomic Energy Research and Development Part II, United Kingdom and Canada,** pp. 31-32.

34 (AECA) AJA Roux: **Atomic Energy Research and Development, Part I, United States**, pp. 11-31.

the country, it was recommended by Dr Roux that the investigation which the AEB had already embarked upon be seriously pursued.[38]

According to AR Newby-Fraser, the AEB originally thought that South Africa could produce heavy water economically (more economically than any other country) because of [illegible] power and the large hydrogen resources at SASOL. After investigation, the possibility of heavy water production highlighted the fact that the energy cost was by no means so important as was thought initially. The capital costs of the project, which would have had to be a big project, was perhaps not prohibitive, but certainly an extremely high and important factor militating against heavy water production in South Africa.[39]

There is no doubt that the decision in connection with heavy water production in South Africa would involve great expenditure. The extensive investigations by the AEB and especially by Dr Roux, as to the pros and the cons of such a project, indicate that decisions were not hastily taken and that as much knowledge as possible was accrued from overseas countries. This is of importance considering that future decisions involving even larger costs would have to be taken, if South Africa progressed to the stage on nuclear power production. It may be said that this was the beginning of a pattern followed by the AEB to weigh all factors before making a decision. This was surely the most arduous task facing the South African Atomic Energy Board for the country could not afford to remain behind in the development of nuclear power, for both industrial and strategic reasons. South African scientists and engineers would wish to be part of world progress in this field, but scientific progress was moving at a rapid pace and the country could not afford to embark on costly ventures that, after only a few months or years, would have to be terminated because the authorities had not sufficiently planned ahead. This was a most

38 (AECA) AJA Roux: **Proposed Atomic Energy Research and Development Programme for South Africa**, p. 62.

39 Comment by tape-recording, AR Newby-Fraser, 18 July 1991.

difficult situation for South Africa in particular, for the country had a limited budget and many commitments. The thorough investigation into the economic production of heavy water illustrates prudent deliberation that can only negate certain criticism that would later be put forward that extensive expenditure was too great for South Africa's economy.

If South Africa wished to develop its uranium potential and nuclear power capability, South African graduates would require tuition and be given the opportunity to work at laboratories and nuclear plants to acquire advanced training.

From Dr Roux's reports it is clear that in 1957, the United Kingdom, the United States, Canada, France, Norway, Sweden and Holland were willing to offer facilities for the training of South African scientists, an essential aspect for the establishment of nuclear energy research in South Africa.[40]

Facilities which were available in the United States for the training of scientists and students from foreign countries were examined and discussed with the authorities concerned. In the United States the International School of Nuclear Science and Engineering (ISNSE), was established in March 1955, to assist in the implementation of President Eisenhower's Atoms for Peace Programme. The course offered was given with the co-operation of various universities, including North Carolina State College, and Pennsylvania State University. The basic course-work of the programme was presented at the universities in a first seventeen week period, and the more advanced material was offered in a second seventeen week period at the Argonne National Laboratory, Lemont, Chicago. The basic course-work covered six subjects: Nuclear Reactor Engineering, Nuclear Reactor Physics, Nuclear Reactor Instrumentation, Nuclear Reactor Chemistry,

40 (AECA) AJA Roux: **Atomic Energy Research and Development, Part II, United Kingdom and Canada**, p. 89; AJA Roux: **Atomic Energy Research and Development, Part III, Continent of Europe**, pp. 16-18, 29-30, 48, 60-61.

Chemical Engineering of Reactors and Metallurgy of Reactors. The course-work was divided into primary and advanced levels, so that students might select topics of special interest or concentration as they entered the second phase of the programme.[41]

The basic courses would be sufficient for the training of most scientists and engineers, but some would have to attend specialized courses. The question whether the US AEC national laboratories would accept foreign students for specialized training was discussed with Dr Hilberry, Director of the Argonne National Laboratory, who indicated at that time they were not allowed to accept foreign students for such purposes, because of the classified nature of some of the work of the laboratory. He indicated, however, that the US AEC was working on a declassification scheme and he thought that by September 1958, the national laboratories would be permitted to allow foreign scientists to work in laboratories. However, this matter was subsequently discussed with Dr Libby, one of the Commissioners of the US AEC, who confirmed what Dr Hilberry had told Dr Roux, but was extremely sympathetic, and gave Dr Roux to understand that they would in all probability accept South African scientists for such specialized training at the Argonne and Oak Ridge national laboratories, even if certain restrictions were not lifted.[42]

Argonne was particularly well-equipped for specialized training in reactor engineering, reactor physics, metallurgy and research reactor design and operation. The same conditions applied to Oak Ridge National Laboratory, Tennessee, USA which was most outstanding in the training of scientists in chemical technology, radio-chemistry, metallurgy, metal physics and research reactor design and operation. If South Africa proceeded with a programme concerned with chemistry, improved methods of extraction, and processing of uranium, the

41 (AECA) AJA Roux: **Atomic Energy Research and Development, Part I, United States,** pp. 85-86.

42 **Ibid.,** pp. 89-90.

chemistry and methods of extraction of thorium and the metallurgy of uranium in relation to its uses as a nuclear fuel, the Oak Ridge Laboratory would be the ideal place for specialized training of staff to be employed.[43]

The Special Training Division of the Oak Ridge Institute of Nuclear Studies offered a four week course in radio-isotope techniques. The course was very largely a basic training course which the student had to supplement by experience and extensive reading on the subject. Each four week course was set up so that the schedule included about 24 hours of special topics seminars directed by specialists in various fields, 16 hours of nuclear science background lectures, and 48 hours of laboratory and experimental work. Because of the large number of applicants, it had become necessary to accept only persons of the highest research calibre, usually having doctorates or the equivalent in their field of specialization.[44]

Taking into account the number of authorities Dr Roux spoke to and nuclear establishments he observed there can be no doubt that Dr Roux was in a position to assess how the divisions of Engineering, Physics, Chemistry, Cladding Materials, Fuel Element Research, Radiation and Radio-active Isotopes, etc. were incorporated in the nuclear research programmes of at least ten leading countries in the world and could therefore formulate one to suit South Africa's needs.

Dr Roux, having investigated natural resources and nuclear energy programmes in Europe, discovered that German uranium requirements were at that time small, but that "it would be in the interest of South Africa to explore the market for uranium without delay, not only in Germany but also in other countries on the continent of Europe."[45]

43 (AECA) AJA Roux: **Atomic Energy Research and Development, Part I, United States**, pp. 90-93.

44 **Ibid.**, pp. 84-85.

45 (AECA) AJA Roux **Atomic Energy Research and Development Part III, Continent of Europe**, p. 86.

Discussions with European nuclear authorities revealed those countries that had relatively small coal reserves and natural nuclear energy resources. It was, therefore, in South Africa's interest that markets for uranium were explored in, for example, Germany, Switzerland, Norway and other countries in Europe.

Considering, on the one hand, that in the early fifties South Africa had the largest known reserves of uranium in the world, and on the other hand, the advancements that had taken place in nuclear power development abroad by 1957, it seems logical that South Africa should have prepared itself to supply uranium in a form most competitive on the international market. The two types of reactors furthest developed in the United States were the Pressurised Water Reactor (PWR) and the Boiling Water Reactor (BWR). Both these reactors employed enriched uranium as fuel.

Dr Roux's findings indicated that South Africa would have to make up lost ground if it wished to contend with nuclear power development in the future.

According to Dr JP Hugo (appointed Head of Reactor metallurgy (1960) and Deputy President of the AEB (1970)) the refinement of uranium was not an over-ambitious ideal. Any country would, if it were at all possible, try to refine natural power resources to the grade that they would be most competitive on the world market. In addition, if a country with uranium resources wished at some future date to enrich its own uranium the first step would be to refine and purify its uranium ore.[46]

There are certain indications that suggest that Dr Roux, in the formulation of his Atomic Energy Research and Development Programme, would have entertained the possibility that South Africa could enrich its own uranium. In the late 1950's there was literature

46 Interview with Dr JP Hugo, 26.4.1991.

available on the possible ways in which uranium could be enriched.[47] The very comprehensive programme that he ultimately proposed substantiates this premise.[48]

Dr Roux was aware that the position that South Africa occupied in 1958 in regard to the production of uranium was undoubtedly the most important single factor which contributed to the country a having permanent seat on the Board of Governors in the International Atomic Energy Agency.[49] It was doubtful whether South Africa would be able to maintain that leading position in the Agency unless it was prepared to participate on a sufficiently large scale in nuclear research and development.[50]

Dr Roux's Proposed Programme

The general approach adopted by Dr Roux in attempting this formidable task, was to consider very carefully the need for South Africa to enter the expensive field of nuclear energy research. The particular directions in which research would prove of greatest benefit to the country and the manner in which such a programme of research could be implemented so as to make maximum use of trained personnel, facilities already available in the country, thereby reducing

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47 Interview with Dr WL Grant, 27.7.1989.

48 While in Western Germany Dr Roux learned that Professor Groth, at the Institut für Physikalische Chemie of the University of Bonn, had for many years been engaged in research into the separation of isotopes employing the ultra-centrifuge method. AJA Roux: **Atomic Energy Research and Development, Part III, Continent of Europe**, pp. 87-88.

49 As mentioned in the previous chapter South Africa was only guaranteed a seat on the Board of Governors of the IAEA if it continued to be the member of the IAEA most advanced in the technology of nuclear energy, including the production of source materials in the region of Africa and the Middle East.

50 (AECA) AJA Roux: **Proposed Atomic Energy Research and Development Programme for South Africa**, pp. 75-76.

technology which is associated with nuclear power, thereby enabling it ultimately to manufacture for the domestic market and even capture a portion of the overseas market for reactors or reactor components and associated equipment.[52]

According to Dr Roux it was generally recognised that there were three ways in which developments in the non-military field of nuclear energy affected mankind in general, and the scientific and industrial life of a nation in particular. These resulted from the fact that certain raw materials had assumed or were likely to assume greater importance; the world had been presented with a new power source and through the use of radio-active isotopes, a new technique had become available for the solution of scientific and technical problems. It was for this reason that the research and development programmes of most countries made provision for work in all three directions. Dr Roux added to these a fourth additional direction: Fundamental Research.

The Proposed Atomic Energy Research and Development Programme was composed of twelve main themes. The majority of them (namely eight) related directly to materials.

Themes I to VIII dealt with the following: the improvement of uranium mining and extraction methods; the study of further steps in uranium processing; the study of the properties of uranium to its use as a nuclear fuel; prospecting for thorium; the development of extraction and processing methods for thorium*; expansion of exploration for reactor materials; the development of extraction and processing methods for reactor materials and the study of economic heavy-water production possibilities.[53]

The two other main directions were embodied in the next three themes. Themes IX to XI dealt with the following: research and development

52 (AECA) AJA Roux: **Proposed Atomic Energy Research and Development Programme for South Africa**, pp. 11 and 12.

53 **Ibid.**, pp. 3-4.

on a power reactor concept appropriate to South Africa; the promotion of the established uses of radioisotopes and radiation; and research to establish new uses of radioisotopes and radiation. The twelfth theme recognised the importance of universities and dealt with fundamental research basic to nuclear energy development.[54]

In the final sections of the Proposed Atomic Energy Research and Development Programme, Dr Roux included recommendations on aspects required for the execution of the programme. These were as follows: facilities; research reactor; staff and staff training; cost; control and finance.[55]

The specific projects, which were to fall under Theme I Dr Roux discussed in detail with DG Maxwell, Consulting Metallurgist of the Central Mining and Finance Corporation, and ET Pinkney, Consulting Chemist of the Anglo American Corporation, as well as the Uranium Technical Sub-Committee, during a formal meeting held on 21 June 1957.[56]

Theme II dealt with the institution of a limited programme for the study and research into the methods of the processing of uranium. Dr Roux recommended that the possibility of improving the grade of the product exported be studied. Processes then being developed at Chatillon, France and Oak Ridge, USA for that purpose, could be investigated in South Africa.[57]

Theme III of the Proposed Programme dealt with research of the properties of uranium to its use as a nuclear fuel. Dr Roux stressed the

54 (AECA) AJA Roux: **Proposed Atomic Energy Research and Development Programme for South Africa**, pp. 4-5.

55 **Ibid.**, pp. 91-136.

56 (AECA) AJA Roux: **Proposed Atomic Energy Research and Development Programme for South Africa**, pp. 21-25; **Annual Report, South African Atomic Energy Board**, 1957, p. 8.

57 (AECA) AJA Roux: **Proposed Atomic Energy Research and Development Programme for South Africa**, pp. 25-29.

fact that South Africa, as one of the largest producers of uranium in the world, should for that reason also be one of the leading countries in the field of research on the use of uranium as a fuel. Research and development work in that field was essential because it would keep the country in close contact with developments, and South African nuclear authorities could then decide in what form its uranium product could most profitably be marketed. Dr Roux believed that the extent to which plutonium would be used in future would to some extent depend on the efforts that uranium producing countries were putting into development of cheaper and more efficient uranium fuels.[58]

Themes IV and V dealt with a prospecting programme for thorium in South Africa as well as the development of methods for the extraction of thorium from South African ores.[59]

Apart from the prescribed materials uranium and thorium, there were a number of other materials, which had assumed special significance by virtue of their particular properties which suited the stringent requirements of reactor technology.[60] As development in the field of nuclear power proceeded, so the demand for these materials would increase. South African deposits of these materials were to be ascertained in order to ensure that the maximum benefit would be derived from them. Themes VI and VII dealt with these aspects.

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58 (AECA) AJA Roux: **Proposed Atomic Energy Research and Development Programme for South Africa**, pp. 29-36.

59 **Ibid.**, pp. 36-40.

60 The following is a list of the materials that fall in this category: aluminium, beryllium, bismuth, boron, cadmium, carbon, cobalt, hafnium, lead, lithium, magnesium, molybdenum, nickel, niobium, potassium, rare earths, sodium, stainless steel, tantalum, titanium, tungsten, vanadium, zirconium, and in addition heavy water and organic materials such as polyethylene, diphenyl and hydrocarbons. Most of these are regarded as restricted materials, but only beryllium had, in terms of the Atomic Energy Act, been proclaimed a restricted material. Some of these materials were produced by South Africa during 1959. (AECA) **Annual Report of the South African Atomic Energy Board**, 1959, p. 6.

With regard to Theme IX, Dr Roux realized that the application of nuclear power in a country should be preceded by a careful study and a period of preparation. For this purpose a limited programme of research and development in the field of nuclear power was essential. In view of the extent of the field of nuclear power, the programme of a small country like South Africa, would have to be limited and have specific objectives. The objectives were mainly to enable South Africa to be kept abreast of developments in nuclear advancement overseas; to ensure that nuclear power development in South Africa took due account of the nuclear conditions pertaining there; to enable the country to make, in proportion to its size and economic position, a contribution to the vast and important field of nuclear research and development. The way in which it was proposed to limit the South African research and development programme, was to select only one type of reactor system for study and investigation. In the choice of the particular type, the determining factors would be the availability of raw materials in the country and other local conditions. The reactor concept would, therefore, be based on natural uranium and beryllium, heavy water or graphite as moderators.[61]

Dr Roux's Programme included a schedule to extend the already established uses of radio-isotope and radiation in South Africa and to conduct research with the object of establishing new uses of radio-isotopes and radiation particularly in regard to important problems which were peculiar to South Africa (Themes X and XI).[62]

Apart from the fundamental research which would form an essential part of the investigations, efforts would be made to stimulate fundamental research (Theme XII) in the country in those sciences which were basic developments in the field of atomic energy. These were physics, physical metallurgy, chemistry and engineering. Without

61 (AECA) AJA Roux: **Proposed Atomic Energy Research and Development Programme for South Africa**, pp. 76-79.

62 **Ibid.**, pp. 80-90.

such a programme of basic research, the country would only lag further behind other countries and its applied programme would suffer. This part of the programme was of particular importance as far as uranium enrichment was concerned, as this provided for the establishment of facilities where research in that field could be done.[63]

Having outlined the twelve themes of the programme Dr Roux made certain recommendations as to the execution of the programme.

How and where would the Proposed Programme be carried out? The South African Atomic Energy Board would execute the programme, making full use of the then existing facilities at the Government Metallurgical Laboratory, the Geological Survey and the laboratories of Industry, CSIR, universities and other organizations. The Board would refer to those institutions, for execution on an agency basis, projects that would be carried out and for which they were suitably equipped.[64]

The parts of the Proposed Programme which would require the use of a research reactor or which should be carried out in close collaboration with other groups around the reactor, were the following: studies relating to the application of reactor materials; research and development work on nuclear power; and the production of isotopes. This work would be done by the AEB and the facilities for doing so on a reactor site. In view of the practical necessity that the reactor centre be located as close as possible to the major industries concerned, particularly the uranium industry, ESCOM and the heavy engineering industry, the AEB would acquire a site for the reactor centre, so chosen that it was in the closest possible proximity to the major industries concerned with the programme, the CSIR, the GML and the universities of the Witwatersrand, Pretoria and Potchefstroom. The site would have to accommodate all future developments in the research programme. The facilities would be available to all the other

63 (AECA) AJA Roux, **Proposed Atomic Energy Research and Development Programme for South Africa**, p. 90a.

64 **Ibid.**, pp. 104-116.

universities and it was the intention of the AEB to assist them financially for any work to be carried out on behalf of the AEB.[65]

The scale on which the programme would be implemented, would determine the annual cost. This was naturally a serious considerations and it was necessary to determine the minimum rate of implementation and execution which would still enable the country to derive those benefits which were vital to it. Under those conditions it was essential that the rate at which the programme was implemented and executed be defined very clearly in terms of targets which should be aimed at with respect to time. Dr Roux recommended that the first five-year period (1950-1965) of the programme be a period of preparation in which staff would be trained and facilities established. By the end of that period the bulk of the programme would be implemented and in progress. Developments in the field of nuclear energy moved so rapidly that it was not advisable to attempt to circumscribe the exact trends of development of the South African programme beyond the first five years.[66]

In the second five-year period South Africa would likely have reached the stage at which there would be much clearer indications which reactor materials were preferred and markets for such materials. South Africa could by then (1965-1970) give serious consideration to the introduction of nuclear power. To reach the objectives on the time-scale outlined above, it was planned to engage some 75 professional scientists in the course of the first five-year period. The bulk of staff would be recruited from young graduates, a large percentage of whom would have to be sent overseas for specialized training. With so little

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65 (AECA) AJA Roux, **Proposed Atomic Energy Research and Development Programme for South Africa**, pp. 117-118; AJA Roux, "Atomic Energy Research and Development Programme for South Africa", **SA Mechanical Engineer**, 9, Dec 12, 1959, p. 113.

66 (AECA) AJA Roux, **Proposed Atomic Energy Research and Development Programme for South Africa**, pp. 120-121.

Dr S Meiring Naudé

(Source: Atomic Energy Corporation)

knowledge of atomic energy in the country the AEB would introduce a bursary scheme for specialized training in the field of atomic energy.[67]

On this basis, and taking into account the rate at which staff would be recruited, the estimated cost of the programme for the first five-year period was £4 000 000 or £800 000 per annum. In relation to the country's national income, this expenditure on nuclear energy research and development was small in comparison with the amounts spent even by the smaller countries of Western Europe.[68]

The Reaction of the Government, Scientists and Industry

Dr Roux was convinced that the Atomic Energy Research and Development Programme of South Africa was of paramount importance and should be proceeded with without delay. He presented his Proposed Programme for Atomic Energy to the assembled members of the Atomic Energy Board on June 12, 1958. It was a formidable task that he had completed.

The Programme should be looked upon as a joint effort of many people. Although Dr Roux had the privilege of preparing the original draft, it was modified first by the Research Advisory Committee of the Atomic Energy Board, and subsequently by the Board in consultation with the Council for Scientific and Industrial Research.[69]

Time soon proved that there were differences of opinion concerning the implementation of the nuclear programme. In 1958, Dr SM Naudé was President of the CSIR. It was his considered opinion that the programme should be undertaken by the CSIR. Dr Roux was

67 (AECA) AJA Roux, **Proposed Atomic Energy Research and Development Programme for South Africa**, p. 9, pp. 119-120, pp. 121-122.

68 **Ibid.**, pp. 128-131.

69 AJA Roux: "Atomic Energy Research and Development Programme for South Africa", **SA Mechanical Engineer**, 9, Dec 2, 1959, p. 116.

convinced that the programme should be implemented as a separate organization. This difference of opinion between two outstanding scientists would be publicly settled by the Government's acceptance of the proposals of the programme in 1959, but their personal differences on the matter were never quite resolved.[70]

Dr SM Naudé believed that the facilities established at the CSIR could be developed and extended in order to accommodate the nuclear energy research and development programme. The National Mechanical Engineering Research Institute of the CSIR (metallurgy) was in 1958/59 doing investigations involving macro- and micro-hardness and tensile testing, heat treatment of materials and components, and metallographic examinations. Stress corrosion and fatigue in metals were specific projects undertaken.[71] Therefore, according to Naudé's view facilities had already been established at the CSIR that could with some extensions test materials for nuclear reactors. Dr Roux did not agree with Naudé. Investigations into an nuclear power plant would initially be limited, but in the long term, he believed that there would be much expansion. Although the CSIR had made a start in investigating problems encountered in power plants and relating to nuclear engineering, a separate organization would allow more scope for development in the various fields of nuclear research.

In 1959 a financial limit of 7½ percent was placed by the government on the expansion of the CSIR, despite the fact that the output of industry continued to increase.[72] Therefore the CSIR would have gained financially had it been decided to implement the nuclear programme at the CSIR. The CSIR would also lose key members of research teams in the development phase of a separate organization.[73]

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70 Interview with Dr WL Grant, 27.7.1989.

71 (SAB) **Fourteenth Annual Report of the CSIR (1958-1959)**, pp. 261-263.

72 (SAB) **Fifteenth Annual Report of the CSIR (1959-1960)**, p. 5.

73 (SAB) **Sixteenth Annual Report of the CSIR, (1960-1961)**, p. 3

In November 1958, Dr Naudé completed his Proposals in Connection with a Nuclear Energy Programme for the Union of South Africa. Both this Programme, as well as Dr Roux's Proposed Programme for Atomic Energy Research and Development, were submitted to the Minister of Mines, Senator J de Klerk, and he had to decide between the two.[74]

Dr Naudé was of the opinion that the research programme should not make excessive demands on the country's financial resources. He was in agreement with Dr Roux on certain aspects of the programme, but saw the need to move cautiously into a very extensive programme.[75]

It was Dr Naudé's suggestion that the South African Atomic Energy Research Development Programme be undertaken by the CSIR, that would evoke the indignation of Dr Roux. The suggestion was however understandable and in keeping with certain aspects of Dr Naudé's programme. He was in agreement that uranium prospecting and extraction should be undertaken, but had reservations concerning the processing of uranium for nuclear fuel purposes. He suggested a nuclear power programme, but not a full-scale South African reactor programme.[76] Naudé favoured participation in the OEEC reactor scheme.[77]

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74 Interview with Dr WL Grant, 24.4.1991.

75 Dr Naudé referred to Australia and Holland where nuclear projects had been undertaken and proved too ambitious. (AECA) SM Naudé: **Proposals in Connection with a Nuclear Energy Research Programme for the Union of South Africa**, Introduction, pp. 1-7, 11 - 12, 24.

76 SM Naudé: **Proposals in Connection with a Nuclear Energy Research Programme for the Union of South Africa**, pp. 9-22.

77 Dr Naudé favoured a suggestion put forward by Dr Schonland that South Africa should, as soon as possible, apply for membership of the OEEC (Organization for European Economic Co-operation) group which was undertaking a programme of work on development of a high temperature gas-cooled reactor. Britain had started research on that type of reactor and it had promising possibilities for the future. South African engineers and scientists would have to be made available to work on the scheme. According to Naudé South Africa's participation in the scheme would have certain

SM Naudé's final cost estimate for his Nuclear Energy Research Programme was less than that of Dr Roux's Proposed Programme.[78] However, Dr Roux's more comprehensive programme provided for a future where the peaceful applications of nuclear energy would play an ever-increasing role and achievement in this field would effect South Africa's international status, politically and strategically. These were aspects that would have to be considered in South Africa's position of increasing isolation in the late fifties.[79]

When the Atomic Energy Board was originally constituted, it was done with the main object of controlling the production and sale of uranium oxide to the Combined Development Agency. During the early fifties committees had been appointed (such as the Research Committee and Nuclear Committee). The various committees would submit reports. In this way the Atomic energy Board had by 1958, developed into an independent department. In 1958 the Minister of Mines, Dr van Rhijn, introduced the Atomic Energy Amendment Bill (No. 34 of 1958) which was to provide for a changed Atomic Energy Board to cope with the new circumstances. During the Second reading of the Atomic Energy Amendment Bill, on 20 August 1958, Dr van Rhijn referred to "the big programme which lies ahead of us".[80] This was a definite indication that the Government was contemplating a comprehensive programme of research and development, a year before it became official.

Towards the end of August 1959, the Minister of Mines, Senator J de Klerk, accepted the arguments proposed in Dr AJA Roux's programme, and on 5 September he announced at Carletonville, Transvaal, that the

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advantages. SM Naudé: **Proposals in Connection with a Nuclear Energy Research Programme for the Union of South Africa**, p. 18, pp. 25-32.

78 **Ibid.**, pp. 32-33; (AECA) AJA Roux: **Proposed Atomic Energy Research and Development Programme for South Africa**, p. 130.

79 See Chapter 9.

80 **Assembly Debates**, vol. 97, 4 July - 25 August 1958, 20 August 1958, col. 2573.

Atomic Energy Board could proceed with the Atomic Energy Research and Development Programme.[81]

On 12 November 1959, at a meeting of the SA Institute of Mechanical Engineers (attended by scientists and representatives of the industrial sector) at the University of the Witwatersrand, Dr Roux presented the Proposed Programme for Atomic Energy Research and Development in South Africa. In his opening address Dr Roux said he believed that developments in the nuclear field in the late 1950's would have an impact on every country, however small, and that South Africa would have to participate more actively in these developments in the future than it had in previous years. This was necessary if South Africa wished to stabilize and improve its position as it was at that time amongst the industrial countries of the world and particularly if it was to maintain the leading position it held on the continent of Africa. He was aware of the rapid changes that had taken place in the world during the 1940's and 1950's. South Africa had become uncertain of her position and the direction that future developments would take in the world at large and, more particularly, in the field of technology. That state of affairs he attributed to the tremendous progress made in the knowledge of the structure of matter and of the conditions necessary for the release, application and control of nuclear energy. At that time mankind was living too much at the threshold of the development of nuclear energy to fully appreciate the implications and the changes that it would bring about. It was incumbent on those living at that time to gradually orientate themselves to the new world that was emerging.[82]

In the vote of thanks and discussion that followed the presentation of the Proposed Programme one can ascertain how prominent persons in the various fields of engineering, mining and industry accepted the nuclear programme. CS McLean, Member of the AEB and president

81 AR Newby-Fraser: **Chain Reaction**, p. 42.

82 AJA Roux: "Atomic Energy Research and Development Programme for South Africa", **SA Mechanical Engineer**, 9.12.1959, pp. 103-104.

of the Transvaal Chamber of Mines, was confident that the uranium industry would benefit from the Proposed Programme presented.[83]

Dr HJ van Eck, Chairman of the Uranium Advisory Committee of the AEB, commented on that part of the programme in which the engineering industry of South Africa would play a role. He believed that South Africa had some of the finest engineering workshops in the world, yet at that point in time they were languishing because there was no great activity in the capital goods market. There was no question of their ability to supply enormous quantities of machined castings and welded constructions in ordinary and special alloy steels at costs much below the American and European costs. They could supply them with shorter delivery times. The Proposed Programme provided for development and production in South African engineering workshops and this would promote expansion in the engineering industry.[84]

Dr Van Eck quoted JA Jukes, the economic advisor to the United Kingdom Atomic Energy Authority, who predicted that capital costs for nuclear stations would fall. There would be improvements in fuel performance and reductions on fuel cost. This would reduce the cost of electricity from new and existing nuclear stations in Britain by ten percent. South Africa would have to invest a large amount of money in electricity generation in the years following, and it would be of great advantage if the money could remain circulating in the country. According to Van Eck South Africa should make the most of its own natural resources and he emphasized the importance of training scientists and technologists.[85]

Professor WJ Walker, Department of mechanical Engineering, University of the Witwatersrand, welcomed the programme. He

83 AJA Roux: "Atomic Energy Research and Development Programme for South Africa", **SA Mechanical Engineer**, 9.12.1959, pp. 116-117.

84 **Ibid.**, pp. 117-119.

85 **Ibid.**, p. 119

mentioned that there was always the possibility that nuclear development could in future dispense with the thermodynamic element in energy transformation and proceed directly to electrical or mechanical energy from nuclear energy. This was not clearly in sight at that time, and would mean complete re-orientation of proposed development. This was, however, no cause that development work should be held back by reason of problematical contingencies of such an order.[86]

For Dr TEW Schumann, Deputy Chairman of the AEB, the presentation of the programme was a very happy occasion. Compared to what America and Britain were spending on nuclear energy research, South Africa's proposed expenditure was very small. According to S Craib, member of the Uranium Technical Committee, South Africa's engineering industry had expanded during the war years, and this had placed it in a position to produce equipment for mining and industry. The seventeen uranium plants, with many specialized items, and the nine ancillary sulphuric acid plants were very largely built from equipment made in South Africa. During the execution of the programme to establish the extraction plants, all stainless steel castings were imported, while the last plant built used only those of South African manufacture. Some overseas engineering industries had either established their own manufacturing organizations in this country, or had become partners with existing concerns. This linking of growing manufacturing facilities and knowledge of conditions in South Africa, could only be advantageous to both parties and in implementing the Proposed Programme.[87]

According to ET Pinkney, Member if the Uranium Technical Committee, and consulting Metallurgist Anglo American Corporation of SA Ltd., the programme presented by E. Roux had been criticized

86 AJA Roux: "Atomic Energy Research and Development Programme for South Africa", "Discussion" and "Vote of Thanks", **SA Mechanical Engineer**, 9, Dec 1959, pp. 120-121.

87 **Ibid.**, pp. 120-123.

because it was said to give too great emphasis to the applied and developmental aspects of nuclear energy. Clearly, this criticism was not justified, because it would be impossible to carry out research effort of that type without the fullest utilization of all the talents and facilities available for fundamental research in the country. The development aspects were of great importance and might well have great impact in the overall industrial activities of the Union. He emphasized that the establishment of the uranium industry had resulted in greater use of instrumentation, automatic control and improved analytical techniques, better materials of construction and cleaner design, particularly in new plants.[88]

Professor S Smoleniec, of the Department of Mechanical Engineering, Witwatersrand University, was of the opinion that the Proposed Programme included the immediate need of improving South Africa's position as one of the chief suppliers of nuclear fuels against continuously increasing competition. This would be achieved by producing uranium in metallic form, or a highly refined uranium oxide ready for immediate use in a reactor. For the future, however, it would be in South Africa's interest to find attractive applications for other nuclear fuels and reactor materials that it could produce.[89]

Professor FRN Nabarro, a university professor of physics (University of the Witwatersrand), and a visitor to the presentation by Dr Roux, believed the main emphasis of the Proposed Programme lay in raw materials and the acquisition of a medium sized reactor of research, and those he believed were the most important aspects. In his nuclear programme Dr Roux considered the interests of the universities. The site of his main establishment would be within easy access of the three universities of the Transvaal. He stated that the Proposed Programme had not dealt with the question of whether South Africa could

88 AJA Roux: "Atomic Energy Research and Development Programme for South Africa", "Discussion" and "Vote of Thanks", **SA Mechanical Engineer**, 9.12.1959, pp. 123-124.

89 **Ibid.**, pp. 124-125.

profitably manufacture fuel elements, unless the country was also prepared to go to the very great expense of setting up chemical processing plants to deal with the spent fuel elements and recover the uranium and plutonium for refabrication.[90]

Dr Roux's Programme was supported by leading South African engineers and scientists and the uranium industry. Of importance was the financial backing that the uranium industry was prepared to contribute in order to set in motion an nuclear energy programme as comprehensive as that proposed by Dr Roux.

Dr SJ du Toit believes that the fact that Dr Roux obtained the support of the Chamber of Mines and the uranium industry for the research and development programme was of particular significance.

Dr Roux realised that in order to have his Atomic Energy Research and Development Programme implemented he would not be able to rely on Government funds alone. He realised that the mines would be the beneficiaries in a South African Atomic Energy Research and Development Programme. As soon as he returned from his mission overseas he convened a meeting with the Chamber of Mines. He informed the Chamber that a nuclear programme that could stimulate uranium sales would be in their interest, and in this way gained substantial financial support for the Proposed Programme. Dr du Toit believes that this was a brilliant move by Dr Roux and most probably the factor that swayed the Government to accept Dr Roux's Programme.[91]

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90 AJA Roux: "Atomic Energy Research and Development Programme for South Africa", "Discussion" and "Vote of Thanks", **SA Mechanical Engineer**, 9, Dec 1959, pp. 125-126.

91 Interview with Dr SJ du Toit, 9.1.1992

CHAPTER SEVEN

THE IMPLEMENTATION OF THE NUCLEAR RESEARCH AND DEVELOPMENT PROGRAMME

Amendments to the Atomic Energy Act were introduced in Parliament in 1958 and 1959 to provide for a changed Atomic Energy Board and to prepare for the implementation of the new programme of research and development. During 1959 and the early sixties Dr Roux and leading nuclear authorities set about the organization of the Atomic Energy Research and Development Programme. The work was started with great intensity. By July 1961 construction to accommodate South Africa's first research reactor had commenced on the site for the new South African nuclear centre at Pelindaba. Meanwhile two other major projects were being implemented, namely, the first South African power reactor development programme and the Gas Cooling Project. It was believed by the scientists undergoing nuclear training in the United States that to build Pelindaba into a centre of excellence in nuclear science an original reactor concept suited to South African conditions could be a central theme to give relevance to the divergent nuclear interests to be developed on the site. The main features of the concept which originally saw the light of day towards the end of 1961 were natural uranium as fuel, heavy water as moderator and sodium as coolant. It became known as the PELINDUNA Project. Towards the end of 1966 both PELINDUNA and the Gas Cooling Project had almost simultaneously reached the stage where each required, as a next step, the construction of a large demonstration or pilot plant for which the financial implications were very heavy. The Republic of South Africa could not finance both projects. A choice had to be made. The decision was taken to go ahead with the Gas Cooling Project and to shelve PELINDUNA.

New Legislation

The decision of the Combined Development Agency not to purchase all of South Africa's uranium compelled the Government to introduce measures to meet the new circumstances. This was essential for much money had been invested in uranium - an estimated total sum of R66 million when all the plants and the ancillary sulphuric acid plants were in operation. Except for the cost of plant and equipment purchases overseas, this sum represented new money injected into the economy of the country.[1]

In 1958 the Minister of Mines, Dr van Rhijn, introduced the Atomic Energy Amendment Bill (No 34 of 1958) which was to provide for a changed Atomic Energy Board to prepare for the new programme of research and development.[2]

The Minister named some of the changes. Once the research programme was embarked upon the Atomic Energy Board would expand more and more. Although the Minister of Mines would officially be the Chairman of the Board, a Deputy-Chairman would be appointed in a full-time capacity and could preside at the meetings of the AEB. (The Minister would preside at occasional meetings.) As a result of the expansion that was to take place, it would be quite impossible for the Minister (who was then both Minister of Mines and Minister of Economic Affairs) to cope with two large Departments and to attend to all the work of the Atomic Energy Board. Therefore, the Deputy-Chairman, who would be in constant touch with the work of the Board and the activities of the committee, would be a liaison between the Board and the Minister.[3]

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1 (AECA, Pelindaba) AJA Roux: **Proposed Atomic Energy Research and Development Programme of South Africa**, p. 15.

2 **Statutes of the Union of South Africa**, Act No 27 of 1958, pp. 139-141.

3 (SAL) **Assembly Debates**, vol. 97, 4 July - 25 August 1958, 20 August 1958, col. 2573-2574.

The Government, acting upon a recommendation by Dr Roux, reorganized the Board, and so that its scientific and technical function was integrated with its business function. The following changes were brought about by The Amendment to the Atomic Energy Act (No 27 of 1958). The Minister of Mines would remain the Chairman of the Board, there would be two representatives from the uranium industry, one from the CSIR and one from ESCOM. One member would represent commerce and one those industries particularly interested in the sale of uranium. The latter two representatives were chosen specifically to deal with the new markets for uranium. The Secretary for Finance and the State Mining Engineer were no longer members of the AEB. This had been done at their own request as they felt that they were not really needed on the Board. They could, however, be consulted on financial matters. Committees would be appointed to assist the Board. They, in turn, would co-opt outside persons considered capable of assisting in certain matters. There would be a Sales Committee which would take care of uranium sales to countries which did not form part of the Combined Development Agency.[4]

The AEB was reconstructed to give representation to all the interested parties. An approach was then made to those private institutions that would benefit, for contributions to meet the cost. The response was enthusiastic and a total of £471 000 (R942 000) was guaranteed.[5] With the contribution from the State of £290 000 (R580 000) per annum the funds required for the first five-year period of the programme had

4 **Ibid.**; (AECA) **Annual Report, South African Atomic Energy Board**, 1957, pp. 3-4. (These changes in the AEB had also been made with the view of implementing the Atomic Energy Research and Development Programme.)

5 The contributions comprised the following: Uranium industry £400 000 p.a.; ESCOM £50 000 p.a.; Iscor Group of Industries £16 000 p.a.; John Thompson Limited £3 000 p.a.; First Electric Corporation SA Ltd. £1 000 p.a.; Associated Electrical Industries SA (Pty) Ltd. £1 000 p.a.; the contribution in each case being guaranteed for the first five years of the programme; AJA Roux: "Atomic Energy Research and Development Programme of South Africa", **SA Mechanical Engineer**, No 9, December 1959, pp. 115-116; **Assembly Debates**, vol. 101, 4 May - 5 June 1959, 22 May 1959, col. 6487; (AECA) **Annual Report of the South African Atomic Energy Board**, 1960, p. 5.

almost been found. It was expected that the balance of the amount required would be made up by contributions from some of the other heavy engineering and manufacturing firms.[6] Dr Roux stated that the large contributions placed a responsibility on the AEB and its staff to carry out the programme. It was a difficult task, but it would be undertaken with enthusiasm. It would add materially to the industrial and economic prosperity of the country.[7]

On 22 May 1959, the then Minister of Mines, Senator J de Klerk, read the Atomic Energy Amendment Bill (No. 56 of 1959) for a second time. In the debate that followed he informed the House of Assembly that the world was on the threshold of new developments in the peaceful application of nuclear energy, and the watch-word in that connection was research. For that reason representation on the AEB had been granted in 1958 to industry, to commerce and to ESCOM.[8] The Bill he said, was being introduced to make this research possible. He informed the House that certain institutions had offered grants of considerable amounts for research purposes. The Government had accepted that offer and had, in turn, undertaken to contribute considerable amounts to research annually. Consequently, the State's

6 Roberts Construction Company also donated funds for the Research Programme; (AECA) **Annual Report of the Atomic Energy Board**, 1960, p. [illegible]

7 AJA Roux: "Atomic Energy Research and Development Programme of South Africa", **SA Mechanical Engineer**, No 9, December 1959, pp. 115-116.

