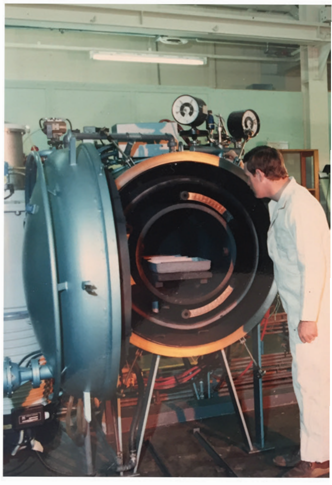
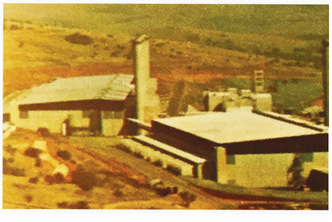
REVISITING SOUTH AFRICA'S NUCLEAR WEAPONS PROGRAM

ITS HISTORY, DISMANTLEMENT, AND LESSONS FOR TODAY





David Albright with Andrea Stricker

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Institute for Science and International Security

The Institute for Science and International Security is a non-profit, non-partisan institution dedicated to informing the public about science and policy issues affecting international security. Its primary focus is on stopping the spread of nuclear weapons and related technology to additional nations and to terrorists, bringing about greater transparency of nuclear activities worldwide, strengthening the international non-proliferation regime, and achieving deep cuts in nuclear arsenals.

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INSTITUTE FOR SCIENCE AND INTERNATIONAL SECURITY
JUNE 2016

Dedicated to all those who strive
for a world free of nuclear weapons.

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PREFACE

Twenty five years ago South Africa acceded to Nuclear Non-Proliferation Treaty after dismantling its nuclear weapons. Yet, the full story of that nuclear weapons program was not revealed publicly at that time. Parts were hidden from the International Atomic Energy Agency as well. Now, after many years of work by the media and independent experts, with the cooperation of a number of former members of the nuclear weapons program, a much fuller picture of South Africa's nuclear weapons program has emerged.

At the Institute for Science and International Security, work on South Africa's nuclear program goes back to its founding in 1992. One of its first projects was working with African National Congress (ANC) officials, who were interested in learning more about nuclear non-proliferation in anticipation of assuming key government positions in a democratic South African government. This cooperation led to contacts with several former members of South Africa's nuclear weapons program and a range of collaborative endeavors with them. It included two tours of the old nuclear weapons production sites. On the trip in August 2002, Albright was allowed to photograph the old weapon production sites before they were modified beyond recognition of their original purpose. Many of these images appear here for the first time.

We at the Institute are pleased to present the first comprehensive, technically-oriented history of South Africa's nuclear weapons program and its dismantlement. Although not every question could be answered, this history reveals a great deal of new information about that program.

This book also takes stock of the lessons today of this dynamic and complicated nuclear weapons program. Although none of the nine states that currently possess nuclear weapons appear on the verge of following South Africa's example, the South African case contains many valuable lessons in non-proliferation, disarmament, export controls, and verification.

We hope that this book will therefore be regarded as a useful contribution to policy debates and a compendium of information on South Africa's nuclear weapons program and its dismantlement.

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We would also like to thank members and officials from the African National Congress, Armscor, and the Atomic Energy Corporation, and its successor organization South African National Nuclear Corporation. Several individuals at the International Atomic Energy Agency (IAEA) were also invaluable, and we thank them as well.

We also thank Jerrica Goodson, who while working at the Institute, assisted in the preparation of this report. Finally, we thank the participants of a May 2016 presentation at the George Washington University Elliott School of International Affairs who informed and improved this report.

CHAPTER 1
LAYING THE FOUNDATION

South Africa's nuclear development dates back to World War II when the US Manhattan Project was looking worldwide for uranium to make nuclear weapons. In 1944 Great Britain requested South Africa's Prime Minister Jan Smuts to investigate reported deposits of uranium in South Africa and South West Africa (now called Namibia).[1] Following an extensive investigation, Smuts announced that uranium had been discovered in many of South Africa's gold mines.[2]

After several years of exploration and development, South Africa started its first full-scale uranium extraction plant in 1952, built with extensive US and British aid. By 1955 sixteen uranium extraction plants were in operation.[3] Until the mid-1960s, South African uranium was sold to the Combined Development Agency, the purchasing organization created by Britain and the United States to obtain adequate uranium supplies for their nuclear weapons programs.

Initially, the development of uranium production was controlled directly by the South African Prime Minister's office. However, in 1948 the country's Atomic Energy Board (AEB) was established by an Act of Parliament to control all nuclear matters, particularly the production and sale of uranium on behalf of the government.

The First United Nations Conference on the Peaceful Uses of Atomic Energy, held in Geneva in 1955, stimulated the AEB's interest in creating an indigenous South African nuclear research and development program. Upon its return, the South African mission to the UN conference recommended that South Africa send scientists abroad for training to enable them to build an experimental reactor. It also recommended the construction of a nuclear power reactor at Cape Town.

In November 1956, the AEB established the Research Advisory Committee. One of its first acts was to appoint A. J. A. "Ampie" Roux, then a senior official at the Council for Scientific and Industrial Research (CSIR), to draft a nuclear research and development program. The committee also hired the AEB's first two research engineers. They were charged with surveying the processes for producing heavy water as a moderator in nuclear reactors.

One month later, the government created a national Commission of Enquiry into the Application of Nuclear Power in South Africa, under terms of reference drafted by the AEB. The commission appointed Roux to draft a plan for a South African nuclear research and development program.

While Roux was producing his report, the two AEB engineers started to investigate heavy water in the first applied research undertaken by full-time AEB staff. The AEB had come to believe that it could economically produce heavy water. After six months of study in South Africa, the two AEB engineers spent 18 months working intensively with the Heavy Water Group at the Harwell Atomic Energy Research Establishment in Britain. They also visited heavy water plants in Germany.

NATIONAL PLAN

Roux spent about a year and a half developing his draft plan for a South African nuclear research and development program. After visiting ten countries, interviewing hundreds of experts, and seeking the views of South African governmental, mining, and industrial authorities, he presented his plan to the AEB in June 1958.

Roux's ambitious plan recommended a dramatic shift in South African industry from a "repair and maintenance" industry to a highly sophisticated industry capable of manufacturing nuclear reactors.[4] The plan's objectives included enabling South Africa to derive additional benefit from its position as a major uranium producer and permitting it to make significant contributions to nuclear energy. Roux was also reportedly aware of the need for a program that could keep South Africa's best scientists and engineers from immigrating to other countries.

Roux's plan recommended the pursuit of four major avenues:

- Development of the production and refining of nuclear materials, including heavy water and thorium, but especially uranium. The materials effort was to include the improvement of uranium mining and extraction methods and for the study of further steps in uranium processing with the goal of improving the uranium's worth;
- Investigation into the application of nuclear energy for electricity production, including the development of a power reactor concept appropriate to South Africa;
- Research into the uses of isotopes and radiation in medicine, agriculture, commerce, industry, and research;
- On-going research fundamental to a nuclear energy program.

The goal of this plan was to set up a comprehensive nuclear energy program that would allow South Africa to "become as independent of foreign influence concerning its needs in this area, as possible."[5] A major aspect of the plan was to provide financial and other assistance for the training of researchers in nuclear energy, both in South Africa and abroad.

In September 1959, the then Minister of Mines Jan de Klerk announced that the Cabinet had approved the proposed nuclear research and development program and its relative independence. Interestingly, Jan was the father of F.W. de Klerk, who would become President in 1989 and end the nuclear weapons program and accelerate the process that led to major downsizing of South Africa's nuclear energy programs.

Roux should be considered the father of nuclear development in South Africa. Shortly before his draft nuclear plan was approved, he became the Research Director of the AEB. Later his title was changed to Director General. In 1967, he was appointed Chairman (later renamed President) of the AEB, a position until then reserved for the Minister of Mines.

PELINDABA

The AEB needed a more suitable site to carry out its program than its office suite in Pretoria. A new site would need to be relatively isolated to permit the safe operation of reactors, but also close to major population centers, universities, and industries. The site would also need a major source of water, adequate electricity supply, and good access to roads.

The AEB picked a site south of the Hartbessspoort Irrigation Dam and on the east side of the Crocodile River, located about 30 kilometers west of Pretoria. The site was acquired in the early 1960s and construction of the National Nuclear Research Center started shortly thereafter. The first buildings, including the administration building, the chemistry building, and the Van de Graff building, were occupied starting in late 1963.[6]

A prospective name for the site was selected in a similar way as other major nuclear centers in the world, namely by referring to the town or village serving the establishment.[7] Although no settlement was located near the site, the scientists learned of former plans to create the township of Pelindaba right down the road.

Before picking Pelindaba as a name, however, the scientists decided to research its meaning. They learned that Pelindaba was the conjunction of two indigenous African words, "Pelile" meaning "finished" and "Indaba" meaning "a council." Put together, they imply the end of discussion. "That's it," Roux reacted, "We have talked enough; now we get on with the job."[8]

The job was formidable. To implement its nuclear research and development program, the AEB needed to recruit and train a staff, obtain significant amounts of nuclear and nuclear-related information, construct research and support facilities at Pelindaba, and procure and install a wide range of equipment, including research reactors and other complex facilities. Toward these objectives, South

Africa depended extensively on its civil nuclear cooperation agreements with the United States and Britain.

Perhaps the most pressing need of the new program was qualified scientists. Starting immediately after the program received government approval, the AEB recruited South African scientists with proven ability and sent them for overseas training in nuclear science and technology in the United States and Europe. In the late 1950s and early 1960s, eleven South Africans, including those who became the initial Research Division Heads at the AEB, participated in the US Argonne International School of Nuclear Science and Engineering and its successor organization.[9] A seven-man team was sent concurrently for training at Oak Ridge National Laboratory. Upon their return, the Division Heads developed the organization of their divisions and the recruitment of scientific personnel, including sending their new employees for training overseas.

A substantial number of nuclear scientists who set in motion Pelindaba's program were provided with highly specialized training at universities, research institutions, and industrial organizations in Britain, Canada, France, the Netherlands, Scandinavian countries, the United States, and West Germany.[10] Through 1970 about 90 South African scientists were trained at Argonne National Laboratory, Oak Ridge National Laboratory, and elsewhere in the United States.[11]

In 1977 Roux specifically acknowledged the help of the United States at a seminar in Johannesburg. He told the audience, "We can ascribe our degree of advancement today in large measure to the training and assistance so willingly provided by the USA during the early years of our nuclear program, when several of the Western world's nuclear nations cooperated in initiating our scientists and engineers into nuclear science."[12]

The program also needed extensive amounts of technical information, and South Africa's nuclear agreements for cooperation with Britain and the United States gave South Africa access to considerable amounts of it. For example, the agreement with Britain provided South Africa with information on reactors, specifications and properties of reactor materials, reactor components, reactor physics, reactor engineering, environmental and safety considerations, and the production of heavy water.[13]

Although the information obtained under these bilateral agreements is unclassified, South Africa also sought sensitive information. Early on, Roux was aware of the difficulty of obtaining sufficient information for his program. According to his draft plan presented to the AEB in 1958, "some of the most important developments in the field of nuclear power, particularly in the more highly developed countries such as the US and Britain, have so many military implications that no reference would be found to them in the unclassified literature."[14] Yet, he wrote of the key role of South African cooperation with Western countries, particularly in research areas, in obtaining information: "Any [research] contribution, however small, that can be made, will assist greatly in obtaining secret information from other countries which they would not otherwise be prepared to divulge. We have already experienced this in the little work we have done in connection with the production of heavy water."[15] Program personnel would obtain secret information about nuclear explosives, European gas centrifuges, and nuclear re-entry vehicles for ballistic missiles.

Even before the Pelindaba site was selected, the AEB ordered a research reactor from the United States. The reactor, a type called the Oak Ridge Reactor (ORR), had the power of about seven megawatts-thermal (MWth). Its power, however, could be increased with relatively minor adjustments to 20 MWth. The United States also agreed to provide weapons-grade uranium (WGU) fuel, and along with Britain agreed to receive the irradiated fuel for reprocessing. The reactor, which was named Safari-1, went critical in 1965.

At the 1977 seminar in Johannesburg, Roux also acknowledged that "much of the nuclear equipment installed at Pelindaba is of American origin, while even our nuclear philosophy, although unmistakably our own, owes much to the thinking of [American nuclear scientists]."[16]

By the mid-1960s, Pelindaba had a wide-range of facilities and equipment to satisfy the ambitions of its newly-trained nuclear research scientists. According to Wynand de Villiers, who by 1967 was Director of the Reactor Development Division and later succeeded

Roux as the President of the AEB, the "R&D program had been firmly established." The two most ambitious programs were an indigenous nuclear reactor and a uranium enrichment program.

URANIUM ENRICHMENT

By 1961, when the senior AEB scientists had returned from their overseas training, the future of enriching uranium locally was a frequent topic of debate.[17] A major purpose of the research and development program was to develop methods to process uranium into a form more advanced than yellow cake; enriched uranium was the ultimate goal of the AEB. The AEB believed that enriching domestically produced uranium could be lucrative financially. Another, related motivation was a South African "can-do" mentality that did not want to be denied high-tech nuclear projects. Others suspect that the leaders of South Africa also saw enrichment as a path to nuclear weapons.

The scientists realized that building a gaseous diffusion plant would require an enormous capital investment and access to highly secret information; thus, it would be beyond South Africa's financial and scientific capabilities. Building gas centrifuges, which were then under development in Germany, the Netherlands, and Britain, was similarly beyond South Africa's reach at that time. Roux challenged his colleagues to find an enrichment method that would be substantially smaller than the giant US gaseous diffusion plants and not require the extreme demands of gas centrifuges with their problems of vibration, sealing, and high-speed bearings.[18]

Wally L. Grant, then Chief Engineer of the AEB who would later became Director General of the AEB, put forward a proposal in 1961 to evaluate the use of the vortex tube principle for the separation of uranium isotopes. The separating element is best likened to a "stationary walled centrifuge" based on the aerodynamic principle. As eventually developed, a gaseous mixture of uranium hexafluoride and the carrier gas hydrogen enters the sides of the separating element at high speed and spins inside the cylinder, causing separation of the uranium isotopes.

The South African scientists were well aware of the politically sensitive nature of uranium enrichment, which would likely have been perceived as a potential sign that South Africa was seeking nuclear weapons.[19] As a result, the AEB went to great lengths to keep the existence of the project secret. The project was code-named the "Gas Cooling Project" and was divided into three separate components, from which came another code-name the "XYZ project."