8 In 1958 the Atomic Energy Board comprised the following persons: Chairman: Senator, the Hon. J de Klerk (Minister of Mines); Deputy Chairman: dr TEW Schumann; members: JJA Nel (Secretary of Mines); CS McLean (Transvaal and Orange Free State Chamber of Mines); HC Koch (Transvaal and Orange Free State Chamber of Mines); ACM Cornish-Bowden (Director of Industrial and Financial Companies); Dr AJ Visser (Managing Director, Wolnit); Dr SM Naudé (President, Council for Scientific and Industrial Research); Dr JT Hattingh (Chairman, Electricity Supply Commission); Professor SE Oosthuizen (Pretoria University); DH van Gend (Attorney at Law); GP Jooste (Secretary for External Affairs); Research Director: Dr AJA Roux; Secretary: JA Reid; (AECA) **Annual Report of the South African Atomic Energy Board, 1959**, p. (i).

contribution for research had already been included in the Department's budget for the 1959 financial year.

The chief object of that Bill was to provide for the inclusion in the funds of the Atomic Energy Board of money made available by the State and granted by private institutions for research purposes. The Government was providing the foundation for a separate Atomic Energy Research Account. The money on the account not required immediately, would be deposited with the Public Debt Commissioners in order to earn interest.[9]

During the debate on the Atomic Energy Amendment Bill in May 1959, RP Plewman, United Party member for Johannesburg (North), was critical of the amendment. He said that the need for secrecy and for withholding the financial results of the AEB from Parliament was no longer justified in 1959. He was referring to sub-clause 7 of the proposed amended section. The effect of that particular sub-clause was that the accounts of the AEB and the reports of the Auditor-General, instead of being submitted in the normal way to Parliamentary supervision, were submitted to the Governor-General. He said that provision was a carry over from the 1948 Act. The provision had been inserted when the 1948 Act was passed and uranium was regarded as a mineral of strategic value. It deprived Parliament of its prerogative of having financial control over the money it granted to a body of its own creation, the AEB. He was of the opinion that the prerogative of Parliament, to exercise control over the money it voted, should be restored. In August 1958, Dr B Wilson, Member of the House of Assembly for Hospital, Cape, had made a similar request. He believed the secrecy with regard to nuclear energy had passed. He said that he

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9 (SAL) **Assembly Debates**, vol. 101, 4 May - 5 June 1959, 22 May 1959, col. 6488.

had learnt much of what was happening in South Africa from a Report of the United Kingdom Atomic Energy Authority.[10]

In reply the Minister of Mines said that he agreed with Plewman that the report of the Auditor-General should be submitted to Parliament. The difficulty was that a research fund was being established. It was impossible, at that time, to determine to what extent the proposed programme for nuclear research and development would demand secrecy. Should nothing in the research programme demand secrecy, a short Bill would be introduced the following year to confirm the principle that Plewman was advocating.[11]

The Acts to amend the Atomic Energy Act, 1948 (No 27 of 1958, No 35 of 1959) provided the required legislation for the Nuclear Research and Development Programme.[12]

Organisational Measures

In translating the twelve themes of Dr Roux's Research and Development Programme into action the Atomic Energy Board adopted a philosophy of appointing to committees members of organizations such as the CSIR, the mining industry, the Government Metallurgy Laboratory and staff of the AEB itself. In this way the experience and advice of a wide range of interests became available. Advisory bodies such as the Nuclear Power Committee, the Marketing Advisory Committee and the National Committee of Control over Radio-active Waste Disposal, which provided advice not only to the Board, but also

10 Debate on the Atomic Energy Amendment Bill (No. 34 of 1958), **Assembly Debates**, vol. 97. 4 July - 25 August 1958, 20 August, col. 2575.

11 **Assembly Debates**, vol. 101, 4 May - 5 June, 22 May 1959, col. 6487-6490.

12 **Statutes of the Union of South Africa.** Act No 27 of 1958 and Act No 35 of 1959, pp. 139-141 and pp. 360-364.

on a national level to establish a uniform policy throughout the country, came into being.[13]

The actual execution of the Atomic Energy Research and Development Programme would be under the direction of Dr AJA Roux in his capacity as Research Director of the Atomic Energy Board. However, before the programme could be properly implemented, the twelve themes of the research programme had to be broken down into specific projects. South Africa had capable scientists and engineers working in various operations, but not necessarily qualified in nuclear fields of science. It was, therefore, essential that suitably qualified scientists, with capabilities to further their competence in nuclear science be appointed and sent overseas for further training.

To assist the Research Director with this task the Atomic Energy Board approved the appointment of five experienced senior scientists to head five research divisions. These men would set in motion various programmes and projects of investigation: Dr MG Atmore - Chief Extraction Metallurgist (Raw Materials Research and Development); Dr SJ du Toit - Assistant Chief Physicist; Dr WL Grant - Chief Engineer; Dr LJ le Roux - Chief Chemist; and Dr JP Hugo - Principal Research Officer (Reactor Metallurgy).[14] All these appointments were permanent except in the case of Dr Atmore, who had been seconded to the Board's staff from the uranium industry, for a period of two years.[15]

The various directions or themes of Dr Roux's programme, i.e. raw materials, nuclear power, radio isotopes and fundamental research, had to be made a reality by establishing laboratories, where practical investigation and research could be carried out. Theme I of the

13 (AECA) **The Way to Pelindaba**, AEB publication, p. 2.

14 AR Newby-Fraser: **Chain Reaction**, p. 61.

15 **Ibid.**, p. 61; (AECA) **Annual Report of the South African Atomic Energy Board**, 1960, p. (iv); 1961, p. (vi).

programme (research and development to improve methods of mining and extraction of uranium) became largely the preserve of the mining industry.

Several months before the nuclear energy programme was finally accepted, approval was obtained to proceed with one specific project which had been provided for in Theme II and Theme III of the proposed programme.[16] The themes concerned the processing and refining of uranium for reactor fuel. Dr Roux informed the Management Committee of the Government Metallurgical Laboratory (GML) that certain aspects of the Programme dealing with the production of nuclear-grade uranium and uranium compounds would have to be undertaken by the GML in conjunction with the uranium industry and the AEB.[17] The GML and the uranium industry had the trained staff, experience and facilities for undertaking work in that field. Dr Atmore, then the chief metallurgist at the GML, was responsible for the formulating in more detail the refining of uranium. In a very short time, a project team of experienced men consisting of Dr Atmore as project superintendent, Dr RE Robinson and JS Freer, both seconded from the uranium industry, and A Beal seconded from African Explosives and Chemical Industries was set up.[18] The Atomic Energy Board had direct control over the work done at the GML.

As a result of releases of technical information from overseas, the first stage of the project progressed much more rapidly than originally envisaged, and the second stage was initiated at the end of November 1959. The second stage consisted of the design and construction of a pilot plant to produce a nominal output of 100 tons of nuclear grade uranium per year. The plant would incorporate the following three

16 As mentioned in a previous chapter Themes I, II and III of Dr Roux's, Atomic Energy Research and Development Program dealt with the processing of uranium.

17 J Levin: **The Story of Mintek, 1934-1984,** pp. 142-143.

18 (AECA) **Annual Report of the South African Atomic Energy Board,** 1959, p. 8.

basic processes: the "Wet way process" from concentrates of uranium dioxide to uranium tetrafluoride*; the "Dry way process" from uranium concentrates to uranium tetrafluoride and the "Wet fluoride process" from uranium concentrates to uranium tetrafluoride. It included facilities for the production of uranium dioxide pellets and vacuum remelted uranium. It was anticipated that the project would advance rapidly enough for uranium metal* to be produced by the end of 1960.[19]

Dr Atmore's appointment as Head of the Extraction Metallurgical Division brought about that in November 1960 he became Director of the Government Metallurgical Laboratory.[20] (Dr Atmore held these positions until April 1961 when he returned to his position at Anglo American Corporation.)

It was under the direction of the AEB and the supervision of Dr Atmore that the pilot plant for nuclear grade uranium was constructed at the GML in a remarkable short space of time. In March 1961 the pilot plant constructed at the Government Metallurgical Laboratory was officially opened by the Minister of Mines, Senator J de Klerk, and a few months later the first ingot of high purity uranium metal was cast.[21] By 1961 it was in a position to produce several of the range of nuclear grade uranium materials essential for power reactor and uranium enrichment research.

Dr RE Robinson held the dual position of Head of the Extraction Metallurgy Division and Director of the GML from April 1961. The Government maintained a controlling position in the affairs of the

19 (AECA) **Annual Report of the South African Atomic Energy Board**, 1959, pp. 7-9.

20 An agreement drawn up between the AEB, the Mines department and the University of the Witwatersrand (which officially came into effect in April 1961) stated that the Head of the Extraction Metallurgical Division of the AEB should also be appointed Director of the GML. See J Levin: **The Story of Mintek, 1934-1984**, p. 145.

21 (AECA) **The Way to Pelindaba**, p. 16.

GML. The Minister of Mines appointed a Supervisory Committee to monitor work carried out by the Extraction Metallurgy Division and the GML. The Minister, Senator de Klerk, appointed Dr AJR van Rhijn (Minister of Mines from 1953-1958) as Chairman of the Supervisory Committee. Other members were Dr AJA Roux, JJA Nel (Secretary for Mines), Professor WG Sutton (Rector of the University of the Witwatersrand) and Dr RE Robinson (Director of the GML).[22]

Dr Roux was fully aware of the urgency of a supply of cylinders clean, high quality uranium hexafluoride.[23] It is a critically important material in the production of enriched uranium as it is the only compound of uranium which is gaseous at normal temperatures and pressures. This property is essential for all enrichment processes. A supply of uranium hexafluoride was therefore a necessity if the research programme was to get under way. With the production of uranium hexafluoride highly specialized production techniques have to be utilized. Very stringent safety precautions must be taken in the design of a uranium hexafluoride plant, in the selection of materials for its construction, and in the operation of the plant for which sophisticated instrumentation and control systems are essential Work on a plant to produce UF_6 was started in the early 1960's by the GML. The controversial processes for uranium tetrafluoride and uranium hexafluoride production both required either anhydrous hydrofluoric acid or fluorine gas, neither of which were produced in South Africa. Consequently an alternative method, the so-called FLUOROX process*, involving the oxidation of UF_4 was developed.[24]

Dr RE Robinson who was appointed as the AEB's first Director of Extraction Metallurgy in 1961 believed that although the uranium extraction process in use on the mines was operating satisfactorily,

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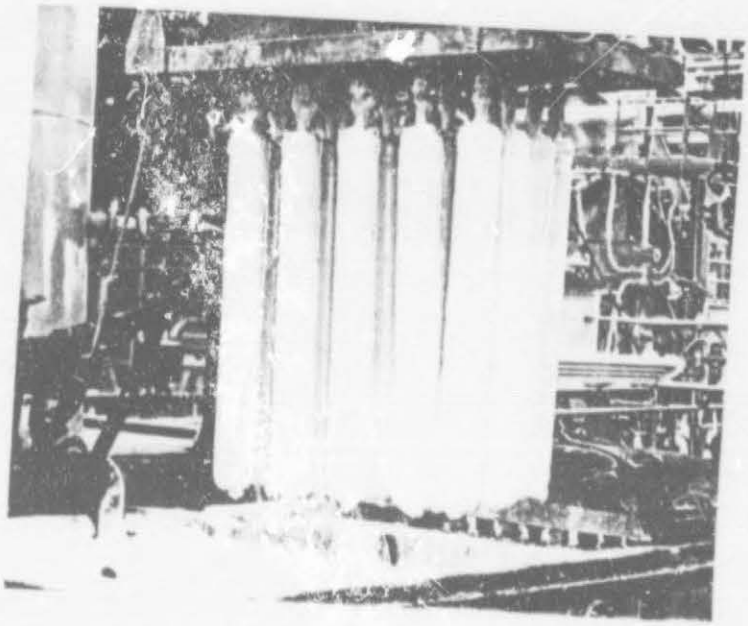
22 J Levin: **The Story of Mintek, 1934-1984,** pp. 152-153.

23 **Ibid.**

24 AR Newby-Fraser: **Chain Reaction**, p. 74.



Dewatering yellow ammonium diuranate before dispatch to the central calcining plant

(Source: AR Newby-Fraser: **Chain Reaction**)

there was tremendous scope for the improvement of those processes and the development of new ones. In the early sixties The Central Calcining Plant collected the ammonium diuranate* (ADU) slurry from the extraction plants on the various mines and processed it to a dry uranium oxide (U_3O_8) or yellow cake of consistently high standard for export. Dr Robinson believed that the extraction processes could be developed to a stage where the ammonium diuranate could be converted to uranium oxide, uranium tetrafluoride and uranium hexafluoride without the need for additional purification steps. He was in the advantageous position of being able to draw on the knowledge and expertise of his own AEB staff, of the GML and the mining industry itself, and so to fulfil his mandate of placing South Africa in a position to produce any form of uranium that might be required by the nuclear power industry at the lowest possible cost.

The Raw Materials Recovery Programme involved investigations into the uranium leaching processs and the development and implementation of the Bufflex solvent extraction method.[25] This method contributed to the production of a high purity ammonium diuranate suitable for the conversion uranium hexafluoride. The AEB, in a joint undertaking with the staff of the Buffelsfontein Gold Mine and the General Mining and Finance Corporation incorporated the Bufflex process at the Buffelsfontein uranium plant. The investigation known as the Bufflex Project commenced in October 1963.[26]

The field of Raw Materials Development would be the responsibility of the Geological Survey. In the execution of the programme the AEB

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25 See Technical Addendum for the explanation of the Bufflex solvent extraction method. During the 1970's the Purlex solvent extraction method and the countercurrent ion exchange (CIX) process were developed to improve the quality of the ammonium diuranate. AR Newby-Fraser: **Chain Reaction**, p. 71; J Levin: **The Story of Mintek, 1934-1984**.

26 (AECA) **The Way to Pelindaba**, AEB publication, p. 16.

also made full use of existing facilities at institutions in industry, the CSIR and the South African universities.[27]

Although Dr Roux's Research and Development Programme might have created the impression that it would involve applied research only, this was not the case. In many of the proposed investigations it was essential that fundamental research would be conducted so as to provide the data on which to base the applied programme. Much of the technical data could not be obtained from overseas literature, therefore fundamental studies would have to be initiated and a research reactor acquired as soon as possible.

SAFARI I and the Establishment of Pelindaba

The same immediate progress (as was achieved with the raw materials programme) was not possible with the rest of the programme, which was more directly concerned with nuclear energy. The detailed formulation and implementation of that would require the specialized training overseas of both senior as well as junior staff members, and the provision of specialized facilities.

The acquisition of a research reactor by South Africa was an essential in the implementation of a nuclear energy research and development programme in the country. Reactors are built for specialized tasks. South Africa required a research reactor that would provide radiation of varying intensity for a variety of experiments. During Dr Roux's overseas tour in the latter half of 1957, he was able to visit a representative type of all the research reactors which were in operation in the Western World. Full details of most of these were contained in

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27 (AECA) **Annual Report of the Atomic Energy Board, 1959**, pp. 7-8.; **The Way to Pelindaba**, pp. 7-8; (AECA) AJA Roux: **Proposed Atomic Energy Research and Development Programme of South Africa**, pp. 110-119.

his overseas report.[28] In Dr Roux's **Proposed Atomic Energy Research and Development Programme of South Africa** a list is given of those research reactor types from which a choice would have to be made for the South African programme. All the American multi-purpose research reactor types selected by Dr Roux, were fuelled with enriched uranium.

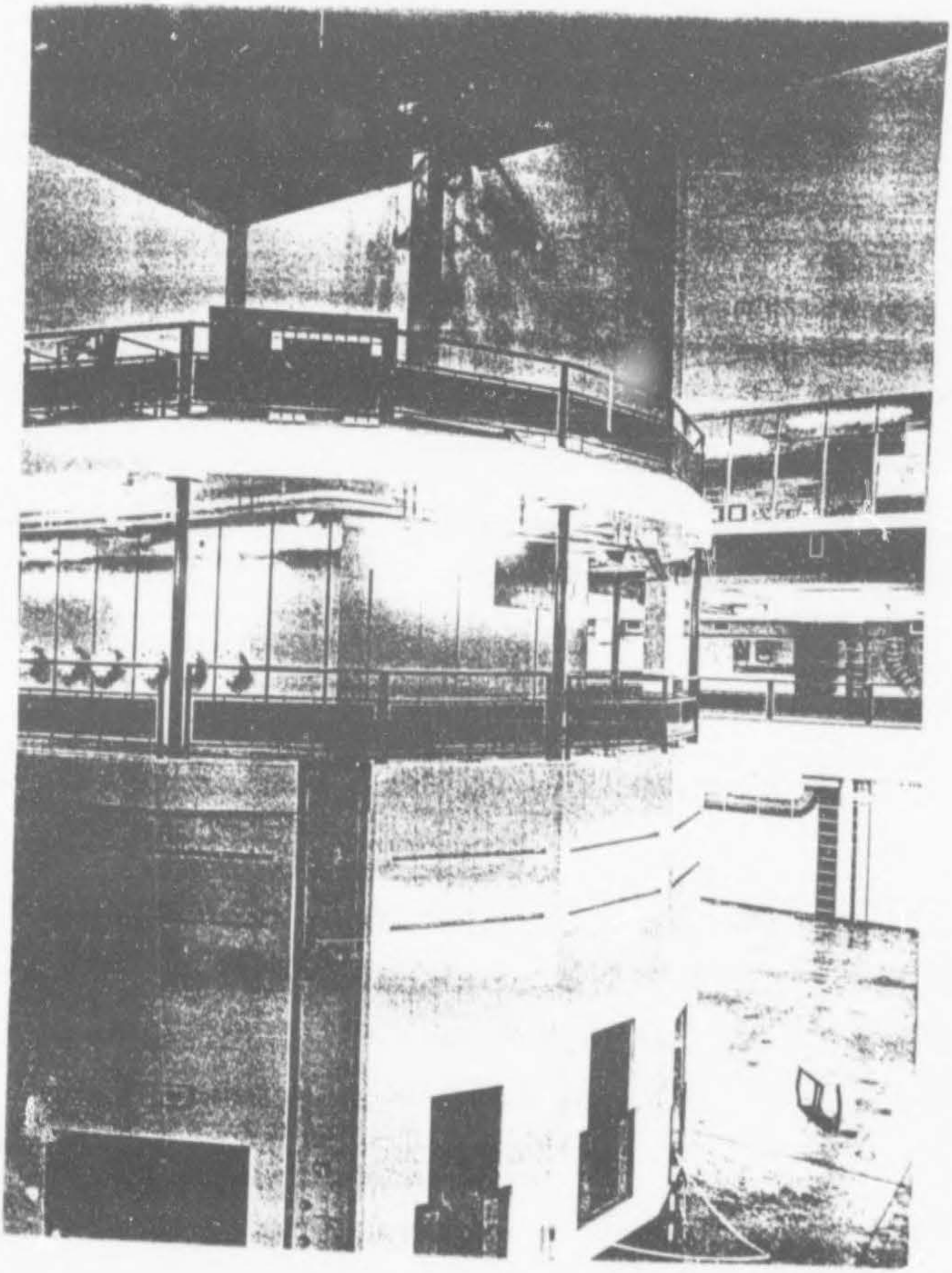
Dr Roux selected a number of American, British and Canadian multi-purpose research reactor types from which the one most suitable for South African research would be selected.[29] The cost of these reactors ranged from 1 million dollars to 4½ million dollars. All these reactors would provide adequate research reactor facilities for the South African programme. Dr Roux was convinced that it would be short-sighted to buy a reactor with a low neutron flux and as the selection of possible research reactors indicated most of the reactors suitable for South Africa would have to be fuelled with enriched uranium.[30]

When the Government approved the Board's Research and Development Programme, approval was also granted for the purchase of a nuclear research reactor. That portion of the programme directly concerned with the reactor, would be carried out by the Atomic Energy Board. As mentioned previously, the bilateral inter government agreement between the USA and South Africa (July 1957) had provided

28 Vid. **Atomic Energy Research and Development**, vol. I, II, III: Research Reactors.

29 Reactor types selected by Dr Roux: (The percentage enriched uranium (U-235) required for fuel is given in brackets.) *American*: Engineering Test Reactor (ETR) (93.4%); Materials Testing Reactor (MTR) (93.4%); Oak Ridge National Laboratory Research Reactor (ORR) (Fully enriched U-235); Argonne Research Reactor (CP-5) (20%); MIT Research Reactor (Highly enriched); Omega West (90%); Water Boiler Reactor (88% enriched uranyl sulphate); Swimming Pool Reactor (20% or more). *British*: BEPO (Natural uranium metal and oxide); LIDO (Uranium 235); DIDO (90%); PLUTO (90)%; MERLIN (80%). The Canadian Multi-Purpose Reactors selected were: NRX (Natural uranium) and NRU (Natural uranium). (AECA) AJA Roux: **Proposed Atomic Energy Research and Development Programme of South Africa**, pp. 91-98.

30 AJA Roux: **Proposed Atomic Energy Research and Development Programme of South Africa**, pp. 91-98.



A view of SAFARI I from the observation gallery. (Source: AEB SAFARI I Pretoria, 1965) for the acquisition of a research reactor for South Africa. Despite mounting political differences the "letter of intention" for the purchase of the research reactor, called SAFARI I, was signed on June 17, 1960, in Washington, USA. (SAFARI is the abbreviation for South African Fundamental Atomic Reactor Installation. "I" indicates that it was the first research reactor).[31]

The Oak Ridge National Laboratory Research Reactor (or ORR-type) was selected by the South African nuclear authorities as being the most suitable for the South African research programme. Despite political disagreement between the two countries, training of personnel was not hindered during the first five years (1960-1965) of the Research Programme. A seven-man research reactor operations team was appointed in 1960 and sent for training to the Oak Ridge National Laboratory USA, where the ORR-type reactor had been designed and developed. There they familiarized themselves with the intricacies of the reactor. On their return they were responsible for the safety and efficiency of SAFARI I.

Before the Cabinet had actually approved the proposed nuclear research and development programme in September 1959 the Atomic Energy Board, confident that the programme would be approved, had authorised the commencement of a survey to locate a suitable site for the SAFARI I reactor and the future National Nuclear Research Centre. To AR Newby-Fraser and John R Colley who had some years of experience in the heavy chemical industry fell the task of defining the applicable criteria to which the South African Centre should conform and of undertaking in situ investigations of all possible locations for the Centre.

The criteria to which the South African Nuclear Research Centre should conform were those of (a) proximity to the mining and manufacturing industries, the CSIR and the three northern universities of Pretoria,

31 (SAL) **SAFARI I**, AEB publication, Pretoria 1965.

Potchefstroom and the Witwatersrand and (b) the vicinity of a river with a constant minimum daily flow of some 5 000 cubic meters.[32]

These two criteria dictated that the new Centre would have to be located within a reasonable distance of the Crocodile, Sterkstroom, Mooi or Vaal Rivers, but not closer than 16 km from any substantial centre of population. Reconnaissance of selected areas in a large area of Transvaal, bounded by the line Vaal Dam to Potchefstroom, in the south, and Rustenburg to Pretoria in the north, was undertaken by Newby-Fraser and Colley. Each evening the two engineers recorded their findings and finally by a process of elimination, six possible sites remained as possibilities. The most promising site was at Pelindaba immediately south of the Hartebeespoort Irrigation Dam, and the second choice was located just north of the Dam, but even these had drawbacks. The latter bordered on an area of intensive small farms watered by canals from the Dam, while the acquisition of the Pelindaba site on the east bank of the Crocodile River would have required no fewer than fifty-seven separate negotiations with the different owners of the properties involved. However, the general Pelindaba area remained the first choice and the Department of Lands was instructed by the Atomic Energy Board to keep a watch for any suitable property which might be acquired. At that critical time the farm Welgegund, bordering the east side of the Crocodile River, unexpectedly changed hands, but the deal was not completed. The Department of Lands stepped in and bought the land on behalf of the Atomic Energy Board. That it had been bought by the Atomic Energy Board was not revealed, strict secrecy being maintained to preclude any possibility of land speculators getting wind of the project and buying up land in the areas of interest. AR Newby-Fraser commented that it was no easy task avoiding searching questions from local residents.[33]

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32 AR Newby-Fraser: **Chain Reaction**, p. 47.

33 **Ibid.**, pp. 47-48.

Pelindaba

(Source: Atomic Energy Corporation)

As the Department of Lands had to take a quick decision to buy the Welgegund farm, an in-depth investigation as to the suitability of the 1 000 hectare area, for a nuclear research centre, followed after the purchase. The conclusions reached by the investigating team were more than satisfactory. The AEB approved the acquisition of the site and authorized the steps necessary to complete the purchase.[34]

Throughout the world it was accepted practice to refer to research centres by the name of the town or village serving the establishment, for example Oak Ridge, Harwell, Chalk River and others.[35] Enquiries brought to light that during the 1920's plans had been drawn up to establish a township there to be called Pelindaba, a project that never came to fruition. The meaning of the word was a conjunction of two African words *pelile* meaning "finished" and *indaba* meaning "council". The Director of the AEB, Dr Roux, felt that the meaning, implying "the end of the discussion", was appropriate: enough had been discussed, it was time to get on with the establishment of a nuclear centre.[36]

Work was started on the design of the centre at Pelindaba during the middle of 1960. At 11:00, June 5, 1961, a small informal group of scientists, businessmen and pressmen watched the Deputy Chairman of the Atomic Energy Board, Dr TEW Schumann, turn the first few spadefuls of red earth on the site of the SAFARI I reactor building - a symbolic gesture repeated by JD Roberts, Managing Director of the company chosen as main contractors for construction of the reactor complex. By July 1961 construction was commenced on the site.[37]

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34 AR Newby-Fraser: **Chain Reaction**, p. 48.

35 **Ibid.**, p. 48.

36 (AECA) **The Way to Pelindaba**, p. 14.

37 **Die Burger**: 6 Junie 1961: "Werk begin aan Kernreaktor" ; AR Newby-Fraser: **Chain Reaction**, p. 51.

During the 1950's, the small administrative staff of the AEB was housed on the fourth floor of the Merino Building in Central Pretoria. The administrative personnel of the AEB moved to Pelindaba in July 1963 and in the same month the Reactor building was occupied by additional staff members. Also at Pelindaba the Chemistry building, Accelerator, Water Purification Works and a portion of the Reactor Engineering building were completed by the end of 1963.[38]

The establishment at Pelindaba centred around the research reactor SAFARI I. With the design of SAFARI I virtually completed, the South African scientists who had been working on it at Oak Ridge, USA, returned to the Republic and set about the task of integrating the activities in order to prepare the construction that would house the reactor.[39] Stage succeeded stage as the gaping excavations were filled with massive concrete foundations and the grey walls and heavily reinforced reactor pool structure rose upwards to be finally topped with a dome roof. Only then could the kilometers of pipework, the intricate cabling and the aluminium components be installed. Accidental damage to the completed reactor vessel in the USA - then undelivered - set the project back.[40] Although scheduled for completion by the end of 1963, this was only achieved by the end of 1964.

The installation of the reactor vessel and the construction of the concrete base slab posed some difficult problems, but with perseverance these were overcome and the reactor went critical at sunset (18:30) on 18 March, 1965.[41] In order to operate the reactor, South Africa was completely dependent on a supply of 90% enriched uranium from

38 (AECA) **Pelindaba**, AEB, Brochure No. 2, 1964, p. 5.

39 (AECA) **Annual Report of the South African Atomic Energy Board**, 1964, pp. 7-8.

40 There was speculation in some South African circles that it could have been deliberate on the part of an unknown individual. Interview with DB Sole, 12.12.1990.

41 (SAL) **SAFARI I**, AEB Publication, Pretoria, 1965; AR Newby-Fraser: **Chain Reaction**, pp. 52-54.

overseas. At that time it was supplied from the United States of America.[42]

A trilateral agreement was signed by the Republic of South Africa, the United States and the IAEA (26 February 1965). Since that date the Agency has been applying safeguards to materials, equipment and facilities transferred to the Republic. The United States Government was prepared to renew an amended Agreement for Cooperation between that Government and the Republic of South Africa on 7 July 1967.[43]

In the design of the centre at Pelindaba the Republic was in the fortunate position of being able to draw on the experience of other countries. The expansion of nuclear research facilities in Europe, the USA and Britain had taken place at a phenomenal rate during the post-war period. Much of the development and the mistakes that came with it, could not have been foreseen by even the most far-sighted. The overall practical design philosophy adopted at Pelindaba reflects to a large extent the general consensus of opinion on the subject at the beginning of the sixties. Generally speaking, the site could be divided into "Hot" and "Cold" zones. Hot areas mean those where there is a possibility of radio-active contamination taking place; cold areas, where there is no possibility of contamination.[44]

It became clear at an early stage in the design of the centre that large portions of the various buildings would be constructed in reinforced concrete, one of the most suitable materials for radiation shielding. It was also the most economical and generally accepted method of frame construction in South Africa. Internal protection walls were constructed in brick. Air-tightness was desirable between laboratories

42 (Private collection DB Sole) DB Sole: "The Rise of Nuclear Sanctions against South Africa", **American Review**, Jan. 1986, p. 3.

43 (AECA) Agreement for Cooperation as amended, Article IV (A2); Article VII (A).

44 (AECA) **Pelindaba,** AEB Publication, Brochure No 2, 1964, p. 10.

and elsewhere.[45] A system was installed to extract radio-active matter from contaminated liquid wastes. The Waste Disposal Centre would deal with the disposal of solid radio-active wastes and the decontamination of equipment which had become radio-active.[46]

The Pelinduna Project

As mentioned, the research reactor, SAFARI I was one major project initiated by the Atomic Energy Board in the early sixties. The second major project was the development of the natural uranium reactor concept.

The Commission of Enquiry into the application of Nuclear Power in South Africa published its findings on 21 April 1961.[47] It concluded amongst other things that even though South Africa had no immediate need for a nuclear power plant it seemed inevitable that nuclear energy was the power source of the future.[48] Therefore, although nuclear power production in South Africa in the 1960's was not an urgent one, the availability of low cost uranium indicated that nuclear power might be economical in South Africa in the not too distant future.

The South African scientists undergoing nuclear training at Argonne National Laboratory believed that a start should be made in developing a type of reactor suitable to South African conditions, a project on which scientists of various disciplines could work together. Even though it was known in the early sixties that enriched uranium would eventually replace natural uranium as fuel in nuclear reactors, the South

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45 (AECA) **Pelindaba**, AEB Publication, Brochure No 2, 1964, p. 10.

46 **Ibid.**, p. 28.

47 RP 23/61, 21 April 1961 **Report into the Application of Nuclear Power in South Africa** (under the chairmanship of DD Forsyth).

48 **Ibid.**, pp. 40-41.

African Government was resolute that South Africa should not be dependant on a foreign source for reactor fuel.[49]

For South Africa to embark on the development of a nuclear reacter, which was still in the experimental stage, as it had not been developed anywhere else in the world, would involve considerable expense.[50]

The investigation into heavy water production in South Africa in the 1950's by the AEB (in which Dr WL Grant had been involved) was part of the reason why a power reactor based on natural uranium as fuel, heavy water as moderator and liquid sodium as coolant was considered.[51] Dr WL Grant on his return from Argonne in 1961 designed and developed a power reactor concept - PELINDUNA - based on natural uranium and heavy water. He was assisted by Dr JWL de Villiers and Dr DJ Everett. The name PELINDUNA was composed from "PELIN" for Pelindaba (the centre for nuclear research), the first letter of deuterium or heavy hydrogen (D) and the chemical symbols of uranium (U) and Sodium (Na). Although this concept had earlier been examined by the USA, it had not been developed. PELINDUNA was an original reactor concept specifically devised to accommodate South African conditions. As this design had not yet been put to the test fully in any other part of the world, it presented a challenge to engineers and scientists and an opportunity to become familiar with nuclear technology in practice.

Within a few months of his return to the Republic, Dr Grant submitted his proposals for research in that direction to the Atomic Energy Board. His recommendation was approved and the proposed power reactor concept - the PELINDUNA project - could commence. Attention had to be given to numerous considerations. Aspects of the concept had

49 Interview with Dr WL Grant, 27.7.1989.

50 AJA Roux: "Kernkrag en die aanwending daarvan onder Suid-Afrikaanse omstandighede", **Tegnikon**, 12 October 1959, pp. 95-96.

51 Commentary by tape-recording, AR Newby-Fraser: 18.7.1991.

previously been discussed by Dr Grant and Dr De Villiers, whilst training at the Argonne National Laboratory in 1960. Following that, certain Division Heads had contributed in pointing out implications and problems, as well as putting forward suggestions which finally resulted in the formation of the "Proposed Power Reactor Concept for Development in South Africa". The Division Heads that were involved were Dr SJ du Toit (Physics); Dr LJ le Roux and Dr DM Kemp (Chemistry); Dr RE Robinson (Extraction Metallurgy); Dr JK Basson (Isotopes and Radiation) and Dr JP Hugo (Physical Metallurgy).[52]

The reactor type considered for power generation would have to make use of materials that were available in South Africa or that could be made available if required.[53] Furthermore, the components for the reactor would have to be readily manufactured in South Africa. The development of the reactor had to involve those techniques that would keep the research teams and the South African industry in close touch with the nuclear reactors being built overseas, and which would have the most potential for the application to electric power production, e.g. development of ceramic fuels, liquid metal techniques, high temperature heat exchangers, etc. The concept had to be capable of allowing scientists of the AEB and in the universities to work on aspects of reactors which would help to keep abreast with the most advanced developments overseas. The concept would have to show decided potential for economic power generation.[54]

As stated in the introduction of the Concept, it would not be possible to select a reactor that would conform to all the requirements. Some of

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52 (Dr WL Grant: Private collection) WL Grant et al: **Proposed Power Reactor Concept for Development in South Africa**, Document No. AEB 25/62. R1/0/7/62, Preface. SD Ferguson who had written the section on hazards appraisal and Dr AJA Roux, Director of the AEB who had given guidance, criticism and encouragement during the entire duration of the preparation of the proposed concept, were thanked by the authors.

53 (Dr WL Grant: Private collection) WL Grant et al: **Proposed Power Reactor Concept for Development in South Africa**, Document No. AEB 25/52. R1/0/7/62, pp. 3-4.

54 **Ibid.**, pp. 3-5

the reactor types that were being developed overseas would, to a large extent, conform to many of the above requirements. The pros and cons of all reactor types in use and under development overseas were considered, but the conclusion was reached that to bring South African industry in contact with the most important reactor techniques, the natural uranium, heavy water moderated, liquid sodium-cooled reactor would be the best choice.[55]

From the start the PELINDUNA project had certain advantages. The concept held promise of a reduction in power generating costs. Before any large-scale experiments were conducted, a complete theoretical investigation of the system was performed, which required the development of calculation methods for the reactor-physics parameters, an undertaking in which the lack of a suitable computer demanded a series of lengthy hand calculations dependent on a number of simplifying assumptions. Difficulties were encountered and a change was made to a computer-based model. Initially the facilities of the CSIR were used and later the computer centre of the AEB.

Owing to the complexity and size of the proposed uranium fuel elements, and to the fact that refined computer calculations certain assumptions still had to be made, experimental confirmation of some of the calculated reactor core parameters was necessary. To this end a sub-critical or so-called exponential assembly was constructed, with the entire manufacture of both the assembly and fuel elements carried out by South African industry.[56]

As work progressed modifications and improvements inevitably made their appearance, affecting the various original design features.[57] Many

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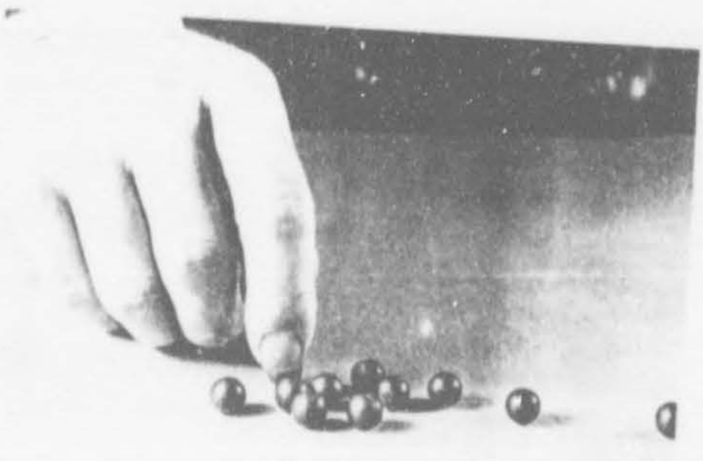
55 (Dr WL Grant: Private collection) WL Grant et al: **Proposed Power Reactor Concept for Development in South Africa**, Document No. AEB 25/62. R1/0/7/62, pp. 3-5.

56 AR Newby-Fraser: **Chain Reaction**, pp. 117-118.

57 The original approach of providing each fuel element with its own electromagnet coolant pump and heat exchanger was found to be cumbersome for high fuel ratings and was replaced by a manifold system with common



Uranium spheres manufactured as fuel for the PELINDUNA project

(Source: AR Newby-Fraser: **Chain Reaction**)

problems were overcome, but some not fully resolved. The original fuel-element design employed unclad uranium metal spheres* of 10 mm diameter. With unclad fuel spheres there was the ever-present possibility of fission products escaping into the coolant and this was something which required early clarification.[58]

The metallurgists involved in the project had to produce the uranium fuel in the form required, but had also to determine in advance the behaviour of the fuel and other components under reactor operating conditions. A method was found to produce the natural uranium spheres of 10 mm diameter and a production method was developed to meet the first requirement of 600 000 spheres. Many studies involving the fuel spheres were carried out.[59]

All the reactor engineering studies indicated that the PELINDUNA concept was even more promising than was originally expected.

The third major project that was initiated by the Atomic Energy Board in the early sixties was the Gas Cooling Project. This was the code name for the uranium enrichment investigations carried out by scientists and engineers of the AEB. (The project will be discussed in detail in the following chapter.)

Towards the end of 1966 both PELINDUNA and the enrichment project had almost simultaneously reached the stage where each required, as a next step, the construction of a large demonstration or pilot plant for which the financial implications were very heavy indeed.

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pumps which could be mechanical, with the heat exchangers alongside the reactor. AR Newby-Fraser: **Chain Reaction**, p. 119.

58 AR Newby-Fraser: **Chain Reaction**, pp. 119-120.

59 For example, the mechanical behaviour of fuel spheres under controlled temperature and irradiation conditions, for which a loop, to perform the irradiation of capsules containing the uranium fuel spheres, was installed at the side of the SAFARI I pool. AR Newby-Fraser: **Chain Reaction**, pp. 119-120.

Dr JWL de Villiers

(Source: Atomic Energy Corporation)

The Republic of South Africa could not finance both projects at the same time and no compromise was possible - a choice had to be made.

At a Gas Cooling Project meeting on November 25, 1966, Dr AJA Roux who had just returned from overseas, informed his colleagues at the meeting that if the Enrichment Programme was fully implemented all projects at Pelindaba would have to be brought to a standstill and all available manpower would be involved with enrichment. He suggested that if that happened, the reactor development programme would have to be slowed down for about three or four years, and at that future stage a new assessment of the circumstances would have to be made.[60]

At the meeting in November 1966 Dr JWL de Villiers who had played a significant role in the development of the PELINDUNA concept was adamant that the PELINDUNA project continued in earnest. He believed that if all efforts were concentrated on the PELINDUNA concept, and the pace of the project accelerated, either using natural uranium or enriched fuel, a prototype could most likely function by 1973. The go-ahead for the building of a prototype based on the development of the concept up to that point, should be given as soon as possible.[61] Dr De Villiers did not agree with the suggestion put forward by Dr Roux that the scientists involved with the PELINDUNA project could interrupt their research programme for five years and then be expected to resume with the same enthusiasm where they had left off after that length of time had elapsed.[62]

Dr Roux suggested that a nuclear reactor could in the future, if required be purchased from a foreign country. Dr De Villiers stressed the fact

60 (AECA) Meeting of the Gas Cooling Project, Pelindaba, 25.11.1966, p. 17. Present at the meeting were: Dr AJA Roux (Chairman), Dr JK Basson, Dr IE Bock, JR Colley, Dr DK Craig, Dr JWL de Villiers, Dr SJ du Toit, Dr WL Grant, Dr PC Haarhoff, Dr JPB Hugo, Dr DM Kemp, D Lion-Cachet, Dr RS Loubser, Dr MB Nel, Dr NP Pienaar, Dr RE Robinson, Dr E van der Spuy, Dr JW von Backström, Dr JJ Wannenburg, B von M Louw.