The project was first housed in central Pretoria in a nondescript warehouse. Experimental equipment was assembled and operated in the rear portion "away from prying eyes," and the front half comprised the workshop, which, "any casual enquirers were told, was manufacturing scientific equipment."[20] Later, the experimental work required stricter security and was transferred to the equally unobtrusive Shamrock Building in Pretoria before finally moving to Pelindaba.

The first separation of uranium occurred in November 1965, just in time for a visit by Prime Minister H. F. Verwoerd, who was a staunch supporter of the project. By 1967 the scientists had demonstrated the feasibility of the vortex-tube enrichment method in the laboratory. Although several problems remained, the AEB recommended that a pilot plant be constructed. Because of the cost involved in such an endeavor, the government undertook a lengthy, independent review of the project. In February 1969, the government approved the building of a pilot plant and additional research funds for the next five-year period. The plant, called the Y Plant, would be designed to make weapons-grade uranium, not just low enriched uranium.

PELINDUNA

According to de Villiers, another key goal of the initial research and development program at Pelindaba was the indigenous construction of a power reactor. By choosing a design specifically tailored to suit South Africa's conditions, the AEB believed it could provide a central theme to the divergent research interests of the various disciplines practiced at Pelindaba and further stimulate the research groups to become familiar with nuclear science in practice. By doing so, the AEB hoped to build a center of excellence in nuclear science.[21]

In 1962 the AEB decided to pursue a natural uranium, heavy water moderated, sodium-cooled power reactor, which became known as Pelinduna (Pelindaba Deuterium Uranium Sodium (Na)). The same concept had been examined by the United States but not pursued. However, soon after Grant, the AEB's Chief Engineer, returned home from 17 months of overseas training in the United States, he proposed that the AEB pursue this reactor concept based on pressure tubes. He reasoned that this concept could significantly reduce power generating costs because the use of sodium as a coolant would transfer heat better and eliminate the need to build expensive pressure vessels, which were beyond the capability of South African industries to produce. Overall, the approach appealed to the AEB as an advanced reactor concept that South African industries could produce. Moreover, such a reactor project would encourage South African industries to improve their ability to work with nuclear-grade materials and their specialized manufacturing techniques.

The first step was to conduct a series of theoretical calculations describing the reactor system. The first calculations were done by hand, a time-consuming process with limited usefulness. Next, the Council for Scientific and Industrial Research computer facilities were used for the calculations, until the AEB built its own computer center at Pelindaba.

To obtain the first experimental data, Grant's team built a subcritical model of the reactor system. These data improved the computer calculations, enabling good agreement between measured and calculated values and the development of more sophisticated mathematical models of the reactor system.

However, more data were needed. The next step was to build a critical facility to check operational values, such as temperature coefficients, power distribution, and control-rod values. Because of the high cost of such a facility, the AEB decided to use two percent enriched uranium fuel instead of natural uranium fuel. In this way, the reactor would need only four fuel elements instead of 19 elements, enabling a considerably smaller and cheaper facility. The critical assembly, called Pelinduna 0/4, reached criticality in November 1967.

It depended on a US supply of 606 kilograms of two percent enriched uranium and 5.4 tonnes of heavy water.[22] The operation of the criticality facility marked a major milestone in the development of reactor physics in South Africa.

Meanwhile, engineers were designing a prototype reactor and a full-scale power station. The prototype reactor was envisioned to be 30 MWth and use slightly enriched uranium fuel. A by-product of this reactor would have been plutonium. Although no significant work appears to have been done on creating a capability to separate plutonium at this time, South African nuclear engineers may have been thinking about such a capability. Later, in the late 1970s, the AEB would start to develop it.

Overall, by 1966 Pelindaba's scientists and engineers had solved many, although by no means all, of the problems in designing and building the Pelinduna power reactor. However, its most outstanding advantage, namely its high specific power, also meant that an economical reactor would need to produce about 1,000 megawatts of electricity using natural uranium fuel. This was a problem for the South African designers. In the mid-1960s, South Africa seemed unlikely to be able to integrate such a large unit into its electrical generating system until the 1980s. Although the power of an individual reactor could have been reduced considerably by using one to two percent enriched fuel, South Africa did not then possess enrichment facilities and the envisioned pilot enrichment plant would have been too small, requiring import of enriched uranium. However, the goal of the project was to develop a reactor independent of overseas fuel suppliers.[23] The cost of the project was also becoming an issue, as the AEB realized that electrical power production by a heavy water moderated reactor would be more costly than by a light water reactor.

Another significant factor was the "phenomenal success of the uranium enrichment project."[24] The two projects had reached the point almost simultaneously where each required the construction of an expensive pilot plant. In the late 1960s, South Africa was unable to afford the construction of both plants. An enrichment plant seemed more able to deliver on the goal of increasing the worth of

South Africa's plentiful uranium supply. As a result, the AEB cancelled the Pelinduna project in 1967.

By coincidence, the name Pelinduna had a far different nontechnical and indigenous interpretation that ended up being prescient. From "Pelile Induna," the meaning is "the chief is finished, the chief is dead."[25]

Although the Pelinduna project was terminated in 1967, the critical facility continued to operate for a few more years. Before the enriched uranium was returned to the United States in 1971, the slightly irradiated fuel was sent to Britain for reprocessing.[26]

Needless to say, many problems remained unsolved when the Pelinduna project ended, but South Africa learned a great deal about reactor physics, nuclear reactors, and the manufacture of critical facilities. That foundation would be important in the nuclear explosive program and a later reactor project whose main purpose was the production of plutonium and tritium for nuclear weapons.

PEACEFUL NUCLEAR EXPLOSIVES

With the end of the Pelinduna project, South Africa decided secretly to use the expertise gained by the Reactor Development Division for the pursuit of nuclear explosives. In 1969 the AEB appointed an internal committee to investigate the economic and technical requirements for nuclear explosives for civil applications. Referred to as peaceful nuclear explosives (PNEs), these nuclear devices were being pursued by the United States and the Soviet Union for a variety of civil purposes, such as creating harbors, mines, mountain passes, and gas exploitation. The Nuclear Non-Proliferation Treaty (NPT) which entered into force in 1968 allowed for non-nuclear weapons states to use PNEs under certain, highly constrained conditions. Thus, one motivation for South Africa's own PNE program would have been to match, albeit on a smaller scale, work that was being done then by the major nuclear powers.

The decision to develop PNEs combined the knowledge and experience gained in the Pelinduna reactor project with the potential offered by enriching uranium sufficiently for use in nuclear explosives.[27] This project also had the advantage of providing a means to retain the specialists in the reactor development division. Moreover, according to Tielman de Waal, former managing director of Armscor, in the 1960s "the idea to look into the feasibility of developing nuclear explosives for peaceful applications emerged as a scientific endeavor out of a technological 'can-do' mentality."[28]

South Africa's interest in PNEs was not secret at first. The AEB reported in its 1969 annual report that it was researching the use of nuclear explosives for earth-moving.[29] The CIA stated, based on open literature, that during 1968 to 1969 at least one South African scientist was in the United States studying the application of PNEs.[30] This was likely Johann V. Retief, an AEB engineer in the PNE program who published in 1971 a Stanford University technical report, *Use of Nuclear Explosives for Water Resources Development in Arid Regions*.[31] In 1970 the Johannesburg *Star* reported the South African government was "keeping abreast of the latest developments in the use of nuclear explosives in civil engineering projects."[32]

However, the bulk of the AEB's work on nuclear explosives was secret, particularly its plans to develop and build them. Moreover, South Africa intended to explore developing a wide variety of types of nuclear explosives, which involved highly classified work. In its secret 1970 report, the internal AEB committee recommended the development of different types of peaceful nuclear devices:

- Gun- and implosion-type fission devices, referred to as type A. This category included also a boosted fission device called A* which involved a lithium-6, deuterium, tritium tablet at the center of the type A device;[33]
- A thermonuclear device with a fission detonator, called type B.

In March 1971, the Minister of Mines approved the first research and development work on the type A devices. Two years later, the Minister also approved theoretical work on type B devices.

ONLY A PEACEFUL PROGRAM IN THE 1950s AND 1960s?

Despite repeated denials by past and current South African nuclear officials, many outside experts and African National Congress (ANC) officials rejected the proposition that South Africa's nuclear program was built only as a civil, scientific nuclear program.[34] In particular, they rejected that in the late 1960s and early 1970s the South Africa leadership intended to build only PNEs for civil applications.

Officially, the key indicator of military intentions is the high level government decision to weaponize the nuclear devices, which later will be shown to date to 1977 and 1978; however, it is acknowledged that defense ministry interest in the bomb happened earlier. The political scientist Peter Liberman, based on an interview with Grant, established that "defense people" were involved in 1975.[35] A recently released official document confirms that participation was initiated by then Defense Minister P.W. Botha.[36] He said that "as far back as 1975, I, as Minister of Defense, initiated dialogues related to the possibilities of bringing about nuclear weapons" in South Africa."[37]

There is also some evidence that by the end of 1973, the leadership of the AEB was starting to refer in private to nuclear weapons. In 1973 apparently as part of a process of recruiting a South African physicist to come work at Pelindaba, Louw Alberts, then Vice President of the AEB, told him explicitly that South Africa had started a nuclear weapons program focused on developing gun-type, implosion-type, and thermonuclear weapons.[38] While working at Pelindaba from 1974-1977, including contributing to the work on the nuclear devices, he was told consistently that this effort was a nuclear weapons program. He was also told of a budding nuclear strategy that South Africa would use the nuclear option when facing insurmountable odds requiring an act of supreme heroism, referred to as Kragdardigheit, in Afrikaans.

Although a nuclear weapons motivation can be established as far back as the early to mid-1970s, what about the 1960s? Documentary evidence focusing on nuclear weapons prior to the early 1970s is currently lacking and almost all of the participants are no longer living, making confirmation difficult. However, critics of official declarations are skeptical that the South African government would have supported the nuclear program so vigorously in the late 1950s and 1960s for only a civil rationale, particularly given South Africa's growing international isolation. Instead, critics believe that another fundamental goal of the nuclear program was also acquiring the capability to make nuclear weapons. To these critics, the AEB was putting in place two paths to the bomb, one based on plutonium and the other based on weapons-grade uranium. Faced with budget constraints, the uranium enrichment pathway was selected as the way to produce nuclear explosive material.

Critics have presented as evidence statements made by South African officials during the 1960s. Below are listed several of these statements:

- Roux said in 1960 that South Africa was capable of producing its own nuclear explosives if it was "prepared to isolate the best brains in the country and give them all the funds they needed."[39] Roux repeated his 1960 statement in 1962, but added, "It is my sincere hope that we shall never be called upon to engage in this activity."[40]
- Prime Minister Verwoerd stated during the inauguration ceremony for the Safari I reactor in 1965, that with respect to nuclear materials: "It is the duty of South Africa to consider not only the military uses of the material, but also to do all in its power to direct its uses to peaceful purposes."[41]
- Grant, speaking for the AEB in 1965, said: "On several occasions the Director-General [Roux] has indicated that South African scientists, in common with those from most developed countries, do have the technical ability to develop nuclear weapon," but he denied that any military research was being done in that area.[42]
- In 1965, Andries Visser, a member of the AEB, said: "We should have the bomb to prevent aggression from loud-mouthed Afro-Asiatic states…money is no problem. The capital for such a bomb is available."[43]
- General H. J. Martin, the Army Chief of Staff, stated in the December 22, 1968 edition of the *London Sunday Express* that South Africa was ready to make its own nuclear weapon.[44]

All of these statements are ambiguous about any underlying nuclear weapons purpose in the 1960s. However, these quotes show that the senior political and nuclear leadership of South Africa was well aware of the full potential of its nuclear program. This general awareness is confirmed by the extensive work done by Liberman.[45] He observed, "The South African leadership knew that a successful PNE program would generate a de facto nuclear weapons capability."[46] One has to conclude that the South African leaders of the nuclear program and the senior leadership also knew that a nuclear weapons capability depended on having a plutonium or enriched uranium pathway. They must have realized that the creation of such a pathway would take many years, far longer than the time needed to master the building of a relatively crude type A nuclear explosive device.

So, with regard to the 1960s, we are left with a series of possibilities. Three cases can be considered which vary based on the intentions of the nuclear and political leadership:

1. The first case is that the program had no explicit nuclear weapons component until the mid-to-late 1970s, and the founders, including the political leadership, had no intention of building nuclear weapons. In this case, the leaders wanted a large nuclear program for reasons of prestige, energy security, and adding value to South Africa's large uranium resources. The extensive support of Prime Ministers Verwoerd and B.J. Vorster of the enrichment program during the 1960s would have been without national security motivations. Even the PNE program would have to be interpreted as one of only prestige, scientific prowess, and civil applications. The South African government has said essentially that this case is the true state of affairs.
2. The second case is that through the 1960s the political leadership wanted to develop the option to build nuclear weapons, but the scientists, perhaps including Roux, did not want to operationalize this capability or did not see nuclear weapons as necessary. The military was not interested in any case. In this scenario, the AEB would be committed to developing the wherewithal to produce weapons-grade

uranium or an indigenous reactor that could make plutonium, but the scientists would intend to use these facilities and materials for civilian purposes. This case is at least plausible. Based on interviews with participants in the nuclear weapons program, many AEB scientists were against acquiring nuclear weapons. While many scientists or engineers may have tolerated working on PNEs, they would have balked at working on a program that contemplated building nuclear weapons. Moreover, the South Africa nuclear program depended critically on foreign assistance. Thus, even if South Africa intended to obtain nuclear weapons, it would benefit from keeping this ambition absolutely secret, or else risk undermining the support of Western suppliers. Even in the 1960s, Western countries were unlikely to support giving South Africa major nuclear assistance if they believed that the AEB was putting together a program to build nuclear weapons. Even a PNE program would need to be pursued in secret to avoid a backlash as more countries lost interest in PNEs and increasingly viewed them as thinly-disguised nuclear weapons. However, the political leadership would have known that once the AEB developed the capability to make nuclear explosive materials and nuclear explosives, the government could order the AEB or another agency to build nuclear weapons. Given that the AEB was a well-funded, centralized, and secretive organization, the government would have believed it could shift the purpose of the nuclear program relatively easily and quickly. From the political leadership's perspective, South Africa would have lost little if the scientific leadership viewed the program as civil only.

3. The third case is that both the political and nuclear leaders intended from the start of the program to obtain nuclear weapons in addition to a large civil nuclear program. In this case, strategic considerations of energy security and national security were at the heart of the program.

ANC officials have supported the third case and, to a lesser extent, the second one. The official declarations center on the first case, while sometimes acknowledging the possibility of the second one.

On balance, neither the first nor third case seems compelling. The first case requires a belief that the nuclear leaders were remarkably naïve during the height of the Cold War and amidst rising international isolation. The third case suggests a level of organization and effort that would have been expected to emerge in oral statements, intelligence records, or South African historical documents.

Case two would imply a level of deception on the part of South Africa's nuclear and government leaders but it remains the most plausible scenario. It also recognizes Roux' remarkable accomplishments and vision for South Africa. As pointed out by Johann Viljoen, who joined the nuclear weapons program in the 1970s and remained until the end, the second case recognizes Roux as someone who wanted South Africa to be seen as a first world power, who could have had the idea of a nuclear weapon in the back of his mind, perhaps even viewed such weapons as an exciting possibility for the future.[47] However, he also likely did not want to make the decision to build the bomb. Granted, the AEB was going to develop a nuclear weapons capability. For Roux, the question to the national leadership would have been: do you want it? Until about 1975, the military was simply not that interested and the political leadership felt no pressure or need to decide to build nuclear weapons.

Case two also more clearly tracks the international perceptions of South Africa's efforts to achieve a nuclear weapons capability. This perception includes the growing view in the late 1960s and early 1970s that PNEs should be viewed as nuclear weapons, despite not strictly being so in the South African military sense, which prizes deliverability, reliability, and an ability to destroy a target.

NOTES

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18. Chain Reaction, op. cit., p. 95.

19. Chain Reaction, op. cit., p. 96.

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21. Chain Reaction, op. cit., p. 116.

22. The Export Reorganization Act, 1975: Hearings before the Committee on Government Operations, United States Senate, 94th Congress (April 21, 30, and May 1, 1975), p. 102.

23. Chain Reaction, op. cit., p. 124.

24. Chain Reaction, op. cit., pp. 35 and 124.

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31. http://www.osti.gov/scitech/biblio/4716026-use-nuclear-explosives-water-resources-development-arid-regions See also Johann V. Retief's 1971 AEB report (in Afrikaans) Seismic damage and the economy of the use of nuclear explosions. Abstract:

> One of the most important restrictions on the constructive use of nuclear explosions is the damage caused to buildings and structures situated at great distances around the explosion as a result of the seismic waves generated. The effect of seismic damage on the economy of the use of nuclear explosions in general is investigated. Results of the investigation are applied to conditions in South Africa. Various phases in the mechanism of seismic damage are discussed, namely generation by the explosion, propagation by the earth's crust, amplification by the geological structure of foundations and damage to structures. Predictions are made of reaction spectra as a function of explosive force, explosive depth, placing material and distance to the observation point. The nature, extent and cost of seismic damage as a function of distance and population of urban centers and density of rural population are stimulated. Information on population distribution in South Africa are analyzed, and areas where explosions can be detonated without serious seismic damage are indicated with the aid of predictions of the cost of seismic damage. Charges with an explosive force of 10 to 100 kt can be detonated over large areas in South Africa, but bigger charges (1000 kt) are restricted to the sparsely populated areas of the Northern and Northwestern Cape. See http://www.osti.gov/scitech/biblio/4395627-seismic-damage-economy-use-nuclear-explosions

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47. Interview of Viljoen with one of the authors.

CHAPTER 2
DEVELOPING NUCLEAR DEVICES

To a small number of key scientists and engineers at the Atomic Energy Board (AEB), the 1970s started with work on what they believed was a peaceful nuclear explosive (PNE). The goal was to complete the first "type A," or gun-type device, when the Y Plant had finished making enough highly enriched uranium (HEU), planned originally for mid-1977. Once both efforts converged, the plan called for an underground test of the device. However, the actual date when the first device could be assembled would turn out to be two years later. Although the device development and test site construction were completed as planned, the production of enough HEU was delayed two years.

When the PNE program formally started in 1971, André Buys was a young engineer beginning his career at the AEB. He had received funding for his university training from the AEB with the proviso that he would work for the AEB afterwards. In 1971 he was assigned to the PNE project at Pelindaba that was just taking shape, but as he worked in the program, Buys was increasingly troubled. He saw no reports that PNEs were viable economically or technically. He often asked his superiors what would be their purpose. His superiors told him that they would find a use for them and encouraged him to focus on this interesting scientific and engineering work. Whenever he asked if it was really a bomb program, he was told no. Buys developed an impression that the AEB under Ampie Roux could easily obtain funds from the government to do what it judged important, and the AEB viewed the prospect of developing PNEs as an exciting technical challenge, one that could occupy the defunct Pelinduna reactor team. Yet developing an agreement of the purpose and scope of what would gradually become a full-blown nuclear weapons program would drive Buys throughout his career, first at the AEB and then as a leader of the nuclear weapons program in the 1980s at the Armaments Corporation, or Armscor.

REACTOR DEVELOPMENT DIVISION

With the cancellation of the Pelinduna reactor project and the start of the PNE program, the Reactor Development Division was transformed into an organization centered on the major tasks of building a nuclear explosive device, absent delivery system integration. Its primary task was developing a gun-type nuclear device, but in parallel, it started rudimentary work on implosion-type and thermonuclear devices.

The old names of the Division were preserved, serving as crude codenames for the new PNE work. In their authoritative book *Armament and Disarmament: South the Africa's Nuclear Weapons Experience*, Hannes Steyn, Richardt van der Walt, and Jan van Loggerenberg, all of whom participated importantly in the former nuclear weapons program, describe the new responsibilities of the key groups for making PNEs in the transformed Reactor Development Division:[1]

- Nuclear Engineering Group studied the possible civil applications of nuclear devices in South Africa. It established a rock mechanics laboratory to determine the effects of an underground explosion on the surrounding geology and to develop methods for plugging the test shaft so as to prevent the release of radioactive elements. It also conducted experiments with conventional explosives to calibrate computer programs being developed to predict the effects of underground nuclear explosions.

- Theoretical Reactor Physics Group developed computer codes for the design of nuclear devices, including neutron data, criticality studies, and explosive yield estimates. Their work was based on earlier work on thermal reactor designs.
- Theoretical Nuclear Physics Group estimated predetonation probabilities and material properties at the extremely high temperatures and pressures of a nuclear explosion. This group also was responsible for theoretical designs of possible future thermonuclear devices.
- Experimental Reactor Physics Group, which was originally responsible for the Pelinduna critical facility, built a critical facility and a fast pulse reactor. It also developed the equipment for measuring the reactor's dynamic properties, as well as planned for the collection of data at a possible fully instrumented nuclear explosion.
- Reactor Engineering Group was in charge of obtaining sensitive high pressure and temperature data unavailable in the open literature. It developed and operated the necessary equipment to acquire these data. It was also responsible for the engineering design of nuclear devices, as well as the manufacture and assembly of nuclear explosive devices.
- Electronic Engineering Group identified and then built or procured all the electronic equipment for the entire program.
- Process Metallurgy Group was responsible for uranium metallurgy, particularly in developing the methods to convert HEU hexafluoride into metal, which is the chemical form most desirable for nuclear explosions.
- Physical Metallurgy Group developed and deployed methods to melt, cast, and machine enriched uranium into suitable geometries with tight specifications. It was also charged with producing all other metallic materials for the program.
- Nuclear Chemistry Group handled investigations into the production of thermonuclear materials.

With an enrichment program expected to make a considerable amount of weapons-grade uranium (WGU), the PNE program decided to first focus on making a gun-type nuclear weapon. This type of weapon requires a great deal of WGU but is generally viewed as easier to build than an implosion-type, which would require less than half the amount of WGU.

However, the Reactor Development Division did not have the experience to work with propellants or understand ballistics sufficiently for the firing of a WGU plug down a barrel to mate with the rest of the WGU, achieving a supercritical reaction.[2] There was also concern about the noise involved in repeatedly firing a gun-type device, albeit one with a surrogate material, at the Pelindaba site. By the early 1970s, this site housed a considerable number of personnel and visitors who did not know about the PNE program. As a result, the decision was made to build a temporary test and development facility at the National Institute for Defense Research (NIDR) of the Council for Scientific and Industrial Research at Somerset West

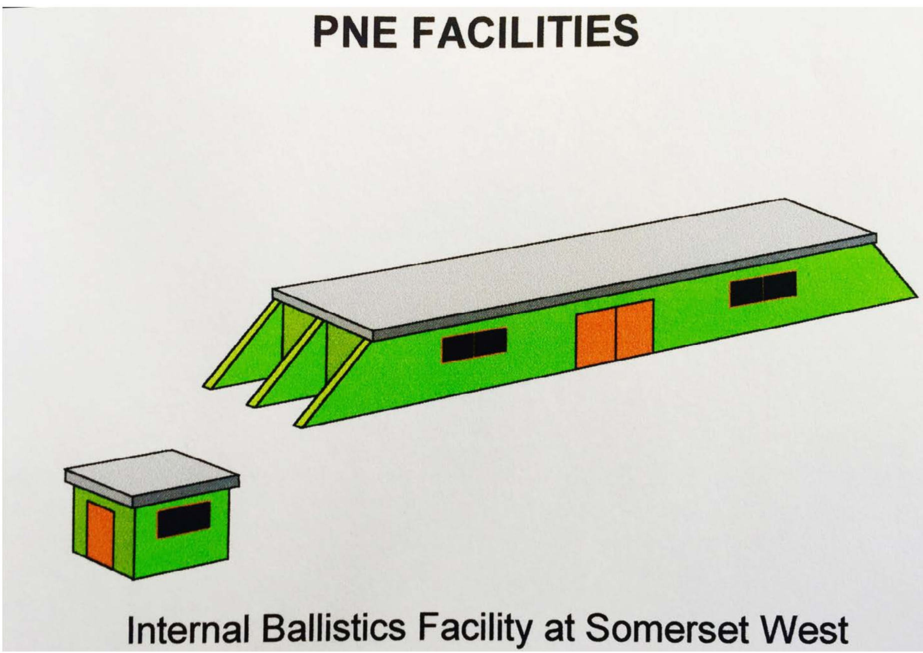

Figure 2.1: A schematic of the facility at Somerset West involved in developing the gun-type nuclear device in the early 1970s. Credit: André Buys

(later part of Somchem) (see figure 2.1). Located in the Cape Province, this military facility was already involved in the development and manufacture of explosives and propellants, so a small research facility studying a gun-type device would not stick out as it would at Pelindaba. Moreover, this institute had the experience in making guns and propellants and sophisticated measuring equipment. Buys observed that the relatively small facility dedicated to developing a gun-type nuclear explosive was the least noticeable of the facilities at Somerset West.[3]

A small team of three engineers from the Reactor Development Division, including Buys, were sent in 1972 to this site to carry out research and development work on the mechanical and pyrotechnical subsystems of a gun-type device. They started with a shortened naval gun to fire the projectiles.[4] The NIDR staff aided the AEB personnel in developing expertise in both propellants and ballistics.

At the new site, South Africans worked on the mechanical and pyrotechnic subsystems for a gun-type device. The first experiment at the internal ballistics test facility was conducted in September 1973. The team fired heavy (50 kilogram) tungsten projectiles from a bored-out four inch naval gun. Internal ballistics parameters were measured for a theoretical model for the device, according to the South African declaration to the International Atomic Energy Agency (IAEA).

Using this information, the team designed a scale model which, with a projectile constructed of tungsten, was tested at Somerset West in May 1974. This demonstrated that a nuclear explosive was feasible. The team tested, with extensive instrumentation, the first full-scale model of the gun-type device using a natural uranium projectile in 1976. This test proved the mechanical integrity of the design.

In designing the device, the AEB team at Somerset West faced several challenges, including achieving the repeatability of projective velocity and symmetry requirements when the projectile flies into the core.[5] The latter meant that the end of the device had to be reinforced — in essence it caught the plug fired down the tube. This unique approach was necessitated by the lack of a neutron initiator, a device that generates neutrons to start the chain reaction in the supercritical material. South African devices were designed to use background, or stray, neutrons to initiate the chain reaction. Calculations showed that the chain reaction would start within a few milliseconds after the HEU projectile merged into the fixed HEU core. Thus, for a nuclear explosion to occur, the shape of the assembled highly enriched uranium had to be spherical for at least on order of milliseconds, one of the more challenging engineering feats the team had to overcome.

Because nuclear weapons information is generally classified, the South African program lacked key information about gun-type nuclear devices and other designs. Through research and development efforts, it learned certain classified information. However, according to one of the participants, people in the South African program had the idea to monitor open source publications by top US nuclear weapons experts. After assembling a list of their names, South Africans searched their publications and realized that these experts were publishing highly useful nuclear weapons information piecemeal or couched within civil subjects.

In 1974 unable to answer certain pressing questions about the gun-type device, an engineer working on it at Somerset West went to the United States to attend a high explosive conference where leading US nuclear weapons experts were to deliver talks. Posing as an employee working on civil high explosives at the Council for Scientific and Industrial Research, South Africa's leading civilian scientific and technology research organizations, he had ample opportunities to ask detailed questions of the US nuclear weapons experts. He was pleased that these experts engaged in discussions with him in which they were frank and helpful.

However, South Africa later saw this type of approach as a security risk and discontinued it. The South Africans realized that the information could go the other way too. Asking certain questions could lead the US nuclear weapons experts to gain insights into what South Africa was actually working on.

For the personnel in the program, according to one leading member of the nuclear weapons program at the time, the view of the AEB was that the program could be kept secret only if the first rule was: No contact with outsiders at all. Of course, in practice, this was not always possible.

PNE FACILITIES AND ACTIVITIES AT PELINDABA

While the team progressed at Somerset West, other groups in the Reactor Development Division were working on other parts of the PNE program. One key question was where to house the growing number of people associated with the program while also keeping their work secret. The PNE program was growing to about 50-100

Figure 2.2 Pelindaba staff recreation area, with baboons, in early 1994.

people, while the Pelindaba and Valindaba enrichment sites at the time had about 3,000 personnel. To keep the PNE program hidden from the other personnel at Pelindaba and Valindaba, and to prevent foreign visitors who could be working for intelligence services from discovering the work, the AEB decided to remove the PNE program from the main site; however, they did not want to go too far away. So, the idea was to "be close but not too close," according to Buys. In this way the program could easily still draw upon the infrastructure of the main site, including for any emergencies.

In a valley on the southwestern side of the Pelindaba site was already a staff recreation center by the Crocodile River (see figure 2.2). Thus, personnel were known to travel into the valley.