61 (AECA) Meeting of the Gas Cooling Project, Pelindaba, 25.11.1966, p. 16.

62 **Ibid.**

that the reason for the progress in the PELINDUNA project was ultimate success. The nuclear scientists and engineers working on PELINDUNA believed that a South African built nuclear reactor would be functional and could eventually be incorporated in the South African electricity generation system. According to De Villiers the acquisition of a reactor from overseas would have a quelling effect on the South African reactor development programme.[63]

Taking into account the complexities of uranium and nuclear power development (1964-1967) it was difficult to make the decision to shelve PELINDUNA and to go ahead with the enrichment programme.

The following aspects favoured power reactor development. The status of nuclear power in the middle sixties indicated that a country would necessarily in future have to meet the demands of nuclear reactor development and have available in the country the manpower required, technical skills and industrial infrastructure.[64] A second aspect that had to be reflected upon was the progress that had taken place in nuclear power reactor development. By 1966, South African nuclear engineers and scientists were seriously considering a nuclear power reactor for the Republic.[65]

In the minutes of the meeting of the members of the research and development programme of the Gas Cooling Project held on 15 December 1966 it was stated that both the enrichment programme and PELINDUNA would go ahead uninterruptedly till the end of 1967. The PELINDUNA reactor design would be developed so that the

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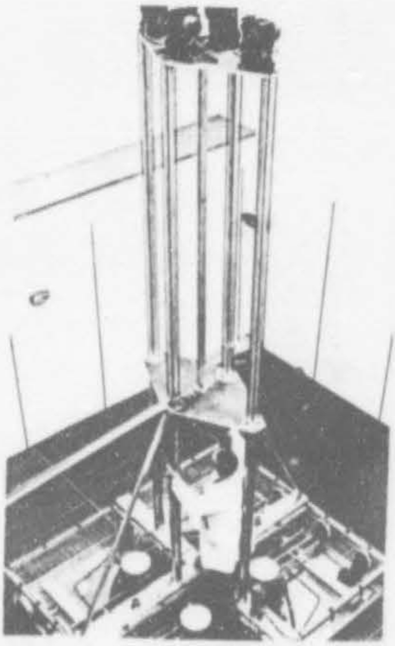
63 (AECA) Meeting of the Gas Cooling Project, Pelindaba, 25.11.1966, p. 21.

64 Address by VS Emelyanov, President of the Conference: **Proceedings of the Third International Conference on the Peaceful Uses of Atomic Energy**, 31 August - 9 September 1964 vol. I, pp. 27-28; GF Tape et al: "Future energy needs and the role of nuclear power", **Proceedings of the Third International Conference on the Peaceful Uses of Atomic Energy**, vol. I, pp. 69-70.

65 See Technical Addendum: "Nuclear Power Reactor - Proposed Reactor Schemes" 15.12.1966. (AECA) **GVP Navorsings- en Ontwikkelingsprogram**, Minutes of meeting 15.12.1966, pp. 4-5.



The critical assembly, PELINDUNA designed and constructed to determine essential operational facilities, shows the four fuel elements which used 2% enriched uranium.

(Source: AR Newby-Fraser: **Chain Reaction**)

implications thereof could be evaluated.[66] However, in August 1967, the Atomic Energy Board and the Nuclear Power Committee took the decision to conclude the PELINDUNA project.[67] The project was allowed to continue till November 1967. On 30 November 1967 a critical assembly based on the PELINDUNA concept reached criticality - a date which must be considered as a major milestone in the development of reactor physics in South Africa, especially as it was the first such assembly of indigenous design and construction on the African Continent.[68]

The final decision to end the PELINDUNA project was brought about mainly by the fact that the concept would have been more effective if the natural uranium was replaced by slighty enriched uranium. Dependence from foreign countries for fuel supplies for energy production, as well as the disadvantage of using natural uranium as fuel, would most likely make the Government, as well as ESCOM reluctant to support the establishment of a reactor based on PELINDUNA.

The PELINDUNA project, which would have employed heavy water as a moderator, kept the possibility of heavy water in South Africa alive. Had the PELINDUNA project gone ahead, there would have been considerable more thought given to the prospects of erecting a production plant in this country. The production of heavy water in South Africa remained a very real possibility right up to 1967 when the decision was taken to shelve PELINDUNA.[69]

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66 (AECA) **GVP Navorsings- en Ontwikkelingsprogram**, Minutes of meeting, 15.12.1966, pp. 13-14.

67 (AECA) HL de Waal: **Uraanverryking in die Republiek van Suid-Afrika**, sp. 32; PEL 175 E, AEB **Report on the Investigation into the Possible Introduction of Nuclear Power in the Republic of South Africa**, May 1968, pp. 6 and 7.

68 AR Newby-Fraser: **Chain Reaction**, p. 118.

69 Commentary on heavy water by tape-recording, AR Newby-Fraser: 18.7.1991.

The PELINDUNA project was not an unavailing undertaking. Besides the advancements in nuclear engineering and science, South African industry had to face up to the problems associated with nuclear-grade materials and their specialized manufacturing techniques. Certain project management methods were developed, that would later be applied to specific projects in the uranium enrichment programme. Skilled workshop teams that were involved in PELINDUNA could also be readily incorporated in the production of equipment for the uranium enrichment undertaking.[70] According to Dr Grant PELINDUNA was significant in South African nuclear scientific and technological development. He believed that "PELINDUNA's flexible design encompassed some of the most advanced and progressive techniques in nuclear power production. From this we learned a lot that will never be lost. It enabled us to take a tremendous step forward in nuclear power technology", according to Dr Grant.[71]

A Nuclear Power Plant

The termination of South Africa's own power reactor project did not mean that investigations concerning nuclear power in South Africa did not go ahead.

In the latter half of the 1960's much research was undertaken. In June, 1965, the Atomic Energy Board was requested by JFW Haak, Minister of Mines and Planning, to undertake an investigation into the possible application of nuclear power in the Republic of South Africa. The Board requested that the responsibility for the investigation be given to its Nuclear Power Committee which, in 1965, had the following membership: Chairman: Dr HJ van Eck (Industrial Development Corporation of South Africa Limited); Vice-Chairman, Dr AJA Roux (Atomic Energy Board), and nine other members representing Mining,

70 Interview with Dr RS Loubser, 28.7.1989.

71 AR Newby-Fraser: **Chain Reaction**, p. 125.

ESCOM, the Atomic Energy Board and the Iron and Steel Industry.[72] The Committee decided to form a special Sub-Committee on July 6, 1965, to direct the investigation. A Study Group under the leadership of JR Colley and members of the AEB and ESCOM was formed to prepare interim reports for the Sub-Committee's consideration. Valuable contributions were made by the many other organizations, in particular the Atomic Energy of Canada Ltd., the United Kingdom Atomic Energy Authority and the Commissariat l'Energie Atomique. Assistance had been requested from these three nuclear energy organizations in particular, because they were leaders in the development of the types of reactor of particular interest to this investigation. The report was accepted by a combined meeting of the Special Sub-Committee and the Nuclear Power Committee on March 26, 1968, and approved by the AEB on April 1, 1968.[73]

Whereas the Commission of Enquiry into the Application of Nuclear Power in South Africa, 1961, had found that there would be no economic advantage for the substitution of nuclear power in the Cape Western area, the Report of 1968 determined that those estimations were no longer valid.

The 1965-1968 investigation was the first serious attempt, since the report of the Commission in 1961, to evaluate nuclear power in South Africa. In the intervening six years a considerable amount of data had become available as a result of reactor experience overseas and it was

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72 The nine other members were: Dr MG Atmore (Anglo American Corporation); Professor FL Clarke (African Explosives and Chemical Industries Ltd.); S Craib (General Mining and Finance Corporation Ltd.); Dr IMK de Villiers (Electricity Supply Commission); Dr WL Grant (AEB); Dr CM Kruger (South African Iron and Steel Industrial Corporation Ltd.; Dr RS Loubser (AEB); Dr FA Raal (Diamond Research Laboratory); NT van der Walt (Electricity Supply Commission).

73 AEB PEL 175 E, **Report on the Investigation into the Possible Introduction of Nuclear Power in South Africa**, May 1968, p. 2.

felt that there was then sufficient information for a meaningful evaluation of the possible introduction of nuclear power.[74]

It was stressed in the report of 1968 that the uninterrupted operation of a commercial nuclear power station in South Africa must not be subjected to any uncertainty regarding enriched fuel supplies. According to the report, reliable supplies of enriched fuel were at that time subject to grave doubts. For this reason the report that was based on information accumulated between 1965 and 1968, only reactor types capable of operating on natural uranium fuel were considered. Reactors obtaining an economic benefit from the use of enriched fuel, but which could be operated on natural uranium during emergencies, were also considered.[75]

By the middle sixties several studies showed that the boiling water reactor (BWR) and pressurized water reactor (PWR) power stations (both fuelled with enriched uranium) would be competitive with fossil-fuelled stations in many regions of the USA, and evaluations made during 1965 and 1966, showed that these power reactors had by then become economical even in regions where low cost fossil-fuels were available. These findings resulted in a dramatic increase in orders by other countries for large commercial power stations of those two types. In the USA alone, 24 nuclear plants, totalling 20 000 electrical megawatts were ordered during 1966, and orders for a further 30 power reactors with a combined generating capacity of 25 000 electrical megawatts were placed during 1967.[76]

In 1968, Britain still had the largest installed nuclear generating capacity in the world, and had generated more electricity by nuclear means than the rest of the world. When appreciable reductions in the

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74 AEB PEL 175 E, **Report on the Investigation into the Possible Introduction of Nuclear Power in South Africa**, May 1968, p. 8.

75 **Ibid.**, pp. 8-9.

76 **Ibid.**, pp. 6-7.

cost of power from the Gas-Cooled Graphite Reactor (Magnox*) stations in Britain did not appear possible, attention was directed to enriched uranium reactor systems, since enriched fuel was (in 1968) soon to be available from the British diffusion plant. The result was the Advanced Gas-Cooled Reactor (AGR), which utilized much of the technology of the Magnox reactors, but had lower capital and fuel costs.[77]

The investigation was confined to those reactor types where at least an electricity generating prototype had been satisfactorily operated, and for which the economies and operating characteristics of a similar station were considered to have been adequately proven. From a purely economic point of view it was clearly desirable to use enriched uranium as fuel, but it was essential that the supply of fuel for a South African reactor must be assured for the operating lifetime of any commercial nuclear power station, i.e. for 25 years to 30 years.[78]

The evaluation of many factors relating to the introduction of nuclear power to South Africa were investigated: e.g. the economies of electricity generation; the conservation of natural resources; and the effect on local industry.[79]

Nuclear reactor development clearly indicated that enriched uranium would be required if nuclear power production was to be introduced to the Cape Western area. If South Africa was not to be subjected to uncertainty regarding enriched fuel supplies the logical solution was own production.

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77 AEB PEL 175 E, **Report on the investigation into the Possible Introduction of Nuclear Power in South Africa,** May 1968, pp. 9-10.

78 **Ibid.**

79 **Ibid.,** p. 18.

CHAPTER EIGHT

THE DEVELOPMENT OF AN ORIGINAL URANIUM ENRICHMENT PROCESS

In the early sixties it became clear that nuclear power in the future would be based very largely on enriched uranium fuel. There were a number of known methods to separate uranium isotopes, but to find a method that was practically effective and economical was both difficult and extremely expensive. While Dr WL Grant was head of the section, Heat Propagation and Thermodynamics of the National Research Institute for Mechanical Engineering at the CSIR, certain experiments with a vortex tube indicated that water vapour could be separated from air. This phenomenon made Dr Grant speculate as to its application as an isotope separation mechanism. Trial experimentation was begun in December 1961. After much hard work and effort the vortex tube method of isotope separation was proved in the laboratory. An Investigation Committee appointed by the Government, set about assessing the viability of a pilot uranium enrichment plant. Having reviewed the findings of the Committee the Government came out in favour of the project. Under the direction of Dr WL Grant, the top management began the extensive organization to establish a pilot plant (the Y-project). On July 20, 1970, the Prime Minister, BJ Vorster, announced to Parliament and foreign representatives that South Africa had developed its own uranium enrichment process. In the November of that year, the Board of Directors of the Uranium Enrichment Corporation (UCOR) of South Africa was appointed in order to coordinate the actual production of enriched uranium.

The Main Considerations for Uranium Enrichment in South Africa

The third major project to be undertaken by the Atomic Energy Board in the early sixties, and which would eventually lead to a great technological triumph for South African nuclear scientists, was fundamental research in uranium enrichment technology. This highly classified investigation became known as the Gas Cooling Project.

There were a number of reasons why fundamental research in uranium enrichment was undertaken. South Africa required 90% enriched uranium to fuel its research reactor SAFARI I. This could be obtained from the United States, but own production would be an advantage should economic sanctions against the Republic ever include nuclear fuel. Secondly, in the early sixties nuclear physicists and engineers were well aware of the lower capital costs associated with the use of enriched uranium as reactor fuel. The majority of future nuclear reactors would in all probability require enriched fuel rather than natural uranium fuel. The reduction of the quantity of uranium oxide sold in the early sixties enhanced the prospect of lucrative prices that could be obtained from the enriched product. With South Africa's substantial uranium resources, these aspects could not be overlooked. Manufacturing uranium in its most sophisticated form (i.e. enriched), would have to be initiated because the rewards would be extremely beneficial to the country. Uranium marketed in an enriched form would mean virtually doubling the foreign-exchange returns from uranium sales.[1]

As far as nuclear experts in South Africa could judge the situation, 1960 marked a turning point in the development of nuclear power in the world, in the sense that it then became clear that nuclear power in the future would be based very largely on enriched uranium fuel. It was, therefore, natural that South Africa, as a country with large resources of uranium and at the same time a young industrial country which for its future development had adopted a policy of marketing its raw materials in the most advanced form should have looked at ways and means of enriching at least some of its uranium reserves. South Africa had for such an undertaking the advantage of low cost power and an industrial infrastructure developed to the point where it was capable of embarking on the development and construction of sophisticated projects. At the beginning of the sixties South Africa was on the eve of a very large nuclear power programme. South African nuclear authorities believed that in order to meet increasing power demands (estimated at 2000 megawatts (electrical) by the end of the

1 (AECA) AJA Roux: "Uraanverryking", Referaat gelewer tydens byeenkoms van die Suid-Afrikaanse Akademie vir Wetenskap en Kuns, Kanseliersgebou, Universiteit van Pretoria, 19 Maart 1971, pp. 34 - 35.

century) a nuclear power station would be economical in the Western Cape. If such a programme could be based on enriched uranium, it would result in a very marked capital saving. However, such a course could only be followed if the supply of enriched uranium could be guaranteed, which, considering South Africa's international position, implied own production.[2]

By 1961, when the senior AEB scientists returned from their overseas training, the future of enriched uranium as well as the possibility of its being produced locally, was frequently discussed. As was indicated earlier, there are a magnitude of difficulties that have to be overcome in developing an uranium enrichment process. The most important methods of enrichment that were developed in overseas countries were: Gaseous diffusion, Thermal diffusion, Electromagnetic separation, Ultra-centrifuge and Separation nozzles.[3]

Not one of the numerous processes of uranium enrichment, that were to be found in scientific literature of the time, held promise and could be developed to contend the gaseous diffusion method, except, possibly a process based on the ultra-gas centrifuge. This technique had been tried by United States engineers and scientists, in the forties, but was abandoned during the Manhattan Project.[4]

The initial studies as well as the continued investigations into uranium enrichment in the Republic of South Africa can be linked to the

2 (Dr WL Grant: Private Collection) AJA Roux and WL Grant: **Uranium Enrichment in South Africa, Presentation to European Nuclear Conference**, April, 1975.

3 (AECA) HL de Waal: **Uraanverryking in die Republiek van Suid-Afrika**, pp. 27-28. See Technical Addendum: "uranium enrichment - an explanation of the gaseous diffusion method given by Dr AJA Roux."

4 (AECA) AJA Roux: "Uraanverryking", pp. 19-21; (SAB) **Assembly Debates**, vol. 29, 17 July 1970-23 August 1970, 27 July 1970, col. 471; After the Second World War scientists in Holland and Germany continued researching the gas centrifuge for uranium enrichment. (In later years Britain, Germany, Holland combined in a joint organization to form the commercial uranium enrichment company URENCO). See (AECA) HL de Waal: **Uraanverryking in die Republiek van Suid-Afrika**, p. 28.

Dr WL Grant

(Source: Atomic Energy Corporation)

professional career of Dr WL Grant[5] and a number of scientists and engineers who assisted him.

While Dr Grant was head of the Department: Heat Propagation and Thermodynamics of the National Research Institute for Mechanical Engineering at the CSIR in the fifties, a special project was undertaken for the Chamber of Mines relating to underground environments and their psychological effects on human beings. As part of this project, Dr Grant wrote a thesis illustrating that he had devised a method of preparing cool air for the dew point meters which utilized a vortex tube.* Although it proved unsuitable for that purpose, the experiments indicated that water vapour was being separated from the air in the tube. This phenomenon made Dr Grant speculate as to its application as an uranium isotope separation mechanism.[6]

The vortex tube was described for the first time by the German scientist, MG Rangue, as early as 1933. After 1946 a number of publications appeared in which the vortex tube principle was utilized. An interesting observation in the vortex tube action was that when a gas, under pressure, was blown into the tube, the gas could be separated into two streams: one stream in which the temperature was lower than the inlet gas, and another stream in which the temperature was higher than the inlet gas. For this phenomenon, an explanation had to be found. The general flow pattern is that the gas moves in a special flow from the inlet to the warm outlet and that the cold air

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5 Dr Grant was appointed as a mechanical engineer to the staff of the CSIR on March 1st, 1948. There Dr Grant initiated work on a flow meter and a pressure regulator and investigated a heat transfer theory for the construction of a wind tunnel. During Dr Grant's ten years with the CSIR his work remained orientated towards heat transfer and thermodynamics - experience which was to be invaluable in his later achievements. (AECA) HL de Waal: **Uraanverryking in die Republiek van Suid-Afrika**, pp. 10 - 11.

6 When Dr Grant joined the Atomic Energy Board as Senior Engineer in October 1959, he was involved with the manufacture of heavy water. He saw a possible application of the vortex principle in the production of heavy water.

stream moves in a spiral flow from the warm outlet disc to the cold outlet.[7]

Dr Grant realised that only a cheaper and less sophisticated method of enrichment would be within the bounds of practicality for South Africa. An enrichment process in which the high separation factor of the gas centrifuge method and the high flow-through per enrichment stage of the gaseous diffusion technique could be combined, would have great practical advantage. In this concept the vortex tube seemed to have great potential.[8] Dr Grant deliberated on the idea that if a vortex tube could separate water vapour from air, it could perhaps be developed into a separating element which might separate uranium 235 from the majority of uranium 238 atoms - a separating element which would have the tremendous advantage over the gas centrifuge of employing no moving parts.[9] This was the fundamental source of the eventual attainment of enriching uranium.

It was on the basis of Dr Grant's premise that Dr Roux convened a meeting of a select few and advised that the various known methods of enriching uranium should be looked into. On 23 August 1961, Dr AJA Roux informed the Executive Committee of the Atomic Energy Board concerning the advantages of using enriched uranium as fuel rather than natural uranium.[10] It was at this stage that the Executive Committee decided that research on a method of enriching uranium should be commenced.

In 1961 no one was under any illusion as to the politically sensitive nature of uranium enrichment. (This aspect will be elucidated in the

7 (AECA) HL de Waal: **Uraanverryking in die Republiek van Suid-Afrika,** p. 14.

8 **Ibid.,** pp. 13-14.

9 **Ibid.,** pp. 15-16.

10 Members of the Executive Committee of the South African Atomic Energy Board, 1961: Chairman: Dr TEW Schumann; Members: CS McLean and JJA Nel.

following chapter.) Research would have to be handled with unquestionable discretion and accordingly the project was classified. It was given the designation of the Gas Cooling Project (GCP) which still later was divided into three separate components, namely: X the experimental stage of development, Y the pilot plant and Z the full scale production plant. The Gas Cooling Project as a whole was therefore also referred to as the XYZ-project.[11] This chapter deals mainly with the X-project and preparations for the Y-project. (To a lesser extent preparation for the Z-project). However, the three components should be regarded as an entirety for all the research and technical experimentation was done with a view to eventual commercial production. (The Y and Z projects would only be completed in the 1970's and 1980's.)

The first building to house the early experimental work, was in Du Toit Street, in central Pretoria. These premises were kept as unobtrusive as possible. Partitioned into a front and rear section, the experimental equipment was assembled and operated in the rear portion, and the front half comprised the workshop where casual enquirers were told scientific equipment was being manufactured. Later it became necessary to transfer the experimental work to new premises. This was the equally unobtrusive Shamrock Building in Skinner Street, Pretoria. Stricter security was exercised there.[12]

The Experiments to separate Uranium Isotopes and the Scientists involved

In December 1961, experimentation with the vortex tube was begun. The research that commenced, was based on investigations that had been done in connection with moisture measures at the CSIR. The

11 Interview with Dr WL Grant, 17.7.1989; (AECA) HL de Waal: **Uraanverryking in die Republiek van Suid-Afrika,** pp. 41 - 43; (AECA) Minutes of the Meeting of the Executive Committee (Production) of the AEB for uranium enrichment, 20 March 1969, p. 4.

12 AR Newby-Fraser: **Chain Reaction**, pp. 96-97.

proposed vortex tube process has a high separation value. As this value is so much better than the theoretical maximum for a uranium hexafluoride diffusion process it was decided that research should be continued.[13]

Investigations at the CSIR had not demonstrated the separation principle beyond all doubt and a new experimental assembly was constructed to repeat what had been done years before, and to confirm the earlier observations. Initially Dr Grant's team was convinced that the experiment with the vortex tube, that had been done years before would succeed, but this was not the case. Dr Grant recalled the day, Christmas Eve, in the summer of 1961. The experiment was done over and over again, but with no success. Some of the members of the team were in a festive mood and were in an adjacent room. When they returned to where the apparatus had been set up to enquire whether the experiment was successful, the scientists could only, to their consternation, reply that there was no separation of air and water vapour. Again and again the experiment was repeated - week after week, but to no avail. After three months, by which time autumn had brought a chill to the air, the team began to understand why. The elementary explanation became apparent. The relative humidity in the air had in the summer been too low. With the coming of winter it gradually changed. The relative humidity in the air was higher. Having accommodated this external effect in the experimentation the separation mechanism was proven successful and the scientists could proceed to the next stage of investigation.[14]

In his recollection of the year 1961 Dr Grant recalled the following circumstances which are for this study of interest. Soon after his return from the United States, he remembered standing on Church Square, watching the inauguration of the first State President of the Republic of

13 (AECA) HL de Waal: **Uraanverryking in die Republiek van Suid-Afrika**, p. 16.

14 Interview with Dr WL Grant, 27.7.1989.

South Africa, CR Swart. The country would, at that point, pursue its future outside the British Commonwealth of Nations. On his return Dr Grant suggested to Dr Roux, then Director of the Atomic Energy Board, that they should investigate the enrichment of uranium. At that point Dr Grant realised that enriched uranium reactors would be of far greater advantage than natural uranium reactors. They would be a far more economic proposition and more versatile. The decision to investigate a method of enriching uranium was, according to Dr Grant, a scientific deliberation. Having assessed progress in the United States, he could speculate as to the future of both natural uranium reactors and enriched uranium reactors. Approximately thirty years later he is convinced that the correct decision was taken, as early as 1961, to pursue a method of enriching South African uranium.[15]

The Minister of Mines, Dr N Diederichs, was consulted at the time. The economic advantages of enriched uranium as illustrated by Dr AJA Roux prevailed and the Minister conceded that research be commenced on an enrichment process. For political reasons the whole effort would be confidential. Only the most senior members of the Board would be informed of the progress made. This course of action was largely due to the apparent economic advantages of enriched uranium in nuclear power reactors.[16] However, the decision to enrich uranium would alert the international community that South Africa could in future be in a position to produce nuclear weapons and this had to be taken into account.[17]

Most of the initial experimentation was done by Dr Grant himself, assisted by a small team of scientists. When, in the autumn 1962, it was discovered that air and water vapour could be separated they

15 Interview with Dr WL Grant, 27.7.1989.

16 (AECA) Review of the XYZ-project by Dr AJA Roux, Minutes of the meeting of the Executive Committee (Production) of the AEB for uranium enrichment, 20 March 1969, p. 2. (AECA) HL de Waal: **Uraanverryking in die Republiek van Suid-Afrika,** p. 42.

17 Interview with Dr RS Loubser, 28.7.1989.

progressed to where they could separate argon isotopes from air. During these initial experiments gases (such as argon) which are non-reactive and easily handled, were used. When Dr Grant and his team succeeded in separating argon isotopes from air, it was realised that extra financing would be required if they were to proceed to experiments involving the separation of uranium isotopes. The feed material for the separation of uranium isotopes is uranium hexafluoride (UF_6). The UF_6 for the enrichment process should be clean and of high quality. In the early stages of the X-project, UF_6, was obtained from overseas (France).[18] If this uranium compound were to be produced, on a scale for experimental laboratories researching the separation of uranium isotopes, government financing would have to be conceded.[19]

Therefore adequate laboratory facilities were required to permit the making and the safe handling of UF_6 and also to extend experimentation on chemical and metallurgical aspects of the research. An estimate of the requirements produced the figure of one million Rands.[20]

On March 25, 1963 Dr Roux and Dr TEW Schumann were granted a personal interview with Dr Verwoerd in order to obtain governmental financing. At the meeting were present Dr Dönges, Minister of Finance, and Dr N Diederichs, Minister of Mines. This was a highly confidential meeting, not even the other members of the Cabinet were informed. The enrichment programme required a million Rands for a project which might prove successful, but on the other hand might fail. Dr Grant provided Dr Roux with a sheet of paper on which some details were given of how they proposed to separate certain gasses, which were required to produce UF_6, and an indication of the laboratory envisaged, in which the separation of uranium isotopes could be done. These were the main objectives. Dr Roux explained the processes as logically as possible. He made it known to the Prime

18 Interview with Dr JJ Warnenburg, 25.4.1991.

19 Interview with Dr WL Grant, 27.7.1989.

20 **Ibid.**

Minister that there was the possibility that it might not succeed, but that it could only be proven with the necessary experimentation and adequate facilities. It was disclosed to the Prime Minister and the other Cabinet Ministers that a pilot plant would have to be erected for the production of UF_6, as well as a special building with air purifying installations. The facilities of a separate workshop at Pelindaba was required and at some stage suitable compressors would have to be constructed for UF_6. Dr Roux informed Dr Verwoerd as to the importance of the success of development of the process, and indicated the economic advantages as well as the international implications of South Africa becoming a nuclear power.[21]

Any doubts or fears which the two members of the AEB may have entertained regarding the reception of their proposals were soon allayed by the intense interest displayed in them. On being told that preparation of designs and drawings for the necessary building and the call for tenders would probably require about eight months before construction could be commenced, Dr Verwoerd asked whether some of the formalities could not be by-passed to achieve earlier completion of the work. In the course of a weekend, the funds were obtained. Approximately at ten o'clock on the Monday morning April 1st, 1963 Dr Schumann telephoned Dr Grant to inform him that the money had been granted for the programme to proceed. It can be said that this was the direct result of Dr Verwoerd's perception, that the possibility of the success of an uranium enrichment venture was worth some risks, and could only be accomplished with large governmental financial support. An important consideration was that this was an undertaking inherent to South Africa. It was the beginning of a relationship of trust that existed between the scientists of the AEB involved with uranium enrichment and the Prime Minister and his successor. The scientists made every

21 (AECA) Review of the XYZ-project by Dr AJA Roux, Minutes of the meeting of the Executive Committee (Production) of the AEB for uranium enrichment, 20 March 1969, p. 2. Interview with Dr WL Grant, 27.7.1989; (AECA) HL de Waal: **Uraanverryking in die Republiek van Suid-Afrika**, p. 31.

effort to enlighten the Ministers concerned as to all the nuclear scientific and technological implications of the project. They were fully aware of the risks involved and how the funds would be applied. The envisaged programme was approved by the Cabinet in May 1963, as well as the financial provision until 1968/69.[22]

The South Africa enrichment process is characterized by a high separation factor.[23] This was a major factor in obtaining funds from the Government for Dr Grant's uranium enrichment premise would have to indicate precedence over known methods of enrichment. The challenge to research and develop an enrichment process totally South African was an exiting experience to the nuclear scientists involved. It was an opportunity to be involved directly with enrichment technology development. Universally this was a dream of many scientists but the privilege of only a few. The nuclear scientists that were engaged in Dr Grant's undertaking were fully aware of this.[24]

The scientists that were involved with the early experiments of the X-project fully supported Drs Roux and Grant and were exceptionally dedicated. Funds were limited and initially there were only a few scientists involved. Enthusiasm was, however, such that scientists almost pleaded to be included in the undertaking. There were times that the team had to be totally resolute in their perseverance, as the research was dogged by innumerable complex problems that required repeated experimentation. The scientists were determined to make the project succeed. At times they were required to work overtime, for which they were not compensated, beyond the vision of ultimate

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22 Interview with Dr WL Grant, 27.7.1989; (AECA) HL de Waal: **Uraanverryking in die Republiek van Suid-Afrika**, p. 31; AR Newby-Fraser: **Chain Reaction**, pp. 98-99.

23 (Dr WL Grant: Private collection) AJA Roux and WL Grant: **Uranium Enrichment in South Africa, Presentation to European Nuclear Conference**, Introduction, April, 1975. See Technical Addendum: "Uranium enrichment" "South African process".

24 Interview with Dr DM Kemp, 2[illegible].4.1991.

Dr RS Loubser

(Source: Atomic Energy Corporation)

success. This enthusiasm was a great inspiration to those leading the project.[25]

According to Dr Grant the experimental work on the South African process was a success as a result of the inventive work done by key individuals. One of these persons was Dr RS Loubser. At the beginning of 1964 Dr RS Loubser joined the AEB. Dr Loubser was appointed Assistant Director with the specific task of assisting Dr Roux in Technical Administration. In that capacity he became more directly involved with the manufacture of project equipment. The technical services section of the Atomic Energy Board devoted most of their time and expertise to Dr Grant and the Gas Cooling Project. It was therefore with the manufacture of technical equipment for the uranium enrichment experimentation that Dr Loubser became involved with the Gas Cooling Project. One of the first things that became quite clear to him was that the success of Dr Grant's concept depended on the "separating element". As the experimentation and studies progressed it became more and more apparent that the separating element would have to be a particularly fine and accurate piece of mechanism. It would have no moving parts, but would nevertheless have to be made with absolute precision. At the same time it would have to be manufactured economically. If this could not be done it would have made the whole undertaking far too costly. From the beginning of the development of the separating element, Dr Loubser took the lead. It was as a result of his technical skill that the prototypes of the separating element were precision made and the ultimate uranium enrichment process was a success.[26]

A prominent scientist that made a vital contribution to the Gas Cooling Project was Dr JJ Wannenburg. In the early sixties, Dr JJ Wannenburg was a lecturer in Mechanical Engineering at the University of Stellenbosch. He was investigating axial compressors.* These turbo-

25 Interview with Dr WL Grant, 27.7.1989.

26 Interviews with Dr RS Loubser, 28.7.1989 and Dr WL Grant, 27.7.1989.

type machines are also used in aeroplanes. Late in 1963, Dr Roux and Dr Grant attended an academic conference in Stellenbosch and considered Dr Wannenburg's interest in this field as commendable for research in the Gas Cooling Project. Dr Grant informed him that they were involved with highly secretive investigations concerning uranium enrichment. For experimentation to proceed, it was essential that an axial flow compressor be developed. Dr Wannenburg's expertise was employed to overcome complex problems involving the pumping of the highly corrosive feed material. Dr Roux was very persuasive and Dr Wannenburg decided to leave the university, accept the challenge and proceed to Pelindaba. When he arrived in Pretoria at the beginning of 1964, the laboratory facilities for the enrichment investigations had been moved from Pretorius Street and were established at Pelindaba.[27]

Dr Wannenburg joined Dr Grant's team and he was in charge of the compressor, which was a vital component in the enrichment process. He later played an important part in the development of the compressor. It was agreed by these three key figures in the programme, Dr Grant, Dr Loubser and Dr Wannenburg, that they would not desert the uranium enrichment project by accepting other appointments offered them until the experiments had succeeded and an uranium enrichment pilot plant had been put into operation. Many appointments had been turned down by them.[28]

After the completion of the Laboratory in the Engineering building at Pelindaba, by November 1964, the gas cooling apparatus was set up, financed from the funds received from the Government.[29]

For the trial experiment to separate uranium isotopes, uranium hexafluoride was used, at first mixed with hydrogen and later with helium. The process was, therefore, of an aerodynamic type. The feed

27 Interview with Dr JJ Wannenburg, 25.4.1991.

28 Interview with Dr RS Loubser, 28.7.1989.

29 Interview with Dr JJ Wannenburg, 25.4.1991.

Dr JJ Wannenburg

(Source: Atomic Energy Corporation)

material was difficult to use as it reacted with materials with which it came into contact. A diaphragm compressor was developed by Dr Wannenburg, and this was used in the early experiments. The equipment was not of a standard to successfully accommodate uranium hexafluoride-gas. The first attempts at using a uranium hexafluoride and hydrogen mixture were disastrous; the compressor could be used only for a single day before it had to be completely dismantled and thoroughly cleaned. The gas itself would rapidly vanish as a result of its attack on constructional materials and the formation of HF (hydrofluoric acid). Some of the tubes were metallic, some glass. As the gas flowed through the tubes the scientists would observe how the colourless gas changed to a yellow-green, then to a dark hue and eventually it would simply eat away the glass or corrode the metal. Later it was found that this was caused by water vapour. The early diaphragm compressor was a flat construction that was inclined to leak at the part where the compressor clasped the diaphragm. This caused water vapour to enter the system and much damage was done to the tubing of the apparatus. It was an on-going endeavour of building up the apparatus and then damaging it by the experimentation - once again having to rebuild it. The result was that the endless repetition of reconstruction and experimentation that was time consuming and demanded unlimited patience on the part of the scientists involved.[30]

In his article "The Development of Compressors for a Uranium Enrichment Plant in South Africa" Dr Wannenburg indicates some of the difficulties connected with the development of a uranium hexafluoride compressor and possible solutions of the these problems. Types of compressors were mentioned that might meet the demands of the process.[31]

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30 Interview with Dr WL Grant, 27.7.1989.

31 (AECA) JJ Wannenburg: "Die Ontwikkeling van Kompressore vir 'n Verrykingsaanleg in Suid-Afrika", November 1964: HL de Waal: **Uraanverryking in die Republiek van Suid-Afrika**, p. 23.

By way of summary one can say that, during the first half of 1965, the experimentation on the vortex tube was continued, and the forming of hydrofluoric acid in the apparatus caused countless problems. Intensive research on compressor development was carried out. The study of effective temperatures, cascade linkage, isotope separation, uranium hexafluoride tests, the specific energy consumption of the separation process, cost estimations, etc. were intensively investigated. The results indicated that the vortex tube most definitely had advantages as compared to the gaseous diffusion methods, as well as the centrifuge method that the French were investigating at that time.[32] The toil and laborious efforts of the team were to be rewarded in the second half of 1965.

During the first half of 1965 a mixture of uranium hexafluoride and hydrogen was used as the process gas in the enrichment experimentation. In July, 1965 it was decided to try uranium hexafluoride with helium. It proved to be less corrosive. One of the problems that was particularly back-breaking to the team was the fact that once experimentation had begun, the apparatus could not be left unattended. As much as possible had to be done before the uranium hexafluoride would react with the encasements and bring the process to a halt.

The Breakthrough: The Discovery of a Unique Process

By October 1965 the scientists had not yet succeeded in separating the isotopes of uranium. All efforts were devoted to a round the clock programme to achieve this all-important milestone, before a scheduled visit in November by the Prime Minister, Dr Verwoerd, who retained a deep interest in the Gas Cooling Project.

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32 (AECA) AJA Roux and WL Grant: "Vorderingsverslag oor 'n nuwe metode van Uraanverryking", 31 March 1966; HL de Waal: **Uraanverryking in die Republiek van Suid-Afrika**, p. 29.

Dr DM Kemp

(Source: Atomic Energy Corporation)

The team managed to separate the isotopes a mere two weeks before the visit. They succeeded in accomplishing this by using a mixture of uranium hexafluoride and helium. Once separation was achieved, there would be an enriched stream and a depleted stream. Samples had to be taken to assess whether isotopes had been separated. During the early experimentation two persons were responsible for taking samples and managing the test bench, Bill Grant (brother of Dr WL Grant) and Rob Sinclair. One afternoon in November 1965 about two weeks before the scheduled visit of the Prime Minister (Dr Grant recalled the actual test) the gas cooling apparatus was set in motion for the umpteenth time and experimentation began. Sam van Rensburg, under the direction of Dr DM Kemp, was in charge of the mass spectrometer, which would indicate whether separation had occurred. Samples were taken and the analysts worked through the night. It was about four o'clock the following morning when Dr Grant was informed by the telephone, that the isotopes had been separated. This was a significant breakthrough, but the low-mass isotope was appearing at the outlet where the high-mass isotope should be discharged. The morning Dr Roux was invited to come and see what had been achieved. **It was perhaps the most important day in the history of the Gas Cooling Project.** Approximately two weeks of intense activity followed and when the inspection visit took place as planned, it was possible to separate uranium 238 in a helium-uranium hexafluoride mixture.[33]

With this stage achieved, it was then possible to expand the programme and conduct a detailed investigation of corrosion resistant materials for construction. It was in these investigations that Dr Conrad Johannes played a significant role. He was the chemical engineer in charge of the uranium hexafluoride preparation. (He may be regarded as the first uranium enrichment physicist of the AEB.)[34] It was his task to prepare

33 Interview with Dr WL Grant, 27.7.1989; Interview with Dr JJ Wannenburg, 25.4.1991.

34 (AECA) HL de Waal: **Uraanverryking in die Republiek van Suid-Afrika,** pp. 21-22.

the uranium hexafluoride so that it could be used in the experimentation in a purified form. This was essential in order that experiments might succeed. He conducted his own research into types of claddings and encasements that could withstand the corrosive action of uranium hexafluoride. It was on his recommendation that certain materials were used in the apparatus that contributed largely to the success of the project.[35]

The materials that could be used for the construction were limited: metals, aluminium, copper, alloys of nickel, alloys of copper (such as monel),[36] pure nickel and stainless steel (however, large areas of stainless steel were unsuitable). Teflon was the only non-metallic substance that could be used. Teflon had the unique property of having a low friction coefficient. It could be used where one would normally use oil as a lubricant.[37]

When Dr Wannenburg started making analyses he realised that for the flow that was required, an axial flow compressor was not the answer. There were two other alternatives. The one was a rotor compressor* and the other alternative was a piston engine.*[38] The piston engine had less disadvantages. The greatest difficulty that had to be overcome was the sealing of the piston rod. Ultimately a teflon bellows was developed to seal the piston rod. With numerous improvements a

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35 Interview with Dr WL Grant, 27.7.1989; Dr C Johannes later left the country to live in France where he died. He had porphyry and Dr Grant recalled how, with sore and bleeding fingers, he pursued his investigations with uranium hexafluoride. His dedication was remarkable.

36 (Dr JJ Wannenburg: Private Collection) Monel: 67% nickel, 30% copper and 3% iron, "Monel magic in Nuclear Technology", **Focus on Atomic Energy Corporation** (supplement in **Engineering Week**, 23.11.1990) p. 7.

37 Interview with Dr JJ Wannenburg, 25.4.1991; JJ Wannenburg: "Die Ontwikkeling van Kompressore vir 'n Uraanverrykingsaanleg in Suid-Afrika", Part II, July 1965; HL de Waal: **Uraanverryking in die Republiek van Suid-Afrika,** pp. 23-24.

38 See Technical Addendum "Rotor Compressor" and "Piston Engine".

bellows was eventually constructed that could be used in the pilot plant.[39]

Dr Grant used mass spectrometers as analytical instruments in the development of the project. This method was a handicap, it impeded the progress of the undertaking because the analyses essential to the experimentation could not be done quickly. Only a few analyses could be carried out per day and even that was only accomplished with much effort. It was in this sphere that Dr Haarhoff (later Professor Haarhoff[40]) would play significant role. In 1961 Dr Haarhoff received a scholarship from the AEB to further his studies at Cambridge University. There he worked on molecular reactions and as part of his study, became particularly interested in mass spectrometry as an expedient in scientific research. Dr Grant, aware of Dr Haarhoff's abilities in this field, approached Dr Roux to make available some of Dr Haarhoff's time for an investigation into the mass spectrometric analyses of the Gas Cooling Project. Dr Grant believed that he had the ability to improve that aspect of the research. Initially Dr Haarhoff was only employed part-time to help with the Project. Each step of the analytical procedure was systematized and thus helped to shorten the time in which results could be produced. Dr Haarhoff became particularly interested in the Gas Cooling Project and later became a full-time member of the team. The problems connected with time-consuming analytical results were eventually overcome to a point where any amount of analyses could be done accurately and as quickly as they were required. This was largely due to the expertise and dedication of Dr Haarhoff - an accomplishment invaluable to the progress of the Project as a whole.

Dr Haarhoff's most significant contribution to the development of the South African uranium enrichment project was the technique he

39 Interview with Dr JJ Wannenburg, 25.4.1991.

40 In 1977 Dr Haarhoff joined the staff of the University of Pretoria and was Head of the Department Mechanical Engineering.

Dr PC Haarhoff

(Source: Atomic Energy Corporation)

discovered to reduce the many stages of enrichment in the enrichment process and in this way reducing the ultimate cost of the projected pilot plant.[41]

In the gaseous diffusion method developed by the United States and the Becker process developed by Germany, scientists in the middle sixties had not solved the problem of reducing the number of stages of enrichment (also known as "cascades"). This was a major factor in making enrichment so extremely expensive. Vast constructions were built with hundreds of stages of enrichment.[42]

Dr Haarhoff started researching the cascade aspect in 1965.[43] Dr Grant believed that with some good thinking and inventiveness a method could be discovered to reduce the number of stages in an enrichment cascade. Dr Haarhoff focused his attentions on the problem and contemplated various possible solutions. He believed that the answer lay in not how the stages themselves worked, but how the stages were connected to each other. He took 20 small stages, each with a different composition and tried to find a way of combining them into one compact unit. With some inventive thinking he formulated a totally new method of connecting the stages of a cascade, quite unique in the world.[44]

As the uranium enrichment process requires uranium tetrafluoride (UF_4) and uranium hexafluoride (UF_6) the following aspects should be mentioned. The conventional processes for UF_4 and UF_6 production both require either anhydrous hydrofluoric acid or fluorine gas, neither of which was produced in South Africa. An alternative method, the so-called Fluorox process, involving oxidation of UF_4 was developed and

41 See Technical Addendum: Stages of enrichment.

42 Interview with Dr Haarhoff, 28.7.1989.

43 PC Haarhoff: "Oorwegings by die ontwerp van 'n kaskade", October 1965; HL de Waal: **Uraanverryking in die Republiek van Suid-Afrika**, pp. 24-25.

44 Interview with Professor PC Haarhoff 29.7.1989.

in 1967 a pilot plant for the production of uranium hexafluoride was established at Pelindaba by the Nuclear Fuels Corporation.[45]

The South African process must be regarded as a combination of the (vortex tube) separating element which in effect is a high performance stationary-walled centrifuge (with a high separation factor), using uranium hexafluoride in hydrogen as process fluid, and the new cascade techniques that were developed to deal with a small uranium hexafluoride cut. The new cascade techniques made it possible to achieve the desired enrichment with a relatively small number of large separating units by fully utilizing the high separation factor available.[46]

By the end of 1967 the feasibility of the vortex-tube enrichment method had been fully demonstrated on laboratory scale, while the scientific and technical problems which still remained were by no means regarded as insurmountable.

The Decision to build a Pilot Plant

Whether the process would be viable for a full-scale enrichment plant, was dependent on the acquisition of economic and industry-related data which no laboratory-scale work could provide. In short, this information could only be derived by building a full pilot plant based on the vortex-tube separation element. The cost and effort involved in

45 Ownership of uranium was, according to the Atomic Energy Act (1948), vested in the State. In 1967 the Act was amended (Act No. 90 of 1967) and one of the changes was the restoration of this ownership to private enterprise. As a consequence, the Chamber of Mines, Uranium Sales Organization (which negotiated on behalf of the mines terms and conditions of uranium sales) was replaced by the Nuclear Fuels Corporation of South Africa (NUFCOR). NUFCOR was founded to act as a selling agent on behalf of all individual uranium-producing gold mines. It also took over operation of the Central Calcining Plant which collected ammonium diuranate slurry from the extraction plants of the various mines.

46 (AECA) AJA Roux and WL Grant: **Uranium Enrichment in South Africa, Presentation to European Nuclear Conference**, Process Description, April, 1975; Interview with Dr JJ Wannenburg, 25.4.1991.

Dr HJ van Eck

(Source: Atomic Energy Corporation)

this, however, would be of a very different order to those injected into laboratory work. It was realised that the Government could not be expected to take a major decision on whether to proceed with the next stage purely on the recommendation of the top scientists and engineers engaged in the project.

It was on the recommendation of Dr Roux that an impartial expert committee was appointed by the Government in the first quarter of 1968 to draft a recommendation to the Cabinet regarding the future production of uranium enrichment in South Africa.[47] According to Dr WL Grant, as early as the beginning of 1966 Dr Verwoerd had said a commission should be appointed to investigate whether it would be beneficial to enrich uranium in South Africa. After the 1966 general election he would attend to the matter. Persons such as Dr HJ van Eck (Chairman of the Industrial Development Corporation) and Dr Straszacker (Chairman of ESCOM) should serve on such a committee.[48] On 7 March 1966, Dr HJ van Eck as Chairman of the Nuclear Power Committee of the AEB, discussed the possibility of the construction of uranium enrichment plants (a pilot plant and later a full scale plant) with Drs Roux and Grant in Johannesburg.[49]

Dr Verwoerd was assassinated on September 6, 1966. The enquiry into the future production of enriched uranium was, therefore, delayed by approximately two years, as a result of the death of Dr Verwoerd. The scientists that were aware of Dr Verwoerd's enthusiasm for the project, were shattered by the news of his death.[50] A new Prime Minister (BJ

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47 AR Newby-Fraser: **Chain Reaction**, p. 100.

48 Interview with Dr WL Grant, 27.7.1989.

49 (AECA) HL de Waal: **Uraanverryking in die Republiek van Suid-Afrika**, p. 31.

50 Interview with Dr WL Grant, 27.7.1989.

Vorster) and a new Minister for Mines (Dr C de Wet) had to be enlightened as regards the uranium enrichment programme.[51]

At the Gas Cooling Project Meeting that was held on 15 December 1966 it was decided that the enrichment programme would go ahead uninterrupted. At the end of 1967 the cost of South Africa's enriched uranium, based on the process of the South Africa Atomic Energy Board, could be assessed in comparison to the price of the enriched uranium of the United States and other enrichment methods.[52]

Considerations that would favour the issue of whether to build a pilot plant to test Dr Grant's method were the following: In the Republic the foreign exchange value of natural uranium reached an all-time low in 1965 and 1966. Although enrichment was an expensive undertaking there were great marketing possibilities for low enriched uranium.[53]

In an exchange of letters between Dr AJA Roux, the Chairman of the United Kingdom Atomic Energy Authority, Dr JM Hill, in September and October 1968, the existing collaboration Agreement between the United Kingdom Atomic Energy Authority and the South African Atomic Energy Board was extended to July 1977.[54] Although the Agreement was extended, the arrangements could be subject to veto by the United States Government.[55] South African nuclear authorities

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51 (AECA) Review of the XYZ-project by Dr AJA Roux, Minutes of the meeting of the Executive Committee (Production) of the AEB for uranium enrichment, 20 March 1969, p. 3.

52 (AECA) **GVP Navorsings- and Ontwikkelingsprogram**, Minutes of meeting, 15.12.1966, pp. 13-14.

53 **Ibid.**, pp. 9-10.

54 (AECA) Letter from Dr JM Hill to Dr AJA Roux, 19 September 1968; Letter from Dr AJA Roux to Dr JM Hill, 11 October 1968; (AECA) Agreement for Cooperation as amended, 7 July 1967, Article IV (A2).

55 (AECA) **Report on the Investigation into the Possible Introduction of Nuclear Power in South Africa**, PEL 175 E, AEB, May 1968, p. 10; AR Newby-Fraser, **Chain Reaction**, p. 8.

were convinced that South Africa should not be dependent on a foreign source for nuclear fuel.

By 1968 considerable progress had been made: factual foundation of the process and a basis for the design of a future pilot plant was established.[56] D Lion-Cachet (Head Technical Services AEB) examined various aspects of the plant, such as power supply, labour, raw materials, equipment, mechanical capacity, staff, transport, security, programming, etc.[57]

On 18 March 1968 the Minister of Mines, Dr de Wet, in consultation with the Prime Minister, BJ Vorster, appointed an impartial Investigation Committee to look into the possibility of the establishment of an enrichment plant. The Committee, whose members had not up to that point been involved with the development of the process, were required to draft an independent recommendation to the Cabinet regarding the future production of enriched uranium in South Africa. The Committee was under the chairmanship of Dr HJ van Eck; Dr TF Muller (member of the Transvaal and Orange Free State Chamber of Mines) and Dr RL Straszacker (Chairman, Electricity Supply Commission) were members; and B von M Louw was appointed secretary.[58]

The Committee lost no time in fulfilling its responsibilities. On 5 April 1968, Dr AJA Roux sent letters to the members of the Investigation Committee in which he provided a list of reports which he regarded as

56 AGM Jackson: "The Separation of UF_6-H_2 and UF_6-He Mixtures by Freeze Condemnation "; AGM Jackson: "The Separation of UF_6-He Mixtures by Fractional Permeation through Membranes"; WW Grant and HA Behrman: "Die Opbou and Inbedryfstelling van die Vier-draai-kolkbuis Parallelskakelingaanleg"; HL de Waal: **Uraanverryking in die Republiek van Suid-Afrika,** pp. 34-35.

57 D Lion-Cachet: "Construction of a Pilot Enrichment Plant"; HL de Waal: **Uraanverryking in die Republiek van Suid-Afrika,** p. 35.

58 (AECA) Review of the XYZ-project by Dr AJA Roux, Minutes of the meeting of the Executive Committee (Production) of the AEB for uranium enrichment, 20 March 1969, p. 3; (AECA) HL de Waal: **Uraanverryking in die Republiek van Suid-Afrika,** p. 35.

important for the Committee to study and evaluate in their arbitration of the enrichment project. In this way Dr Roux believed that the Committee would be well-informed prior to their investigations at Pelindaba.[59]

After a study of the reports and other documents pertaining to the work of the preceding years, the Committee spent three days, from Tuesday, April 16th to Thursday, April 18th, 1968, at Pelindaba, inspecting the laboratories and other facilities. They conducted interviews with Dr AJA Roux, Dr WL Grant and other specialists in the various aspects of the vortex tube enrichment process.[60]

On Friday morning, 19 April 1968, Dr Van Eck dictated the Report on the pilot uranium enrichment plant which the Investigation Committee wished to present to the Minister of Mines, Dr C de Wet. Within three days (22 April 1968) the Committee presented its report and recommendations to the Minister.[61]

In the Report it was stated that the Investigation Committee had been fully informed regarding the Gas Cooling Project, by numerous reports and specialists at the South African Atomic Energy Board. The conclusion reached by the Committee was that, despite the many impediments implicit in any new process, it seemed, even at that early stage, that the South African process could later be developed in a large production plant which, in both capital output and operating costs,

59 Documents for review by the Investigation Committee concerned: Technical Aspects of the GCP; Experimental Work on the Vortex Tube; Laminary Flow in the Vortex Tube; Compressor Development; The Corrosion of Metals in UF_6 gas; Report on Instruments that had been developed; Cost Estimates and the Construction of a Pilot Plant; Letters from Dr AJA Roux to Drs HJ van Eck, TF Muller and RL Straszacker, 5 April 1968.

60 (AECA) HL de Waal: **Uraanverryking in die Republiek van Suid-Afrika,** pp. 35-36.

61 (AECA) Review of the XYZ-project by Dr AJA Roux, Minutes of the meeting of the Executive Committee (Production) of the AEB for uranium enrichment, 20 March 1969, p. 3: HL de Waal: **Uraanverryking in die Republiek van Suid-Afrika,** pp. 35-36; AR Newby-Fraser, **Chain Reaction**, p. 100.

could compare favourably with existing foreign enrichment plants. It was the Committee's opinion that a pilot plant should be erected before embarking on the construction of a full-scale installation, so that the new process could be tested on a much larger scale than was possible in the Laboratory.[62]

This recommendation by the Investigation Committee was based on the following: firstly, the high separation factor of Dr Grant's method. In the laboratory, the new method indicated a far higher degree of enrichment per stage, compared to that of the vast gaseous diffusion plants in the United States, United Kingdom and France. It was even higher than the separation that could be achieved theoretically by the gaseous diffusion method. There was the possibility that an even higher separation factor could be attained in future.[63]

Secondly, uranium enrichment had economic advantages. Enriched uranium would have a far higher foreign trade value. In 1968, South Africa was the third largest uranium producer in the world. The uranium reserves of the Republic, at that time, were 200 000 tons that could be exploited at $8 per lb. At that price it would yield a total value of about R2 500 million. If the uranium were enriched to an average of 3%, its value would increase by at least $20,5 per kg, or about R2 900 million. If the enriched uranium could be processed and marketed as fuel elements, the value would further increase by at least R1 000 million.[64]

A further advantage noted by the Committee was the availability in South Africa of enriched fuel for power generation. Enriched uranium instead of natural uranium would lower the capital costs of a nuclear power plan. It was estimated in the Report that by 1980, South Africa

62 (AECA) HL de Waal: **Uraanverryking in die Republiek van Suid-Afrika**, pp. 36-38; AR Newby-Fraser, **Chain Reaction**, p. 101.

63 (AECA) HL de Waal: **Uraanverryking in die Republiek van Suid-Afrika**, p. 38.

64 **Ibid.**, p. 39.

would require an additional 1 000 MW generated power each year. If enriched uranium power plants were installed, there would be a cost reduction of R40 million per year. Within ten years that figure could increase to twice the amount (R80 million). The South African process had the advantage that it would consume less water than was required by overseas production plants.[65]

The report also stressed the advantages of South Africa being independent of foreign sources for enriched fuel, the greater marketing possibilities of the enriched product and the benefits of an enrichment plant to the engineering industry.[66]

The Investigation Committee stated in the Report that considerable progress had been made in the development of suitable materials for the separation apparatus, and that a larger plant could be considered. It had required much ingenuity and intensive research to accommodate the very corrosive and poisonous gas UF_6 in the pipes, valves, couplings, measuring instruments and compressors of the experimental plant. It was realised that much would still have to be done in that particular aspect in order to achieve the required maximum efficiency. However, the prospects were promising and the anticipated course of research, in order to improve materials and casing, was clearly defined.[67]

It was also realised that an enrichment plant would consume a great deal of electricity. In the United States, the three enrichment plants, with an annual capacity of 17 000 tons of uranium, required approximately 6 000 megawatt power (approximately 3 100 kWh per unit separative work*). According to calculations, the South African process would consume only half the American requirement. With regard to the equipment for the pilot plant, the largest single source of

65 (AECA) HL de Waal: **Uraanverryking in die Republiek van Suid-Afrika**, pp. 38-40; AR Newby-Fraser, **Chain Reaction**, p. 100.

66 **Ibid.**, p. 40.

67 (AECA) HL de Waal: **Uraanverryking in die Republiek van Suid-Afrika**, pp. 38-40; AR Newby-Fraser, **Chain Reaction**, p. 38.

expenditure would be the compressors. These would have a considerable capacity and a large number would be required. The advantages of large compressor units were considerable, especially the economic benefits, but also for the process itself. It was, therefore, on compressor development and improvement that subsequent research would be focused.[68]

In July 1968 the Prime Minister, BJ Vorster, Dr C de Wet and the Minister of Finance (Dr N Diederichs) were given further information regarding the proposed pilot uranium enrichment plant.

The large sum of money that the Government would have to make available for the pilot plant, required careful consideration. By the end of 1968 no final decision had been made by the Government. On February 11, 1969, the Prime Minister, BJ Vorster, and his Cabinet came out firmly in favour of the Van Eck recommendations, and voted the funds for not only the construction of a complete enrichment pilot plant, but also for continued research for the next two years.[69]

In order to co-ordinate all the activities preceding the establishment of the pilot plant for uranium enrichment, the Minister of Mines appointed the Executive Committee (Production) for Uranium Enrichment: Dr AJA Roux, President of the Atomic Energy Board (Chairman), JP Coetzee (Managing Director of ISCOR), Dr TF Muller, Dr RL Straszacker, Dr HJ van Eck, Dr WL Grant (Director of the Atomic Energy Board), B von M Louw, JGW van Zyl and Mrs P Oliver (clerk).[70]

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68 (AECA) HL de Waal: **Uraanverryking in die Republiek van Suid-Afrika**, pp. 38-40.

69 AR Newby-Fraser: **Chain Reaction**, pp. 101-102.

70 (AECA) Review of the XYZ-project by Dr AJA Roux, Minutes of the meeting of the Executive Committee (Production) of the AEB for uranium enrichment, 20 March 1969, p. 1; HL de Waal: **Uraanverryking in die Republiek van Suid-Afrika**, p. 42.

Dr WL Grant recalled Prime Minister Vorster's visit to Pelindaba after the Van Eck Report had been accepted by the Government. Dr Roux informed the Prime Minister that a sum of R550 million would be required for the establishment of a pilot plant. Mr Vorster asked Dr Roux whether the project could not prove to be a white elephant. He said that he was not a scientist, but if Dr Roux considered it a venture to be undertaken, he would support it.[71]

Therefore, from the beginning it was apparent that the cooperation that the nuclear scientists had experienced with the Nationalist Government under Dr Verwoerd, would be continued under the leadership of Mr Vorster.

All efforts were aimed at bringing the pilot enrichment plant into operation as soon as possible, although even a small-scale plant for uranium enrichment was clearly a large undertaking. There were many problems in incorporating laboratory results on uranium enrichment to a pilot enrichment plant. These problems, however, were not insurmountable.[72]

The plant was to be a research and development facility, the most important aim being to demonstrate the new process on an industrial scale to establish the design and cost parameters of a full-scale plant.[73] The pilot plant was to demonstrate that the South African process could compete economically with the foreign processes. Consequently, mass production methods of manufacturing separation elements, for instance, became a matter of high priority.[74]

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71 Interview with Dr WL Grant, 29.7.1989; "Kernaanleg van R550 miljoen. Verrykte uraan vir die hele vrye wêreld", **Die Burger**, 25 May 1973.

72 AJA Roux: Talk on the Radio programme, "Top Level", 27.6.1971.

73 (WL Grant: Private Collection) AJA Roux and WL Grant: **Uranium Enrichment in South Africa**, Presentation to the European Nuclear Conference, April, 1975, p. 3.

74 AR Newby-Fraser: **Chain Reaction**, p. 102.

At the first meeting of the Executive Committee (Production) of the AEB on 20 March 1969, Dr AJA Roux welcomed the members of the Committee to the meeting and gave a short review of the history of the XYZ-project. He mentioned that since 1963 (when the Verwoerd Government granted the first funds for uranium enrichment) to 31 March 1969, the sum allocated for the XYZ-project by the Government amounted to R3, 29 million.[75] At this meeting Dr Grant informed the Commitee that the uranium enrichment research group was in full swing and co-ordinating activities in the various sub-groups, namely vortex tube development; compressor development and compressor components; security; instrumentation and management; plant and process development; analytical and chemical research; theoretical studies; and economic studies.[76]

As soon as the Executive Committee (Production) set about organizing the Y-project, the purely research character of the enrichment group changed to one with production as the goal. This necessarily resulted in economic factors playing a more significant role.

The top management, headed by Dr Grant, set about organizing every facet of the enrichment pilot plant. Three aspects were crucial: enough separating elements had to be manufactured at a competitive price, compressor development had to be finalised and the technique of linking the stages of separation had to be perfected.[77] A fourth aspect, not as vital as the first three, but essential, was accommodating hydrogen and uranium hexafluoride (UF_6) in the pilot plant process.[78]

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75 (AECA) Review of the XYZ-project by Dr AJA Roux, Minutes of the meeting of the Executive Committee (Production) of the AEB for uranium enrichment, 20 March 1969, p. 2.

76 **Ibid.**, p 4.

77 The achievements of Drs RS Loubser, PC Haarhoff and JJ Wannenburg on these aspects have been mentioned.

78 Interview with Dr RS Loubser, 28.7.1989.

A plant to produce uranium hexafluoride was established in 1967. By means of the Fluorox process the quantities of UF_6 required for the pilot enrichment plant were produced.[79]

In 1969, when it had been decided that a pilot enrichment plant would be built, fundamental and applied research of uranium hexafluoride was undertaken at an accelerated pace. It was a most difficult time as the chemistry team was placed under great pressure to provide proficient answers. The only premises available was the laboratory of the Atomic Energy Board. Being a new field of research, a laboratory had to be built up from scratch and equipped for these specialized investigations. In 1969 there was little, if any, collaboration with other organizations. The investigations of the chemical scientists were too specialized and security too stringent. That they were working with uranium hexafluoride or hydrogen was not mentioned outside the laboratory.[80]

Dr Roux favoured that both the pilot plant as well as the large commercial plant be built in close proximity to Pelindaba. Other important aspects that were given, were a possible site for the proposed pilot (Y) plant; a water supply for cooling and the necessary power supply from ESCOM for the Y-plant.[81]

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79 Interview with Dr DM Kemp, 24.4.1991; AR Newby-Fraser: **Chain Reaction**, pp. 74-75; Since much, if not all, of the uranium sold by South Africa was destined to pass through an enrichment plant, an economic evaluation of the feasibility of UF_6 production in South Africa, using established technology, was undertaken by NUFCOR. The conclusion was reached that from a purely commercial point of view it would not be an attractive investment because, if a purchaser were to require uranium in the hexafluoride form, it would be more economical to ship the concentrate to Britain for toll conversion to UF_6 and then on to the final destination. The Atomic Energy Board would itself have to become directly involved with UF_6 production for commercial purposes. A joint decision was taken by NUFCOR and the AEB. A UF_6 pilot plant would be established at Pelindaba, and a UF_4 pilot plant to feed it would be purchased and erected by NUFCOR at their works. Both ventures would be jointly financed by the AEB and NUFCOR. The UF_6 plant was successfully commissioned in 1976.

80 Interview with Dr DM Kemp, 24.4.1991.

81 (AECA) Minutes of the meeting of the Executive Committee (Production) of the AEB for uranium enrichment, 28 April 1969, p. 6.

At the third meeting of the Executive Committee (Production) on 30 June 1969, Dr PJ Riekert attended in the place of Dr HJ van Eck who had taken ill. Progress on the XYZ-project was reported. Aspects such as conditions of service of the staff and the delivery date of the mass spectrometers were discussed. Dr RH Loubser was appointed Chief Executive and Dr JJ Wannenburg Chief Engineer of the Y-programme. It was decided that the pilot plant would be located in the immediate vicinity of Pelindaba.[82]

On 8 August 1969 the senior officials of the XYZ-programme were appointed by the Executive Committee (Production) in consultation with the Minister of Mines: Dr WL Grant (Director General - Production Research); Dr RS Loubser (Director of the Y-programme); Dr JJ Wannenburg (Assistant-Director of the Y-programme) and B von M Louw (Senior Administrative Official). On 1 November 1969 RA Barbour was appointed (Assistant-Director - Planning and Design); J du P Dippenaar (Assistant- Director - Construction) and Messrs SW Liebenberg (Head - Internal Manufacture); WC Botha (Head - Quality Control) and D Lion-Cachet (Advisor to the Chairman and the Executive Staff).[83]

Dr Roux (Chairman of the Executive Committee, Production) would be responsible for the pilot enrichment plant policy in general, financial control, appointment in general, financial control, appointment of senior officials, and both the design and the development of the site for the Y-plant. Dr Grant would be in charge of the research and development programme of the pilot enrichment plant as well as the technical and scientific aspects thereof. Dr Loubser was given the task of planning and designing the pilot plant. Manufacture, construction and the setting in motion of the Y-project at a given time was also his

82 (AECA) HL de Waal: **Uraanverryking in die Republiek van Suid-Afrika**, p. 44.

83 **Ibid.**, pp. 44-45; (AECA) Meeting of the Executive Committee (Production) of the AEB for uranium enrichment, 8 August 1969, pp. 2-5.

responsibility. The scientific and technical features would be designed in consultation with Dr Grant.[84]

In August 1969 an uranium enrichment draft bill was put before the Executive Committee (Production) for consideration as the Cabinet wished to come to a decision before the end of August 1969 concerning legislation regarding uranium enrichment that would have to be introduced to Parliament during the following parliamentary session. It was not definite that legislation would be put through Parliament during 1970 for various strategic apparatus had to be imported from overseas before the uranium enrichment process could be made public. However, the Executive Committee (Production) accepted the draft bill for uranium enrichment in principle on 8 August 1969.[85]

At the August meeting Dr Roux said that the site for the uranium enrichment research and development programme would require stringent security. For this reason the Atomic Energy Board had obtained permission from the Cabinet to acquire sites 62 and 64 of the farm Welgegund, owned by the Preller-brothers and situated near Pelindaba. There was much to recommend close proximity of to Pelindaba. Since in the selection of Pelindaba's location in the early sixties the choice had deliberately fallen on a sparsely populated area, there was space to spare for the new establishment in the immediate vicinity. The Department for Agricultural Credit and Land Tenure was negotiating to buy the properties from the Preller brothers for R100 000. Dr Roux said that a second area, site 24 of the same farm Welgegund which was in close proximity to the former area and in private ownership should for security reasons also be acquired by the

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84 (AECA) HL de Waal: **Uraanverryking in die Republiek van Suid-Afrika**, p. 5.

85 **Ibid.**, pp. 7-8.

AEB. The areas mentioned were chosen by Dr Roux because they were concealed and level for construction purposes.[86]

In February 1970 Dr JJ Wannenburg indicated that the experimental work on the suction compressors was proceeding very well and that he believed the crucial problems connected with sealing and the piston rings of the suction compressor would be resolved before the end of 1970.[87] The compressor was an essential part of the enrichment plant. The manufacture of the separating element and the development of the compressors were the two most difficult aspects of the Y-project.[88] Originally suction compressors were designed for the low flow stages of the plant, and screw compressors for the high flow stages. Experimental work on the suction compressor had progressed faster than that done on the screw compressor. However, at that point much work still remained to be done on the valves for the suction compressor. The development of suitable valves was a particularly delicate aspect and required extensive research. It was decided that only suction compressors would be used in the pilot plant, and that priority would be given to suction compressors rather than screw compressors in the development programme. Research would proceed on the screw compressor until September - October 1970, and then a final decision would be made as to whether the research would continue.[89] At the meeting of 11 February 1970, it was decided that the firm AH Pullman and Son would be appointed to manufacture 15 - 20 prototype suction compressors.[90]

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86 (AECA) HL de Waal: **Uraanverryking in die Republiek van Suid-Afrika,** pp. 8-9.

87 (AECA) Meeting of the Executive Committee (Production) of the AEB for uranium enrichment, 11 February 1970, p. 4.

88 Interview with Dr RS Loubser, 28.7.1989.

89 (AECA) HL de Waal: **Uraanverryking in die Republiek van Suid-Afrika,** pp. 45-46.

90 (AECA) Meeting of the Executive Committee (Production) of the AEB for uranium enrichment, 11 February 1970, p. 8.

Early in 1970 site 24 of the farm Welgegund near Pelindaba for the site of the uranium enrichment undertaking was purchased. The new site would be named Valindaba - from the Zulu verb "vala" meaning "to close" and "indaba" meaning "the council"; hence "the council is closed".[91]

Dr HJ van Eck passed away on 19 February 1970. In a tribute to Dr van Eck, Dr Roux said that Dr van Eck had made a significant contribution to the economic development of South Africa. As a member of various committees of the Atomic Energy Board, Dr van Eck had through the years worked in close co-operation with the Board. The Executive Committee (Production) recommended to the Minister of Mines that Messrs Brand Fourie (Secretary of External Affairs) and MT de Waal (Deputy Manager of the Industrial Development Corporation) be appointed on the Executive Committee (Production). The Minister approved the recommendation. At the meeting of the Committee (Production) on 16 April 1970, Drs Straszacker and Muller (Member of the Chamber of Mines) congratulated Dr Grant and his staff on the remarkable progress that had been made with the XYZ-project after April 1968, when they and Dr Van Eck were called upon to assess the vortex tube enrichment process.[92]

It was decided that Roberts Construction Company would be approached as the building contractors and building consultants for the pilot plant.[93] This firm had constructed the buildings that housed the SAFARI I reactor. Dr Roux had personal contact with the managers and regarded the firm as reliable for such a highly scientific undertaking. Because of the secrecy of the project, as well as the security risks involved, there was no question of calling for tenders. S

91 (AECA) HL de Waal: **Uraanverryking in die Republiek van Suid-Afrika,** pp. 46 and 49.

92 **Ibid.,** p. 47; Meeting of the Executive Committee (Production) of the AEB for uranium enrichment, 16 April 1970, pp. 1-2.

93 (AECA) Minutes of the meeting of the Executive Committee (Production) 16 April 1970, p. 9.

van der Walt was appointed Project Manager by Roberts Construction Company. The management of the construction of the pilot plant was, therefore, largely in the hands of Dr RS Loubser and S van der Walt. Dr Loubser had the scientific know-how and Van der Walt the practical knowledge of building and construction.[94]

By the beginning of 1970 it was possible to establish accurate estimations for the Y-project. The confidence that the management of the Y-project had that the undertaking would be economically viable and the product would be competitive on the world market, was not just speculation, it was grounded on a thorough investigation in the classified Report UKP 18/70: Specifications and Nuclear Statistics for the Pilot Plant compiled by Drs WL Grant and RS Loubser in conjunction with the scientific personnel.[95]

The point had been reached at which detailed planning could be undertaken, purchases and contracts could be negotiated and even the date on which the pilot plant would be set in motion, (namely, April 1974), could be determined. On 13 November 1970 a few men made their way along a farm road on site 24 of Welgegund. Drs Roux and Grant dug a few spadefuls of soil as a symbolic beginning of construction, and Roberts Construction Company could commence their immense task.[96]

The Uranium Enrichment Process becomes Public

Inevitably more and more organizations and persons other than AEB staff members became involved in the preliminary work, and the

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94 Interview with Dr RS Loubser, 28.7.1989; (AECA) Minutes of the meeting of the Executive Committee (Production) 16 April 1970, pp. 9 - 10.

95 (AECA) HL de Waal: **Uraanverryking in die Republiek van Suid-Afrika,** p. 48.

96 **Ibid.,** p. 49.

possibility of maintaining secrecy as to the nature of the activities receded. Before long many hundreds of workers would be invading the selected site, and at that stage it would be inevitable that sufficient loose talk would take place for the purpose of the project to become known. The Prime Minister was consulted. It was Mr Vorster's decision that the uranium enrichment process should be made public.[97]

The general public in South Africa had little, if any, knowledge of the scientific developments taking place at Pelindaba. An indication of this, is illustrated by the following extract. Dr A Radford (MP for Rosettenville), in the debate in Parliament on 26 May 1967, that followed the Second Reading of the Atomic energy Bill (No. 93 of 1967) said that he believed the Bill was not a "forward-looking Bill". He was not disputing the control that the Government was placing on source materials (such as uranium) and the prospecting and mining of these materials, but he thought the Atomic Energy Board was not doing enough to encourage the endeavours of research scientists in South Africa. He wondered whether scientific discoveries relating to nuclear energy would be allowed to be developed in South Africa.[98]

In answer to Dr Radford, the Minister of Mines, Dr C de Wet, gave the House of Assembly an indication that South Africa was doing significant research as far as nuclear energy was concerned. He allayed fears that the Atomic Energy Board was not sufficiently qualified to judge the merit and significance of scientific accomplishments, as well as the value of South Africa's nuclear resources. He said that he could not go into details but that: "we are doing research in this country which might - and here I want to be very careful - put South Africa on the map as never before. We are certainly giving a lead in the atomic energy field. I have personal knowledge of this based on the part

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97 (AECA) HL de Waal: **Uraanverryking in die Republiek van Suid-Afrika,** p. 48.

98 **Assembly Debates**, vol. 21, 1 May - 15 June 1967, col. 6751-6752.

played by the Director General (of the Atomic Energy Board) and other officials at international conferences."[99]

Although it was decided by the South African government to develop the South African enrichment process, there were factors that delayed a public announcement. The discovery of a unique South African process was very significant politically, financially and internationally.

Firstly, there was the whole question of security. The Prime Minister was not in favour that all the employees of the Atomic Energy Board at Pelindaba should be informed about the project. A separate organization would be brought into being that would control uranium enrichment and work in conjunction with the Atomic Energy Board. This separate organization would have to have legal status. A bill would in time be drafted and introduced to Parliament. This would take time as the preparatory work of the Executive Committee (Production) with regard to the pilot plant would largely have to be completed before the bill could be finalised.[100]

Secondly, the Executive Committee (Production) in consultation with the Prime Minister and the Minister of Mines had to consider whether a financially strong foreign partner should be brought into the South Africa enrichment undertaking. Collaboration could only take place after much consultation and after the Prime Minister was fully informed concerning the process and the pilot plant. The United States of America would have to be informed that South Africa had developed a new process for uranium enrichment before collaboration with a foreign partner could be undertaken.[101] According to Dr RS Loubser, South Africa was not prepared to share its nuclear discoveries either for commercial or any other reasons. In addition, South Africa's political

99 **Assembly Debates**, vol. 21, 1 May - 15 June 1967, col. 6753-6755.

100 (AECA) Minutes of the meeting of the Executive Committee (Production) of the AEB for uranium enrichment, 20 March 1969, pp. 3 - 4.

101 **Ibid.**, pp. 8 - 9.

policy and refusal to sign the Nuclear Non-Proliferation Treaty in 1968 would deter foreign collaboration with the South African Atomic Energy Board.[102] Foreign financial support would have resulted in a far larger enrichment endeavour. Going it alone and utilizing local manufacture had a tremendous effect on how the pilot enrichment project was undertaken.[103]

Other aspects that delayed the public announcement in Parliament were the problems acquiring a suitable location for the plant, negotiating the necessary water and electricity supplies and finalising the plans for the internal construction of the plant.[104]

On Friday, July 18, 1970, and Saturday, July 19, 1970, Dr Roux and Dr Grant met with Mr Vorster and members of his Cabinet at Groote Schuur, the official residence of the Prime Minister in Cape Town, in order to make recommendations and to assist the Prime Minister in the final draft of the speech which he was to deliver in the House of Assembly, the following Monday, announcing the discovery of South Africa's unique process. Present at the meeting were Dr Carel de Wet, Minister of Mines; Dr H Muller, Minister of External Affairs; PW Botha, Minister of Defence; Dr N Diederichs, Minister of Finance, and Brand Fourie, Secretary of External Affairs. Mr Vorster informed the scientists and Cabinet Ministers present exactly what he was going to announce in Parliament. The announcement was prepared in both official languages of the country, English and Afrikaans. It was decided that all the foreign ambassadors would be invited to the official announcement, and that the speech would be delivered in English so that the press and overseas countries would clearly understand what had

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102 Nuclear Non-Proliferation Treaty: see also Chapter 9.

103 Interview with Dr RS Loubser, 28.7.1989.

104 (AECA) Meetings of the Executive Committee (Production) of the AEB for uranium enrichment, 28 April 1969, p. 6; 11 Feb. 1970, pp. 3 - 4; 16 April 1970, pp. 2 - 3.

been achieved and how the Government intended dealing with the implications thereof.[105]

Speaking in English for the benefit of foreign visitors and pressmen, on 20 July 1970, the Prime Minister announced to Parliament that scientists of the Atomic Energy Board had succeeded in developing a new and unique process for uranium enrichment, as well as the extensive associated technology. The Atomic Energy Board had concerned itself with uranium enrichment particularly for two reasons. It was more lucrative to market uranium in the enriched form and South Africa was considering a large nuclear programme of its own. According to Mr Vorster the South African process was developed to the stage where it was estimated that under South African conditions, a large-scale plant could be competitive with existing plants in the West.[106]

The Prime Minister said that it was impossible to mention the names of all the scientists and technical personnel who contributed to that important development, but he mentioned the names of Dr AJA Roux and Dr WL Grant specifically.[107]

He emphasized that South Africa's nuclear research and development was directed entirely towards peaceful purposes. South Africa was prepared to collaborate in the exploitation of the process with any non-communist country desiring to do so. Such an agreement would, however, safeguard South Africa's interests. Although South Africa had not yet acceded to the Non-Proliferation Treaty, the Government had on various occasions clearly stated that it would consider

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105 Interview with Dr WL Grant, 29.7.1989.

106 (AECA) AEB, **Aankondiging deur Die Eerste Minister, Maandag 20 Julie 1970,** pp. 1-5; **Assembly Debates**, vol. 29, 17 July to 23 August 1970, 20 July 1970; **The Argus,** "Uranium, Benefits for South Africa".

107 **Ibid.**

participation as soon as the safeguards system to which South Africa would be subjected, was known.[108]

The decision to build an uranium enrichment pilot plant to prove whether Dr Grant's method could ultimately be used for commercial production was a watershed in South African uranium and nuclear energy development. The decision involved certain implications. A few of these were highlighted by the Minister of Mines and members of the House of Assembly during the debate on the Uranium Enrichment Bill: The Atomic Energy Board and Pelindaba were geared for research. A commercial corporation would have to be brought into being in order to coordinate production and later enter the field of commerce. Because the South African process was unique, secrecy was of the greatest importance. Although the AEB consisted of persons of the highest integrity, they represented a number of organizations. Therefore it was advisable to establish a corporation that would solely deal with uranium enrichment.[109] This would not cause a duplication of costs. The corporation would cooperate very closely with the Atomic Energy Board, and would make use of certain expensive facilities which the Atomic Energy Board already had at its disposal, as well as the expert services of the National Metallurgical Institute (NIM).[110]

Control of the enriched product had to be established. The exercising of the general powers of the corporation would be subject to the directions of the Minister of Mines and the relevant provisions of the Atomic Energy Act. The provisions of the Act would retain control

108 (AECA) AEB, **Aankondiging deur Die Eerste Minister, Maandag 20 Julie 1970,** pp. 1-5; **Assembly Debates**, vol. 29, 17 July to 23 August 1970, 20 July 1970; **The Argus,** "Uranium, Benefits for South Africa".