The decision was made to put the PNE facilities on the other side of this valley. Frank Pabian, a leading expert on South Africa's nuclear programs, while a Senior Fellow at the Joint Research Center in Italy, pointed out that this valley was hidden by a ridge, consistent with concealment via "terrain masking.[6]

By the mid-1970s, a new series of non-descript buildings were being created for all major aspects of the planned PNE program. Figures 2.3 (a) and (b) show commercial satellite images of the major facilities involved in the PNE program in the valley below the main Pelindaba nuclear site, including:

- Building 5000, also known as (aka) Hall A
- Building 5100, aka Hall B
- Building 5200, aka Hall D
- Building 5300, aka Hall C
- F1 High Explosive Magazine
- F2 High Explosive Outdoor Test Site

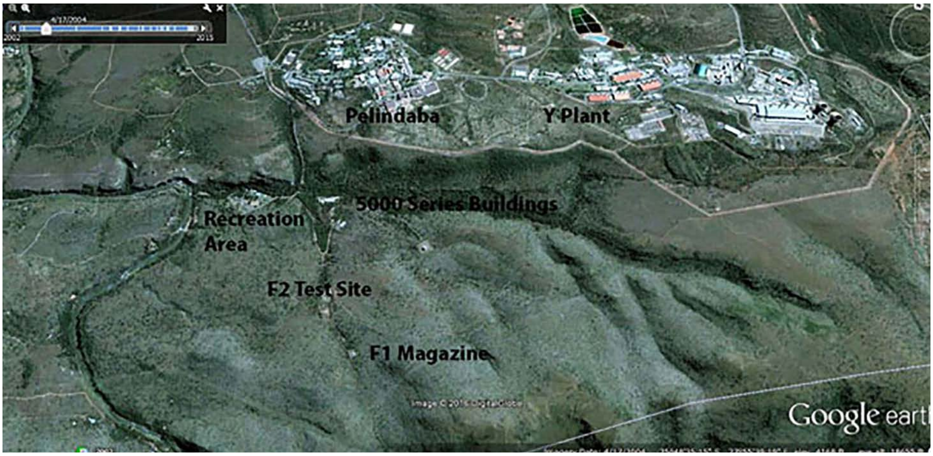

Figure 2.3(a) Commercial satellite images showing the main facilities in the PNE program in the valley below the Pelindaba site.

Figure 2.3(b) Commercial satellite image of the main 5000-series facilities in the PNE program.

Figure 2.4 Buildings 5100, 5200, and 5300 (barely visible) in the valley below the Pelindaba site.

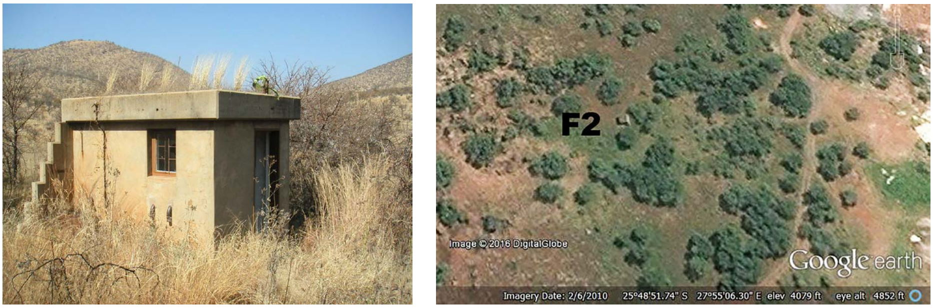

Figure 2.5 The F2 outdoor high explosive building, visible near the center of the commercial satellite image.

F1 and F2, which were further away from the main site, were a high explosive magazine and an outdoor high explosive test site, respectively. Both were used in the development of implosion-type nuclear devices. Figure 2.4 shows Buildings 5100, 5200, and 5300 in the valley below the main Pelindaba site. Figure 2.5 shows F2 in a commercial satellite image.

In parallel to the work at Somerset West, one of the first challenges was the development of a range of neutronic, thermodynamic, and hydrodynamic computer codes related to nuclear explosive devices. According to a former member of the team, the PNE program drew upon a team of theoretical specialists at the main site. Several members of the theoretical team had US trained in the United States and were nuclear physicists. However, some of the members were less than enthusiastic about working on nuclear explosives,

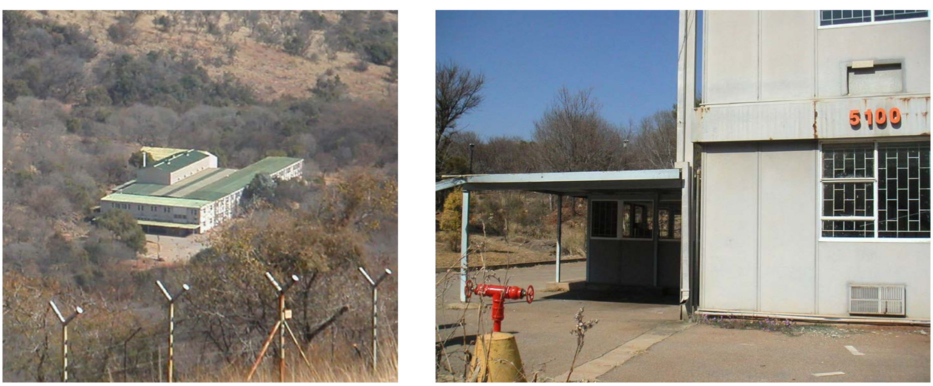

Figure 2.6 Building 5100 and its front entrance as it appeared in 2002 during a visit by one of the authors.

according to a former member. They saw the work as a distraction of the civil nuclear work they wanted to do at the main site.

The theoretical nuclear explosive work was based in the main PNE building, code named Building 5100 or Hall B (see figure 2.6).

Figure 2.7 shows a vault for classified documents in the second floor hallway in the design section of Building 5100. Members of

Figure 2.7 Vault in design section of Building 5100.

theoretical group in Building 5100 did basic research on compression, hydrodynamics, photon cross sections and neutron multiplication, according to a former member of the nuclear weapons program.

The program needed advanced computers for their calculations. To that end, it secretly ordered one from Europe. Later, the pattern was for a civil company to order computers abroad and the nuclear weapons experts would use them off-hours or remotely, according to a former member of the nuclear weapons program.

Building 5100 also housed a small-scale light gas gun (referred to as a "six millimeter system," by Armscor personnel) used to determine the equation of state of materials subject to high temperature and pressure, critical to the design of nuclear explosives. These essential data for uranium and plutonium are classified but are critical to the theoretical models related to nuclear explosives.

Based on the prototype gas gun in Building 5100, the program built a full-scale, two-stage light gas gun in Building 5200 that was 20 meters long (a "29 millimeter system"). Figure 2.8 shows the front of Building 5200 as it appeared in 2002, and its side entrance where heavy pieces could be brought into the building.

The program also needed to learn to make sensitive HEU components for nuclear weapons, too sensitive to make at the main site. These parts were made in Building 5100 in a first floor workshop located off the covered courtyard of the building and below the device design section on the second floor (see figure 2.9). The door was in a

Figure 2.8 Building 5200, from front and side of the building. The side is closest to Building 5100, showing entrance for heavy items, as it looked in 2002. The first nuclear explosive device was assembled in this building.

covered courtyard to allow vehicles to enter and unload outside the purview of overhead surveillance.

Once HEU was available, starting in 1978 and 1979, criticality experiments were done in Building 5200, which also had vaults to store HEU. These straightforward experiments verified the neutron multiplication factors of the two parts of the gun-type device separately, providing additional confidence that the gun-type design would work. The subcritical experiments used a neutron injector designed by physicists brought into the PNE program from the main site.

One advantage of a gun-type design is that the need for a full-scale test can be replaced by a certain type of criticality test that will experimentally verify theoretical models. This type of experiment is sometimes referred to as "tickling the dragon's tail," suggesting the danger inherent in the test. In essence, a simplified "dragon" machine, or pulsed fission reactor, involves a slug of highly enriched uranium sliding down a wire or track through a cylindrical annulus of highly enriched uranium, simulating in slow motion what occurs in firing a gun-type design. The United States conducted such experiments in early 1945 at Los Alamos during the Manhattan Project.

South Africa's dragon experiment involved a pulse reactor in Building 5000, designed to verify its new nuclear device computer models. Figure 2.10 shows the inside and outside of the building

Figure 2.9 The door led to the workshop that made HEU parts. The door was in a covered bay in Building 5100. In photo on right, the door is hidden by the small white building behind the auto.

as of 1994, during a visit by one of the authors. Although ready by about 1975, it was not used until 1979 when enough HEU became available. This type of reactor goes critical after inserting a final rod of HEU into a larger HEU mass surrounded by a steel reflector. The pulse reactor was designed to use a tungsten reflector, but that reflector was not finished by the time of the test. The critical reaction is stopped by the heating of the core and springs that push apart the HEU pieces. Instruments measure the neutrons produced. The 1979 experiment, according to a former senior official close to the IAEA, involved about 35 kilograms of 80 percent enriched uranium, implying a thick neutron reflector surrounded the HEU core.

These types of experiments can be risky. If a slug had become stuck in the US dragon machine, the highly enriched uranium would have become supercritical, causing a small nuclear explosion (on order of tens or hundreds of kilograms of TNT). Thus, any dragon-type reactor must be built with safety as a primary concern, and it must be operated carefully. South Africa apparently attempted to mitigate this danger in several ways. It built Building 5000 at the bottom of a depression surrounded by hills in an isolated portion of its main nuclear site (see figures 2.11 and 2.12). The control room was in Building 5100, which was almost three quarters of a kilometer away and shielded from the reactor by a hill. After the dragon test, the reactor was never used again. The facility was shut down in the early 1980s.

Figure 2.10 Building 5000, where South Africa performed a dragon experiment. An overhead crane is visible in the right image. The images were taken in 1994, when no trace of the experiment remained.

Johan Slabber, the former director of the Reactor Development Division, has spoken of a "mishap" in an experiment with the pulse reactor.[7] In this case, the reactor was shut down just in time to prevent a serious radiological accident from happening.

Figure 2.11 Building 5000 was isolated from the other facilities in a depression.

Figure 2.12 The control room of the reactor had been located on the first floor of Building 5000, facing the reactor. All the reactor equipment was emptied from the room, years before this picture was taken in 2002.

5000 SERIES BUILDINGS IN THE 1970s

Building 5000–This facility contained a pulse reactor for the experimental verification of theoretical computer models. In 1979 the reactor was used as a fast critical assembly in an experiment often referred to as "tickling the tail of the dragon" that proved the design of the gun-type device. The reactor was never again used as a pulse reactor and the facility was shut down in the early 1980s.

Building 5100–This building contained the control room for Building 5000, offices, research and development laboratories, and machining facilities for uranium metal. At its height, about 100 people worked in the building, according to a former employee from the era.

Building 5200–This building housed a large, two-stage light gas gun. Criticality experiments using HEU were done in this building to verify the multiplication factors of the two parts of a nuclear explosive device, providing confidence that the gun-type design would work. The first nuclear explosive device was also assembled in this building in 1979. Vehicles and cabling for the Kalahari test site were kept here, in essence because this building was the staging area in case of the decision to test.

Building 5300–This building was designed exclusively as a laboratory for high explosives. In the early stage of the South African nuclear weapons program, small quantities of high explosives were pressed and machined into shapes at this facility.

IMPLOSION-TYPE NUCLEAR DEVICE

The development of implosion technology was part of the PNE program from its inception. Theoretical work started in the early 1970s. However, there was no significant pressure to finish a design, given the emphasis on the gun-type device.

For example, an implosion type device would have required a neutron initiator to start the chain reaction at a critical moment. Some work was done in the 1970s on an electronic accelerator type of initiator but the work did not progress very far.

Nonetheless, the AEB did build facilities to pursue high explosive technologies associated with implosion. Building 5300 was designed mainly as a laboratory for high explosives work related to implosion technology. As such, at this facility small quantities (about 50 grams) of high explosives were pressed and machined into shapes aimed at learning about the process of imploding a spherical core. It also produced high explosives for experiments to measure the impact of an explosion on rock as part of designing the nuclear test site. Figure 2.13 shows the front and side of the building. This narrow building contained a number of concrete bays for work with high explosives.

Small high explosive tests for an implosion design were done at an outdoor high explosive test facility called F2. Figure 2.14 shows the building that held the instrumentation, where the explosive tests would have been detonated in front of the building. When it

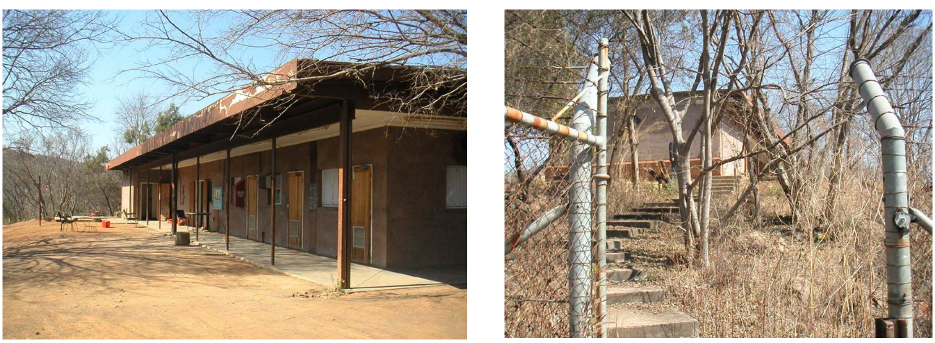

Figure 2.13 Building 5300 had a number of small high explosive cells behind the outer doors. Image on right, pathway from Building 5100 to Building 5300.

was used, its front concrete wall and the roof were covered in dirt. Nearby, a magazine, F1, stored high explosives for the program (see figure 2.15).

Figure 2.14(a) F2 outdoor high explosive test site, south of the 5000 buildings.

Figure 2.15 F1 Magazine that stored high explosives

THERMONUCLEAR AND BOOSTED DEVICES

The 1971 decision to proceed with type a devices included approval to work on a "boosted" nuclear explosive, referred to as type A*. This device was envisioned to use a mixture of lithium, tritium, and deuterium inside the fission device that would dramatically increase the overall explosive energy of the device. In August 1973, the Minister of Mining approved theoretical work on type B, or a thermonuclear device with a fission detonator, referred to as a two stage thermonuclear nuclear device.