109 **Assembly Debates**, vol. 29, 17 July to 23 August 1970, 27 July 1970, col. 462-463.

110 **Ibid.**; The Government Metallurgical Laboratory's name was changed to the National Metallurgical Institute (NIM) in April 1966.

over the enriched material for the Atomic Energy Board. This, the Minister regarded as a very important point.[111]

Financing uranium enrichment was a major consideration. The Minister called attention to clauses 5, 6 and 7 of the Uranium Enrichment Act which dealt with the finances of the corporation. As far as the finances of the corporation were concerned, a sum of R50 million was mentioned in clause 5 (1). The Minister of Mines could not guarantee that this would be the amount required. It could be less, or could be far more. The costs of the large-scale installation (pilot plant) for the enrichment process were impossible to calculate accurately at that point. The amount not required immediately would be invested with the Public Debt Commissioners. Clause 7 made provision for the tabling of the reports and statements of account of the corporation, unless disclosure of reports and statements in the opinion of the government, would jeopardize the safety of the State or be contrary to the public interest.[112] With reference to Clause 8 of the Bill, the Minister stated that regulatory control would be essential when the corporation's activities came into full operation, but that it would not be practicable to control all these activities by way of legislation as such.[113]

Other aspects that would have to be considered were whether market experts in industrial know-how should be appointed to the controlling board of the corporation and to what degree would private enterprise be represented in the corporation. Provision would have to be made that workers did not come into contact with health hazards, unless suitably

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111 **Assembly Debates**, vol. 29, 17 July to 23 August 1970, 27 July 1970, col. 46-.

112 Uranium Enrichment Act (No 33 of 1970) clauses 5, 6 and 7. **Government Gazette**, 21 Aug 1970, No 2783, p. 8.

113 **Ibid.**

protected and that compensation should be provided for harm done to the health of workers.[114]

The Minister stated in his closing address that it was the intention of the Government to appoint not only scientists but persons in commerce and industry to the board of the uranium enrichment operation. South Africa would not deal with Communist countries and that the corporation was subject to all the laws of the country relating to pollution and health hazards.[115]

Although South African industries were not participating financially, they were making a very substantial contribution in the erection of the pilot plant - in this way benefitting financially.[116]

In order to realize the government's decision to enrich uranium and to put into effect the stipulations of the Uranium Enrichment Act every effort was put into the construction of the pilot plant which was to be completed in 1974.

Perfecting the enrichment process as well as the coordination of the building of the pilot plant and furnishing it with sophisticated technical equipment was assigned to the Uranium Enrichment Corporation (UCOR). The corporation was brought into being by the Uranium Enrichment Act (Act 33 of 1970) on 21 August 1970.[117]

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114 **Assembly Debates**, vol. 29, 17 July to 23 August 1970, 27 July 1970, col. 465-468.

115 **Ibid.**, col. 475-47?.

116 **Assembly Debates**, vol. 29, 17 July to 23 August 1970, 27 July 1970, col. 475-478.

117 **Government Gazette**, No. 2783, 21 August 1970, pp. 3-11. On 16 November 1970 the Board of Directors of the Uranium Enrichment Corporation of South Africa was appointed. Dr AJA Roux (Chairman); Dr RL Straszacker (Vice-Chairman); JP Coetzee, BG Fourie, Dr GSJ Kuschke, Dr TF Muller, Dr PJ Riekert and JW Shilling (Members). The Board of Directors of UCOR was, therefore, much the same as the Executive Committee (Production). (AECA) HL de Waal: **Uraanverryking in die Republiek van Suid-Afrika**, pp. 49 - 50; For security reasons the Minister

With the founding of UCOR economics would play a predominant role. The ultimate objective in the founding of UCOR was to make South Africa an independent producer of enriched uranium, and to produce a product for its own power reactors, as well as to be a supplier on the world market. In other words, uranium enrichment would become an extensive State-controlled business undertaking.[118] The Republic, then the third largest supplier of uranium concentrates in the Western World, would also enter the international arena with the enriched product. In 1970 the United States of America still had the monopoly. The United Kingdom, France, Holland, the Federal Republic, China and the Soviet Union were all contemplating production plants for uranium enrichment.[119]

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of Mines decided that the names of the Directors would not be made public. Vid **Assembly Debates,** vol. 29, 17 July to 23 August 1970, 27 July 1970.

118 On 1 April 1971, the Uranium Enrichment Corporation (UCOR) was established as a Government Corporation. It was announced by the UCOR Chairman, Dr AJA Roux, who at that time was also President of the Atomic Energy Board. (According to the Atomic Energy Amendment Act (No. 34 of 1970), the title of the head of the Atomic Energy Board was changed from "Chairman" to "President".) **Government Gazette**, No. 2783, 21 August 1970, pp. 3-7; **Assembly Debates**, vol. 29, 17 July to 23 August 1970, 20 July 1970, col. 480.

119 (AECA) Uraanverrykingskorporasie van Suid-Afrika, Beperk, Persverklaring van die Kantoor van die Voorsitter, 1/71, 1 April 1971; HL de Waal: **Uraanverryking in die Republiek van Suid-Afrika,** p. 45.

CHAPTER NINE

THE SOUTH AFRICAN URANIUM INDUSTRY IN POLITICAL AND INTERNATIONAL PERSPECTIVE

South Africa's international position during 1955 to 1970, and the realization that it would have to protect its vital national interests against an increasing hostile world, would determine the course of nuclear energy development and give the implementation of nuclear power in South Africa a further dimension of strategic importance. In 1963 South Africa was not one of the nations that signed the Nuclear Test Ban Treaty. The United States and other Western countries were wary of South Africa's hesitation. This led to a deterioration of relations between South Africa and both the United States and the United Kingdom. In the IAEA South Africa found it difficult to maintain status. South Africa was becoming aware of increasing animosity from the international community. The international situation gave greater impetus to the initiatives of South African scientists and engineers to develop a South Africa uranium enrichment method. South Africa's outstanding enrichment achievement would inevitably bring about political repercussion and some could just not believe that it was a South African scientific achievement. Although the sanctions measures did not effect nuclear development before 1970, there was an awareness that economic sanctions would ultimately also lead to nuclear sanctions.

Instigating Forces behind the Establishment of the Uranium and Nuclear Industries in South Africa

Without doubt, the accelerated endeavours of Western scientists to create an implosive assembly before the Axis powers, had a direct bearing on the discovery of uranium in South Africa. South Africa's uranium which is of a low grade, was assiduously assessed by the combined efforts of the United States, the United Kingdom, Canada and South Africa, primarily because it was discovered at a time when the known deposits of the world were in the hands of the enemy and inadequate for future needs. The urgency of the investigations was intensified by the Cold War situation that developed between the Western Allies and the Soviet Union during the late 1940's and the post-war international relations contributed to the establishment of the uranium industry in South Africa.

General Smuts took a keen interest in the development of nuclear science and uranium during the war. Both he and Dr Schonland favoured the British connection in South Africa. According to Dr SJ du Toit who played a leading role in the nuclear development from the 1940's to 1970, South Africans today do not realise how Anglicized technology and science were during the 1940's. On nuclear decisions General Smuts and the Uranium Research Committee were more inclined to consult with British Authorities as to what to do, and then come to a decision.[1]

Although decision making concerning the investigations of uranium during the 1940's lay with General Smuts and the Uranium Research Committee, the establishment of the uranium extraction plants at a number of mines on the Witwatersrand were executed under National Party leadership.

As South Africa provided the United States and Britain with huge amounts of uranium for employment in various military programmes during the early fifties, a basis for good nuclear cooperation between South Africa and the Western Nations was created. According to William A Hance, during the late fifties and early sixties, uranium oxide ranked as the number one United States import from South Africa. It's value declined considerably in 1964 and 1965 owing to the fulfillment of contracts.[2]

1 Interview with Dr SJ du Toit, 9.1.1992.

2 William A Hance (ed): **Southern Africa and the United States**, p. 121.

President Eisenhower's Atoms for Peace plan that led to the cooperation agreements between the United States and South Africa and the United Kingdom Atomic Energy Authority and the South African Atomic Energy Board contributed to the establishment of the nuclear industry in South Africa.

Fissile material was made available in South Africa for reactor research, research reactors and nuclear power production. South Africa could therefore consider nuclear power as a future alternative power source.

Dr Malan placed a great emphasis on local manufacture. He insisted that the cyclotron be manufactured in South Africa. This was an illustration of how the Nationalist Government would stress independence from Britain and overseas countries, and place the accent on the exploitation of South African resources for the benefit of the country.[3]

The Government wished to advance nuclear studies in South Africa. According to the Minister of Mines, Dr AJR van Rhyn, it was essential and justified that £330 000 was invested in the National Physical Laboratory and its highly technical equipment. South Africa should not rely on research done overseas or import experts from abroad. South Africa, with her limited resources, could contribute something worthwhile to the development of nuclear science.[4]

The peaceful uses of nuclear energy compelled South African industrialists and scientists to look beyond the borders of South Africa. Firstly, they investigated advancements abroad, and secondly, deliberated South Africa's power resources and considered whether nuclear power production could be an alternative. It was essential that

3 Interview with Dr SJ du Toit, 9.1.1992.

4 (Dr D Reitmann: Private Collection) Address by Dr Van Rhyn, Minister of Mines and Economic Affairs, at the official inauguration of the cyclotron on January 1956, pp. 3-6.

progress that had been made in nuclear research be evaluated before South Africa embarked on nuclear development. Advancement was so rapid that a country could not afford to be ignorant of the very latest improvements and new technologies. Of particular importance were centres of learning where South African graduates would be able to further their studies in nuclear science and engineering.

The knowledge gained by South African nuclear scientists at Argonne National Laboratory, Lemont, Chicago, which was particularly well-equipped for specialized training in reactor engineering, reactor physics, metallurgy and research reactor design and operation, as well as the Oak Ridge National Laboratory, Tennessee, USA contributed greatly to nuclear development in South Africa.

The major decision, whether South Africa would institute a nuclear energy research and development programme, ultimately lay with the Nationalist Government. The Government, realising that energy was one of the most important cornerstones for economic growth, strove to make South Africa economically resourceful. The composition of the Strijdom and the Verwoerd Cabinets in the second half of the 1950's has bearing on the development of nuclear energy in South Africa. Men in key positions in the Government had for the aforegoing twenty years been directly involved with the republican goal. Economic factors were a priority, for the Government wished South Africa to become a republic within the Commonwealth of Nations such as India, Pakistan, Ghana and Ceylon and in this way maintain its international economic connections. Interference with South Africa's internal policies by members of the Commonwealth compelled Dr Verwoerd to withdraw his request for South Africa to remain a member of the Commonwealth.[5] It is difficult to assess exactly to what extent these motivations and the diplomacy of isolation in the late fifties and early

5 PW Coetzer and JH le Roux: **Die Nasionale Party**, vol. 4, pp. 114-125; AN Pelzer: **Die Afrikaner-Broederbond: Eerste 50 Jaar**, pp. 46, 54-55, 155-156, 168; BM Schoeman: **Die Broederbond in die Afrikaner Politiek**, pp. 7-8, 10-11, 17-19; D Geldenhuys: **The Diplomacy of Isolation**, pp. 11, 22-24, 31; GC Olivier: **Suid-Afrika se Buitelandse Beleid**, pp. 61-63.

sixties, contributed to nuclear energy decision-making by the Nationalist Government, but certainly they cannot be disregarded.

From the aforegoing history the role of Dr TEW Schumann might be assessed. Dr Schumann, formerly a Public Service Commissioner and head of the South African Weather Bureau, had had a long association with members of the Strijdom and Verwoerd Cabinets.[6] He understood the aspirations of the Government and in turn, the leaders of the Government knew that he shared their sentiments and would advise the Government as a colleague and compatriot. Although the Government certainly approved his appointment, Dr Schumann did not promote any specific sectarian interests. He was a man of integrity and a committed Afrikaner. As a senior member of the AEB (in years and as Deputy Chairman), he played a fatherly role and did not intercede in scientific programmes.[7] As Deputy Chairman of the AEB, he attended three major nuclear conferences during 1958, i.e. The Second International Conference on the Peaceful Uses of Atomic Energy at Geneva, the Meeting of Commonwealth Nuclear Scientists in London and the Second General Conference of the International Atomic Energy Agency in Vienna.[8]

The Nationalist Government would very largely depend on the judgment and recommendations made by Dr Roux of what he had learned about nuclear developments abroad. It was the general opinion among his contemporaries that it was Dr Roux's unique ability to put it across that he firmly believed in nuclear development in South Africa (in combination with his extensive knowledge of nuclear development overseas) that encouraged nuclear decision-making on the part of the government.

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6 **Annual Report of the South African Atomic Energy Board**, 1958, p. 3; (SAL) DB Sole: **This Above All** (Unpublished manuscript), p. 201.

7 Interview with Dr SJ du Toit, 9.1.1992.

8 **Annual Report of the South African Atomic Energy Board**, 1958, p. 3.

The United Nations Organization

During the years 1948-1956 the Nationalist Government, entrenched a racial policy that would later lead to great opposition against South Africa. In the early 1950's the government passed a number of Acts enforcing complete social and residential segregation.[9] Resistance against South Africa's apartheid policy did not only come from within the country's borders. The sharpest criticism came from overseas and countries of Africa.

The racial policy of South Africa in the form of the treatment of Indians had been before the General Assembly from the beginning of the United Nations, but it was not until 1952 that the policy of apartheid appeared on is agenda. From 1952, a growing number of resolutions regarding South Africa's racial policy were passed by the General Assembly of the United Nations. Up to 1960, however, these resolutions were largely verbal indictments and had no impact on the South African Government's determination to pursue its chosen course.[10] During the 1950's South African racial policy also had little effect on uranium and nuclear relations with First World countries. However, during the 1960's there would be signs of change and caution on the international front.

Resolutions condemning the policy of apartheid that appeared regularly on the agenda of the General Assembly established the claim of United

9 Population Registration Act (1950); Group Areas Act (1950); Separate Representation of Voters Act (1951). Prevention of Illegal Squatting Act (1951); Native Building Workers Act (1951); Native Services Levy Act (1952); Native Laws Amendment Act (1952); Bantu Authorities Act (1953); Bantu Education Act (1953).

10 Amry Vanderbosch: **South Africa and the World,** pp. 228-237; The Simonstown base and the sea route round the Cape were still important factors in British foreign policy, as the 1956 Suez crisis made clear. Their usefulness, however, could not have been extended by more precise definition of Alliance. The Anglo-South African naval Agreement of June 1955 created no political obligations for either party. JE Spence: **The Political and Military Framework,** pp. 9-10.

Brand Fourie and Minister Eric Louw during a debate in the General Assembly of the United Nations, October 1960

(Source: Brand Fourie: **Brandpunte**)

Nations to discuss issues, which although technically domestic, were deemed to involve accepted human rights and became therefore the concern of the international community of states. The Sharpeville shootings[11] of 1960, coincided with an increase in the African membership of the UN and brought the conduct of South Africa to the attention of the Security Council which passed resolution (5/4300) in April 1960 with only Britain and France abstaining, stating that the government's policies had led to international friction and if continued might endanger international peace and security. The support of the United States for the resolution marked a dramatic change in its attitude to South Africa. The British abstention was translated as a positive vote against South African policies in the General Assembly debate in April 1960 when a condemnatory resolution (1598 (XV)) received a massive majority of 96 to 1.[12]

In 1962 a resolution asking for economic and diplomatic sanctions was passed by the United Nations General Assembly, 67 votes to 16 with 23 abstentions. This resolution (1761, 6 November 1962) included a request to member states to close their ports and airports to South African ships and aircraft and refuse the sale of arms. A special committee was also established to consider further action. Although the resolution obtained a two-thirds majority, its application was not mandatory on member states. The United Kingdom and the United States voted with the minority.[13]

South Africa's predominant position as world producers of gold and diamonds and the country's geographical location were strong arguments against an isolation policy. They made isolation itself

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11 In quelling demonstrations against the pass laws on 21 March 1960 the South African police killed 69 Africans and wounded 178. Reaction to this event was immediate and worldwide. Amry Vanderbosch: **South Africa and the World,** p. 240.

12 JE Spence: **The Political and Military Framework,** pp. 105-106.

13 LES de Villiers: **US Sanctions against South Africa**, p. 47-48.

unreal.[14] Uranium being essential for the development of nuclear weapons, placed South Africa politically in a strong position. The world would want South Africa's uranium and South Africa would be regarded as an important bastion of Western Civilization.

It was not just the fact of South Africa's commercial importance and its production of gold that cultivated Western caution in the face of black African impetuosity; there were also strategic considerations: increased Soviet deployments and the fact that Western Europe was heavily dependent upon oil supplies transiting the Cape of Good Hope.[15] In addition to those strategic considerations there was a moral one: if economic pressures were used black South Africans would suffer the most.[16]

Under pressure from the African states, the United Nations had in late 1963 established a group of experts to advise it on the course of action concerning the problem of apartheid. When South Africa refused its cooperation, on the grounds of interference in its own domestic affairs, the Security Council appointed a new committee (June 18, 1964) to study the "feasibility, effectiveness and implications of economic sanctions". The vote was 8 for, none opposed, 3 abstentions (Czechoslovakia and the USSR wanted stronger action; France wanted weaker action). The affirmative United States and United Kingdom votes were coupled to reservations that these nations did not agree in advance to accept the committee's recommendations. More than five years later the United Nations General Assembly, on November 20, 1969, recommended voluntary sanctions against South Africa 80 to 5

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14 RB Hagart: "National Aspects of the Uranium Industry", **JSAIMM**, 57, April 1957, p. 578.

15 Western Europe's total daily oil needs in 1970-1971 amounted 12.3 million barrels a day, 4.2 million barrels of which came via the Cape route.

16 FH Hartmann: **The Relations of Nations**, pp. 541-542.

(Australia, Portugal, South Africa, the United Kingdom and the United States), with 26 abstentions.[17]

The IAEA

The pressure against South Africa in international organizations extended to the Specialized Agencies of the United Nations. The International Atomic Energy Agency (IAEA) was possibly the only scientific and technical organ of the United Nations to resist successfully the intrusion of politics for a very considerable time.[18] The Board of Governors was made up of representatives from a number of different countries. Every year the Board of Governors would elect its own Chairman. It was an accepted convention that none of the four atomic powers, the United Kingdom, the United States and the USSR would fill the Chairmanship of the Board of Governors.[19] The Board of Governors of the IAEA met for five sessions every year. (About ten or eleven weeks a year.) On the Board of Governors, nuclear scientists were very much in the minority. Nuclear scientists of the principal atomic countries normally led delegations to the General Conferences of the IAEA.[20]

Despite increasing political isolation, South Africa, as a major producer of uranium, in the late fifties, maintained status on the IAEA. With the establishment of the IAEA in Vienna, many countries maintained two diplomatic missions in the Austrian capital. South Africa's representative, DB Sole, was both Envoy Extraordinary and Minister

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17 LES de Villiers: **US Sanctions against South Africa**, p. 60; FH Hartmann, **The Relations of Nations**, pp. 194 and 541.

18 AR Newby-Fraser: **Chain Reaction**, p. 12.

19 (SAL) DB Sole: **This Above All** (Unpublished manuscript), p. 198.

20 **Ibid.**, p. 199.

Members of the South African delegation to the Fifth General Conference of the IAEA in Vienna (1961)

Left to right: DB Sole, South African Envoy Extraordinary and Minister Plenipotentiary in Vienna; JG Stewart, Under-Secretary of the Department of Foreign Affairs and AR Newby-Fraser, Head of the AEB's Liaison and Information Division

(Source: Annual Report of the South African Atomic Energy Board, 1961)

Plenipotentiary to Austria, as well as South African Governor and Resident Representative on the IAEA.[21]

In 1959, DB Sole was unanimously elected Chairman of the Board of Governors of the IAEA. During his years of office DB Sole made it his objective to base the Board's decisions on consensus, rather than on votes. No Board paper would be issued unless and until he was satisfied that it was in a form best suited to reaching Board Consensus. The use of this technique Sole believed, shortened the decision-making procedure to a considerable extent, minimizing political or ideological differences that existed in the Board, promoted a sense of teamwork and induced a spirit of compromise.[22]

As a member of the Board and during his year as Chairman (1959), Sole served as leader of the South African delegation to the Annual General Conference of the IAEA in Vienna. In this capacity he got to know the heads of the various atomic energy authorities in Britain, France, the United States, Canada, India, Argentine, Brazil and the Soviet Union.[23]

DB Sole returned to South Africa after the Fifth General Conference (1961) and JG Stewart was appointed Envoy Extraordinary and Minister Plenipotentiary in Vienna. After the Vienna Board Meeting in June 1963, Stewart warned that trouble was building up against South Africa in the IAEA and that the General Conference in September 1963

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21 As mentioned in a previous chapter South Africa secured a permanent seat on the Board of Governors. South Africa was regarded as the member most advanced in the technology of atomic energy in the region of Africa. IFA de Villiers believes that South Africa's participation in technical and scientific councils in Africa in the 1950's played a role in South Africa acquiring a seat on the Board. Interview IFA de Villiers, 15.8.1991.

22 (SAL) DB Sole: **This Above All** (Unpublished manuscript), pp. 200-201.

23 **Ibid.**, p. 201.

could be the occasion for an attack on South Africa's position in the IAEA.[24]

The Vienna Conference (September 1963) was the most difficult that DB Sole ever had to handle. Ghana wished to propose a resolution calling for the suspension or withdrawal of South Africa from the IAEA. In a personal account of what happened behind the scenes, Sole stated that Ghana could rely on 32 votes for such a resolution and South Africa could not be sure of more than 25 to 28 votes against, owing to the number of states that would abstain. The problem was that, although Western countries like the USA, the United Kingdom, France and Australia, were prepared to vote against any resolution directed against South Africa, they were not willing to speak against such a resolution, so there was no one to give a lead to the wobblers (those who were unsure of which way to vote). It was difficult to establish and maintain an initiative so that South Africa's opponents would not realise their weakness in votes. Behind the scenes the South African representatives played fully on the divisions in the African and Asian camps (notably between Ghana and Zaire and between India and Pakistan), sowing confusion where they could. No resolution was introduced in 1963.[25]

There was no attack on South Africa's position on the June 1964 IAEA Board of Governors session. (The June session "designated" the Governors for the next year in terms of the requirements of the IAEA Statute.) In the September 1964 General Conference there was no attempt to expel South Africa or deprive her of her rights.[26]

The Republic of South Africa maintained international nuclear relations at top level, even though at times the practical problems of distance and the demand on the time of the South African scientists and engineers

24 (SAL) DB Sole: **This Above All** (Unpublished manuscript), p. 247.

25 **Ibid.**, p. 248.

26 **Ibid.**, p. 248.

were taxing. The most important of the conferences was the Third International Conference on the Peaceful Uses of Atomic Energy held in Geneva, 31 August to 9 September, 1964. The South African delegation was Dr AJA Roux (head), Dr TEW Schumann, Professor SF Oosthuizen (Professor of Radiology) and Dr RL Straszacker (Chairman, ESCOM). The delegation was accompanied by some thirty-three advisors.[27] So many of the Board's scientists attended the Conference that the laboratories at Pelindaba seemed quite empty. However, the Atomic Energy Board derived much benefit from the large attendance at the Conference.[28]

As far as the International Atomic Energy Agency was concerned South Africa got off to a good start in 1965 because of a successfully negotiated trilateral safeguard agreement between South Africa, the United States and the IAEA regarding the application of Agency safeguards to the SAFARI I research reactor at Pelindaba. By the agreement South Africa provides the mandatory reports and accepts inspection visits by IAEA inspectors several times each year, whenever these may be required. The 1965 agreement was replaced two years later by a similar updated version which will remain in force as long as the reactor continues to be operated. Despite the baseless allegations levelled against South Africa, the terms of the agreement have always been meticulously observed, to the great satisfaction of the Agency and its international staff.[29]

As mentioned earlier, the concept of an organization to control nuclear materials and equipment and ensure their peaceful utilization, was entrenched in the Statute of the International Atomic Energy Agency (IAEA). This safeguard system bound the nuclear weapons signatory powers not to transfer nuclear weapons technology to any non-nuclear

27 **Proceedings of the Third International Conference on the Peaceful Uses of Atomic Energy**, vol. I, pp. 463-464.

28 **Annual Report of the South African Atomic Energy Board**, 1961, p. 8.

29 AR Newby-Fraser: **Chain Reaction**, pp. 10-11.

state. Signatory states were required to accept the IAEA safeguards system. Inspection was undertaken by inspectors appointed by either the country supplying the equipment and material, or subject to the consent of the supplier, by inspectors of the IAEA. The IAEA administered the inspectors as a service to its member states. With the establishment of nuclear plants for peaceful purposes in many countries of the world, more and more plutonium was being produced. All the plutonium was placed under the watchful eyes of the IAEA inspection system, except supplies in the nuclear power countries, i.e. USA, UK, USSR, France and China. The main problem was to try and make the inspection so secure that all plutonium that was formed could be accounted for. If this could have been done the danger would not have existed that a country with belligerent intentions could manage to embezzle small amounts for military purposes without being apprehended. By the sixties it was realised that a method would have to be found to totally contain nuclear proliferation.[30]

In June 1965, South Africa's representation had difficulty concerning South Africa's re-designation to the Board of Governors. Zaire proposed Israel (as the country most advanced in the technology of nuclear energy in the region of Africa and the Middle East) in South Africa's place. However, after a two hour debate, South Africa's re-designation went through. The 1965 General Conference of the IAEA in Tokyo proceeded well. The setback to the initiative by Zaire in the Board of Governors meeting in June had diminished the enthusiasm of the African representatives. DB Sole remained the South African Governor on the Agency's Board of Governors for ten years (1956-1966). His moderating influence and the high esteem in which all the other governors held him are acknowledged as having had a very

30 AJA Roux: "Uraanverryking", p. 26; Statute of the IAEA, Annex 4, in A McKnight: **Atomic Safeguards. A Study in International Verification,** pp. 205-218.

significant and progressive influence on the development of the IAEA.[31]

In 1966, when Brand Fourie had taken over from Gerard Jooste as Secretary for Foreign Affairs, it was decided that Dr AJA Roux would take over the leadership of the South African delegations to the IAEA General Conferences.

The United States, South Africa and Nuclear Proliferation

As was mentioned in a previous chapter the inability of the nuclear powers to agree on controlling nuclear weapons had left them by 1955 to explore the possibility of merely inspecting such armaments as each side decided to possess.[32] Neither the United States nor the Soviet Union trusted each other sufficiently to institute nuclear or conventional disarmament on a basis of good faith. It was unlikely that the superpowers would have been prepared to allow international inspection teams to probe arsenals at will anywhere in the world at any time. If no area could be blocked off as "unsuitable" for inspection there could be no more military secrets. The stabilization of nuclear arsenals at an agreed rate, without inspection was equally improbable. The danger was once nuclear tactical weapons had been developed and atomic "bombs" took the shape of artillery shells and could be numbered in the thousands, the chances for successful duplicity were great.[33]

According to George F Kennan, the Khrushchev era, and particularly the years from 1955 to 1960, presented what was unquestionably the most favourable situation that had existed since the 1920's for an improvement of relations between the United States and the Soviet

31 AR Newby-Fraser: **Chain Reaction**, p. 10.

32 FH Hartmann: **The Relations of Nations**, p. 291.

33 FH Hartmann: **The Relations of Nations**, p. 291; A Le Roy Bennet: **International Organizations, Principles and Issues**, p. 217.

Union, and for a tempering of what was by that time becoming a dangerous, expensive, and undesirable competition in weapons systems. Kennan believed N Khrushchev, the Soviet leader, to be intensely human, even in relations with an ideological opponent. He was someone with whom one could communicate.[34]

The Khrushchev period was not lacking in serious crises: the Hungarian rebellion of 1956, the Berlin crisis (1958-1962), the Suez crisis (1956)[35] and later the Soviet Union and the United States were preparing to arm themselves with nuclear weapons, capable of inflicting incredible damage to each other. With such weapons in place, the illusion of winning a war faded. Aware of the dangers, leaders in both countries began to develop proposals for arms limitation. They were however hampered by mistrust of each other.[36]

The major Soviet goal after the Korean War (1953) was a security agreement in Europe, preferably one that gained American recognition of the Soviet sphere of influence in Eastern Europe. American strategic thinking was that a rearmed Germany integrated into the Western alliance was essential to European and ultimately American security.[37]

The Soviet response to the rearming of Germany was benign. Rearming was tolerable to the Soviet leadership. Acknowledgement of the West German leader, Konrad Adenauer's was the Soviet Union's wisest choice.[38] In the mid 1950's there were some indications that the Cold War might be winding down. In February 1956 Khrushchev

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34 GF Kennan: **The Nuclear Delusion,** pp. 27-38.

35 **Ibid.,** pp. 38-40.

36 WI Cohen: **The Cambridge History of American Foreign Relations,** vol. IV, p. 88.

37 **Ibid.,** pp. 89-90.

38 H Hanek: **Soviet Foreign Policy since the Death of Stalin,** pp. 57-60.

delivered his famous speech to the Twentieth Party Congress in which he denounced Stalin and endorsed peaceful coexistence.[39]

However, the road to negotiations with the Soviet Union over disarmament proved rocky. In February 1958, Poland's Foreign Minister, Adam Rapacki, advanced a plan, supported by the Soviets calling for a zone in Central Europe comprising Poland, Czechoslvakia and the two Germanies to be kept free of nuclear weapons. Eisenhower and Secretary of State, JF Dulles, both said that such a small nuclear free zone would add nothing to the security of Europe.[40]

Early in May 1958, the United States through the United Nations, advanced a plan of its own calling for an international inspection zone in the arctic to guard against a surprise attack by either Russians or Americans. The Soviets vetoed it. They objected because the Soviet territory subject to inspection would be larger than the American. Basically, since the Russians feared an attack from Central Europe most and the United States dreaded an arctic attack, the Soviet and American plans were irreconcilable.[41]

In 1958, attention began to focus on proposals for achieving a nuclear test ban. Considerable world opinion feared the ever-rising radio-activity in the atmosphere resulting from tests. The nuclear powers had a certain mutual interest in encouraging the cessation of nuclear testing before such devices became more widespread among nations.

Those nations (like South Africa) that had initiated nuclear energy research and development programmes and could in future progress to nuclear testing, would not easily be able to defend a nuclear testing

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39 WI Cohen: **The Cambridge History of American Foreign Relations,** vol. IV, pp. 90-91.

40 A De Conde: **A History of American Foreign Policy,** p. 792.

41 **Ibid.,** p. 793.

programme by committing themselves to a test ban treaty. In this way nuclear proliferation would be curbed.

In July and August of 1958 technicians from both sides of the iron curtain conferred in Geneva. The United States and Britain had suggested that their scientists join Soviet scientists in ascertaining whether or not nuclear tests could be detected. They agreed in principle that tests could be discovered through a world-wide system of detection stations.[42]

A three power (USA, UK and Soviet Union) conference on the "Discontinuance of Nuclear Weapons Tests" opened in Geneva in October 1958.[43] Americans hoped would produce a political agreement on the control of broader agreements on general disarmament.

By late 1960 the political conference had evolved a draft treaty that, although incomplete, represented substantial progress. The Control Organization envisaged was to have joint teams that would monitor blasts from stations around the world. The teams would be granted access "to the site of any element of the System or any where an on-site inspection (would) be conducted."[44] Although the number of such permitted inspections proposed by Russia on July 26, 1960 was in the US view inadequate (only three), this proposal represented the first occasion on which the Soviet Union had gone so far as to give a figure. In 1961 the United States and the Soviet Union were able to agree on once more improving the UN disarmament machinery. As a result, in 1962, the UN sponsored Eighteen Nation Disarmament Committee (ENDO) began functioning in Geneva. It was eventually to become a

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42 A De Conde: **A History of American Foreign Policy**, p. 793.

43 After three years (October 1958-October 1961) of interrupted negotiations and 353 fruitless sessions, the conference brought about agreement on minor matters, but no final agreement. A De Conde: **A History of American Foreign Policy**, p. 793.

44 FH Hartmann: **The Relations of Nations**, p. 292.

forum to which the super powers would initially present agreements worked out between them.[45]

Progress in the next two years was interrupted by new crises centering on Berlin and Cuba. The abrupt breaking off of the negotiations and the large-scale resumption of testing by the Soviets in October 1961, culminating in their fifty megaton explosion, shocked public opinion around the world. The United States also resumed testing.[46]

In the aftermath of the two crises, Nikita S Khrushchev, the Soviet leader, indicated new interest in an agreement to ban tests. In December 1962, secret conversations were initiated, but the Soviets were still unwilling to permit more than two or three "on-site" inspections, whereas the minimum US figure was eight to seven. Because US insistence on its figure stemmed from the difficulty of distinguishing underground blasts from seismic disturbances, and because underground testing only has limited military advantages and does not pollute the atmosphere, the deadlock was overcome by divorcing the two categories of tests. The United States was confident that US monitoring systems were adequate to detect all above-ground blasts. The negotiations of mid-1963 now went forward rapidly, the issue of inspection was shelved and the treaty banning atmospheric tests was signed on August 5, 1963, and ratified by the US Senate by 80 to 19 on September 4. By the end of 1963, 113 nations had signed or acceded to the treaty. Some 336 nuclear explosions in the atmosphere over a thirteen-year period by the United States, the Soviet Union, and Great Britain were then ended.[47]

The Nuclear Test Ban Treaty prohibited tests in three environments: the atmosphere, outer space and under water. Parties to the treaty also

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45 FH Hartmann: **The Relations of Nations**; A Le Roy Bennet: **International Organizations, Principles and Issues,** pp. 211-212.

46 FH Hartmann: **The Relations of Nations**, p. 292.

47 **Ibid.,** pp. 292-293; A Le Roy Bennet: **International Organizations, Principles and Issues,** p. 216.

bound themselves to prevent the escape, beyond their natural boundaries, of radioactive debris from underground explosions and promised not to encourage or participate in any nuclear explosion anywhere that would violate the restrictions assumed under the treaty. South Africa did not sign this treaty, the reasons being that under the strictest security South Africa was in 1963 experimenting with the enrichment of uranium and South Africa was not the only country to abstain from underwriting the agreement for both France and Communist China refused to sign or be bound by the Nuclear Test Ban Treaty (NTBT). Their explosions continued.[48]

The achievement of the NTBT, despite these drawbacks registered an important change in the approach of the superpowers to questions of arms control. Beginning at this time, the superpowers began to abandon their essentially useless competition to sway the UN to their opposed point of view and instead sought direct agreement between themselves. This significant change in attitude continued in the following years.[49]

In general, the continent of Africa is less important to the United States than Europe, Asia and Latin America. The strategic interests of the United States in Southern Africa in the 1960's were of only minor importance to their security. Of greater interest was American business investment in South Africa.[50]

According to Anthony Lake, United States policies towards South Africa after 1945 were marked by caution, compromise and muddle, by inconsistency between rhetoric and action, and by a "low profile" uncharacteristic of most of America's post-war foreign policies.[51] On

48 A Le Roy Bennet: **International Organizations, Principles and Issues,** p. 216.

49 FH Hartmann: **The Relations of Nations,** pp. 292-293.

50 William A Hance (ed): **Southern Africa and the United States**, pp. 25-26, pp. 119-128.

51 Anthony Lake: **Caution and Concern,** p. 44.

September 13, 1960, agreement was reached between the United States and South Africa on three NASA facilities in South Africa. This agreement, coming six month's after Sharpeville, exemplified the gap between verbal criticism and the reality of cooperation.[52]

The Agreement for Cooperation between the Government of the Republic of South Africa and the Government of the United States of America concerning the Civil Uses of Atomic Energy was renewed (with few amendments) and signed in Washington on June 12, 1962.[53] According to the agreement, highly enriched fuel would be delivered on a lease basis to South Africa at intervals as ordered. By this time political ideological differences between the two countries were apparent. As stated the United States supported the United Nations resolution (S/4300), of April 1960, and an arms embargo. Political ideology would have a direct effect on the practical implementation of the Agreement and obstacles would have to be overcome. As far as international politics was concerned, considering the determination of the United States to negotiate terms with the Soviet Union on arms control, South Africa had reason to be cautious of being dependent on the United States for a supply of enriched uranium for SAFARI I research reactor or, more important, for a possible power reactor using enriched fuel that may be acquired at some future date.

In 1962 it became clear that the United States would not be able much longer to resist African pressures at the UN for action against South Africa.[54] Since its inception (in 1953) the American Committee on Africa pressed for total United States disengagement from South

52 The agreement covered a minitrack radio tracking station, a camera optical tracking station and a deep space probe tracking station near Johannesburg. Anthony Lake: **Caution and Concern**, p. 83; William A Hance (ed): **Southern Africa and the United States**, p. 25.

53 (AECA) Agreement for Cooperation between the Government of the Republic of South Africa and the Government of the United States of America concerning the Civil uses of Atomic Energy. As amended. May 1962.

54 LES de Villiers: **US Sanctions against South Africa**, p. 47.

Africa. This Committee under the leadership of its founder George Houser took its sanctions campaign against South Africa to real boycott action in 1963 when at Brooklyn docks a South African ship was prohibited to unload its goods.[55]

Although neither the United States nor the United Kingdom was prepared to accept the South African situation as a threat to international peace and security or to support sanctions, the decision to accept a ban on the sale of arms was, from an Afro-Asian point of view, a significant victory. In 1963 the Organization for African Unity laid plans for new pressures on South Africa. In August of that year the Security Council began a debate on a resolution calling for a ban on all arms sales to South Africa. President Kennedy, anticipated the vote and going beyond the recommendations of his advisors, had his ambassador unilaterally declare on 2 August that the US would sell no additional arms to South Africa after the end of that year.[56]

The arms embargo reflected the general pattern of the Kennedy policies toward South Africa. It was a significant step in demonstration of opposition to apartheid, but still falling short of majority opinion at the UN and American rhetoric itself.[57]

In 1966 during testimony before congress George Houser specified the type of sanctions that he would like to see applied to South Africa. Amongst these was the cessation of nuclear cooperation by the American Atomic Energy Commission with the South African Atomic Energy Board. According to LES de Villiers, far fetched as these goals may have seemed in 1966, they would ultimately become grist for the

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55 LES de Villiers: **US Sanctions against South Africa**, pp. 53-55.

56 Anthony Lake: **Caution and Concern,** p. 94.

57 **Ibid.,** p. 96.

mill in a number of other activist groups that followed the American Committee on Africa on the road of sanctions against apartheid.[58]

President Johnson, in regard to South Africa was prepared to take action. In September 1966 the Johnson Administration barred the sale of three French jetliners to South Africa and proceeded to stricter observance of the arms embargo.[59]

The Nixon administration's policy toward South Africa of "communication and cooler rhetoric" was reflected in its approach at the United Nations. In November 1969, the US did not abstain but voted for the first time in many years, against the annual anti-apartheid resolution at the United Nations. In the same year this policy of caution showed when the US refused to vote for a Security Council resolution which set a date for South Africa's withdrawal from Namibia. According to Anthony Lake United States policy during the period 1945-1970 never included a forceful effort to make its anti-apartheid action equal to its anti-apartheid rhetoric.[60]

It is of particular significance in the history of uranium and South Africa nuclear power, that during the early sixties the United States indicated caution with regard to the cooperation agreement with South Africa.[61] It would not have gone unnoticed by the American Government that South Africa had not supported the United States in its efforts to curb Soviet nuclear proliferation. However, South Africa's

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58 LES de Villiers: **US Sanctions against South Africa**, pp. 55-56; Anthony Lake: **Caution and Concern,** pp. 108-109.