Most of the focus of this early effort was on obtaining thermonuclear materials. In the early 1970s, the program started work on separating the isotope lithium 6 from natural lithium. Lithium 6 becomes tritium after neutron irradiation and is often used in thermonuclear devices or as a target in a reactor to make tritium. The AEB started testing a process to separate lithium 6 based on a mercury exchange progress. This work was done in Building 5100. Figure 2.16 shows a two-story bay, located off the covered courtyard where this work on lithium separation took place in the 1970s. A small amount of lithium 6 was produced in 1973.[8] Later in 1983, work started on an atomic vapor laser isotope separation (AVLIS) process to make lithium 6 that utilized copper vapor lasers.

Figure 2.16 The two-story bay where lithium 6 separation was done in the 1970s. Image was taken in 2002.

Building 5100 was also involved in separating small amounts of heavy water. Heavy water contains deuterium, which is also a thermonuclear material.

South Africa received a significant amount of tritium in a nuclear exchange with Israel where it provided natural uranium.[9] South Africa received four full cylinders in 1977, which contained almost 20 grams of tritium. Other than the initial taking of a small sample, the PNE program (or subsequent nuclear weapons effort) did not use any of this tritium in developing thermonuclear or boosted weapons. Nonetheless, in anticipation of using the tritium in the PNE program, the AEB built a tritium handling laboratory, called the Gas Laboratory, on the main site (Building P1600). It was completed in about 1981.

The actual work on thermonuclear or boosted weapons during the 1970s was minimal. The priority remained the development of a gun-type device.

INITIAL GUN-TYPE DESIGNS

By 1976 the AEB had completed the design of a full-size device that was 4.4 meters long, 0.61 meters in diameter, and weighed 3,450 kilograms. The first device was designed to be tested underground in conjunction with extensive instrumentation to learn more about nuclear explosives.

As discussed later, in 1977 South Africa realized that a full-scale underground PNE test would be impractical. Yet, the program had also realized that such a test was not needed in any case. The Reactor Development Division turned to designing a new, smaller design. The second device, finished in 1978, was two meters in length and 0.360 meters in diameter, and it had a mass of 750 kilograms, or about half the size and almost one-fifth the weight of the first device. According to Slabber, in 1978 his team conducted a cold test of this design using natural uranium instead of highly enriched uranium.[10]

The program still did not have enough HEU and would need another year to accumulate the required amounts. After South Africa did so in 1979, it completed the dragon test in Building 5000 and final criticality tests in Building 5200. Afterwards, it assembled its first nuclear explosive device in November 1979 in Building 5200 using about 56 kilograms of about 80 percent HEU. The Y Plant was still not able to make weapons-grade, or 90 percent enriched, uranium. The theoretical group estimated that the explosive yield would be about six kilotons. This yield was somewhat less than half of the yield of the gun-type bomb that destroyed Hiroshima in 1945 but contained a similar amount of about 80 percent HEU.

The South African effort to build a working, gun-type device took about eight years to accomplish. The relatively long development time, however, resulted primarily from the difficulty South Africa experienced in getting its uranium enrichment plant to produce sufficient amounts of highly enriched uranium for its first nuclear explosive device. The actual time needed to develop and prove a gun-type device was considerably less. In fact, by the time there was enough HEU, the device had been miniaturized.

NOTES

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2. *Armament and Disarmament: South Africa's Nuclear Weapons Experience,* op. cit., p. 39.

3. Interview with André Buys, January 23, 2003.

4. *Armament and Disarmament: South Africa's Nuclear Weapons Experience,* op. cit., p. 39.

5. Fax from Armscor to Mark Hibbs, *Nuclear Fuel*, April 27, 1993.

6. Frank V. Pabian, "The South African Denuclearization Exemplar," *Nonproliferation Review,* 2015, Vol. 22, No. 1, pp. 27-52. http://www.tandfonline.com/doi/full/10.1080/10736700.2015.1071969

7. Pabian, "The South African Denuclearization Exemplar," op. cit.

8. Atomic Energy Corporation, "Tritium Programme," unpublished, undated (about 1993).

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10. Timothy McDonnell, "International Conference: the Historical Dimensions of South Africa's Nuclear Weapons Program" (Washington, D.C.: The Wilson Center, January 4, 2013). https://www.wilsoncenter.org/article/international-conference-the-historical-dimensions-south-africas-nuclear-weapons-program

CHAPTER 3
GETTING HIGHLY ENRICHED URANIUM

Following the government decision in 1969 to build a pilot uranium enrichment plant, the Atomic Energy Board had to dramatically scale up from an enrichment research program to an industrial program.[1] It had to find and hire many qualified personnel, accelerate the planning of the new plant, overcome engineering problems, engage in massive procurements domestically and abroad, and start large-scale manufacturing operations for the components of the plant.

Although the enrichment project was shrouded in intense secrecy, the government decided that such a large construction project could not be hidden for long. In July 1970, then Prime Minister John Vorster announced in Parliament that South Africa intended to build a pilot enrichment plant based on a "process which is unique in its concept."[2] Many countries and experts skeptically greeted Vorster's announcement, questioning South Africa's ability to develop an enrichment technology on its own.

Not until 1975, when senior South African nuclear officials presented a paper to a European Nuclear Conference in Paris, did South Africa provide partial information about its enrichment process.[3] However, the South Africans did not reveal details about the separating element until the late 1980s.[4]

In his 1970 announcement, Vorster emphasized that the enrichment plant was for peaceful purposes only. One goal of the project was to sell enriched uranium overseas, and Vorster invited any non-communist nation to collaborate in exploiting this new process for civilian, peaceful purposes.[5]

Vorster also stated South Africa's willingness to place all its nuclear activities under IAEA safeguards subject to the following conditions:

- South Africa would in no way be limited in the promotion of the peaceful application of nuclear energy;
- South Africa would not run the risk that details of the new enrichment process might leak out as a result of the safeguards inspection system; and
- The safeguards system, while efficient, would be implemented on such a reasonable basis as to avoid interference with the normal efficient operation of the particular industries.

While not an outright refusal to accept safeguards and the associated Nuclear Non-Proliferation Treaty (NPT), Vorster's announcement appeared to signal that South Africa regarded its nuclear capabilities as a potential bargaining chip.[6] It was "not willing to open up all of its activities to an international community that seemed increasingly hostile to the country and its racial policies."[7] However, this conditionality also suggests that a nuclear weapons arsenal may not have been inevitable in 1970.

Still, Vorster did not mention that peaceful purposes included peaceful nuclear explosives or that the enrichment plant was being designed to make weapons-grade uranium in addition to low enriched uranium (LEU). LEU has the level of enrichment most often associated with overseas exports of enriched uranium and a civil purpose. Weapons-grade uranium is associated with nuclear weapons. If Vorster had been more forthcoming, the international outcry could have been far more pointed.

This deliberate omission fooled many in the international community, who took Vorster's announcement literally and assumed wrongly that the Y Plant would not make weapons-grade uranium. The US government wrote to a Congressional oversight committee that as late as 1976 "all information available to us indicates that the South African enrichment plant is designed for and intended to produce only slightly enriched uranium."[8] Although this view was not a consensus view in the United States intelligence community, South Africa had created ambiguity about the purpose of its unsafeguarded nuclear facilities and its refusal to sign the NPT.

Over the following decade and half, many would use this ambiguity to argue in public and policy debates that South Africa did not have nuclear weapons but only a capability to make them. As pointed out by Frank Pabian, the US expert on South Africa's nuclear program, "Once a threshold proliferant nuclear state has access to sufficient stocks of weapons-grade fissile material to make nuclear weapons, and a strong case can be made that they have requisite motivation to build nuclear weapons, the South African exemplar shows the likelihood that they will build nuclear weapons (and are not simply interested in only acquiring a 'capability' to build them at some distant point in the future."[9]

Y PLANT

One month after Vorster's announcement, South Africa passed legislation to establish a corporation for uranium enrichment. In November, the state-owned Uranium Enrichment Corporation of South Africa Limited (UCOR) was created, and Wally Grant became its first Managing Director and Ampie Roux its first chairman of the Board. The AEB's enrichment project staff was also transferred to UCOR.

A site adjacent to Pelindaba was selected as the site of the pilot enrichment plant, code named the Y Plant, and the ground for the plant was broken in November 1970. Figure 3.1 is a 1991 satellite image that shows the location of the Y Plant near the main Pelindaba site. Although the two sites were distinct, many services, such as security, transport, and library services, would be shared.

According to Newby-Fraser's 1979 *Chain Reaction*, the name of the site was derived by someone asking: "What happens here?"

Others said: “This we do not talk about.” In a similar manner as the name Pelindaba was selected, the new site was named Valindaba, a conjunction of two words common to many of the roughly seventy languages indigenous to the southern tip of the African continent. Individually, the words are “vala” meaning “to close” and “indaba” meaning the council. Together, the meaning of these two words is the “council is closed.” By extension, Valindaba means “no talking about this.”

Newby-Fraser states that some cynically referred to the facility as “no comment.” Although this name did not last, he points out that the term is apt to describe the behavior of UCOR, which maintained extremely tight security over its activities. The 1970 law creating UCOR instructed the government to withhold from the public any information about the corporation and its activities that could be considered “contrary to public interest.”

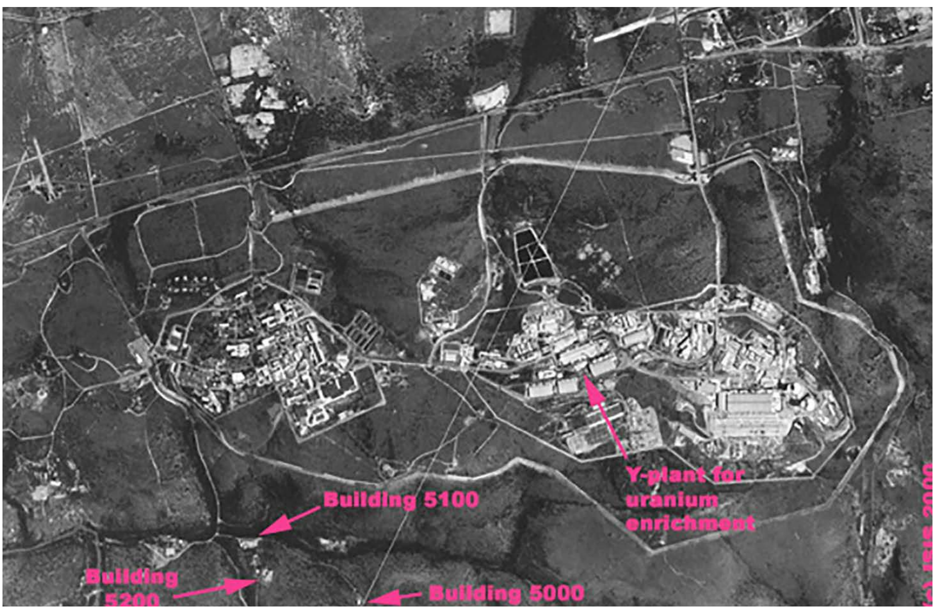


Figure 3.1 A 1991 KVR-1000 satellite image showing the Y Plant; to its immediate left is the main Pelindaba nuclear site (unannotated). Also shown are several 5000-series buildings. Source: www.isis-online.org and www.terraserver.

AERODYNAMIC ENRICHMENT METHOD

The South African aerodynamic enrichment process separates uranium isotopes through centrifugal effects created by the rapid spinning motion of a mixture of uranium hexafluoride gas and hydrogen carrier gas in a small stationary tube. An example of a separating element shown to one of the authors in 1994 by a senior South African enrichment expert was about five centimeters long and about one centimeter in diameter. The expert explained that the gas mixture enters at a high speed through tiny holes in the side of the tube and spirals down the tube. When the mixture reaches the holes at the ends of the tube, its radius of curvature is reduced several-fold, increasing the separation of the uranium isotopes.[10] The heavy fraction, more concentrated in uranium 238, exits to the side. The light fraction, more concentrated in uranium 235, exits straight out at the end. Because each separating element can enrich uranium only slightly, several separating elements are combined into "stages," several thousand of which are linked together by pipes and valves into a "cascade."

The Y Plant was organized into five consecutive enrichment blocks and one "stripper" section, each containing many stages. The blocks were located in three large buildings, named C, D, and E (see figures 3.2 and 3.3). Natural uranium was fed into block 1 in building C. The enriched product from block 1 (less than 2 percent uranium 235) went by pipe to blocks 2 and 3 in building D for additional enrichment up to 10 percent uranium 235. From there, pipes carried the enriched material to blocks 4 and 5 in building E, which discharged the final enriched product containing greater than about 80 percent uranium 235. Depleted uranium was discharged at the bottom of the stripper section in building C. Combined, all these blocks were referred to as one cascade, raising the enrichment level of the uranium from natural uranium, or about 0.7 percent, to 80 to 90 percent or more.

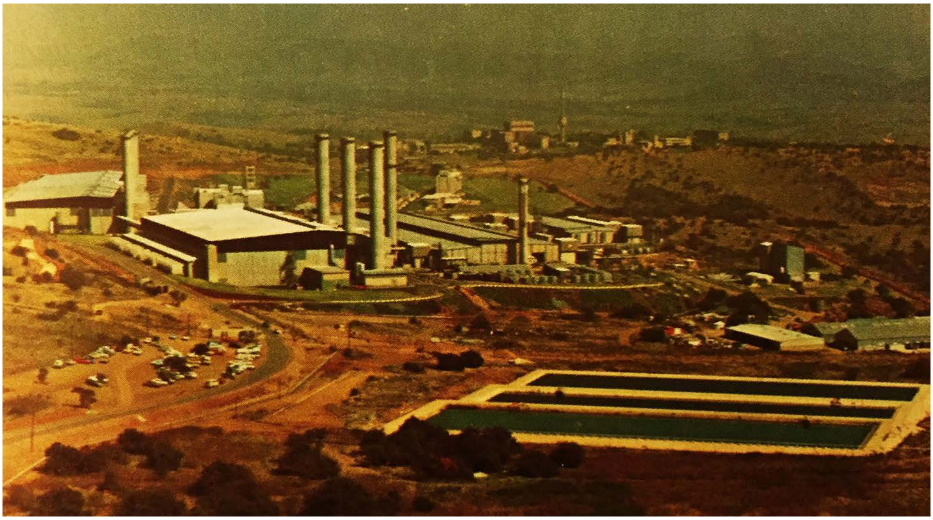


Figure 3.2 Y Plant, with many high stacks, with main Pelindaba site in background. The tall stacks were part of a hydrogen ventilation system aimed at minimizing the chance of an explosion of hydrogen gas used in the enrichment process lines. Photo Credit: Uranium Enrichment Corporation of South Africa Limited

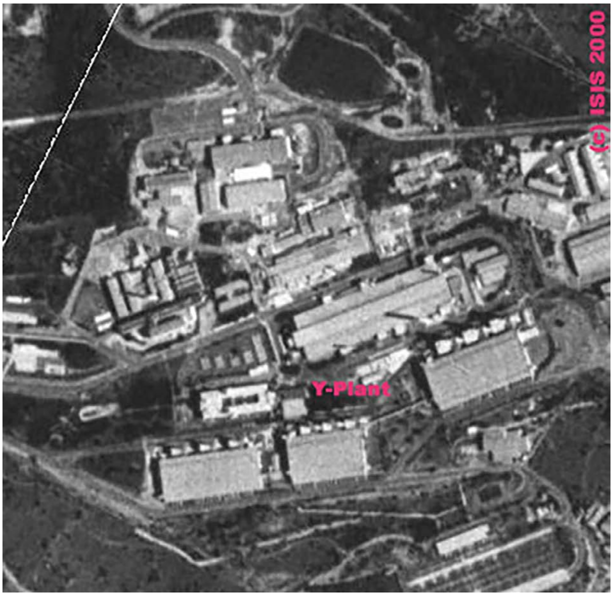


Figure 3.3 Satellite image of the Y Plant, which closed in 1990. The December 1991 image is from www.terraserver.com. Source www.isis-online.org

According to Anthony Jackson, a chemical engineer and the leader of the team responsible for the design and commissioning of the Y Plant, the attainment of an industrial production level required years of trial and error.[11] Learning to mass produce high precision separation elements and other key components for the enrichment plant was time consuming and expensive. “Money was the real issue,” he added, because funding is necessary to “sort glitches out.” Because the plant was for a “strategic” purpose, he said that funding to sort out all the engineering and chemical problems was never an issue. However, the difficulties of getting the process to work cannot be understated. The South Africans had to cope with many technological surprises, which delayed and reduced the accumulation of HEU.

In 1974 the commissioning of individual stages of the cascade started. By October of that year, initial enrichment started in block 3 of building D. The rest of the blocks were commissioned gradually, as development work continued. The full cascade was licensed for operation in February 1977 and the blocks were coupled together to start the run up to the production of 80 percent enriched uranium. After wide fluctuations in the enrichment level throughout the cascade during the first fifty days of operation, the enrichment level started to rise. After about 200 days of operation, the product reached 80 percent enrichment (see figure 3.4).

After start-up problems and the long equilibrium time of the plant, the first and relatively small withdrawal of HEU (80 percent enriched) at the product area occurred on January 30, 1978.[12] A few kilograms of 35 percent enriched uranium had been withdrawn from a lower section of the cascade at the end of 1977.

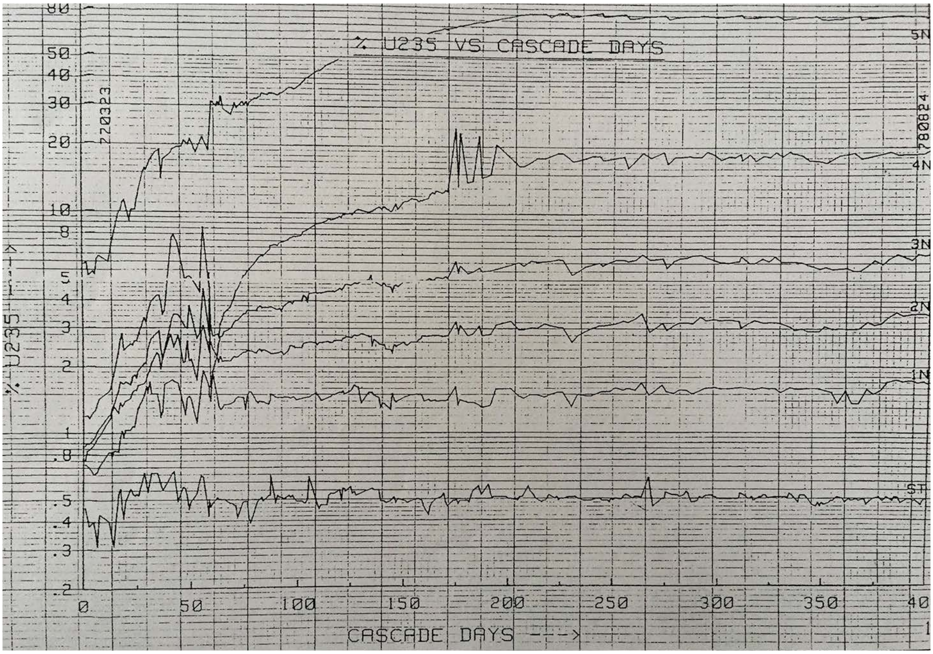


Figure 3.4 The graph, which is taken from the Y Plant's operational records, shows the daily enrichment level at the end of each of the five blocks and the stripping section. The names of the blocks are on the right of the graph and the enrichment level is on the left side on a logarithmic scale. The wide fluctuation in enrichment level is visible during the first fifty days of operation. Source: South Africa.

The Y Plant was designed to make roughly 100 kilograms of weapons-grade uranium per year and to have a nominal enrichment output of about 20,000 separative work units (SWU) per year.[13] Unexpected problems in the plant, however, restricted the enrichment level to about 80 percent during its first few years of operation and led to a production rate of only about half of its theoretical output.

By the end of August 1979, the plant had produced only about 64 kilograms of 80 percent enriched uranium during a period of 1.66 years. Nonetheless, this amount was enough for South Africa's first nuclear explosive, which was completed in November 1979.

The relatively small quantity of HEU produced means that the 1979 "flash" over the ocean south of South Africa picked up by the US Vela satellite could not have been a South African nuclear test.

The lack of HEU does not exclude official South African participation in an Israeli test.

Getting this 64 kilograms of 80 percent HEU was expensive and required the development of a large cadre of skilled engineers and scientists. By 1975, the UCOR project employed 1,200 people, and South Africa had already spent about 100 million Rand ($150 million in October 1974 dollars) on research and development on the enrichment program, excluding expenditures on the Y Plant.[14] By 1975, the cost of the Y Plant amounted to well over 50 million Rand ($75 million in October 1974 dollars).[15] A large proportion of the research and development funds was used to assist South African industrial firms to create the expertise and infrastructure necessary for the various sophisticated manufacturing tasks assigned to them.

About 235 different companies contributed their expertise and craftsmanship to the design and construction of the machines and instrumentation for the Y Plant.[16] In the process, South African companies enhanced their skills and abilities greatly, including importing significantly more sophisticated machine tools, equipment, and materials.

Sensitive work, including the manufacturing of the separation elements, the cleaning of all components, and the assembling of manufactured components, occurred at Valindaba. This work was conducted under tight security.

FOREIGN PROCUREMENT

Although South Africa has consistently said that the Y Plant was an indigenous effort, many key items for the plant were obtained from abroad. Foreign procurement was essential for the Y Plant to operate successfully without experiencing additional delays or complications.

This assessment is not meant to diminish the accomplishments of the South Africans, many of whom have bristled at the suggestion that the program was not indigenous. Although foreign assistance of many different forms was necessary, the Y Plant's success depended heavily on the skill and initiative of South Africa's scientists and technicians combined with the government's willingness to provide adequate resources and on-going support from the highest levels of government.

From the South African government's perspective, it would have been prudent in many cases to acquire an item from abroad rather than make it. In addition, South Africa did not have the industrial base to make all the necessary machine tools, sophisticated equipment, and components. Thus, foreign procurement was necessary for many key items. In its quest to build and operate the Y Plant, South Africa participated in a range of questionable or illegal imports.

During the early 1970s, however, export controls on nuclear or nuclear-related components were nonexistent or weak by today's standards. As a result, few exports to South Africa were controlled. However, the growing anti-apartheid movement in the mid-1970s led Western governments to take action to limit nuclear exports to South Africa. This controversy also led to public revelations of many nuclear exports to South Africa.

The media at the time reported that South Africa acquired items for its uranium enrichment program from US, French, German, and Swiss companies.[17] Important instrumentation for measuring isotopic concentrations of uranium and compressors was imported from Germany. Valves and instrumentation for the enrichment plant were imported via circuitous routes, including Germany, according to a South African who was formerly a senior official in the enrichment program. Additionally, unsafeguarded uranium hexafluoride was imported from France, according to South African nuclear officials. This uranium hexafluoride was the first feed stock into the Y Plant.

In 1975 the US Senate's Government Operations Committee investigated an export of industrial-process computers to the Y Plant from the Foxboro Corporation.[18] Under a US Commerce Department license, Foxboro exported two computers and spare parts during 1971 to 1973 for a price of about $2 million. The licenses were in the name of UCOR, the South African agency responsible for developing the enrichment facility, and the stated purpose on the license was "operation of experimental facilities and pilot plants for nuclear research and development."[19] According to a Foxboro executive interviewed by the committee, the company knew that the computers were to be used for "some sort of uranium plant," although the South Africans were generally secretive.[20] Foxboro learned that the facility was a uranium enrichment plant during the installation of the computers despite South Africa restricting Foxboro personnel to the computer area of the plant and monitoring their activities closely.

According to a former member of the AEB and the nuclear weapons program, South Africa also arranged for foreign companies to build plants that would manufacture components for the enrichment plants. He said the Swiss companies Balzers and VAT built a factory in South Africa largely to make valves and pipes for the enrichment program.

Another important supplier to UCOR was the South African trading company Krisch Engineering (Pty) Ltd, which would later become an important cog in the proliferation network operated by the Pakistani A.Q. Khan. At the time, Krisch was the local agent for the German firms AEG Telefunken and Leybold Heraeus GmbH. It supplied important vacuum equipment to UCOR during the 1970s and early 1980s. Krisch also arranged the manufacture of a highly specialized prototype valve at Leybold Hereaus for the South African enrichment program.[21]

The enrichment program, however, was unable to get everything it needed. For example, a senior member of the enrichment program said in a 1994 interview in South Africa that the program was thwarted in its efforts to obtain special seals for where the rotating shaft enters a compressor. The seal must have extremely low leak rates that can prevent the ingress of oxygen, moisture, and oil, requiring specialized shaft sealing methods.[22] Unable to acquire the necessary components overseas, they were forced to develop the seals themselves, encountering many difficult problems in the process.

BECKER NOZZLE PROCESS

Media reports and members of the African National Congress have asserted that the enrichment plant depended extensively on the jet-nozzle process developed by Erwin Becker and his colleagues at the Karlsruhe nuclear research center in Germany during the 1950s and

1960s. Roux responded to these types of critics: "While there may, in the very early days, have been common features, the UCOR process in its developed form is as far removed from any other enrichment process as the North Pole is from the South Pole."[23]

Becker, however, challenged South Africa's claim for uniqueness right after Roux and Grant delivered their paper at the 1975 European Nuclear Conference. Becker said at a press conference that he had collaborated closely with the South Africans insofar as they had been given the freedom of his research facilities at Karlsruhe.[24] South Africa did not return the courtesy, he noted. On a visit to Valindaba in 1974, he was not allowed to see the separating element or the process equipment. Nonetheless, at the 1975 press conference Becker had to concede that not all the details of the two approaches are the same.[25]

In 1977 Becker reissued his allegation and went further. He said that Roux and other South African scientists had free access to his research and may have succeeded in adapting it.[26]

Both processes are based on the high performance stationary walled centrifuge. Becker's group had avoided using the term "centrifuge" to avoid potential problems with German classification rules that in 1960 had been amended to make all work on gas centrifuges secret.

The Becker and UCOR processes do differ, however. A widely discussed difference is that UCOR developed an ingenious cascade technique, the "helikon" process, which, in combination with the separation element, can be considered a unique process.[27] However, the helikon technique was not deployed in the Y Plant, but in the later semi-commercial Z Plant at Valindaba.

Waldo Stumpf, the head of the Atomic Energy Corporation in the late 1980s and 1990s, which was the immediate successor to the AEB, said in an interview in 1994 that the Germans never solved the problems posed by the mixture of uranium hexafluoride gas and hydrogen gas, which posed many unique challenges in successfully operating the Y Plant. He said that the Becker-nozzle plant that Germany sold to Brazil in 1975 was going to use helium instead of hydrogen. One of the problems posed by hydrogen is that it is explosive in the presence of oxygen. With so much hydrogen in the process gas, the risk of explosion existed within the cascade piping and equipment. South Africa had to institute a variety of measures to keep air out of the cascade and ensure proper ventilation of any hydrogen that escaped the cascade into the atmosphere. The tall stacks visible at the Y Plant are part of that hydrogen ventilation system (see figure 3.2).

STEAG

Another controversial issue is the nature of UCOR cooperation with the German company Steag AG on a joint uranium enrichment endeavor between 1973 and 1976. Steag was a German energy group that controlled the patent rights to Becker's jet-nozzle process. Starting in 1970, Steag worked to develop the Becker nozzle technology for export and its application in commercial enrichment plants.[28] In 1974, Steag built an advanced prototype stage using the Becker nozzle, where all the major components were designed to facilitate serial production for a commercial-scale enrichment facility.

Its collaboration with South Africa followed Vorster's 1970 announcement of South Africa's willingness to cooperate with any non-communist country in exploiting its new enrichment process. Vorster's goal was to build a larger uranium enrichment plant in addition to the Y Plant. In this larger plant, South Africa intended to enrich its domestic uranium and sell it overseas, realizing its long term goal of deriving greater economic value from the uranium it mined.

South Africa understood it could not build a commercial-size enrichment plant alone. It needed partners to share the financial risk and extend the guaranteed market for enriched uranium. In addition, the demands for manpower and manufacturing resources would be beyond South Africa's capabilities, and South Africa would need to rely heavily on the overseas partners in meeting these demands.[29] For overseas collaborators, the benefits would include financial rewards, fruitful scientific and technological collaboration, and an ensured supply of enriched uranium. The last benefit was appealing to several countries that wanted to lessen their then dependence on Russian and US enriched uranium supplies.