59 **Ibid.,** pp. 59-60; Anthony Lake: **Caution and Concern,** pp. 104-105.

60 Anthony Lake: **Caution and Concern,** pp. 125-127.

61 The renewed collaboration agreement between the United States and South Africa was subject to veto by the United States Government. In 1975 the United States ceased to supply enriched fuel for SAFARI I research monitor. LES de Villiers: **US Sanctions against South Africa**, pp. 294-295; DB Sole: "The Rise of Nuclear Sanctions against South Africa", **American Review**, Jan. 1986. pp. 4 and 7.

fierce anti-communist stance[62] combined with its nuclear technological achievement of enriching uranium would have been plus factors in US and South African relations in the event of Soviet or Chinese intervention in the regions of Southern Africa or the Indian Ocean.

An important development in international arms control came in 1966 with United States, Soviet Union and United Nations' agreement on the Treaty on Outer Space, which required the parties "not to place in orbit around the earth any objects carrying nuclear weapons or any other kinds of weapons of mass destruction, install such weapons on celestial bodies, or station such weapons in outer space in any other manner". With further efforts encouraged by this achievement, the United States and the Soviet Union were able in 1968, to agree on the text of a Nuclear Non-Proliferation Treaty (NPT).[63] The two superpowers worked in close cooperation in this effort to combat the dangers of nuclear proliferation.[64]

The NPT bound the nuclear weapons signatory powers not to transfer nuclear weapons or supply weapons technology to any non-nuclear weapons state and required non-nuclear weapons states not to receive nuclear weapons. Non-nuclear weapons signatory states were also required to accept the International Atomic Energy's system (or an equivalent system) to ensure that their non-military nuclear facilities and materials could not be used for military purposes. Although the United Kingdom supported the NPT, France and Communist China announced that they would not adhere to it. Even though the UN General Assembly vote in favour of the NPT was overwhelming, and fifty-nine nations signed the draft treaty on July 1, 1968, there was much dissatisfaction behind this facade of agreement. By the end of 1968, West Germany, Japan, India, Italy, Israel, Brazil and Argentina

62 JE Spence: **The Political and Military Framework**, pp. 76-78.

63 **Ibid.**

64 DB Sole: "The Rise of Nuclear Sanctions against South Africa", **American Review**, January 1986.

had not signed the treaty, pointing to the lack of effort by the superpowers to control the missile arms race. Many states also feared that the NPT could limit their utilization of nuclear power for peaceful purposes. Nonetheless, in November 1969, West Germany signed and Japan soon followed suit. The United States and the Soviet Union ratified the NPT simultaneously in November 1969 and, in an effort to meet some of the criticism, began the Strategic Arms Limitation Talks (SALT) in Helsinki, Finland, that same year. Also in 1969, the UN-sponsored Eighteen Nation Disarmament Committee (ENDC) at Geneva was expanded to twenty-six members and renamed the Conference of the Committee of Disarmament (CCDA). This Committee became explicitly a forum to which the superpowers would present their agreed texts and seek wider support for them. In 1970 ratification of the NPT, nonetheless, continued at a slow pace while the non-nuclear powers waited to see what progress would be made on their complaints that the superpowers would not be able to enforce the control they envisaged and that nuclear power for peaceful purposes would be hindered.[65]

The United States had clearly been vexed by South Africa's refusal to become a party to the 1968 Non-Proliferation Treaty (NPT). The reason for this being that by 1968, South Africa's uranium enrichment method had been proved in the laboratory and the South African Government and the Atomic Energy Board were considering enriched uranium production in the not too distant future, not only for its own reactors, but also for export.[66] South Africa was not alone in refusing

65 FH Hartmann: **The Relations of Nations**, pp. 293-294.

66 In July/August 1977 a Soviet satellite picked up what was claimed to be a nuclear test site in South Africa's Kalahari desert. The United States satellite surveillance quickly confirmed the existence of the alleged test site. The South African government strenuously denied that is was a nuclear test site. DB Sole: "The Rise of Nuclear Sanctions against South Africa". **American Review**, Jan. 1986. p. 4.

to adhere to the treaty, and could not be singled out as unique in this respect.[67]

Those countries that were signatories of the NPT were bound by the treaty not to manufacture nuclear weapons and to allow their nuclear installations to be examined by IAEA inspectors. It would verify their peaceful intentions and ensure that fissionable material would not come into the hands of non-signatory states, but remain under the authority and jurisdiction of the nuclear states.[68]

Although South Africa had not signed the NTBT or the NPT, the Prime Minister, BJ Vorster, had stressed in his announcement of the enrichment process in July 1970, that South Africa had an obligation in this regard. South Africa's enrichment discovery, he said, should benefit South Africa and mankind. He said, that although South Africa had not at that time acceded to the Nuclear Non-Proliferation Treaty, the Government had at various occasions clearly stated that it would consider participation as soon as the details of the safeguards system to which South Africa would be subjected, were known.[69]

It has been established in this dissertation that only by collective security, that is, the United Nations Organization, the International Atomic Energy Agency and a nuclear inspection system, nuclear proliferation could be controlled.

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67 DB Sole: "The Rise of Nuclear Sanctions against South Africa", **American Review**, January 1986, p. 3; Western states were cautious to vote in favour of nuclear weapons as being illegal in the sixties, for Soviet superiority in conventional (that is, non-nuclear) forces in Europe was so great that Western countries would be compelled to use nuclear weapons in order to defend themselves against an invasion of Western Europe; consequently, the Western countries argued that the use of nuclear weapons was not contrary to international law. Michael Akehurst: **A modern Introduction to International Law**, p. 273.

68 AJA Roux: "Uraanverryking", pp. 29-30.

69 (AECA) AEB, **Aankondiging deur die Eerste Minister, Maandag 20 Julie 1970**, pp. 1-5.

The NPT and the inspection system were essential international measures, which all responsible governments supported in principle but they undeniably had inadequacies. The inspection system necessarily incorporated the possibility of the infringement of sovereignty. In other words, the inspection team would know exactly what a country's nuclear potential was. Sovereignty implies power, self-determination, independence, paramountcy and freedom. These attributes were strengthened by a nuclear potential and threatened by the inspection system. If a state would find it necessary to protect its vital national interests, such information would jeopardise the country's status and bargaining power.

South Africa was prepared to subject its requirements for the SAFARI I to the IAEA control system in 1965. However, as far as the gaseous diffusion process was concerned, none of the nuclear powers (USA, UK, USSR, France and Communist China) was prepared to divulge details of technology or supply equipment. This was the case, even though a non-nuclear country like South Africa was willing to establish an enrichment plant for peaceful purposes only, and prepared to accede to the inspection system. The nuclear powers were not prepared to concede to this, firstly, because technological data could leak out through the inspection system, and that would increase the potential of the non-nuclear states to produce nuclear weapons and, secondly, nuclear powers were not prepared to relinqui. . their monopoly of the enriched uranium market.[70]

One might well ask: was the controls system sufficiently secure to prevent dissemination of information to terrorist organizations. As mentioned, the controls system established by the IAEA in the middle fifties was unable to restrain nuclear proliferation. According to **National Geographic Magazine**, on a wintry November day in 1968, the cargo vessel *Scheersberg A*, flying the flag of Liberia, cleared Antwerp harbour with a brand-new crew. Aboard were 200 tons of

70 A.J.A Roux: "Uraanverryking", pp. 26-27.

yellowcake, uranium oxide, made from ore mined in Zaire. It was bound for Genoa. All papers were in order. Once in international waters, beyond prying eyes, the drums of yellowcake vanished. The *Sheersberg A* never arrived in Genoa. When the vessel put into a Turkish port 15 days later, the $3 700 000 cargo was missing. Secret agents tried to trace the shipment. The mystery remains unsolved. Although the IAEA inspectors visited nuclear facilities in many countries to determine that its supplies of fissionable materials were adequately safeguarded, these nuclear watchdogs "lacked teeth".[71]

In 1970 it was impossible for a country to produce its own nuclear weapons unless it had discovered the technical know-how. It would require the industrial potential in order to manufacture the very expensive and sophisticated equipment for either an enrichment plant or a nuclear reactor; and in addition, for the weaponry or the nuclear bomb itself. By 1970, besides the five nuclear powers, there were a number of countries that had acquired sufficient knowledge to produce nuclear weapons.[72]

Considering the aspects related to the NPT and the inspection system given above, should South Africa have signed the NPT in 1968-1970? According to Prime Minister PW Botha South Africa had made the correct decision not to be bound by the NPT.[73] It is reasonable to conclude that the South African Government, unbending in its purpose to pursue its domestic policy amidst mounting threats of African nationalism, taking into account the recommended voluntary sanctions imposed by the United Nations in 1969 (and the possibility of more stringent sanctions to follow), more than ever required its sovereignty totally upheld. South Africa would not run the risk of details of the

71 "The Promise and Peril of Nuclear Energy", **National Geographic Magazine**, Official Journal of the National Geographic Society, Washington, DC, vol. 155, No. 4, April 1979.

72 AJA Roux: "Uraanverryking", pp. 27-28.

73 Conversation with PW Botha, 10.1.1992.

new process leaking out as a result of the safeguards inspection system. On the other hand South Africa's reluctance to sign the treaty had numerous repercussions. Both the United States of America and the United Kingdom had apprehensions about South Africa's refusal to adhere to the treaty. It was believed by some that South Africa would not have had to tread such a thorny path internationally, had she agreed to accede to the NPT. There would be increasing pressure from overseas countries on the Republic to sign the treaty and it definitely played a role in deteriorating negotiations with foreign countries. According to DB Sole, the whole question of safeguards became a constant dispute between the Republic of South Africa and the IAEA after 1968.[74]

South Africa and the United Kingdom

During the late fifties there was close and enthusiastic collaboration between South Africa and the United Kingdom, despite mounting anti-South African opinion in the United Nations. The United Kingdom assisted South Africa by supplying information on nuclear plant safety and health prospects. In 1957, the Chairman of the United Kingdom Atomic Energy Authority, Sir John Hill, visited South Africa.[75] The meeting of the Commonwealth Nuclear Scientists, which took place in London immediately after the Geneva Conference, was attended by the following South African representatives: Dr AJA Roux, Dr TEW Schumann, Dr SM Naudé, JR Colley and AR Newby-Fraser.[76]

Relations with the United Kingdom were, however, deteriorating. The pattern of nuclear cooperation with the United Kingdom had been very

74 Interview with IFA de Villiers, 15.8.1991; Interview with DB Sole, 12.12.1990.

75 DB Sole: "The Rise of Nuclear Sanctions against South Africa", **American Review**, Jan. 1986, p. 5.

76 **Annual Report of the South African Atomic Energy Board**, 1958, p. 2.

much in line with that applicable to the United States. British abstention, in April 1960, from voting against South Africa in the United Nations resolution (S/4300), was seen as a positive vote condemning South Africa's internal policy. From the time of British Prime Minister, Harold MacMillan's, "Winds of Change" speech in Cape Town (February 3, 1960) there was a decline in political cooperation between the United Kingdom and South Africa. This decline was accelerated by the advent of the Labour Governments under Harold Wilson - October 1964 - and later, James Callaghan. DB Sole believed that the Americans were more anti-South Africa and that American influence played a part in the decline of cooperation between the United Kingdom and South Africa.[77]

Germany and South Africa

As stated in an earlier chapter, bilateral nuclear relations between South Africa and the Federal Republic of Germany had been established at the 1955 Geneva Conference on the Peaceful Uses of Atomic Energy, when the South African delegation included Drs HJ van Eck and Meiring Naudé.

South Africa's nuclear collaboration with the Federal Republic of Germany probably took its origins from the contact made between the South African and German delegations at this Conference.[78] In 1955 the official repression of nuclear research in West Germany came to an end. In the Spring of that year, the Federal Republic of Germany was allowed to engage in a nuclear energy development programme of its own. When the international agreements freed Germany from limitations in nuclear research, Germany was relatively unprepared to

77 DB Sole: "The Rise of Nuclear Sanctions against South Africa", **American Review**, Jan. 1986. p. 5.

78 DB Sole: "The Rise of Nuclear Sanctions against South Africa", **American Review**, Jan. 1986, p. 5.

take part in the development of nuclear energy.[79] Germany sent a seventy-member delegation to the Conference, led by Professor Otto Hahn, President of the Kaiser Wilhelm Society for Promotion of Science (renamed the Max Planck Society) of Göttingen. Dr Van Eck and Dr Naudé were two powerful and influential dignitaries possessing particularly close ties with Germany. At that time German nuclear activities were only in their initial stages; their nuclear links had been mainly with the Americans and the British. Quite clearly they welcomed contacts with South Africans who were, of course, at the time, personae grata with the Americans and the British. In the following years there was a considerable expansion of relations between South Africa and the Federal Republic in the nuclear field. South African nuclear scientists regularly visited German nuclear research centres at Jülich and Karlsruhe.[80]

After that time there were ties between the Atomic Energy Authorities of the Federal Republic and South Africa.[81] When DB Sole was appointed as South Africa's Ambassador to the Federal Republic in 1969, his objectives were to serve as catalyst in promoting sales of South African uranium, and to encourage exchange visits by nuclear scientists and to investigate possible German interest in becoming associated with South Africa's enrichment process.[82] According to DB Sole, in his position as South African Ambassador to the Federal Republic he made contact with the two main nuclear research institutions at Jülich and Karlsruhe, Kraftwerk Union (manufacturers of nuclear power stations) and companies concerned with uranium prospecting and enrichment. He was also acquainted with corporations

79 (Atomic Energy Corporation Archives) AJA Roux: **Atomic Energy Research Development**, Part III, **Continent of Europe**, p. 82.

80 DB Sole: "The Rise of Nuclear Sanctions against South Africa", **American Review**, Jan. 1986, p. 5.

81 (AECA) Meeting of the Executive Committee (Production) for the pilot enrichment plant, 28.4.1967, HL de Waal, **Uraanverryking in die Republiek van Suid-Afrika,** p. 44.

82 (SAL) DB Sole: **This Above All** (Unpublished manuscript), p. 323.

having an interest in the nuclear business such as Ruhrkohle Siemens, importers of South African uranium and with the German Minister and senior officials in the German Ministry dealing with nuclear and uranium affairs. Dr AJA Roux and South African nuclear specialists exchanged visits with German nuclear scientists.[83]

World Reaction to the Announcement of the South African Uranium Enrichment Process

Dr Roux, Dr Grant, the Prime Minister and the Cabinet Ministers were fully aware of the negative attitude of overseas countries and the African States towards South Africa's domestic policy. It was realised that the international repercussions could be tremendous. Greater pressure could be placed on South Africa because of her ability to enrich uranium, and having refused to sign the Non-Proliferation Treaty (NPT) in 1968. Allegations would be made that South Africa would be in a position to produce an atomic bomb. The South African Government was seen by the outside world to be unbending in its purpose to enforce apartheid. These factors could, with the announcement of South Africa's enrichment process, escalate into the application of more stringent economic sanctions against the country, the further severing of economic and diplomatic ties and greater antagonism towards the white regime in South Africa.

It was, therefore, with the greatest interest that Dr Roux and Dr Grant listened to the radio broadcasts on the evening of July 21, 1970, following the announcement of the South African enrichment process, to hear what the international reaction would be.[84] The British scientists stated that this was not unusual. In other words, they believed that South Africa had the capability. For them it was logical

83 **Ibid.**, p. 323.

84 The Minister of Mines, Dr Carel de Wet, had asked them and their wives to join him at his residence to hear what the international media would report.

that a country rich in uranium, would refine the metal in a way to deliver the best product for export. To them it seemed a normal course of events.[85] It should be mentioned here that the very day before, 20 July 1970, the new Conservative Government in Britain announced that it was considering lifting its arms sale embargo against South Africa.[86]

The American reaction on the announcement was particularly interesting. They stated that American scientists had already considered all possible methods of uranium enrichment and they did not believe that South Africa could have discovered something new. So they believed it was a bluff. This was an unexpected turn of events. The Americans in the 1970's on the one hand recognised South Africa's enrichment achievement, but on the other hand could just not accept the fact that South Africa had actually mastered the severe technological demands of an enrichment undertaking and that the Republic was a new contender in the enriched uranium world market.[87]

The African States believed the Americans and there was no reaction from them at all. They were not going to be led by what America assumed to be an impossibility. It was only in later years that they reacted on nuclear development in South Africa.[88]

Towards the end of 1969 the *Steinkohlenelektrizitätsgesellschaft* in the Federal Republic, under the leadership of Dr Bund, and in collaboration with Professor EW Becker of Karlsruhe, had decided to

85 Interview with Dr WL Grant, 28.7.1989.

86 FH Hartmann: **The Relations of Nations,** p. 541.

87 Interview with Dr WL Grant, 28.7.1989.

88 Several years later, President Julius Nyerere of Tanzania, stated that Nigeria was going to be the first on the African continent to have nuclear weapons. Nigeria has much uranium, but they would have to obtain technical assistance. For about ten to twelve years the political organizations, the African National Congress, and black South Africans did not interfere in the scientific developments at Pelindaba and Valindaba. Interview with Dr WL Grant, 28.7.1989; vid. "US Scientists Bowled Over", **The Argus**, 21.7.1970.

develop the Becker "jet nozzle" enrichment process on a large scale.[89] When the South African enrichment process was announced to the world in July 1970 and it became known that the South African method was an aerodynamic process, where the feed material is a combination of uranium hexafluoride and a carrier gas, Dr Becker claimed and stated publicly that the two processes were the same in so far as both were based on the principle of the high performance stationary-walled centrifuge. But, he added "that did not mean that all the details were the same."[90]

According to Professor PC Haarhoff, the Germans claimed that South Africa had copied their process, because it made use of a carrier gas as a feed material and both Dr Grant and Professor Becker called their discoveries a "stationary wall centrifuge". Professor Haarhoff gave an explanation of the differences between the two processes. Both are aerodynamic processes. The design of the separating element is the crux of the matter. The "jet nozzle" method, developed by Dr Becker, does not work with a vortex tube and that is the crucial difference. The Becker process is a two-dimentional process: it works with a surface and a crevice; Dr Grant's process is three-dimensional: it has a left side, a right side and a middle. Professor Haarhoff believed that Professor Becker was a bit petulant and willful. He was particularly proud of his achievement and another process endangered his own accomplishment. He was not going to take South Africa's discovery lightly and claimed that South Africa had copied his process.[91]

This misconception appears in publications that the South African enrichment process and Professor Becker's "jet nozzle" enrichment process are the same. Even though German scientists, who had been

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89 (AECA) HL de Waal: **Uraanverryking in die Republiek van Suid-Afrika**, p. 45.

90 "Jet Nozzle Enrichment. South Africa's Way with Uranium", **The Financial Times**, 29.5.1975.

91 Interview with Professor PC Haarhoff, 29.7.1989.

shown part of South Africa's process, had publicly stated that there was no connection between the two, public opinion remained sceptical.[92] The South African Government was also accused by anti-apartheid movements that the Federal Republic of Germany, debarred by its constitution from itself ever becoming a nuclear power, was actively aiding South Africa to acquire the atomic bomb.[93] It was conceded largely on the basis that there was scientific cooperation with the Federal Republic and South Africa, the misconception that South Africa had copied Professor Becker's invention and that Dr WL Grant had visited Karlsruhe in 1970. As these accusations were made after 1970, they do not fall within the field of the study of this thesis.[94]

South Africa maintained secrecy over the separating element. This was based on considerations of South Africa's competitive position in the international market place and her responsibility towards the world for the prevention of nuclear proliferation. At the Paris Conference in April 1975 South Africa was thus only prepared to reveal some technical aspects, namely that the process was an aerodynamic type; that the separating element was a high performance stationary-walled centrifuge using UF_6 in hydrogen as process fluid; and that the process had a high separation factor over the element[95]

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92 (SAL) DB Sole: **This Above All** (Unpublished manuscript), p. 324.

93 **Ibid.**, p. 324.

94 (SAL) DB Sole: **This Above All** (Unpublished manuscript), pp. 324-325; Zdenek Cervanka and Barbara Rogers: **Nuclear Axis**; "Atomgeschäft. Neues Etikett" (Atom Business. New Label), **Der Spiegel**, No. 53, 1977.

95 (WL Grant: Private Collection) AJA Roux and WL Grant: **Uranium Enrichment in South Africa, Presentation to European Nuclear Conference**, April, 1975, pp. 3-4.

CHAPTER TEN

EVALUATION

In order to ascertain the significance of the history of uranium and nuclear energy in South Africa in the period 1945-1970, the evaluation will focus on three issues: The most significant aspects of the development of the uranium and nuclear energy industries until 1970; the contribution of nuclear scientists and engineers as well as the role of leading politicians; and finally a review of the most important consequences of this development.

The commencement of investigations on the gold-uranium ore of the Witwatersrand directly influenced industry in the country. It led to the establishment of uranium extraction plants at a number of mines. The first uranium to be produced came from West Rand Consolidated Mine. This was 29 years, almost to the day, after Cooper had announced his discovery of uraninite to the Chemical, Metallurgical and Mining Society. Production of natural uranium climbed steeply during the 1950's and the foreign trade value reached a peak of R108 533 000 in 1960. After 1960 South Africa could not regard uranium as a stabilising factor on the economy for there was the risk of overproduction, an anticipated drop in the international uranium market price and difficulty in securing new sales contracts. The United Kingdom revealed in 1991 (The British disclose Cabinet confidentiality after thirty years) that one of the main subjects discussed by Dr HF Verwoerd and the British Prime Minister, Mr Harold MacMillan during his visit to South Africa early in 1960, was uranium. Dr Verwoerd was concerned about the impending decline in the demand for uranium.[1] After 1965, however, production was once again geared up in anticipation of a rising demand. In 1970 the NUFCOR processing plant was operating at only two-thirds production. This could be stepped up rapidly if demand justified such action.[2]

South African uranium was a determining factor in the United States and South African relations. When General Groves took the lead in the Manhattan Project early in 1942, he believed tnat if the United States wished to keep the atomic bomb as an exclusive American possession, America would have to have a monopoly of the world's nuclear raw materials. Groves, who never trusted the United States-Soviet Union war alliance knew that the Soviets would not be able to construct nuclear devices without these materials. As chairman of the Combined Development Trust, Groves was able to make decisions independent of the Committee.[3]

At the end of the war Groves intended no slowdown in America's nuclear weapons programme and in 1945 be believed he had preclusive monopoly of the world's raw materials. The Cold War therefore was contributary to the initial investigations on South African uranium ores.[4]

The news that in 1944-1945 South Africa had the world's largest undeveloped reserves of uranium ore capable of early commercial development, brought considerable comfort to the national security planners of the Truman administration and dramatically raised the value

1 **Rapport**, 6 Januarie 1991: "Verwoerd, Macmillan se geheime op die lappe".

2 "Assured fuel supply", **Mining Survey**, September 1971, p. 17. A marked increase in the price of uranium in the 1970's brought the metal into greater prominence.

3 G Herkin: **The Winning Weapon**, pp. 100-104; D Yergin: **Shattered Peace,** pp. 135-137, 344.

4 D Yergin: **Shattered Peace,** p. 109. According to Yergin, Czechoslovakia was the Soviet Union's most important source of uranium. It must have provided a powerful motivation for the Soviet drive to keep Czechoslovakia in its sphere.

of South Africa to the United States on the eve of the Cold War. The Truman administration took a strong stance on apartheid, however, the growing economic interdependence of the two nations and the promise of vast quantities of uranium ore from the Rand assuaged official American concern about an evidently troubled South African future in the 1950's and 1960's.[5]

It was expected in 1950 that if a major United States-Soviet Union war broke out the United States and its allies would lose access to the Middle East, South East Asian and European raw materials. The United States therefore looked to Africa for strategic materials.[6]

The Cold War shaped Eisenhower's approach to mineral issues. He and his advisors within the Government realised America's dependence on foreign countries for vital materials. Relying heavily on low-cost foreign suppliers could be a serious danger to American security in wartime. These factors and the discovery of rich uranium deposits on the Colorado Plateau led to a diminishing dependence of the United States on South African sources of uranium. However, the United States imported $450m worth of South African uranium between 1953 and 1971.[7]

According to T Borstelmann, the most important single interest of the United States during the Truman administration was the uranium of the southern Belgian Congo and the South African Witwatersrand.[8] Therefore, South Africa's uranium contracts with the Combined Development Agency played a significant role in South African, United States relations. The Truman administration permitted top South

5 T Borstelmann: **Apartheid's Reluctant Uncle,** pp. 50 and 84; K Danaher: **The Political Economy of US Policy Toward South Africa,** p. 68.

6 AE Eckes: **The United States and the Global Struggle for Minerals,** pp. 152-153.

7 **Ibid.,** pp. 202, 206-208; J Barker and J Barrett: **South Africa's Foreign Policy**, p. 238.

8 T Borstelmann: **Apartheid's Reluctant Uncle,** p. 198.

African military officials to consult with counterparts in the Pentagon. In 1950, declassified secret documents revealed that on 15 November 1950 the Joint Chiefs of Staff made the assessment that in the event of global war, there would be both offensive and defensive roles for the South African armed forces. The ability of the Union of South Africa to participate in the defence of the area of which it was a part was of importance to the security of the United States.[9]

According to K Danaher, South Africa as an issue in itself was of little concern to the Truman administration. American policy was determined by larger considerations of the Cold War and the need to expand opportunities for American business. American policy under Eisenhower (1953-1961) remained much as it had been under Truman. Military ties continued along the lines laid down during Truman's term in office.[10]

In the early sixties (as related in the previous chapter) US policy toward South Africa became more contradictory. On the one hand it endeavoured to protect the United States' reputation on the question of race, on the other Washington remained a force blocking an international response to South African policies. Until 1970 nuclear cooperation continued, agreements remained in force and South African scientists were permitted to study in the United States.

The development of the uranium industry was particularly beneficial to South Africa. The extraction plants formed a major part of the country's industrial activity. The plants had to be provided with considerable additional electric power supplies as well as equipment. There was a sharp increase in the demand for power, sulphuric acid and certain chemical reagents. Stainless steel fabrication in South Africa

9 K Danaher: **The Political Economy of US Policy Toward South Africa,** pp. 67-68.

10 **Ibid.,** pp. 68-69. In 1950 South African scientists were allowed to participate in the monitoring of United States nuclear weapons tests in the South Atlantic.

grew primarily from the requirements of the uranium extraction plants and the engineering industry throughout the country benefitted from the establishment of the uranium industry.

South Africa's large uranium reserves underlined the necessity to advance nuclear research and nuclear physics. Young South African scientists of the early 1950's, like scientists all over the world, were intrigued by the tremendous advancement in nuclear science during the previous decade. Opportunities for careers in nuclear energy research were created through the establishment of the Council for Scientific and Industrial Research and particularly the National Physical Laboratory.

The Pretoria cyclotron, as a national facility for basic nuclear physics research (utilized in the various fields of nuclear science, education and the manufacture of radio isotopes) made important contributions that were recognised both locally and internationally. Many nuclear scientific publications utilizing the Pretoria cyclotron appeared in the 1950's and 1960's, many of which were published internationally. Specialized university degrees were attained making use of the cyclotron facility. Orders for hundreds of radio isotopes for medicine and industry were delivered both for local and overseas clients.[11]

It seems that scientists and engineers closely involved with the evolution of nuclear energy in South Africa agree that it was the correct decision to establish a new site for the implementation of the South African nuclear energy research and development programme, even though by 1958 the National Physical Laboratory had been founded at the CSIR and the Pretoria Cyclotron had successfully been put into operation. According to Dr SJ du Toit by 1958/1959 the National Physical Laboratory was functioning extremely well and proving to be a particularly successful undertaking. A capable staff of nuclear physicists and scientists were attending to the functioning of the

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11 (NAC Faure) NAC 84-01(SR) "Voorwoord" tot Simposium ter viering van die 25 jaar diens van die Pretoria-siklotron, WNNR, 28 Junie 1983.

cyclotron and the other apparatus used in conjunction with the accelerator. In the middle fifties it was believed by Dr Naudé and others that with some additional manpower and equipment the National Physical Laboratory could have been developed into a nuclear physics laboratory of a particularly high standard. It should, however, be borne in mind that it was a purely nuclear physics laboratory, not nuclear energy as such. If a nuclear energy programme was implemented, it was essential that the various disciplines, i.e. nuclear physics, mechanical engineering, nuclear chemistry and metallurgy, be integrated. It was, therefore, the best decision to establish a new site. Although it was a sensitive decision at the time, in retrospect, it is a manifestation of how rapidly advancements in nuclear energy development were taking place during the 1950's and how problematical it was to remain abreast with progress.

The disagreement between Drs Meiring Naudé and Roux concerning the development of a new site for nuclear research and the acceptance of Dr Roux's proposals for a nuclear research and development programme by the South African government should be mentioned in this regard. Dr Roux had a greater knowledge of the developments of nuclear research abroad, having undertaken the extensive investigations to nuclear research centres in all the major Western countries. The development of a nuclear research centre had to meet the demands of future nuclear developments. In the formulation of his nuclear development programme Dr Roux anticipated the possibility of enriching uranium. The sophisticated technologies relating to uranium enrichment research and ultimate production would inevitably require a separate site. The nuclear research centre would necessitate stringent security, additional power supplies, radiation precaution and extensive available land for future expansion.

According to Dr WL Grant the disagreement between Drs Meiring Naudé and Dr Roux should not be underestimated. Had the government not accepted Dr Roux's programme the uranium and nuclear industries in South Africa might not have developed to the extent that they did in the following years.

In this dissertation the construction of the Pretoria Cyclotron has been discussed in detail because the cyclotron and National Physical Laboratory were established with the specific purpose to train scientists in advanced nuclear physics with a view to nuclear research and development.

It was stated in the 1959 - 1960 annual report of the CSIR that the inadequacy of support for university research was having grave consequences on the training of research workers and consequently on the development of science and industry in South Africa.[12] Dr Meiring Naudé, in his proposals for a nuclear research programme for South Africa laid emphasis on the encouragement of physics research throughout South Africa by the creation of research facilities and in particular by the provision of an accelerator.[13] It was particularly as a result of these recommendations that Dr Roux included the twelfth theme of the nuclear research and development programme, namely: the support of fundamental research basic to nuclear energy development.

According to Dr SJ du Toit the theme Fundamental Research included in Dr Roux's programme brought about practical liaison between the Atomic Energy Board and all the universities of South Africa. This included mainly research in nuclear physics, nuclear chemistry and metallurgy. The Directors of the Atomic Energy Board visited all the universities at least once a year and in this way an enthusiastic relationship was established between the AEB and the universities. At the Physics Laboratory at Pelindaba an extensive fundamental

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12 Fifteenth Annual Report of the CSIR, 1959-60, p. 9.

13 SM Naudé: **Proposals in connection with a nuclear energy research programme for the union of South Africa,** November 1958, pp. 12-14.

programme on neutron physics, specifically in relation to nuclear energy, was carried out under the leadership of Dr D Reitmann.[14]

Fundamental research centres were established in close proximity to, or at universities in order to encourage and stimulate nuclear physics research, not specifically for nuclear energy production. The Nuclear Physics Research Unit of the University of the Witwatersrand, with Professor JFP Sellschop as Director, was formed in the mid-fifties. Several years later it acquired the 1 MV Cockroft-Walton accelerator which the renowned Lord Rutherford used at Cambridge University, United Kingdom. Potchefstroom University had initiated cosmic-ray research shortly after the war, but it was not until 1960 that it entered the nuclear physics field and acquired an accelerator. Dr AJA Roux's Atomic Energy Research and Development Programme would later incorporate the southern universities of Cape Town and Stellenbosch. In 1963 a 6MV Van De Graaff accelerator was commissioned for the Southern Universities Nuclear Institute (SUNI) at Faure in the Cape Province. There, scientists and students from the Universities of Cape Town and Stellenbosch could undertake research in the accessible fields of nuclear physics and chemistry.[15]

As in the case of Drs Naudé and Roux, there was not always consensus of opinion on major resolutions. Dr JWL de Villiers believed that the Van de Graaff accelerator at Pelindaba should rather have been set up at a university for the study of fundamental nuclear physics. This view differed from that of certain other senior physicists and led to Dr De Villiers joining Dr Grant's division, particularly reactor physics, on the PELINDUNA project.

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14 Interview with Dr SJ du Toit, 9.1.1992.

15 AR Newby-Fraser: **Chain Reaction**, pp. 27-29; A large range of detection systems and peripheral equipment was installed. In 1977 the National Accelerator Centre was established at Faure. It is a multi disciplinary research centre and incorporates the former Southern Universities Nuclear Institute. (NAC Faure) **The National Accelerator Centre,** Brochure, 1994.

By the end of 1967, Dr De Villiers was Director of the Reactor Development Division and played a leading role in the development of the PELINDUNA critical assembly. Dr De Villiers was particularly hesitant to terminate the reactor development programme. The acceptance of the resolution to pursue the uranium enrichment project once again brought the argument concerning the decision to establish a new site for nuclear energy research and development to the fore. The reasoning put forward by Dr De Villiers was that if the reactor development aspect of the nuclear energy research and development programme was terminated, then the Atomic Energy Board would essentially be an isotope laboratory, virtually the same as the CSIR laboratory. Dr De Villiers was resolute for he firmly believed that if reactor development was discontinued at that point, South Africa would in future have no choice, but that ESCOM be dependent on a foreign power to supply a nuclear power reactor for South Africa.[16]

Persons directly involved with nuclear energy in South Africa believe that it was the correct decision to develop Dr Grant's vortex tube enrichment process. According to Dr RS Loubser the Government believed that it was an essential undertaking, as it was certain that a nuclear power station would be constructed in the Western Cape and it would be to the country's advantage if South Africa could supply the reactor with enriched fuel. In 1970 it was believed that the process would be economical and that South Africa's enriched product could compete in the world market. No-one could foretell that in later years the international enriched uranium market would become far more competitive.[17]

Dr JWL de Villiers is of the opinion that it was the correct decision to develop the enrichment process for it placed the country in a position to consider various reactor types. He was in favour of a small pilot plant

16 Interview with Dr JWL de Villiers, 10.1.1992.

17 Interview with Dr RS Loubser, 28.7.1989.

to test the process (while continuing with reactor development research). Only when the pilot plant proved to be successful, would a final decision be taken regarding the size of the semi-commercial plant as well as reactor development research.

Eisenhower's Atoms for Peace Programme had a direct effect on South Africa's nuclear power development. In February 1957, the United States was prepared to increase the amount of fissile material, to give to countries developing nuclear energy for peaceful uses, to 20 000 kilograms. This was later increased to 50 000 kilograms.[18] The Cooperation Agreement between the government of the United States and the government of South Africa that followed Eisenhower's decision (July 1957) provided for enriched fuel to be supplied for the research reactor at Pelindaba, the nuclear research centre.

SAFARI I research reactor was essential to the AEB's research programme for potential nuclear materials had to be investigated under radiation conditions. In 1969 its power level was raised from $6^2/_3$ MW to 20 MW. With the upgrading to 20 MW several fast-neutron irradiation facilities were created. The research reactor was put to full use and there were few activities at Pelindaba which did not make use of the reactor directly or indirectly.

The following statement by the Deputy Minister of Mines, M Viljoen in May 1961 indicates that as early as 1961 the aim was to eventually enrich South Africa's uranium. He stated in May, 1961 that nuclear power would assume dimensions that in future there would be "a steady world demand for nuclear material and we are fully confident that we shall be able to deliver such material in whatever form it might be required by that time at highly competitive prices."[19]

Would there be a market for South Africa's uranium? Dr Roux was confident that the future outlook for enriched uranium was favourable.

18 N Moss: **The Politics of Uranium**, p. 45.

19 **Assembly Debates**, vol. 108, 1 May-26 May, 1961, 23 May 1961, col 7016.

He believed that enriched uranium was the cornerstone of the peaceful application of nuclear energy in the world. The provision of adequate power is indispensable for the preservation and further improvement of mankind's standard of living. Nuclear power would play an increasing part in meeting the ever-increasing demand for electricity. For this reason there would be a growing demand for enriched uranium. According to Dr Roux there was simply no alternative to the use of nuclear power in view of the relentless demands of industry for more and more energy.[20]

In the period 1950-1970 it was generally believed that no "shortage" of coal for power production would force South Africa to opt for nuclear power. South Africa has relatively abundant coal reserves. However, energy authorities were aware of the hazards of large coal-fired power stations, especially in the industrial areas such as Witbank in the Eastern Transvaal. Coal is a non-renewable energy source and nuclear power is the only presently known realistic alternative for base load power generation in the RSA.[21]

The government's decision to finance the XYZ-project was favourably influenced by the economic boom of the 1960's. The inherent strength of the economy (1945-1957) was the prelude to one of the greatest waves of economic expansion. Between 1960 and 1970 the gross national product of the Republic increased from about R5,200 million to R12,400 million, rising by R7000 million during the eleven year period. The South African economy with that of Japan probably had the highest growth-rate in the world at that time.[22]

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20 (DM Kemp: Private Collection) AJA Roux: **Uranium - Recent Developments and Future Outlook**, p. 2.

21 WE Stumpf et al: "Nuclear Energy as a Primary Resource in South Africa in the Next Century", p. 2.2/2.

22 DH Houghton: **The South African Economy**, pp. 209-229.

In South Africa the provisions of the Atomic Energy Act of 1948 cast a blanket of secrecy over uranium and thorium prospecting, as well as inventions made in connection with these materials. Only a limited amount of information for this dissertation could be obtained from daily newspapers. An examination of three Cape Town newspapers, **Die Burger**, **The Argus** and **The Cape Times**, has revealed that particular events were published and reviewed in the press. Uranium production and sales in the late 1950's was given much coverage in the press and particularly the implications of the impending overproduction and decrease in the selling price. The announcement of South Africa's enrichment process was front page news in the daily newspapers. However, even today, the contracts of the uranium production programme between the Combined Development Agency and the South African Atomic Energy Board, 1952-1970 are classified and information concerning the contents of these documents can only be obtained from the governments of the United States and the United Kingdom.

During the years 1950 to 1970 there was a certain optimism regarding nuclear power and prospects for the nuclear industry boomed. Towards the end of the fifties it became abundantly clear that the technology involved with nuclear power production was extremely sophisticated and costs in all facets of nuclear power plant construction were rising. The United States had the financial means to develop its nuclear capability and by 1970 orders for nuclear plants flooded into General Electric, Westinghouse and other suppliers.

Contributions of Individuals

The second issue of investigation concerns the roles of particular persons. In the establishment of South Africa's own uranium and nuclear industry there are a number of persons whose positions, resolutions and discoveries were particularly effectual on the South African community.

General Smuts took great interest in the development of nuclear physics during the war. He played a significant role in the establishment of uranium research in South Africa during the 1940's. This history adds a further dimension to the prestigious position that General Smuts held during the war as Prime Minister of a country with an uranium potential - an asset invaluable to the Allied war effort.

Both General Smuts and Dr HJ van der Bijl, the first Chairman of ESCOM, placed great emphasis on developing an adequate electricity network for mining and industry on the Witwatersrand prior to 1950. Much of the same esteem that was enjoyed by Dr Van der Bijl in the Smuts Governments, Dr HJ van Eck would experience with the Nationalist Government after 1948. Dr HJ van Eck was called upon to assess to what degree nuclear energy would contribute to South African industry and the country's total power requirements. His decisions would have far-reaching effects on the development of uranium enrichment and nuclear power in South Africa. Dr Van Eck was directly responsible to Cabinet Ministers and particularly influential in governmental decision making.