Despite high initial expectations, in 1976 Steag ended its collaboration with UCOR, citing disagreements over financial arrangements and the sharing of risks in building a commercial enrichment plant in South Africa. For example, South Africa insisted that Steag was to be financially responsible for any failures in supplies of equipment caused by the worsening international political situation, i.e. growing pressure to impose economic sanctions on South Africa because of its apartheid policy.[30]

South Africa maintains that in the end the two sides conducted only joint feasibility studies on a plant that would produce several million separative work units per year.[31] The goal was to compare the South African and German processes to determine which system was more feasible technically and more viable financially as part of deciding what type of plant to build. *Chain Reaction* maintained the study showed that the South African process could form the basis of a competitive enrichment plant.[32]

The Anti-Apartheid Movement of Germany charged that the collaboration was far more extensive. These charges were laid out in the 1978 book *Nuclear Axis* by Barbara Rogers and Zdenek Červenka. Based on a set of secret documents obtained by the Anti-Apartheid Movement of Germany from the South African embassy in Bonn in 1975, *Nuclear Axis* argues that South Africa received the jet-nozzle process from Steag during this collaboration and this transfer essentially became the UCOR process. The authors claim that the process announced by Vorster in 1970 was not the aerodynamic process, and failed in any case soon afterwards.

The documents show that Steag and the West German government wanted to establish an extensive collaboration with South Africa on an enrichment plant, despite growing public and international opposition to any kind of nuclear and military cooperation with South Africa. But the documents provide only indirect support for the authors' charges that Steag supplied South Africa with its secret jet-nozzle process. The documents indicate that Steag intended to grant UCOR an option for a sublicense for the manufacture of the jet-nozzle process. Because the South Africans viewed obtaining this sublicense an "essential pre-condition" for the start of a comparative economic study, *Nuclear Axis* concluded incorrectly that the comparative study was actually a technology transfer of the jet-nozzle process that would form the heart of the UCOR process.[33]

The West German government challenged the claims in the *Nuclear Axis* and denied that any technology transfer took place. It also appears that the reason the West German government did not allow a transfer appears to have been in response to increasing public and international opposition to nuclear cooperation with South Africa rather than opposition to building a plant overseas. In late 1973, several members of the West German Cabinet opposed Steag's proposal for a joint comparative study for a uranium enrichment plant, fearing the harsh reactions of other African states.[34] Although the proposal did not include anything about actually building an enrichment plant, one member of the cabinet believed that the whole operation made sense only if the plant was built, a step he opposed.[35] The insistence on including a sub-license for manufacturing the jet nozzle in the proposal strengthened this cabinet minister's belief that they intended to build a plant in South Africa.

Despite the lack of support from the West German Cabinet, Steag and UCOR launched in early 1974 a joint comparative economic feasibility study between the Karlsruhe jet-nozzle process and the South African process. However, without German government backing Steag could not obtain funding for an enrichment plant.

Although *Nuclear Axis*'s claims of Steag providing the jet nozzle process to South Africa are not supported by the available information, German and other European companies provided key nuclear or nuclear-related assistance to South Africa's enrichment endeavors. One former South African nuclear official said that UCOR's expectations of its collaboration with Steag were clear. While attending briefings on the enrichment cooperation with West German companies and officials, he learned that South Africa expected that German companies would provide the technology to make a commercial plant work. How much this collaboration helped operate the Y Plant is unclear, especially given the differences in this plant and the planned commercial-scale plant. Nevertheless, the collaboration likely helped facilitate the movement of sophisticated goods to South Africa.

During its cooperation with German companies and laboratories in the 1970s, South Africa may have gained access to both unclassified and secret information about the Becker nozzle process, key suppliers, and methods of overcoming operational problems in operating a cascade. Such information may have helped South African scientists overcome their problems in building, equipping, and operating the Y Plant. Improvements in the separation elements in the mid-1970s, for example, may have resulted from such contacts.

SEMI-COMMERCIAL PLANT, OR Z PLANT

In 1975, despite the lack of clear support from Steag, South Africa decided to build a larger enrichment plant, which South African officials estimated would have a capacity of 5 million SWU per year. But without foreign partners, South Africa subsequently reduced the size of the plant. In the end, South Africa built a semi-commercial plant with a capacity of 300,000 SWU per year, large enough to provide LEU to two light water reactors that it ordered from France in 1976. The Z Plant, built next door to the Y Plant, exploited new methods, such as the helikon technique, which reduced its cost and improved its efficiency compared to the Y Plant. According to Jackson, the motivation was strategic, in the sense that South Africa's growing isolation made it more difficult to buy enriched uranium on the international market.

Construction on this larger plant began in 1979, and commissioning with uranium hexafluoride started in 1984. Because of problems resulting from insufficient prototype experience, enriched uranium production did not begin until 1988.[36] Afterwards, however, operation was not continuous. Problems with uninterruptable power systems and a special cooling system associated with uranium hexafluoride condensers led to the plant operating only about two months in 1990.

This plant produced 3.25 per cent enriched uranium, via batch recycling, for the twin Koeberg power reactors, which required about two-thirds of its optimum annual production of 300,000 SWU. Any spare separative capacity was intended to be sold on the world market.[37]

From 1988 until mid-1993, the semi-commercial plant produced 734,000 SWU, with 95 per cent supplied to the Koeberg reactors and the other 5 percent supplied to foreign customers.[38] The total output for these years corresponds to the production of about 189,000 kilograms of 3.25 enriched uranium at a tails assay of 0.3 percent. The average annual output during each of these five years was about 150,000 SWU per year, or about 38,000 kilograms per year of 3.25 per cent enriched uranium.

The enrichment process remained highly energy intensive and was not competitive with overseas producers, particularly in the oversupplied world enrichment market that existed in the early 1990s. With little prospect of economic viability, the Z Plant ceased operation on March 31, 1995.

PROBLEMS IN THE Y PLANT

South Africa's efforts to find an international partner may have failed but they served to improve the enrichment program's knowledge of the aerodynamic method and opened doors to a variety of foreign high-tech goods that it needed to acquire for the Y Plant and later the Z Plant. This overseas assistance was critical to the success of the Y Plant, which was very much a pilot plant struggling to operate.

As the Y Plant fought to operate in the 1970s, it experienced many inefficiencies and problems. These problems remained hidden for years, emerging only after South Africa signed the NPT in 1991 and instituted a more transparent policy.

The plant's problems reached their peak during August 1979, which the Y plant workers call "chaos day." This unexpected event ended the production of 80 percent HEU for 23 months, until July 1981.

Chaos day resulted from greater than normal chlorine impurities in locally produced uranium hexafluoride feed, which in turn caused a massive chemical reaction in the uranium gas and the hydrogen carrier gas. According to Jackson, the result was solid uranium depositing on the inside of the cascade, reducing the output of the top end of the plant to less than 10 percent instead of 80 percent enriched uranium. The 23-month renovation included the replacement of all the old separating elements whose holes had become blocked. After restart and the reestablishment of equilibrium operation, the plant finally started producing HEU (but still only 80 percent enriched) at the end of July 1981.

Chaos day was the surprise finale of a rash of problems in the Y Plant that had occurred after it started enriching uranium in 1974. These problems, some of which defied explanation, significantly complicated the plant's startup and then reduced its enriched uranium output. During this initial period, HEU output was only half of what was expected.

The first type of problem was due to inefficient mechanical processes in the Y Plant cascade, which stretched throughout the blocks, which led to the enriched and depleted streams combining again after leaving the separator elements, commonly called "mixing." The Y Plant did not use the more advanced helikon technique, which significantly reduced mixing in the semi-commercial plant. It used a "Pelsakon backpump cycle" which, according to Jackson, did not work as well as expected, and resulted in a lower separative work output than expected.[39] Initially, the mixing loss in the backpump phase of the cycle was assumed to be 10 percent. In practice, however, mixing losses were considerably higher.

The plant also suffered from an unexpected loss of separating capacity. The cascade was unavailable more than expected. Impurities, particularly nitrogen, leaked into the process gas, causing additional losses. Over time, the separating elements did not work as designed because of blockages and other problems.

The third loss mechanism involved catalytic chemical reactions between uranium hexafluoride and hydrogen gases.[40] During the first several years of operation of the Y Plant, project personnel spent a great deal of time trying to reduce the loss of enriched uranium from chemical reactions. In 1977 South African officials stated: "Detailed studies in the laboratory backed by extensive plant experience have given the background information on the conditions to be maintained if uranium hexafluoride losses are to be kept below acceptable limits."[41]

Starting in the late 1960s, the enrichment project realized from open scientific literature that the reaction of uranium hexafluoride and hydrogen could cause the formation of solid uranium products and hydrofluoric acid (HF). However, the available public literature suggested that the reaction should occur only above a temperature of 125 centigrade, which was well above the maximum temperature in the Y Plant.

Yet, laboratory experiments in the early 1970s showed that the reaction would occur at much lower temperatures in systems simulating the Y Plant cascade. These systems, which were more complex than those described in the open literature also contained teflon filters, which looked like top hats and were used to filter dust from the rings of rotary compressors, some of which were quite large. The filters ensured that dust did not plug or otherwise damage the separating elements. After 500 to 4,000 hours, these systems exhibited a catastrophic catalytic reaction, where the reaction rate rose dramatically and HF concentrations increased rapidly. In terms of uranium hexafluoride gas concentration, after a slow decrease in the concentration, the gas concentration at the filter would quickly drop toward zero, signaling in essence the plugging of the filter by reaction products. On dismantling the test systems, the operators discovered that reaction products, which were a form of uranium tetrafluoride, were formed uniformly throughout the teflon filters.

Based on knowledge gained in the 1980s, the South African researchers concluded that this catalytic behavior resulted from chlorine contamination on the metal surfaces and in the teflon filter material. During the 1970s, without this knowledge, the plant operators solved the problem empirically. They polished the aluminum surfaces and conditioned the systems with HF and uranium hexafluoride. These steps increased the "incubation" period from 500 to 4,000-10,000 hours. The operators also learned that by replacing the filters, longer periods of stable plant operation could be achieved.

For example, the first block 3 prototype stage (located in building D and called "Maverick") experienced this catastrophic loss rate after 500 hours. Operators stabilized Maverick's operation by replacing its teflon filters.

Subsequently, almost all the stages of block 3 which was the first one constructed, exhibited this catastrophic loss behavior with incubation periods between 1,000 and 4,000 hours. Replacing the filters and cleaning key equipment stabilized these stages. Because operators had learned to chemically clean the metal components, the stages in the other blocks rarely had catastrophic reactions after such short incubation periods.

However, losses from chemical reactions continued. According to Jackson, the plant experienced inexorable losses that were apparently a function of the effective surface area of the cascade, where the filters had a much higher effective surface area than pipes and other metal components.

From cascade day 200 until cascade day 733 (chaos day), for example, the plant withdrew only about half of the expected amount of 80 percent HEU (64 kilograms discharged vs. 130 kilograms expected). About 85 percent of this difference could be attributed to losses stemming from a range of chemical reactions and other losses of uranium material.[42] The chemical losses included catastrophic reactions on filters, non-catastrophic reactions on filters, and to losses during decommissioning and maintenance of stages. As of the early 1990s, no satisfactory mechanism was identified to explain the rest of the losses.

An unusual phenomenon occurred at the top end of the cascade, where the catastrophic reaction in the filters led to small greenish black agglomerations within the filter rather than a uniform distribution as in the lower blocks.[43] South African scientists did not identify the uranium products on these filters, and they could not reproduce this phenomena in the laboratory using natural uranium. They concluded that the most probable reason for the agglomerations was a combination of radiation chemistry effects associated with the higher radiation from HEU and the higher concentration of impurities at the top end of the cascade. In total, during this initial period prior to chaos day, about 13.5 kilograms of uranium 235 were estimated to have ended in these agglomerations in the filters in blocks 4 and 5, of which about 85 percent was in block 5.[44] This loss accounted for almost 30 percent of the total losses in uranium 235 experienced during this initial period leading up to chaos day.

Because of the relatively large amount of high quality HEU material deposited on filters in blocks 4 and 5, South Africa instituted a recovery program. Because these blocks contained only about 15 percent of the teflon filters, in the plant, the vast majority of the filters were stored without recovery. In total, these discarded filters contained a significant amount of enriched uranium that would ultimately take years to accurately measure.

Given all this experience with unexpected chemical reactions, why did chaos day occur? Why did the operators use untested domestically produced uranium hexafluoride? According to Jackson, although they did not know at that time that chlorine was the catalytic agent, he and others argued against using the new material. However, they were overruled.

After the August 1979 crash, the plant operators learned that a similar event could be prevented by using only high purity uranium hexafluoride and managing the reaction problem carefully. The conversion plant that turned yellowcake into uranium hexafluoride removed trace impurities at the end of the process rather than near its beginning. The uranium hexafluoride was sampled for impurities and any material not meeting rigorous specifications was recycled back through the purification process. Operators carefully measured the enrichment levels in the blocks and monitored the uranium buildup on the filters with a unique, highly collimated gamma-radiation detector. The result was that the operators could recognize when a filter was becoming overloaded with uranium and needed to be replaced with a fresh one before the catalytic reactions could get out of hand. In this way, the operators avoided another chaos day and reduced the losses from chemical reactions.

An inadvertent result of this careful record keeping was that the daily operating records were both detailed and maintained over the whole life of the plant. Later, chapter 10 will discuss how fortunate it was for the IAEA's verification effort in the early 1990s that South Africa preserved these records, particularly given the uranium losses in the Y Plant and the lack of accurate records about the amount of uranium in most of the teflon filters.

HEU PRODUCTION

With the resumption of 80 percent HEU production in July 1981, the Y Plant started to significantly increase its output. It also started to make weapons-grade uranium, or uranium enriched over 90 percent, in late 1982. HEU production was further increased with the installation of improved enrichment separating elements.

Until the Y Plant shut down on February 15, 1990, it produced in total about 990 kilograms of HEU with an average enrichment of 68 percent, according to South Africa's March 1994 completeness report to the IAEA. Table 3.1 shows the forms of this HEU and some information about its use. Table 3.2 lists the amount of HEU South Africa assigned to its major programs by 1991.[45]

The South African nuclear weapons program received about 478 kilograms of HEU (average enrichment about 87.4 percent). Of this amount, about 88 kilograms ended up in scrap and were recycled, and about 6 kilograms were lost.

The other major program to which South Africa assigned HEU prior to the closure of the Y Plant was the US-supplied, 20 megawatt-thermal (MWth) Safari-1 reactor, located at Pelindaba. This program was assigned about 215 kilograms of HEU (average enrichment 46 percent by September 1991). About 85 kilograms of this HEU had been sent to the Safari reactor. About four kilograms of this HEU were lost during the processing of the fuel. The rest was stored.

Almost 170 kilograms of HEU were used to blend up stocks of low enriched uranium (LEU) for use in domestic power reactors. Of this amount, 92 kilograms were 90 percent enriched. This blending operation was done in the late 1980s, when South Africa had developed an excess of HEU for its nuclear weapons program. The second blending operation used HEU with an average enrichment of 28 percent that was drained from the Y Plant cascade after shutdown.