In the exploration of the uranium potential of South Africa in the 1940's, the President of the Chamber of Mines, CJ Mclean, the President of the CSIR, Dr BFJ Schonland, the Director of the Government Metallurgical Laboratory, Professor L Taverner, assisted by the members of the Uranium Research Committee played leading roles. The work done by these scientists and researches at the GML prepared the way for uranium and nuclear energy research in South Africa.

The endeavours of Dr SJ du Toit to lay the foundations of nuclear physics research in South Africa as well as his contributions to the development of nuclear energy research as head of the Physics Division at Pelindaba were significant in this history.

During the formative years of nuclear technological development Dr Meiring Naudé, Dr AJA Roux, Dr SJ du Toit, Dr JP Hugo, Dr LJ le Roux and Dr JWL de Villiers made notable contributions.[23]

Dr RS Loubser, Dr JJ Wannenburg, Dr PC Haarhoff, Dr DM Kemp and RA Barbour (Deputy Director, Economic Affairs associated with Uranium Enrichment), should be given, special mention for their significant roles in the establishment of the pilot enrichment plant.[24]

Dr Haarhoff's significant contribution to the development of the South African uranium enrichment project was the technique he discovered to reduce the number of stages of enrichment in the pilot plant. The Pelsakon technique* reduced the stages of enrichment in the pilot plant by ten to twenty times less than would have been necessary with standard techniques.[25] His concept incorporated a number of stages into one large unit which became known as the Helikon technique. This method ultimately succeeded in reducing the number of stages from a couple of thousand to about 30.[26] Ultimately contributing to making the South African method far more economical than the gaseous diffusion method of enrichment.

Dr AJA Roux had the ability to bring people round to his way of thinking. However, this could only be achieved by a command of a thorough knowledge of nuclear development. Dr S.J. du Toit, who accompanied Dr Roux to the United States and Canada, recalls how

23 Interview with Dr WL Grant, 27.7.1989.

24 Interview with Dr WL Grant, 27.7.1989.

25 Interview with Dr JJ Wannenburg, 25.4.1991.

26 Interview with Professor PC Haarhoff, 29.7.1989. The theory of the Helikon technique was later included by Professor Manson Benedict in his advanced courses of nuclear engineering at the Massachusetts Institute of Technology.

dedicated Dr Roux was to the purpose of knowing exactly what progress had by 1958 been made in nuclear energy overseas. Dr Roux's Reports reflect the vast amount of knowledge he acquired and how systematically he investigated overseas nuclear research and development programmes. Dr Roux realised that in order to have his Atomic Energy Research and Development Programme implemented he would not be able to rely on Government funds alone. The financial support that he obtained from the Chamber of Mines and the uranium industry undoubtedly was a crucial factor in the eventual decision to execute his extensive programme. There is speculation as to whether Dr SM. Naudé was aware of the support of the Chamber of Mines for Dr Roux's Programme. Had Dr Naudé known this, he might not have questioned the financial burden of such an extensive programme.[27]

Dr Grant became the second recipient of the Order of the Southern Cross, Gold, on May 25, 1989. He received this high award for his nuclear research and the development of the South African enrichment process.[28] Dr WL Grant's discovery of the vortex tube method of uranium enrichment, which determined the course of nuclear energy development in South Africa, was both a scientific and an historic achievement. Mention should be made of his notable proficiency during the 1960's to have led the research in both the PELINDUNA and Gas Cooling Projects.

It was a phenomenal accomplishment that South African scientists and engineers had mastered the highly complex technology of uranium enrichment. Only the United States of America, the United Kingdom and France in the Western World had uranium enrichment facilities.[29]

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27 Interview with Dr SJ du Toit, 9.1.1992.

28 **The Argus,** 25 May 1989: "Nuclear Physicist Awarded Gold Cross".

29 **Aankondiging deur Die Eerste Minister, Maandag 20 Julie 1970**, pp. 1-5; **Assembly Debates**, vol. 29, 17 July to 23 August 1970, 20 July 1970; **The Argus**, 21.7.1970: "Uranium, Benefits for South Africa".

From the start Dr Grant was the project leader, a task which he, together with his team of scientists and technical personnel, carried through with vigour to eventual success. Dr Grant and Dr Roux, a complimentary team, were closely associated for 22 years in the service of science in South Africa. Through their combined effort and guidance uranium enrichment was made possible.[30] In 1970 Drs Roux and Grant received the HF Verwoerd Prize for their achievements in nuclear science and engineering.

The political leaders, Dr DF Malan, JG Strijdom, Dr HF Verwoerd and BJ Vorster, and their Cabinets all played significant roles in this history. They had the problematical task of deciding the extent of a research and development programme and, most important of all, how much governmental financial aid should be given to such vast undertakings.

Dr Verwoerd was condemned for the rigorous way he endeavoured to establish apartheid between black and white. He was determined to entrench the traditional policy of separation at a time when he believed racial conflict could lead to a situation of chaos. Therefore, Dr Verwoerd's support of an uranium enrichment programme in the early sixties would invite speculation as to his intentions. South Africa was on the threshold of a new constitutional dispensation, she would face the future as a Republic outside the Commonwealth. If the country could develop its own enrichment process it would undoubtedly put it in a position of strength. In a competitive world any leader of a nation would strive to develop his country's natural resources to their full potential. On these grounds Dr Verwoerd's support (and later BJ Vorster's support) of the uranium enrichment project was acceptable. There would however be the surmise that South Africa could misuse strategic materials for its own purposes. For this reason the South

30 **Aankondiging deur Die Eerste Minister, Maandag 20 Julie 1970**, pp. 1-5; **Assembly Debates**, vol. 29, 17 July to 23 August 1970, 20 July 1970; **The Argus**, 21.7.1970: "Uranium, Benefits for South Africa".

African Government's policies increasingly became the target of foreign and internal crusaders for human rights and condemnators of nuclear proliferation.

Significant Consequences

In May 1971 ESCOM took the first definite steps towards a nuclear power programme with its decision to advise potential tenderers that it planned to commission the first South African nuclear power station. A few months later seventeen organizations received notification of ESCOM's intention to issue an enquiry calling for turnkey offers for a power station.

This decision was the culmination of the many studies made as to the possibility of nuclear power production in South Africa. It was certainly no hasty decision, as was related, nuclear cost evaluations had been made in South Africa as early as 1954 and many assessments followed. It was not a prestige effort, but a project based on economic considerations. The PELINDUNA concept was a first step in reactor development and served many proposed purposes. It established a wealth of nuclear expertise for further nuclear research. With the decision to pursue the South African uranium enrichment method, PELINDUNA could not provide a basis for the country's nuclear reactors and ESCOM was obliged to utilize foreign nuclear reactor expertise.

Koeberg would be capable of meeting the future electrical demands of the increasingly industrial Western Cape. Although it would be fully integrated into the national electricity grid, its two reactor units would make the Cape region independent of the generating capacity elsewhere in the country.

The contract for Koeberg was finally awarded to the French consortium of Framatome - Alsthom - Spie Batignolles - Framateg. The formal contract documents embodying the terms of agreement were signed in Johannesburg and Paris on 5 and 6 August 1976, respectively. This represented only agreement on the commercial level, and the project being both nuclear and of very substantial magnitude, it was essential to formalize the negotiations at government level.

To this end a bilateral agreement between the governments of South Africa and France, specific to the Koeberg project, was signed in Paris on 15 October 1976. This was followed by a trilateral safeguards agreement between France, South Africa and the IAEA, in terms of which nuclear safeguards would be applied to the Koeberg nuclear power station to satisfy world opinion that there is no diversion of the reactors or their fuel for non-peaceful purposes. This agreement entered into force on 5 January 1977. The consortium's offer for the supply of capital works, nuclear fuel and services for the two 922 MW reactors (Koeberg Units 1 and 2), together with associated financing facilities, would be effectuated by 31 December 1983.[31] The introduction of nuclear power in the Western Cape was a direct result of South Africa's nuclear industry.

The development of the South African nuclear programme during the 1960's led to further advancements.

As a result the pilot enrichment plant (the Y-project) came into full operation on Friday 4 March 1977. The pilot plant placed South Africa in a position to produce fuel for the SAFARI I reactor if so required. As a result of the development of nuclear science during the sixties, during the middle seventies UCOR was contemplating the third step, the semi-commercial enrichment plant (the Z-project). Construction of

31 AR Newby-Fraser: **Chain Reaction**, p. 128 - 132; It was assumed in 1976 that South Africa's installed nuclear capability would double every 7 years. It could provide 4 000 MW(e) by 1990 and some 12 000 MW(e) by the end of the century. AJA Roux: **Uranium - Recent Developments and Future Outlook**, p. 19.

the semi-commercial plant commenced in 1979 and was completed at the end of 1986.

As was illustrated in this dissertation, South Africa as a founder member of the IAEA played an active role in the Agency's affairs from 1957 up until the mid1970's.[32]

From the inception of South Africa's Atomic Energy Research and Development Programme the Atomic Energy Board (later the Atomic Energy Corporation) and UCOR maintained standards of safety for the protection of health and minimization of danger to life and property in the operations, making use of fissionable material. Well before the end of the first five years of the AEB's research programme it was appreciated that as and when nuclear power stations and other nuclear installations with a potential for nuclear damage came into operation, some form of statutory control over them would be essential to ensure that they would not constitute a hazard to health and safety. This appreciation gave rise in May 1963 to the Nuclear Installations (Licensing and Security) Act No 43. Amongst the provisions of this legislation was the main one requiring all sites housing installations capable of causing nuclear damage to be licensed by the Atomic Energy Board. In addition to this, the liability of licencees for nuclear damage and for the provision of insurance cover was also laid down.[33]

The Atomic Energy Board was committed to ensuring the safety of its personnel with respect to nuclear hazards. These activities include personnel monitoring, practical health physics and studies of environmental radioactivity, and were undertaken by specialists capable of dealing with any aspect of radiation protection.[34] Apart from

32 DB Sole: "The Rise of Nuclear Sanctions against South Africa", **American Review**, Jan. 1986. p. 6.

33 **Statutes of the Republic of South Africa**, Act No 43 of 1963, pp. 434-456.

34 (AECA) Vid. PJ Kruger and JI Feather: "In Vivo Measurement of Uranium in the Human Chest under high background conditions", August 1980, Isotopes and Radiation Division, Pelindaba. AEB PEL 275; D van As: "Activable Tracers in the Control of Pollution and the Study of Environmental Transport Processes", National Conference on the

looking after safety at Pelindaba, the Board's health physicists also advise the Department of Mines and mining companies on radiological protection. Courses in occupational safety are offered to both AEB personnel and outside organi[illegible]ns.

From the fifties the impact of radiation has been exhaustively studied. Although concensus on the effects of low radiation doses has not been reached, it is only because these effects are so small that they cannot be distinguished from other similar but natural effects. The health effects of radiation are better understood than those of any other pollutant. The recommendations of the International Commission on Radiological Protection (ICRP) regarding a system of dose limitation of occupational and environmental protection are applied in South Africa. South Africa applied IAEA safeguards to its SAFARI I research reactor.[35]

Today there are some who query the vast amounts of money that were spent on the establishment of the centre for nuclear research and for the uranium enrichment project.[36] Arguments that are put forward from time to time are: Dr Roux found acceptance with the political leaders of the time, but that the country should not have made those expenditures. It was done at a time when there were sufficient funds, but were those funds wisely spent? There was a certain amount of prestige attached to the entire venture. It should be borne in mind that governmental decisions in the 1950's and 1960's were made at a time when nuclear power was seen as the "shining light" on the horizon. It was an optimism about the possibilities of nuclear power which prevailed throughout the world. It was assumed that the costs of

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Technological Applications of Nuclear Techniques, 1972; JK Basson: "Principles and Hazards of Radioactivity and its Technological Application", Conference on Nuclear Technology, Cape Town, June 1974.

35 (AECA) WE Stumpf et al: "Nuclear Energy as a Primary Resource in South Africa in the Next Century", p. 2.2/1 (undated ca. 1991).

36 **Sunday Times**, 3 October 1993: "Row rages over inflated cost of local uranium".

utilising nuclear power to generate electricity would be minimal compared to other energy sources.[37]

The decision to enrich uranium was certainly also a strategic consideration.[38] During the 1960's Dr Grant was involved with certain weapons programmes.[39] Leading authorities on uranium and in nuclear science and technology from 1960 to 1970 are in agreement that decisions regarding the peaceful applications of nuclear power were never taken without strategic considerations.[40]

To nuclear scientists and engineers uranium enrichment is a scientific and technological challenge. It is in the hands of the industrial giants and the politicians to decide its economic viability. Although no one could in 1970 have predicted that South Africa within a few years would be involved in a border war, it was evident that the South African Government would be reluctant to accept the ruling of the United Nations and the World Court in 1971 that South Africa's presence in South West Africa (Namibia) was illegal. An enrichment programme augments a nation's military capability. Politicians of the time were not oblivious to this fact. It would only be after 1970 that South Africa would proceed to use the capability to enrich uranium to a sufficient extent to build nuclear devices, a fact unknown to the public until the revelation of President FW de Klerk in 1993.[41]

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37 Interview with PC Haarhoff, 29.7.1989.

38 (AECA) HL de Waal: **Uraanverryking in die Republiek van Suid-Afrika**, p. 40.

39 Interview with Dr WL Grant, 27.7.1989.

40 Interviews with Drs WL Grant, PC Haarhoff, RS Louwser and PC Toens.

41 When uranium is enriched, the proportion of uranium 235 is increased not by addition, but by subtraction. Should a country, therefore, possess a facility to enrich uranium to 3,5 percent (for fuel purposes), it is capable of separating out 80 kilograms from 100 kilograms of uranium 238. To get to 90 percent uranium 235 (material for an atomic bomb) only 19 kilograms of uranium 238 more would have to be removed. Most of the work would already have been done. Therefore, a country possessing a plant to enrich

Although the concluding date of this dissertation is 1970 the statement made by the Deputy Minister of Mines, M Viljoen in May 1961 that there would be a future market for nuclear material and that South Africa would be able to deliver such material in whatever form it might be required at highly competitive prices, should be addressed.

The market for natural uranium fluctuated considerably between 1970 and 1989. South African production reached a peak in 1980 and declined to reach the level of 2943 tU in 1989. However, South African production is committed to long term contracts which cushions the South African uranium industry from fluctuations in the uranium market.[42]

Although the production of enriched uranium as well as its foreign trade value is classified information the pivotal question at issue in this dissertation should be addressed: Did the commercial production of enriched uranium succeed or did it prove to be a "white elephant"?[43]

According to P Bredell, General Manager of the uranium enrichment division of the Atomic Energy Corporation's[44] the semi-commercial enrichment plant was built as part of the AEC's uranium enrichment programme which commenced in the mid-1960's. Various studies were undertaken to investigate the feasibility of the commercial enrichment venture, but the decision to proceed with the plant was, however, largely precipitated by the passing of the US Nuclear Non-Proliferation Act in 1968, prohibiting, inter alia, the export of separative work

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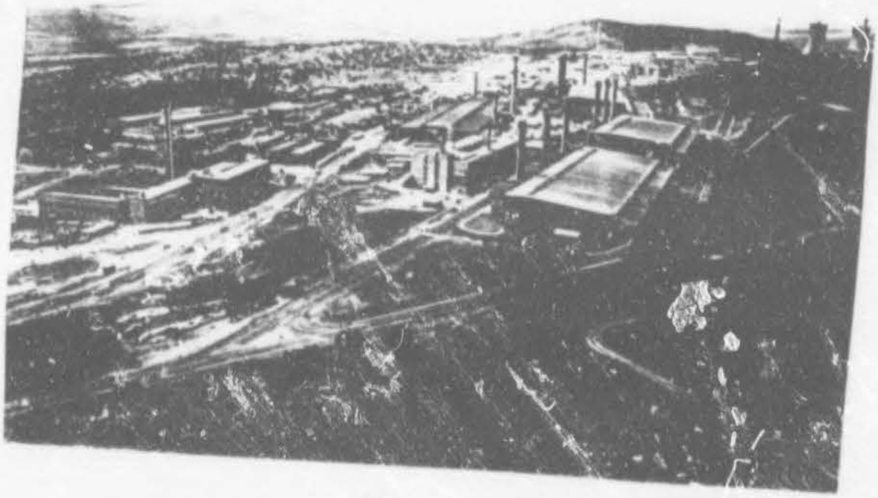
fuel, is three quarters of the way towards making an implosion assembly. N Moss: **The Politics of Uranium**, p. 21.

42 DJ Brynard: "Uranium Resources, production and demand in South Africa", **Engineering Week,** 23 November 1990.

43 Vid. p. 271.

44 The Atomic Energy Board (established 1948) and the Uranium Enrichment Corporation (established 1971) were from 1981 administered under a single corporate structure. D Geldenhuys: **The Diplomacy of Isolation,** p. 152.



Valindaba

(Source: Atomic Energy Corporation)

(enriched uranium) to countries that would not submit all their nuclear facilities to IAEA safeguards, such as South Africa at the time.[45]

Although the plant was completed at the end of 1986, plant commissioning took another 18 months, resulting in the commencement of production in September 1988. Most of the technical problems encountered during the commissioning of the semi-commercial enrichment plant could be traced back to insufficient prototype testing. All process related problems had to be solved within the AEC, which was fortunately well equipped to provide the necessary technical assistance.[46]

According to DB Sole, by the end of 1977 the Co-operation Agreement between the RSA and USA was a dead letter and the United States had reneged on its commitments to supply enriched fuel for SAFARI I research reactor.

Throughout the period 1976-1980 the United States had little or no credibility in the eyes of the South African Government and the reverse was equally the case, despite opinion in the United States that it was unwise to antagonise in the nuclear field a Western country which was the third largest producer of uranium in the Western world with the second largest proven reserves.[47]

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45 P Bredell: "Uranium Enrichment born out of Act excluding South Africa"' **Engineering Week**, 23 November 1990.

46 **Ibid.**

47 **Uranium Resources, Production and Demand**, Joint Report of the IAEA and NEA, December 1983, DB Sole: "The Rise of Nuclear Sanctions Against South Africa", p. 7; HJ Brynard: "Uranium Resources Production and Demand in South Africa", Focus on the AEC, **Engineering Week**, 23.11.1990, p. 4.

In April 1990, nuclear fuel elements produced in South Africa with South African enriched uranium were used to reload the Koeberg Nuclear Plant Unit 2.[48]

Recently it was reported in the South African press that South Africa was of pivotal importance in the battle for Africa between the Soviet Union and United States. This was confirmed by former KGB Chief of Foreign Counter Intelligence, General Oleg Kalugin who was in South Africa in September 1995.[49] Soviet expansionism in Southern Africa was a real threat in the late 1960's and 1970's. Therefore the decision to go nuclear and develop a limited capability in 1974 was strategically valid.

According to Dr Waldo Stumpf, chief executive officer of the AEC, South Africa's total supply of weaponsgrade enriched uranium which was produced at Valindaba during 1978 and 1989 is under IAEA guarantees and sealed by IAEA inspectors. The United States has not compelled South Africa to transfer its supply of enriched uranium to America in order that it might be degraded for commercial use. This supply of enriched uranium will be used in future to produce radio-isotopes. The supply could have been sold to the United States, however, the production of radio-isotopes will increase the foreign trade value of the enriched uranium up to forty times the normal selling price.[50]

Considering these issues as well as the stimulus of the entire enrichment undertaking in South Africa for nuclear and scientific development in Southern Africa the XYZ-project was of value. Criticism of

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48 **Die Burger**, 25 April 1990: "SA maak sy eie kernbrandstof"; 26 April 1990, "Kernkrag: SA gaan 140 M bespaar."

49 **The Argus**, 22 September 1995: "Apartheid 'a boon' to Russia"; **Weekend Argus**, 23/24 September 1995, "The 'life and death' battle for Africa".

50 "AEK smee Amerikaanse bande", **Finansies en Tegniek**, 26 August 1994.

expenditure involved[51] should take all strategic, economic, political and scientific considerations into account.

In an entirely new research project all factors pertaining to the history of nuclear energy after 1970 would have been to be thoroughly examined in order to determine conclusively the success of the vortex tube uranium enrichment project.

51 **Sunday Times**, 13.9.1992: "Nuke fuel wastage".

TECHNICAL ADDENDUM

The purpose of the technical addendum is to give an explanation in nonspecialist words and idiom, scientific and technical terms relating to the uranium and nuclear industries that the average reader may not be familiar with. In the text these words, formulas, concepts and processes are indicated with an asterisk (*) and explained as follows:

A

accelerator: the general principle behind this machine is that charged particles are accelerated by applying a powerful electric charge to them so that they are strongly repelled. JW Kane and MM Sternheim: **Physics** , p. 467; MW Dempsey: **Factbook of Science**, p. 15.

acid leaching: (see "leaching") dissolving soluble minerals or metals out of ore, by the use of acid. **McGraw-Hill Dictionary of Scientific and Technical Terms,** pp. 161, 898.

actinium: a radioactive metal found in pitchblende; atomic number 89; symbol Ac. **Chamber's Twentieth Century Dictionary**, p. 10.

alchemy: combination of primitive science and magic practised from ancient times until the birth of modern chemistry in the 1700's. In trying to transform base metals into gold and transform old age into youth alchemists made several discoveries - for example - of mineral acids - which paved the way for the development of chemistry. **Readers' Digest Library of Modern Knowledge,** vol. 1, p. 190.

alkali: metal hydroxide that is soluble in water and is a strong base. Any compound having highly basic qualities. **McGraw-Hill Dictionary of Scientific and Technical Terms,** p. 51.

alpha particles: fast moving helium nuclei (ions), containing 2 protons and 2 neutrons; emitted with a high velocity during the decay of certain natural radioactive substances; an alpha particle has a short definite range in matter (a few centimeters in air) and produces intense ionization of the atoms along its path. **Readers Digest Library of Modern Knowledge,** vol. 3.

amalgam barrel residues: The amalgam barrel is a mechanical apparatus used to ground gold ores in order to recover the gold by means of the amalgamation process. The residues are the substances left after the gold has been recovered by means of the amalgamation process (see "plate amalgamation process"). **Woordeboek van die Afrikaanse Taal,** deel 1, p. 170; **McGraw-Hill Encyclopaedia of Science and Technology**, vol. 19, p.

ammonium diuranate (ADU): see also "uranium extraction from gold ores". Ammonium diuranate, the product of the gold mines uranium extraction plants, which is an aqueous slurry, is pumped into storage tanks at the processing plant, where it is mixed with ADU from other mines. The calcining plant process starts with a filtration* process, where the ADU passes through filters and is pressed by rollers, through holes in a steel plate, to form spagetti-like extrusions on a dryer belt. During the drying process, these extrusions crack into pellets, determining the characteristic granula texture of the concentrates from the processing plant.

The ADU is further dried in a heated air stream after which the chips of ADU passs into calcining furnaces. These are horizontal cylinders of stainless steel, supported and turned on electrically driven rollers. They are heated externally by Calrod elements and the calcining temperature measured in the bed of the material reaches just under 500°C. The yellow ADU transforms through orange UO_3 (uranium trioxide) to grey green concentrates consisting of a mixture of UO_2 (uranium dioxide) and UO_3 (dry uranium oxide - "yellow cake").

From the U_30_8, commonly referred to commercially as "yellow cake", uranium oxide (UO_2), uranium tetrafluoride (UF_4), uranium hexafluoride (UF_6) and a pure form of uranium metal must be produced. These compounds can be used for research purposes and can, as refined materials, be exported. They would also be essential for uranium enrichment. (SAL) **Uranium: South Africa's Mineral Wealth**, Public Relations Department of the Chamber of Mines and the AEB of South Africa, 1982, pp. 8-9.

anion exchange method: ion exchange is a chemical reaction between substances in which the ions of metallic substances are exchanged for ions of other metals. The ion exchange is brought about by resins in a column. When a metallic substance is passed through them, they attach themselves to the ions in the substance, and ions of different metals are substituted.

Ion exchange is used to purify uranium. A suitable pregnant solution (of uranium) was passed through a column of a strong base* anion exchange* resin. The uranyl ion would then be selectively absorbed as a phosphate or sulphate anionic complex and after saturation of the column, this complex could then be eluted with a suitable eluant (a solution employed to elute the uranium off the resin) from which uranium could be recovered by precipitation as ammonium duiranate. **Readers' Digest Library of Modern Knowledge**, vol. p. 1002; RE Robinson and RG Velthuis: "The Ion Exchange Process as applied to Uranium Extraction", **Uranium in South Africa, 1946-1956**, vol. 1, pp. 332-333.

artificial radioactive elements: Frédéric and Irene Juliot-Curie bombarded boron, aluminium and magnesium respectively with alpha particles and they obtained radioactive isotopes of elements not ordinarily radioactive namely, nitrogen, phosphorous and aluminium. (See also "radioactivity"). Bombardment by neutrons can also change one element into another. A whole new series of chemical elements, not found in nature namely: plutonium and neptinium and others have been made by bombarding uranium and other elements. So far 16 artificial elements have been produced by nuclear bombardment. Like uranium these elements are unstable and intensely radioactive. **The New Encyclopaedia Britannica**, vol 8, p. 602; MW Dempsey: **Factbook of Science**, p. 14.

artificial radioactivity: see "radioactivity". Artificial radioactivity is induced by the bombardment of a substance by neutrons from another radioactive source. Also known as "induced radioactivity". **McGraw-Hill Dictionary of Scientific and Technical Terms**, p. 808.

atom: (a) smallest quantity of an element that can take part in a chemical reaction; (b) portion that cannot be subdivided without loss of chemical identity; (c) commonly the smallest portion of matter, an atom is identified by its mass represented by atomic weight, and the charge on its nucleus represented by its atomic number. The popular model of an atom comprises a nucleus made up of positively charged protons and uncharged neutrons which together constitute virtually the whole mass of the atom and a circumnuclear cloud of negatively charged electrons equal in number to the number of protons in the nucleus. **McGraw-Hill Dictionary of Scientific and Technical Terms**, p. 130.

atomic energy: see "nuclear energy".

atomic pile: early nuclear reactors were called "atomic piles" (c. 1946-1954). After the middle fifties the term "nuclear reactor" was generally used. It was a large device containing uranium in the form of the metal, highly purified. The amount of uranium in a pile depended on its construction and the purpose for which it was designed. The first pile to be successfully put into operation contained about 6,200 kg of uranium metal. A Bleksley: "South Africa will have and atomic pile" **Industrial Review of Africa**, March 1953, p. 17.

atomic weight (or relative atomic mass): isotopes differ in weight among themselves; e.g. the most common hydrogen atom - with one proton and no neutrons - has an atomic weight of 1. Some hydrogen atoms have a nucleus containing a proton and a neutron (deuterium). It is an isotope that weighs twice as much as an ordinary hydrogen atom. **Readers' Digest Great Encyclopaedic Dictionary**, vol. 3, p. 1482.

auto-oxidation process: (for dilute sulphuric acid production). Sulphuric acid and ferric sulphate were found effective for the dissolution (breaking up) of uranium ore. In the leaching process sulphuric acid and ferric sulphate* were established as effective and economical reagents*. There were alternative methods possible for obtaining these reagents from the pyrite of the Witwatersrand ores. Sulphuric acid could be obtained by the "auto-oxidation" process. By introducing sulphur dioxide and air into a solution containing ferrous sulphate, sulphuric acid and ferric sulphate could be formed. The auto-oxidation of sulphur dioxide to produce sulphuric acid and ferric sulphate seemed ideal for supplying these reagents for leaching uranium ores and a study of this process (which was relatively well-known in the 1940's) was commenced at the Government Metallurgical Laboratory towards the end of 1947 and continued for many years. VH Osborn: "South Africa Becomes a Uranium Producer", **Optima**, (3)1, March 1953, p. 14; PA Laxen and MG Atmore: "The Development of the Acid Leaching Process for the Extraction and Recovery of Uranium from Rand Cyanide Residues", **Uranium in South Africa**, 1946-1956, vol 1, pp. 317 - 318; p. 322.

autunite: (geology) a mineral composed of a hydrous phosphate of uranium and calcium (Autun in France, one of its localities). **Chamber's Twentieth Century Dictionary**, p. 70.

axial flow compressor: *axial*: of, pertaining to, or along an axis. *axial flow*: flow of fluid through an axially symmetric device such that the direction of the flow is along the axis of symmetry. *axial flow compressor*: a fluid compressor that accelerates the fluid in a direction generally parallel to the rotating shaft. **McGraw-Hill Dictionary of Scientific and Technical Terms**, p. 135.

B

B (beta) counter: instrument for measuring radioactivity; beta particles or electrons are given off by radium and other radioactive substances. **Chamber's Twentieth Century Dictionary**, p. 100.

ball-mill feed: ore that has been sent through the ball-mill (a pulverizer that consists of a horizontal rotating cylinder, up to three diameters in length, containing a charge of tumbling or cascading steel balls, pebbles or rocks). **McGraw-Hill Dictionary of Scientific and Technical Terms**, p. 148.

barium: atomic no. 56. Soft white easily oxidized metal; **Readers' Digest Great Encyclopaedic Dictionary**, vol. 3, p. 1483.

barren solutions: solutions from "filter cake" washing in which there is little or no recovery value; for example barren cyanide solution from washing of gold cake slimes. **McGraw-Hill Dictionary of Scientific and Technical Terms**, p. 155.

base exchange: replacement of certain ions by others in clay. **McGraw-Hill Dictionary of Scientific and Technical Terms**, p. 158.

beryllium: It is a hard white metal atomic number, 4. This metal has excellent properties for atomic energy purposes. It can be used as a moderator in nuclear reactors because it retains its structural strength at relatively high temperatures and is a good thermal conductor. (AECA) AJA Roux: **Proposed Atomic Energy Research and Development Programme for South Africa**, pp. 42-46.

beta-rays: beta particles - electrons; particularly the fast electrons emitted during radioactive change; they have a long path in air at normal pressure. JW Kane and MM Sternheim: **Physics**, p. 746.

Boiling Water Reactor (BWR): see "nuclear reactor"; "nuclear reactor (types)"; "light water reactors".

brannerite: a complex, black opaque titanite of uranium and other elements in which the weight of uranium exceeds the weight of titanium. **McGraw-Hill Dictionary of Scientific and Technical Terms**, p. 212.

Bufflex solvent extraction method: the process involved the recovery of uranium by ion-exchange and purification and recovery of the uranium by a tertiary amine solvent. In the later Purlex method direct contacting of the leach liquors with the solvent eliminated the ion exchange step. AR Newby-Fraser: **Chain Reaction**, p. 72.

bulk ore: large quantities of low-grade ore of which the high-grade portions have not been segregated. **McGraw-Hill Dictionary of Scientific and Technical Terms,** p. 225.

C

cadmium: atomic no. 48. soft, blue - white metal occurs as a sulphide in zinc ores; as cadmium (also boron, atomic number 5) readily absorbs neutrons it is used for making control rods that control the fission process in the reactor core. MW Dempsey: **Factbook of Science**. p. 19; **Chamber's Twentieth Century Dictionary**, p. 146.

calcine: (1) to heat to a high temperature without fusing - to heat ores, precipitates, concentrated ore residues so that hydrates, carbonates or other compounds are decomposed and the volatile material is expelled. (2) to heat under oxidizing conditions the product of calcining or roasting. **McGraw-Hill Dictionary of Scientific and Technical Terms,** p

calutron system: see "uranium enrichment", "methods of enrichment". "calutron system".

carbon-sulphide flotation: see also "flotation"; the flotation method was initially used to recover uranium. The uranium ores were subjected to flotation with different types of flotation reagents; addition of a frother floated the naturally floatable constituents; xanthate floated the sulphides and finally oleic acid was used to float the uraninite. The concentrates were referred to as "sulphide" and "carbon" concentrates. This method was known as carbon-sulphide flotation. Little of the uraninite contained in the Rand ores was liberated at the coarse grinds employed in these tests. (SAB) Levin, "Concentration Tests on the Gold-Uranium ores of the Witwatersrand for the Recovery of Uranium", **Uranium in South Africa,** vol. 1, 1946-1956, p. 345.

carbon: atomic number 6, known in several modifications: (1) crystalline, as diamond and graphite; (2) amorphorus as soot charcoal, gas-carbon and coke. **Readers' Digest Great Encyclopaedic Dictionary,** vol. 3, p. 1486.

carnotite: oxidized uranium mineral. Hydrated vanadate of uranium and potassium. Important as a source of radium, later of vanadium and later of uranium. **Chamber's Twentieth Century Dictionary**, p. 160.

centrifuge process see "uranium enrichment", "methods of enrichment". "centrifuge process".

chain reaction: In addition to fragments and energy, nuclear fission produces two or three neutrons, which under suitable conditions, can cause fission in other atoms. If that happens, an ever-increasing number of fissions will occur as more and more neutrons are released and cause more fissions in turn. This process, called a chain reaction, releases a vast amount of energy. To produce a chain reaction there must be a certain minimum of `critical' mass of uranium present. If the mass of uranium is too small, too many of the neutrons escape without hitting atoms, and no chain reaction occurs. The only useful naturally occurring fissile material is uranium-235, an isotope of uranium. This occurs in small amounts in natural uranium. When split, uranium-235 produces more than 3 million times the energy released by burning an equivalent amount of coal. If all the nuclei in one kilogram of uranium-235 fission, the energy released is equivalent to that of 20 000 tons of TNT. **Readers' Digest Library of Modern Knowledge,** vol. 1, p. 186; JW Kane and MM Sternheim: **Physics,** p. 767.

cobalt - silver: cobalt: metallic element, atomic number 27. Widely distributed in nature in association with nickel, copper, arsenic and silver. Tenacious and malleable metal. **Readers' Digest Great Encyclopaedic Dictionary,** vol. 3, p, 1490.

coffinite: black unoxidized uranium mineral containing 60% uranium. **McGraw-Hill Encyclopaedia of Science and Technology**, vol. 19, p. 86.

compound: Broadly speaking a substance containing two or more elements combined in definite proportions by weight regardless of the mode of preparation. **Readers' Digest Great Encyclopaedic Dictionary**, vol. 3, p. 1491.

conglomerates: (geology) composed of pebbles naturally cemented together. **Chamber's Twentieth Century Dictionary**, p. 222.

control rod: see also "nuclear reactor". Nuclear reactors contain control rods. These control rods are made of a substance such as boron, which has a large neutron capture probability, and are used to control the fission rate; as these rods are withdrawn from the reactor assembly, the chain reaction grows until the desired rate is reached. Replaced in the reactor assembly neutrons are captured and the rate of fission is controlled. JW Kane and MM Sternheim: **Physics**, p. 767.

copper precipitation process: solids may be separated from a solution by precipitation. When a solution is saturated with a substance (that is when no more will dissolve) at a raised temperature and is then allowed to cool, - a pregnant solution - the substance usually falls to the bottom. Precipitation is a chemical process. The copper precipitation process was developed from the following: When the pregnant solutions were passed over scrap iron for reduction purposes, in preparation for precipitation, a considerable proportion of the total uranium was precipitated on the iron as uranous phosphate. In this process, copper and phosphoric acid were added to the clarified pregnant solution, the copper being dissolved by the ferric sulphate* to form copper sulphate with the simultaneous reduction of the iron salt. The resulting solution was then treated with finely divided metallic iron whereby sponge copper and uranous phosphate were simultaneously deposited. The intention was to wash the cement copper - uranium precipitate, extract the uranium from it by solution in sodium carbonate and return the copper to the circuit. **Readers' Digest Library of Modern Knowledge**, vol. 1, p. 176. L Taverner: "An Historical Review...", **JSAIMM**, 57, Nov. 1956, p. 139.

corduroy concentrates method: method utilising an apparatus with a corduroy surface; used to separate ore or metal from its containing rock or earth. **Chamber's Twentieth Century Dictionary**, p. 218.

critical: 'critical' is used to describe a system which is, or is becoming unstable, so that a small change in conditions may bring about a large change in the system. A "critical mass of uranium" is one in which a U-235 isotope is about to fission and start a chain reaction; "critical wars" are wars involving atomic weapons. **Readers' Digest Library of Modern Knowledge**, vol. 1, p. 196.

crusher slimes: liquid slurry of very fine ore with slime appearance; ore from the crusher (machine for crushing rock and other bulk materials). **McGraw-Hill Dictionary of Scientific and Technical Terms**, p. 388.

cyanidation process: this is the predominant process for extracting gold from its ores. A dilute cyanide solution is added to the finely ground ore for dissolution of the gold; continuous agitation and aeration of the pulp for up to 50 hours is required for complete extraction; process of dissolving powdered gold ores in a weak solution of sodium cyanide or potassium cyanide; the precious metal is precipitated from the solution by zinc. **McGraw-Hill Dictionary of Scientific and Technical Terms**, p. 400.

cyanide residues: substances left after the gold has been removed in the cyanide process of gold extraction. **McGraw-Hill Dictionary of Scientific and Technical Terms**, p. 400.

cyclotron: device for accelerating charged particles to high energies by causing them to pass repeatedly through the same region. JW Kane and MM Sternheim: **Physics**, pp. 467-468.

D

davidite: uranium-titanium-bearing mineral, relatively unoxidized uranium mineral (7-10 percent uranium); occurs in the ore at Radium Hill, South Australia. The Associated Scientific and Technical Societies of South Africa: **Uranium in South Africa**, vol. I, pp. 227 and 377.

distilled water: water that has been converted from liquid into vapour by heat and then condensed again to flow as a liquid. **Readers' Digest Library of Modern Knowledge,** vol. 2, p. 998.

E

Einstein's theory of relativity: As early as 1905 Einstein stated that mass and energy were equivalent and suggested that proof of the equivalence might be found by the study of radioactive substances. He concluded that the amount of Energy E, equivalent to a mass M, was given by the equation: $E = Mc^2$ where c is the velocity of light. This implies that mass can be changed into energy. This, however, can only be brought about by some mechanism. With the discovery of nuclear fission this mechanism was found. In the fission process a nucleus of uranium breaks up into fragments, the total mass of which is less than that of the original nucleus. When this happens, energy is produced in the form of heat and radiation. According to Einstein's equation, $E = Mc^2$, this energy is the result of the conversion of some of the mass of the original atom. When the total mass of the products of nuclear fission is calculated, it is found to be less than the original mass of the atom before fission. So the mass lost during fission reappears as energy. In Einstein's equation c, the velocity of light, is very large (186 000 miles, 300 000 km a second). Therefore E will be very large indeed. If stated in actual numbers, its startling character is apparent. It shows that one kilogram of matter, if converted entirely into energy, would give 25 000 000 000 kilowatt hours of energy, as against 8,5 kilowatt hours of heat energy which may be produced by burning an equal amount of coal. BJ Olivier: "Uranium", **Industrial Review of Africa,** 4(7), Jan 1953, pp. 17 - 33; JW Kane and MM Sternheim: **Physics**, pp. 635 and 765 - 767.

electron: one of the fundamental particles of matter, a constituent of all atoms; electrons carry a negative electric charge, revolve about the positively charged nucleus of every atom in defined orbits. Their number and arrangement determine the chemical properties of the atom and their number is constant for each element. JW Kane and MM Sternheim: **Physics**, p. 117.

electroscope: instrument used to detect electric charge and radiation. **Readers' Digest Library of Modern Knowledge,** vol. 1, p. 199.

element: a substance that cannot be resolved by chemical means into simpler substances; **element abundance:** the relative amounts of each type of atom in the universe. Hydrogen is the most abundant, accounting for 92% of the atoms, followed by helium (nearly 8%); all the other atoms together make up less than 1%. **Readers' Digest Library of Modern Knowledge,** vol. 1, p. 55; **Chamber's Twentieth Century Dictionary**, p. 341

element 94: the element with atomic number 94 which is plutonium. An artificial element not found in nature. MW Dempsey: **Factbook of Science**, p. 14.

enriched material: material in which the amount of one or more isotopes has been increased above that occurring in nature such as uranium in which the abundance of U-235 is increased. See also "uranium enrichment". **McGraw-Hill Dictionary of Scientific and Technical Terms,** p. 547.

enriched uranium: see "uranium enrichment".

enrichment of uranium: see "uranium enrichment".

exponential piles (of uranium): piles that can produce a chain reaction. A Bleksley: "South Africa will have a Atomic Pile", **Industrial Review of Africa,** 4(9), March 1953, pp. 17 - 18.

F

fatty acid float: an organic monobasic acid used in the flotation method of uranium recovery. **McGraw-Hill Dictionary of Scientific and Technical Terms,** p. 590.

ferric sulphate: iron forms two series of salts namely iron II, ferrous and iron III ferric. It is a salt used in industrial chemical processes. **McGraw-Hill Dictionary of Scientific and Technical Terms,** p. 596.

filtration: filtration separates solids from liquids conducting - often under pressure - a mixture through a filter medium. Woven fabric, metal mash, granular materials and porous salts may all be used as a medium. **McGraw-Hill Dictionary of Scientific and Technical Terms,** p. 606.

fissile material: material in which nuclear fission can take place

fission: see "nuclear fission".

flotation method: a process used to separate particulate solids which have been suspended in a fluid, by selectively attaching the particles to be removed to a light fluid and allowing this mineralized fluid aggregation to rise to where it can be removed. PC Schoonees et al (red): **Woordeboek van die Afrikaanse Taal,** D-F.

fluorescence: the property of some substances of emitting, when exposed to radiation, rays of greater wave-length than those received. Emission of light by substances excited by bombardment with electrons or other charged particles, X-rays, or ultraviolet light (adjective: fluorescent). **Readers' Digest Library of Modern Knowledge,** vol. 1, p. 200.

fluorescent: see "fluoresence"

Fluorox process: the conventional processes for UF_4 and UF_6 production require either anhydrous hydrofluoric acid or fluorine gas neither of which was produced in South Africa. Consequently an alternative method, the so-called Fluorox process, involving the oxidation of UF_4 was developed. AR Newby-Fraser: **Chain Reaction,** p. 74.

G

gaseous diffusion method: see ""uranium enrichment", "methods of enrichment""gaseous diffusion method".

Geiger-Müller counter: radiation is detected by observing the ionization it produces in matter. A Geiger counter is a radiation detector. **McGraw-Hill Dictionary of Scientific and Technical Terms,** p. 672.

geysers: a spring that spouts hot water into the air. **Chamber's Twentieth Century Dictionary,** p. 445.

graphite: soft, black carbon in natural form; excellent heat-resisting material; in nuclear reactors it acts as a "moderator"; see also "moderator". **Readers' Digest Library of Modern Knowledge,** vol. 2, p. 1000.

gravity method of extraction: particles in suspension in a liquid allowed to settle under normal gravity. **McGraw-Hill Dictionary of Scientific and Technical Terms,** p. 700.

H

heavy water moderated: see "moderator" and "nuclear reactor".

heavy water: (deuterium oxide; D_2O) is so called because although in nearly all respects it is the same as water, the hydrogen atoms have been replaced by one of hydrogen's heavier isotopes, deuterium. Hydrogen exists in three forms: ordinary hydrogen $_1H$; deuterium or heavy hydrogen $_2H$; and Tritium $_3H$. All water contains a minute amount of heavy water - some 150 parts in a million. Its separation requires large expensive plants. **Readers' Digest Great Encyclopaedic Dictionary,** vol. 3, p. 1505.

hydrocarbon: The simplest carbon compounds are the hydrocarbons, which are made up of carbon and hydrogen atoms only. Elseworth (1928) gave the name thucolite to radio-active hydrocarbon. Thucolite has been retained in mineralogical literature to denote certain natural, solid hydrocarbons that contain uranium - and or thorium-bearing minerals. The Associated Scientific and Technical Societies of South Africa: **Uranium in South Africa**, vol. I, p. 102; **Readers' Digest Library of Modern Knowledge**, vol. 1, p. 180.

hydrogen: the simplest element and the lightest gas; probably the most common element in the universe. Hydrogen has three isotopes. See "heavy water". **Readers' Digest Library of Modern Knowledge**, vol. 1, p. 203.

I

ionizing radiation: (1) Particles or photons that have sufficient energy to produce ionization directly in their passage through a substance; also known as ionization radiation; (2) particles that are capable of nuclear interactions in which sufficient energy is released to produce ionization. **McGraw-Hill Dictionary of Scientific and Technical Terms**, p. 842.

irradiation processes: see "irradiation".

irradiation: (engineering) the exposure of a material or object to X-rays, gamma rays, ultraviolet rays or other ionizing radiation. **McGraw-Hill Dictionary of Scientific and Technical Terms**, p. 844.

isotope: an atom of an element having a different nuclear mass, and hence atomic weight from other atoms of the same element. An isotope of an element is chemically identical with other isotopes of the same element. **McGraw-Hill Dictionary of Scientific and Technical Terms**, p. 852.

isotope uranium-235: see "uranium".

K

kinetic energy: energy possessed by a moving object: the amount of this energy depends on the mass of the object and the speed of its movement. **Readers' Digest Library of Modern Knowledge**, vol. 1, p. 156.

krypton: element; atomic number 36. A curious gas discovered in the air by Sir W Ramsay in 1898; **Chamber's Twentieth Century Dictionary**, p. 591.

L

lime: the white caustic earth got by calcining calcium carbonate. It usually is added to control pH and reduce the harmful effects of accessory material. **Chamber's Twentieth Century Dictionary**, p. 618.

lithium: (symbol Li; atomic number 3) it is one of the lightest known solids. **Chamber's Twentieth Century Dictionary**, p. 622.

low velocity neutrons: neutrons that have been slowed down by a moderator; see "moderator". JW Kane and MM Sternheim: **Physics**, p. 767.

M

magma: (geology) molten rock material. **Chamber's Twentieth Century Dictionary**, p. 638.

"Magnox" reactor: see "nuclear reactor"; "nuclear reactor (types)".

mass spectrograph (mass-spectrometer): instrument for measuring the masses and relative abundances of different kinds of ion. The substance is vaporised and ionised by electron bombardment. The ions pass through a narrow slit, are accelerated by an electric field, pass through a magnetic field in a curved path to another slit and are detected as an electric current. For any given setting of the instrument, only ions of

nitrogen: a gas; atomic number 7; atomic symbol N; forming nearly four-fifths of common air. **Chamber's Twentieth Century Dictionary**, p. 725.

nuclear energy: energy released when a nuclear reaction takes place. This can be (a) fission, the splitting of a heavy nucleus into fragments, (b) reaction of elementary particles with a nucleus, (c) radioactive disintegration; the release of energy is accompanied by a loss of mass predicted by Einstein's special relativity theory. JW Kane and MM Sternheim: **Physics**, pp. 766 - 767.

nuclear fission: In the fission process a nucleus of uranium breaks up into fragments, the total mass of which is less than that of the original nucleus. See "Einstein's theory of Relativity." JW Kane and MM Sternheim: **Physics**, pp. 766-767.

nuclear fuel: uranium-235 and plutonium-239 are nuclear fuels. They are fissionable and can be used in fuel pellets. Millions of pellets in slender fuel rods make up a reactor core. From the chain reaction of fissioning uranium in the reactor core water is heated. Part of the energy that bound the nucleus is released as heat. Heated water produces steam. Steam drives a turbine that operates a generator - a generator produces electricity. "Anatomy of a Nuclear Plant", **National Geographical Magazine**, vol. 155, No 4, April 1979.

nuclear power production: a controlled fission reaction (splitting of the atoms of uranium) takes place inside a nuclear reactor. The uranium is sealed inside fuel elements in the reactor. A coolant fluid circulates past the hot elements, bearing the heat away to a heat exchanger, a device in which heat is transferred from one fluid to another. There it heats water, creating high-pressure steam to drive turbo-generators as in a conventional (fossil fueled) power station. **Readers' Digest Library of Modern Knowledge**, vol. 2, p. 970.

nuclear power reactor: Proposed Schemes (15 December 1966) Five schemes were proposed which would be used as guidelines for nuclear development in South Africa in the following years: Each scheme indicated: 1 type of fuel; 2 initial type of reactor (short term); 3 ultimate choice of reactor (long term). Of the five schemes proposed, three seemed to be the most appropriate: Scheme A, Scheme B and Scheme D.

The reactor proposed in Scheme A would initially be fueled with natural uranium and ultimately with plutonium with barren uranium as fertile material. The type of reactor that would be required for the first stage of Scheme A would be a thermal neutron (heavy water-D_2O) reactor (TNR) which was developed overseas. The ultimate reactor in Scheme A would be the best type of fast breeder reactor that would have been developed overseas at the time in the future that the Republic required it. Scheme B: In the second scheme the reactor would be fueled with natural uranium and ultimately with plutonium and barren uranium as fertile material. The initial type of reactor would be based on the PELINDUNA project. The ultimate reactor would be the South African Atomic Energy Board's Fast Neutron Reactor (FNR) PELIHENNA which would be developed out of the TNR PELINDUNA. (PELIHENNA - the name was derived from "<u>PELI</u>NDABA" and "<u>h</u>igh <u>e</u>nergy <u>n</u>eutron sodium (Afrikaans - <u>na</u>trium)" reactor.) Scheme D: This scheme indicated a reactor that would be fueled with enriched uranium for the TNR and for the first load of the FNR. The first type of reactor would be based on PELINDUNA and the ultimate reactor would be PELIHENNA. **GVP Navorsings- en Ontwikkelings-program**, Minutes of meeting, 15.12.1966, pp. 4-5.

nuclear reactor: assembly of fissionable material (uranium, plutonium) in the form of canned fuel elements separated by a moderator (graphite, heavy water) and controlled to maintain a self-sustaining chain reaction; heat generated in the process is removed by a coolant. A nuclear reactor can be used for power production; all electric power reactors in operation in the United States and elsewhere in the world employ thermal neutrons to induce fission and have several common features. They have fuel rods (tubes containing enriched uranium) along with a moderator and control rods. The moderator serves to slow down the neutrons. The control rods are made of a substance such as boron, which has a large neutron capture probability and are used to control the fission rate. As these rods are withdrawn from the reactor assembly the chain reaction grows until the desired rate is reached. The approximately 1 percent of the neutrons that are delayed play a key role in this process. They permit the operators to gradually adjust the control rods and to make readjustments if the reaction grows too rapidly. JW Kane and MM Sternheim: **Physics**, pp. 767 - 768.

nuclear reactors (types):

light-water reactors: most electric power reactors in the United States, Western Europe and Japan use ordinary light water (H_2O) as a moderator; neutrons slow down when they collide with the hydrogen nuclei in the water. The water also serves as a coolant. There are two types of light water reactors: **boiling water** and **pressurized water**. The energy released in the fission process is converted into heat when the fast moving fission fragments collide with other atoms in the fuel rods. In a boiling water reactor the water carries off this thermal energy in the form of steam that is then used to drive turbines and generate electricity. In a pressurized-water reactor, the pressure of kept high enough that the water never boils. Its heat is transferred through a heat exchanger to water at a lower pressure that boils and produces the steam that drives the turbines. Both types of light water reactors are intrinsically stable against runaway chain reaction. Any unintended rise in temperature reduces the density of the water, thereby reducing the number of nuclei available to moderate the neutrons and slowing the reaction. JW Kane and MM Sternheim: **Physics**, p. 768.

"Magnox" reactor: a "Magnox" reactor utilises natural uranium as fuel, graphite as moderator and is gas-cooled. PEL 175 E, AEB **Report on the investigation into the Possible Introduction of Nuclear Power in South Africa**, May 1968, p. 10.

natural uranium reactor: a type of reactor that utilises uranium in its naturally occurring state. Natural uranium contains only 0.71% of the fissile uranium-235 isotope. (Because of this very low proportion of U-235 to U-238 in "natural" uranium only those reactor systems with low neutron absorption can be operated on natural uranium). PEL 175 E, AEB **Report on the investigation into the Possible Introduction of Nuclear Power in South Africa**, May 1968, p. 10.

nuclear spectroscopy: study of the distribution of energies or momenta of particles emitted by nuclei. **McGraw-Hill Dictionary of Scientific and Technical Terms**, p. 1100.

nuclear test ban: a formal prohibition on the testing of nuclear weapons. **Chamber's Twentieth Century Dictionary**, p. 8a.

nuclei: see "nucleus"; plural of nucleus.

nucleus: see "atom"; central, heavy, positively charged part of the atom around which the electrons move; it consists of protons and neutrons. **Chamber's Twentieth Century Dictionary**, p. 733.

nuclide: a species of atom, characterized by a number of protons, number of neutrons and energy contents in the nucleus, or alternatively by the atomic number, mass number and atomic mass; to be regarded as a distinct nuclide the atom must to capable of existing for a measurable lifetime. **McGraw-Hill Dictionary of Scientific and Technical Terms**, p. 1101.

O

osmiridium: alloy of osmium and iridium; osmiam is an element of the platinum group; osmiridium is found naturally and contains iridium (50-80%) and osmium (15-40%). **Readers' Digest Great Encyclopaedic Dictionary**, vol. 3, p. 1521.

oxide: compound in which oxygen is combined with another element. Chemically oxides can be grouped into three categories (1) oxides of metals (2) oxides of the alkaline - earth metals and (3) oxides of non-metals. The first oxides tend to have the character of "bases", being able to neutralise acids. The second oxides dissolve in water to form alkalis and the third, for example, are the oxides of sulphur and carbon. These are acidic in character, e.g. sulphur trioxide forms sulphuric acid H_2SO_4. (See "sulphuric acid" - used in the uranium extraction process). **Readers' Digest Library of Modern Knowledge**, vol. 1, pp. 2019 - 210.

oxygen: a gas without taste, colour or smell; forming part of air, water etc; supporting life and combustion; atomic number 8. **Chamber's Twentieth Century Dictionary**, p. 768.

P

pegmatite deposits: (geology) deposits of very coarsely crystallised granite. **Chamber's Twentieth Century Dictionary**, p. 798.

Pelsakon technique: in broad outline it is a periodic technique. The process mixture (UF_6 + He or UF_6 + H_2) is pumped in one direction (forward) through the separating element and then, by means of valves, the flow is reversed and the gas mixture is pumped back into the system for a time. After this the gas mixture is pumped forward again. The action is dependent on valves that are linked periodically. The gas is pumped out and back in what is known as transfer volumes. ***Interview with Dr JJ Wannenburg, Valindaba.***

piston engine: a piston engine has a rod that moves up and down and the rod has to be sealed from the atmosphere. This was one problem. The second difficulty was that it required piston-rings that would have to be lubricated. A third problem was that the piston engine would need valves that would automatically open and close according to the change of the pressure.

The greatest difficulty that had to be overcome was the sealing of the pistonrod. (The rod moving up and down would oscillate the piston). The method that Dr Wannenburg ultimately used was to employ a bellows. The bellows was sealed from the inside outward. Considering that the bellows had to accommodate a movement of 100 mm or more at a speed of approximately 500 revolutions per minute, as well as making allowances for metal fatigue - the problems seemed unsurmountable. The initial design of the bellows was a construction of stainless steel plates. The plates were welded together - and in this way the bellows was set up. However, the construction would only last for about one thousand cycles. Moving at 500 revolutions per minute, it would function for a mere two minutes.

With the improvement of welding techniques, as well as construction materials, a bellows was set up which seemed adequate for experimentation. A machine and the bellows were set in operation and it functioned for twenty-four hours. This was indeed an accomplishment for the team and they celebrated the success. When one of the technicians dismantled the machine in order to inspect the bellows, it disintegrated into a thousand pieces. This was a tremendous setback. Ultimately Teflon (a plastic material) was used. With much development and numerous improvements, in conjunction with the manufacturing industry, a bellows was constructed that could be used in the pilot plant. In conclusion (as far as the development of the compressor is concerned) it should be mentioned here that the construction of the pilot plant was started in 1973. Interview with Dr JJ Wannenburg, Valindaba.

pitchblende: a black mineral of resinous lustre, fundamentally composed of uranium oxides; a source of uranium and radium. See also "uraninite" **Chamber's Twentieth Century Dictionary**, p. 830.

plate amalgamation method (see also amalgam barrel residues): method where a copper plate, for the dissolution of gold in mercury, was placed in front of the discharge screen of a stamper that grinds gold ore; a method of gold recovery widely practised prior to cyanidation and in conjunction with it. **McGraw-Hill Encyclopaedia of Scientific and Technical Terms**, vol. 8, p. 162; **Woordeboek van die Afrikaanse Taal**, deel 1 (A - C), p. 170.

plutonium: (symbol Pu, atomic number 4) artificial radioactive element, made by irradiating or bombarding uranium with neutrons in a nuclear reactor. Large quantities of plutonium are produced in fast breeder reactors. One isotope of plutonium (Pu-239) is used as a nuclear fuel. **Readers' Digest Library of Modern Knowledge**, vol. 2, p. 1005.

precipitated (as oxides): a substance (such as uranium) separated from solution or suspension, usually falling to the bottom. **Chamber's Twentieth Century Dictionary**, p. 860.

precipitation (see also copper precipitation process): solids may be separated from a solution by precipitation. When a solution is saturated with a substance (that is when no more will dissolve) at a raised temperature and is then allowed to cool, the substance usually falls to the bottom. Precipitation of uranium is very complex. A solution produced by leaching ore (containing uranium) with sulphuric acid and manganese dioxide, contains uranium and significant quantities of ferric, ferrous, aluminium and magnesium ions, etc. MG Atmore: "The Chemistry of Uranium Oxide Production", **Uranium in South Africa**, vol.2, p. 192.

pressure leaching: in the process used for the extraction of uranium, pyrite was recovered from the ore and used for the production of sulphuric acid, which was then used in the leaching process. Considerable interest was attached to the possibility of generating acid from the pyrites in the ore in situ in a pressure leaching process. If successful, that method of operation would eliminate the need for pyrite recovery plants in many instances, and the need for expensive sulphuric acid plants. (AECA, Pelindaba) AJA Roux: **Proposed Atomic Energy Research and Development Programme of South Africa**, p. 22.

Pressurrised Water Reactor (PWR): see "nuclear reactor"; "nuclear reactor (types)"; "light water reactors".

proton: a constituent of all atomic nuclei with a positive electric charge. See "atom" and "nucleus".

pyrite: a hard brittle brass-yellow mineral with metallic lustre. **McGraw-Hill Dictionary of Scientific and Technical Terms**, p. 1300.

Q

quartz: (geology) the commonest rock-forming mineral, composed of silica, occurring in hexagonal crystals. **Chamber's Twentieth Century Dictionary**, p. 901.

R

radiation: anything that radiates from a source. The term is used in three main fields: (1) the radiation of sound; (2) the radiation of electromagnetic waves, including radio waves, infra-red, visible light, ultra-violet, X-rays and gamma rays; and (3) the radiation of electronically charged particles which can ionise matter through which they pass. **Readers' Digest Library of Modern Knowledge**, vol. 1, p. 214.

radio nuclides: a nuclide that exhibits radio activity; see also "nuclide" **McGraw-Hill Dictionary of Scientific and Technical Terms**, p. 1324.

radio-isotope: an isotope which exhibits radioactivity - also known as radioactive isotope; unstable isotope. **McGraw-Hill Dictionary of Scientific and Technical Terms**, p. 1323.

radioactivity: spontaneous disintegration of atomic nuclei; the majority of atoms are stable, remaining the same indefinitely. However, some change, by giving off nuclear particles in the form of radiation. This process is known as radioactivity. Radioactivity occurs when a atom contains too many neutrons, or too few for the number of protons (that is if the nucleus has too much or too little cement). The nucleus will then be unstable and tends to redress the balance by ejecting one or more nuclear particles. The disintegration involves the emission of (a) alpha particles, the positively charged helium nuclei, (b) beta particles, high energy electrons (accompanied by neutrinos), (c) gamma rays, high energy (short wave-length) X rays. Natural radioactivity is a sign of nuclear instability characteristic of isotopes with high atomic numbers, e.g. radium. Ra is finally transmuted (see ("transmutation") into an isotope of lead, Pb-82. Isotopes of smaller numbers are produced artificially and many of these are radio-active. **Readers' Digest Library of Modern Knowledge,** vol. 1, p. 169; **Readers' Digest Great Encyclopaedic Dictionary,** vol. 3, p. 1528.

radium: a radioactive metallic element; atomic number 88; found in pitchblende and other minerals. Remarkable for its active spontaneous disintegration. See "radioactivity". **Chamber's Twentieth Century Dictionary**, p. 909.

reagent: a substance with characteristic reactions, used in chemical tests. **Chamber's Twentieth Century Dictionary**, p. 918.

radon: (Rn, atomic number 86) Radon is formed when radium decays. Like radium it is radioactive. Traces of radon appears in the air, but in hardly detectable concentrations. Radon traces are higher where uranium mineral ore is crushed. MW Dempsey: **Textbook of Science**, p. 150; **Uranium in South Africa**, vol. 2, p. 150

research reactor: a reactor primarily designed to supply neutrons or other ionizing radiation for experimental purposes; it may also be used for training, materials testing and production of radioisotopes. Also known as teaching reactor. **McGraw-Hill Dictionary of Scientific and Technical Terms,** p. 1363.

resin: any of a class of solid or semisolid organic products of natural or synthetic origin with no definite melting point - generally of high molecular weight. **McGraw-Hill Dictionary of Scientific and Technical Terms,** p. 1364.

Röntgen rays: German physicist Konrad von Röntgen (1845-1923) discoverer of Röntgen rays or X-rays. Röntgen rays or X-rays are electromagnetic rays of very short wavelength which can penetrate matter opaque to light rays. Produced when cathode rays impinge on matter. **Chamber's Twentieth Century Dictionary**, p. 957.

rotor compressor: it functions similar to an Archimedes pump. It has two rotors, machined in the form of two screws. The screws rotate into each other and this turning action pumps the gas. This type of compressor had the disadvantage of having two axles that had to be sealed - a total of four seals. **Interview with Dr JJ Wannenburg, Valindaba.**

run-of-mine: the unscreened output of a mine, or "mine run". **McGraw-Hill Dictionary of Scientific and Technical Terms,** p. 1025.

S

salts: the term "salt" covers any compound formed by the replacement of hydrogen in an acid by a metal; calcium chloride, magnesium sulphate, potassium nitrate, for example, are all salts. **Readers' Digest Library of Modern Knowledge,** vol. 1, p. 175.

sericitic (minerals): sandstone in which sericite (derived by decomposition of feldspar) intermingles with finely divided quartz and fills the voids between quartz grains. **McGraw-Hill Dictionary of Scientific and Technical Terms,** p. 1452.

spring: see "thermal spring".

stages of enrichment: see "uranium enrichment", "stages of enrichment".

stope: to excavate ore in a vein by driving horizontally upon it a series of workings - one immediately over the other, or vice versa - each horizontal working is called a stope because when a number of them are in progress each working area under attack assumes the shape of a flight of stairs; stopes, therefore, areas of mine workings. **McGraw-Hill Dictionary of Scientific and Technical Terms,** p. 1559.

sulphides: chemical compound in which sulphur is united with another element. Sulphide minerals are widespread in nature and include pyrite (see "pyrite"). **Readers' Digest Library of Modern Knowledge,** vol. 1, p. 220.

sulphuric acid: uranium is soluble in sulphuric acid. In the uranium industry it is obtained from the pyrite of the Witwatersrand ores. Sulphuric acid plays as important a part in the recovery of uranium as that played by cyanide in gold production. In order to obtain sulphuric acid a very exhaustive programme of research was conducted into the auto-oxidation process*. The results obtained were regarded as so satisfactory that an auto-oxidation unit was designed and provided the sulphuric acid and ferric sulphate reagent requirements for the small pilot leach plant at the GML. Plants for the production of sulphuric acid were later constructed at several mines associated with uranium production. This was a very convenient arrangement, since the raw material for sulphuric acid production is readily available as a by-product. See also "auto oxidation process" and "pressure leaching". L Taverner: "An Historical Review...", **JSAIMM**, 57, Nov. 1956, pp. 136 - 137; VH Osborn: "South Africa Becomes a Uranium Producer", **Optima**, (3)1, March 1953, p. 14; PA Laxen and MG Atmore: "The Development of the Acid Leaching Process for the Extraction and Recovery of Uranium from Rand Cyanide Residues", **Uranium in South Africa**, 1946-1956, vol.1, pp. 316-317 and 322.

silicates: see "uranium silicates".

T

target (physics): an object or substance subjected to bombardment or irradiation by particles or electro-magnetic radiation. **McGraw-Hill Dictionary of Scientific and Technical Terms,** p. 1611.

tails assay: is the weight percentage U-235 in the ammonium-diuranate (yellowcake) supplied to the enrichment plant. The capacity of an enrichment plant in terms of the tonnage of enriched uranium produced is not fixed. Output depends on the tails assay. The optimum tails assay depends on the price of the raw uranium and the cost of the enrichment. The more expensive the yellowcake is, the lower is the optimum tails assay, given the price of the separative work units. TG Moore: **Uranium Enrichment and Public Policy**, pp. 11-13.

thermal springs: hot outflows of water from the earth. **Chamber's Twentieth Century Dictionary**, p. 1144.

thermodynamical efficiency: thermodynamics originated as the study of the relationship between mechanical and thermal energy (the energy associated with the disordered motions of the atoms and the molecules with in a substance). The second law of thermodynamics sets limits on the efficiency of converting thermal energy to work that is independent of the materials used in the process. Such processes are used in both fossil fuel and nuclear electric power-generating plants. JW Kane and MM Sternheim: **Physics,** p. 260.

thorium: (symbol Th, atomic number 90) a highly reactive element. It occurs in a wide variety of minerals.

thorium: processing methods of: thorium is a fertile material from which a fissile isotope of uranium (U-235) can be bred and used to fuel fast breeder reactors. The application of the thorium cycle was acknowledged in 1958 (Dr AJA Roux's Proposed Atomic Energy Research and Development Programme) as a long-term future possibility. AR Newby-Fraser: **Chain Reaction**, p. 40; **Readers' Digest Great Encyclopaedic Dictionary**, vol. 3, p. 1539.

thorium province: (geology) thorium regions (areas) of the earth. BB Brock et al: "The Geological Background to the Uranium Industry", **Uranium in South Africa**, 1946-1956, vol.1, p. 216.

TNT: trinitrotoluene - a high explosive. **Chamber's Twentieth Century Dictionary**, p. 1176.

torbernite: a bright green radioactive hydrous phosphate of copper and uranium. **Chamber's Twentieth Century Dictionary**, p. 1161.

transmutation: a changing into a different form, nature or substance especially that of one chemical element into another; radium transmutes spontaneously in nature to lead (atomic number 82); tansmutation is achieved by bombarding an element with accelerated atomic particles, such as alpha particles and protons. **Readers' Digest Library of Modern Knowledge**, vol. 1, p. 222.

Twenty percent (20%) in the isotope U-235: see "enriched material"

U

U-235: uranium-235, see "uranium".

U-238: uranium-238, see "uranium".

Unit separative work: Fundamental measure of work required to separate a quantity of isotopic mixture into two component parts, one having a higher percentage of concentration of the desired isotopes and one having a lower percentage. (see also tails assay) **McGraw-Hill Dictionary of Scientific and Technical Terms**, p. 1450.

uraninite: heavy black radioactive uranium mineral. The terms "uraninite" and "pitchblende" are often used synonymously. Rogers (1947) suggested that the term "uraninite" should be applied to the mineral consisting essentially of uranium oxide. They differ in specific gravity and water content. The Associated Scientific and Technical Societies of South Africa: **Uranium in South Africa**, vol. I, p. 86; **McGraw-Hill Encyclopedia of Science and Technology Terms**, vol. 19, p. 86.

uranium: element; symbol U; a hard white metal found in pitchblende and in other minerals. The element uranium is composed of three different isotopes. These are uranium-234, uranium-235 and uranium-238. Uranium-234 consists of 92 protons and 142 neutrons. Uranium-235 consists of 92 protons and 143 neutrons. Uranium-238 consists of 92 protons and 146 neutrons. Uranium-235 represents only 0,71 percent of the total. Uranium-234 represents a negligible amount. Uranium-238 makes up 99 percent of the metal. The artificial fission of uranium, which releases huge amounts of energy, provides the basis of nuclear power. JW Kane and MM Sternheim: **Physics**, pp. 765 - 767.

uranium enrichment: uranium is enriched when the amount of the isotope (uranium-235) has been increased above that occurring in nature. When uranium is enriched the proportion of uranium-235 is increased not by addition, but subtraction. Uranium-238 isotopes are separated out increasing therefore the percentage uranium-235. Should a country, therefore, possess a facility to enrich uranium to 3,5 percent (for fuel purposes), it is capable of separating out 80 kilograms from 100 kilograms of uranium-238. To get to 90 percent uranium-235 (material for an atomic bomb) only 19 kilograms of uranium-238 more would have to be removed. Most of the work would already have been done. Therefore, a country possessing a plant to enrich fuel, is three quarters of the way towards making an implosion assembly. N Moss: **The Politics of Uranium**, p. 21.

methods of enrichment:

- **the centrifuge process of isotope separation:** in this process the heavier isotope 238 is spun to the outside, as in a cream separator.

- **the calutron system of isotope separation:** in the calutron process, uranium tetrachloride was charged to the ion source of an electromagnetic 180° mass separator (calutron) and ionized. The beams of U-235 and U-238 ions, which were separated in the magnetic field, were collected separately in individual pockets of a collector made of graphite.

- **the gaseous diffusion process of isotope separation:** in this process, gaseous uranium hexafluoride is diffused through barriers, or filters, more molecules containing the lighter isotopes, uranium-235 pass through the filter than those containing the heavier isotope, slightly enriching the mixture on the far side. A sequence of several thousand stages would be needed to enrich the mixture to 90 percent uranium.

- **gaseous diffusion method** (an explanation by Dr AJA Roux): To enrich the uranium so that its U-235 ratio of 0,71% (as in the case in natural uranium) is increased to say 90%, the separation process would have to be repeated several thousand times. Each stage of enrichment would essentially comprise three basic components: a compressor to pump the gas; a heat exchanger to get rid of any excess heat and a membrane vessel in which the separation takes place. The specifications of the components, that have to be built into such a plant, are extremely exact, because the feed gas uranium hexafluoride is highly corrosive and extremely poisonous and amply as active as the gas fluorine. In the plant all the uranium hexafluoride gas is under pressure (usually lower than the atmospheric pressure) and because it is highly corrosive, it is essential that there is absolutely no air, oil or water vapour leakage. Water vapour, especially, may not enter the system, because UF_6, in the presence of water vapour, immediately decomposes into UO_2F_2 and HF and the UO_2F_2 precipitates as a fine substance on the walls (of the system) and especially on the diffusion membrane where it causes the blockage of the small pores. The whole system has, therefore, to be made leakproof to standards unknown in conventional manufacturing. For example, it is specified, that maximum allowed leakage of a large valve in the system or through the compressor casing with all its connections, should not be more than about 1 cc per year, if the component is placed in a vacuum.

The diffusion membrane itself has to be manufactured from materials that are totally resistant to the highly corrosive hexafluoride and, therefore, the choice of suitable manufacturing materials are limited and virtually only, nickel, aluminium or politetrafluoro ethylene are suitable. Effective membranes must have maximum porosity, but the pores should not be larger than 200A° in diameter (1 cm = 10^8A°). It is, therefore, essential that no substance should be formed that can block such tiny pores. Additionally, the membrane has to be extremely thin, about $^1/_{10}$ mm. The manufacture of these membranes is extremely difficult and remained one of the closest guarded secrets of technical advancement of the time. So little is published concerning enrichment technology, that every country virtually has to start from the beginning. AJA Roux: "Uraanverryking", pp. 11 - 23, 16-17; McGraw Hill: **Encyclopaedia of Science and Technology**, vol.19, p. 85.

- **South African process:** Its greatest advantage was its high separation factor. Of significance was that all process pressures throughout the system would be comfortably above atmospheric and, depending on the type of "centrifuge" used, the maximum process pressure would be in a range up to 600 kPa (6 bar). The UF_6 partial pressure would be sufficiently low to eliminate the need for process heating during plant operation, and the maximum temperature at the compressor delivery would not exceed 75°C.

An important feature of the separation elements of the process is that they can also be used to yield high purity hydrogen in a single-step separation of UF_6 from hydrogen, when fed with material of approximately the enriched stream composition. Separation factors greater than 10 000 to 1 in a single pass can easily be achieved. This feature is incorporated in the enrichment process to make gas separation by freezing, at the block interfaces, unnecessary.

A valuable feature of a plant based on this process is its very low uranium inventory, which results in a short cascade equilibrium time, of the order of 16 hours for a commercial plant enriching uranium to 3 percent U235.

As far as energy consumption is concerned, the theoretical lower limit to the specific energy consumption element can be shown to be about 0,30 MW.h/kg SW. The minimum figure that could be obtained with laboratory separating elements is about 1,80 MW.h/kg SW, based on adiabatic compression and ignoring all system inefficiencies. It was not believed that the energy consumption could in the short term be drastically reduced, the discrepancy between the above figures illustrates that the process still had a large developmental potential. AJA Roux and WL Grant: **Uranium Enrichment in South Africa, Presentation to European Nuclear Conference**, Process Description, April, 1975.

stages of enrichment: When Dr Grant designed the separating element (vortex tube) it had one particular feature: the uranium-bearing gas that entered the module would leave the module in two streams, one enriched and one depleted. (The evident factor achieved by this type of separating device is asymmetrical, i.e. the enhancement of the isotopic concentration of the enriched stream produced by the device is significantly more that the corresponding reduction in the concentration of the depleted stream.) The uranium content of the enriched stream was about one twentieth of the depleted stream. During the following step, in the following module it would be further enriched, but only with a typical factor of approximately 1,03. In other words, of the feed stream had one percent of 235 isotopes as it entered the module, it would have 1,03 percent as it left the module. Progress would be slow - the next stage would progress to 1,06 percent and so on. If the enrichment process was repeated thirty times one would eventually get to 2 percent. These stages would have to be connected one after the other, in a "cascade". ***Interview with Dr Haarhoff, 28.7.1989.***

reasons for the high cost of an enrichmnent facility:

- uranium enrichment was an expensive undertaking. The two uranium isotopes that have to be separated, U-235 and U-238, only differ by three mass units, while the mass difference ratio is:

$\frac{3}{238}$, therefore about 1.25%.

For example: in the separation of heavy and light hydrogen isotopes, the difference between HD and H_2 is one mass unit and the mass difference ratio is 50%. Besides this, uranium is a hard metal with a relatively high melting-point (about 1 125°C). There are no uranium compounds (except uranium hexafluoride) that have a low melting-point or that are workable and easily available. Uranium hexafluoride is the only compound of uranium that has been applied as feed material in all the enrichments processes in the world. Above 65°C, it is a gas with pressures lower than 1,5 bar. AJA Roux: "Uraanverryking", pp. 11-12.

uranium extraction from gold ore: see also "methods of recovering gold and uranium" The nuclear uses of uranium demand high purity in general, particularly a high degree from certain rare materials, as well as from cadmium and boron, all of which have the ability to absorb neutrone. The extraction from the gold ore is the first stage. The first uranium recovery plants employed a uranium process, namely an ion-exchange system in which uranium-bearing solution was passed through bed of resin* contained in drumlike columns. A two-way exchange took place, with the solution giving up its uranium to the resin and receiving nitrate in return. When saturated with uranium, the resin beds were treated with a mixed solution of nitric acid and ammonium nitrate which drew out the uranium in a concentration ten to twenty times as great as in the original solution. The resulting "eluate" was then neutralised with ammonia and transformed into a bright yellow precipitate, ammonium diuranate (ADU). (SAL) **Uranium: South Africa's Mineral Wealth,** Public Relations Department of the Chamber of Mines and the AEB of South Africa, 1982, pp. 8-9.

uranium hexafluoride (UF_6): is used in the enrichment process and can be prepared by fluorating the metal, an oxide, uranium tetrafluoride, or other compounds with fluorine, hydrogen fluorine, or halogen fluorides. The least amount of fluorine is needed for the fluorination of uranium tetrafluoride. This reaction, the basis of methods for industrial preparation of uranium hexafluoride, occurs at high temperatures, above 400°C (470°F). The hexafluoride may be handled as gas, solid or liquid. Because this process, like much of the industrial chemistry of uranium compounds, entails major usage of highly corrosive fluorine and fluorine compounds, highly sophisticated chemical engineering techniques, standards and equipment are required. **Encyclopaedia Britannica**, 15th edition, 1987, vol. 21, p. 435.

uranium metal: see "ammonium diuranate"; the preparation of uranium metal: of the many processes that may be used for the preparation of uranium metal the one in almost universal use employs uranium tetrafluoride with magnesium as the reducing agent, used for the preparation of uranium hexafluoride. **Encyclopaedia Britannica,** 15th edition, 1987, vol. 21, p. 435.

uranium metal sphere: a round mass of uranium metal about 1 cm in diameter; natural uranium fuel elements used in the PELINDUNA project. AR Newby-Fraser: **Chain Reaction**, p. 109.

uranium oxide: see "ammonium diuranate".

uranium provinces: (geology) uranium regions (areas) of the earth. BB Brock et al: "The Geological Background to the Uranium Industry", **Uranium in South Africa**, 1946-1956, vol 1, p. 21.

uranium silicates: (geology) magma containing compounds of uranium and silicon and uranium and oxygen; when the magma cools uranium deposits are formed; silicates are the most common groups of compounds in the earth. **Readers' Digest Library of Modern Knowledge**, vol. 1, p. 82.

uranium tetrafluoride: see also "ammonium diuranate"; important in making uranium metal, is produced by reaction of uranium dioxide with anhydrous hydrofluoric acid at 450° - 600°C (840° - 1100°F). The higher the temperature the more rapid the reaction rate, but a practical upper limit is imposed by the availability of structural materials and equipment able to withstand attack by hydrofluoric acid and the ability to control the reaction, which produces considerable heat. **Encyclopaedia Britannica**, 15th edition, 1987, vol. 21, p. 435.

uranium-235: uranium isotope 235; see "uranium".

uranium-235 gun assembly: gun assembly method: a projectile, a sub-critical piece of uranium-235 (or plutonium 239) would be placed in a gun barrel and fired into a target, another suc-critical piece of uranium-235. After the mass was joined (now super-critical) a neutron source would start the chain reaction. **Encyclopaedia Britannica**, 15th edition, 1987, vol. 29, p. 579.

uranium-238: uranium isotope 238; see "uranium".

V

vermiculite: light (in weight) mineral. Contains a large percentage of mica. **Chamber's Twentieth Century Dictionary**, p. p. 1228.

vortex tube: A tube causing a whirling action of a gas (if blown into the tube under pressure). See also "stages of enrichment". HL de Waal: **Uraanverryking in die Republiek van Suid-Afrika**, p. 14.

Z

zinc: bluish-white metallic element; atomic symbol Zn; resistant to atmospheric corrosion. **Chamber's Twentieth Century Dictionary**, p. 1299.

zirconium: whitish metallic element; prepared by the reduction of zircon; atomic number 40. **McGraw-Hill Dictionary of Scientific and Technical Terms**, p. 1778.

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