When South Africa signed the NPT in 1991, it had an HEU inventory of over 800 kilograms with an average enrichment of about 70 percent (see Table 3.1). The vast bulk of this HEU was not irradiated and was in readily usable forms.

TABLE 3.1: HEU PRODUCTION IN THE Y PLANT, IN KILOGRAMS

HEU Produced in Y Plant	HEU	U235	% U235 (average)
Shipped as uranium hexafluoride for further processing	515	437	85%
Shipped in the form of uranium bearing process filters for recovery	144	60	42%
Shipped in the form of uranium bearing powder for recovery	93	39	42%
Used for upgrading (blending) imported low enriched uranium (LEU)	92	83	90%
Used for upgrading (blending) domestic LEU	77	28	36%
Other(a)	72	30	42%
Total	**993**	**677**	**68%**

(a) This category includes HEU in additional scrap, cold traps, powders, and filters, and recalculated or re-estimated HEU quantities not included in the initial declaration given to the IAEA in 1991 but added prior to March 1994. A fraction of this HEU is difficult to recover economically into a usable form and is likely considered waste. Adjustments in the total HEU stock made after 1994 or 1995 are not included but are less than 100 kg.

TABLE 3.2: HEU ASSIGNED TO MAJOR PROGRAMS, SEPTEMBER 1991, IN KG(a)

Major Programs	**HEU**	**U 235**	**%U 235 (average)**
Nuclear Weapons Program	478	418	87.4%(b)
Safari Reactor Fuel Program			
Sent to Safari	83	38	46%
Stored elsewhere	130	60	46%
Subtotal	**213**	**98**	**46%**
Protea (zero power reactor)	5	2.3	46%
Blending	169	111	66%
Total	**865**	**629**	**73%**

(a) The difference between the amount of HEU produced by the Y Plant and the quantity assigned to major programs is 128 kilograms. Most of this material was stored. Small amounts of HEU in this category were used in other programs and about 10 kilograms were classified as lost during processing. South Africa stated in 1991 that the Y Plant produced about 921 kilograms of HEU, which implies that about 55 kilograms of usable or recoverable HEU were not assigned to major programs. The other 70 kilograms of HEU were recovered, identified, or measured after the Y Plant closed.

NOTES

1. A. R. Newby-Fraser, *Chain Reaction: Twenty Years of Nuclear Research and Development in South Africa* (Pretoria: Atomic Energy Board, 1979), p. 102.

2. Newby-Fraser, *Chain Reaction*, op. cit., p. 93.

3. A. J. A. Roux and W. L. Grant, "Uranium Enrichment in South Africa," *Nuclear Energy Maturity*, Proceedings of the European Nuclear Conference, Paris, April 21-25, 1975. See also Newby-Fraser, *Chain Reaction*, op. cit., p. 106; and Manson Benedict, Thomas H. Pigford, and Hans Wolfgang Levi, *Nuclear Chemical Engineering* (New York: McGraw-Hill Book Co., 1981), pp. 888-95.

4. Interview with Anthony Jackson, February 1994. See also Daniel Kemp, Pieter Bredell, A. Albert Ponellis, and Einar Ronander, "Uranium Enrichment Technologies in South Africa," Atomic Energy Corporation of South Africa, Ltd. (paper presented at the International Symposium on Isotope Separation and Chemical Exchange Uranium Enrichment, Tokyo, Japan, October 29 – November 1, 1990).. Whether the element itself is actually declassified is unclear. On a 1994 visit to the Y Plant, one of the authors was first told by senior safeguards officials that he could not see the separating element because it was secret. But another senior official allowed him to examine one.

5. Newby-Fraser, *Chain Reaction*, op. cit., pp. 92-94.

6. Johann Viljoen and Deon Smith, *The Birth, Life, and Death of South Africa's Nuclear Weapons Program,* Unpublished manuscript commissioned by the Institute for Science and International Security, 1999.

7. Viljoen and Smith, *The Birth, Life, and Death of South Africa's Nuclear Weapons Program*, op. cit.

8. *Hearings on S. 1439 to Reorganize Certain Export Functions of the Federal Government to Promote More Efficient and Effective Administration of Such Functions*, *US Senate, Committee on Government Operations,* 94th Congress, 2nd session (January 19, 20, 29, 30, and March 9, 1976) (Washington: US Government Printing Office, 1976), pp. 1237-38; James T. Lynn, Director, Office of Management and Budget, Executive Office of the President, "Response to Senate Government Operations Committee Inquiry Dated July 15, 1975," September 15, 1975, discussing the Y Plant.

9. Frank V. Pabian, "The South African Denuclearization Exemplar," *Nonproliferation Review,* 2015, Vol. 22, No. 1, pp. 27-52. http://www.tandfonline.com/doi/full/10.1080/10736700.2015.1071969

10. See also Kemp, Bredell, Ponellis, and Ronander, "Uranium Enrichment Technologies in South Africa," op. cit. Figure 1 in this paper shows this radial effect in a basic separating element.

11. Interview with Jackson in South Africa, February 1994.

12. Waldo Stumpf, "South Africa's Nuclear Weapons Program," undated. See also Kemp, Bredell, Ponellis, and Ronander, "Uranium Enrichment Technologies in South Africa," op. cit.; and International Atomic Energy Agency (IAEA), *South Africa's Nuclear Capabilities* (GC(XXXV)/RES/567), IAEA document GC(XXXVI)/1015, Vienna, September 4, 1992.

13. According to Jackson, the output of the plant should have been about 20,000 SWU/yr.

14. Roux and Grant, "Uranium Enrichment in South Africa," op. cit.; and Benedict et al., *Nuclear Chemical Engineering*, op. cit., p. 889.

15. The figure for the Y Plant is taken from Barbara Rogers and Zdenek Červenka, *The Nuclear Axis* (New York: Times Books, 1978), p. 186. Waldo Stumpf, head of the Atomic Energy Corporation, stated that the total capital costs for the construction of the Y Plant amounted to 200 million Rand or $60 million at 1993 exchange rates. However, he did not make it clear whether that 200 million Rand figure included R&D costs or had been corrected to 1993 values of the Rand, which is the approximate date of his statement. See Stumpf, "South Africa's Nuclear Weapons Program," undated. If the 200 million Rand represents the actual uncorrected expenditures to build the Y Plant, then this value would correspond to about $300 million using the exchange rates in late 1974.

16. Newby-Fraser, *Chain Reaction*, op. cit., p. 113.

17. Frank Barnaby, "Nuclear South Africa," *New Scientist*, October 19, 1978.

18. *Hearings on S. 1439 to Reorganize Certain Export Functions of the Federal Government,* op. cit.

19. *Hearings on S. 1439 to Reorganize Certain Export Functions of the Federal Government,* op. cit., p. 1232.

20. *Hearings on S. 1439 to Reorganize Certain Export Functions of the Federal Government,* op. cit., p. 1226.

21. The State versus Daniel Geiges and Gerhard Wisser, *Summary of Substantial Facts*, High Court of South Africa, undated. See also Albright, *Peddling Peril* (New York: Free Press, 2010).

22. P. Mayfarth, "Special Compressors for Uranium Enrichment," *Sulzer Technical Review*, April 1986.

23. Newby-Fraser, *Chain Reaction*, op. cit., p. 111.

24. David Fishlock, "South African Energy," Report prepared for the Congressional Research Service of the Library of Congress, September 1976. At the time, Fishlock was Science Editor at the London *Financial Times*.

25. Quoted in Fishlock, "South African Energy," op. cit.

26. Jim Hoagland, "S. Africa, With US Aid, Near A-Bomb," *The Washington Post*, February 16, 1977.

27. See for example, Benedict *et al. Nuclear Chemical Engineering*; or W. L. Grant, J. J. Wannenburg, and P. C. Haarhoff, "The Cascade Technique for the South African Enrichment Process," *Developments in Uranium Enrichment, AIChI Symposium Series*, Vol. 73, No. 169, pp. 20-24.

28. E. W. Becker, et al., "Physics and Technology of Separation Nozzle Process," *Nuclear Energy Maturity*, *Proceedings of the European Nuclear Conference,* Paris, April 21-25, 1975.

29. Newby-Fraser, *Chain Reaction*, op. cit., p. 105.

30. Barbara Rogers and Zdenek Červenka, *Nuclear Axis*, p. 207, citing *Japan Times*, August 8, 1970, p. 84.

31. Newby-Fraser, *Chain Reaction*, op. cit., p. 105.

32. See also Roux and Grant, "Uranium Enrichment in South Africa," op. cit.

33. Rogers et al., *Nuclear Axis*, op. cit., pp. 70-74.

34. Rogers et al., *Nuclear Axis*, op. cit., pp. 69-70.

35. Rogers et al., *Nuclear Axis*, op. cit., p. 69.

36. Kemp et al., "Uranium Enrichment Technologies in South Africa," op. cit.

37. J. Jones, "South Africa Enrichment Plant Now Commercial, AEC Head Says," *Nucleonics Week*, January 23, 1992.

38. P. J. Ventor, "Prospects for the South African Front-end Nuclear Fuel Cycle Industry," International Conference on Enrichment, sponsored by the US Council for Energy Awareness, Washington, D.C., June 13-15, 1993.

39. The Y Plant had a complicated operating cycle, which included batch recycling, permitting total reflux at different parts of the cycle, and a complicated Pelsakon gas pumping system (pumping gas forward, then holding it before back-pumping the gas briefly).

40. This discussion of chemical reactions is based, unless otherwise noted, on G. J. Leuner, *Summary Report on the Y Plant Chemical Loss Problem from January 1978 until August 1979*, Atomic Energy Corporation, South Africa, July 1993.

41. A. J. A. Roux, W. L. Grant, R. A. Barbour, R. S. Loubser, and J. J. Wannenburg, "Development and Progress of the South African Enrichment Plant," International Conference on Nuclear Power and Its Fuel Cycle, Salzburg, Austria, May 2-13, 1977, IAEA, IAEA-CN-36/300.

42. Mass balance considerations would provide a difference of 47.6 kilograms of uranium 235 that must be explained via losses. However, approximately 40.3 kilograms of uranium 235 could be accounted for from a variety of loss mechanisms. See *Summary Report on the Y Plant Chemical Loss Problem from January 1978 until August 1979*, op. cit.

43. Because the total amount of uranium on the filters at the high end of the cascade was relatively small, the blackish green flecks were not that noticeable compared to the filters at the lower end where the filter would appear green when the filters system was dismantled. Initially, the reaction products were khaki in color but turned green on exposure to air.

44. *Summary Report on the Y Plant Chemical Loss Problem from January 1978 until August 1979*, op. cit.

45. David Albright, *Highly Enriched Uranium (HEU) Inventories in South Africa, status as of end of 2014* (Washington, D.C.: Institute for Science and International Security, January 31, 2015). http://isis-online.org/uploads/isis-reports/documents/Highly_Enriched_Uranium_Inventories_in_South_Africa_November_2015.pdf

CHAPTER 4
EMERGENCE OF A MILITARY NUCLEAR PROGRAM

The 1970s witnessed a steady movement in the South African government to deciding to create deliverable nuclear weapons. This movement was motivated primarily by South Africa's worsening security situation in Southern Africa, growing isolation internationally, and the opportunities offered by a steadily growing nuclear weapons capability. The process was greatly accelerated by the discovery and international condemnation of South Africa's nuclear test site in 1977.

KALAHARI NUCLEAR TEST SITE

In 1970 PNE program leaders told senior government officials that a full-scale test would be necessary to be certain that the nuclear device design would work. Since PNEs were planned, a full-scale underground test also made sense as a way to better understand the effects of a nuclear explosive. As a result, the government approved the construction of an underground test site that needed to be ready by 1977, when it was originally believed there would be enough highly enriched uranium.

In 1973 as work progressed on the gun-type device at the Pelindaba and Somerset West sites, the AEB started intensively looking for a suitable test site to conduct underground nuclear tests. In 1974 an acceptable remote site under the control of the military north of

Upington in Upper Cape Province was selected. Additional land was purchased to expand the size of the test site, which was named the Vastrap site. The military controlled and developed the site, since any AEB presence at such a remote site would immediately raise suspicions.

By 1976 the first test shaft was drilled to a depth of 385 meters and 0.9 meters in diameter. The shaft was drilled by a renovated mining drill. A second shaft with a depth of 216 meters was finished in 1977. As scheduled, all facilities at Vastrap were ready by the middle of 1977. South African officials thought that they had made the conspicuous drilling equipment to look like it was part of creating an underground military munitions depot.[1]

In mid-1977, the AEB produced a gun-type device without an HEU core. The device was large— 4.4 meters long, 0.61 meters in diameter, and weighed 3,450 kilograms. It was so large in part to accommodate numerous scientific and engineering studies, some of which would have taken place in side tunnels off the vertical shafts, according to a former senior member of the nuclear weapons program.

As discussed earlier, the Y Plant was operating by this time, but it had not yet produced enough weapons-grade uranium for a device. As has happened in nuclear weapons programs in other nations, the development of the devices outpaced the production of the fissile material.

A "cold test," namely a test of an identical nuclear explosive device, except with a core made out of depleted or natural uranium instead of HEU, was planned for August 1977. The test was to be a fully instrumented underground test, albeit one without a nuclear explosive yield. Its major purpose was to test the logistical plans for an actual detonation. All the instrumentation trailers, instrumentation cables, and all other equipment were installed by early August.[2] However, the mock device had not yet been delivered from Pelindaba, although it was being readied for shipment to the site.

How that test was detected in 1977 has been well publicized. The Soviet Union was closely watching South Africa's growing nuclear capabilities. It had placed a spy high in the South African Defense Force (SADF), Commodore Dieter Gerhardt, commander of the

Simonstown Naval Base near Cape Town. The naval barrel for the initial tests at Somerset West came from this naval base, according to a former member of the effort at Somerset West. Gerhardt was arrested as a Soviet spy in 1982 and went to prison. In an interview after his release, he said that the Soviets had expressed their concern about South Africa's nuclear program to the United States a year earlier.[3] A Russian contact told him that the Soviet Union and the United States met about the South African weapons program in 1976. During this meeting, the Soviets presented evidence of South Africa's nuclear program and asked for US cooperation in stopping it. Gerhardt said that one of several options mentioned by the Russians was a preemptive military strike on the Y Plant. He said the United States rejected that option.

By the summer of 1977, Soviet intelligence detected test preparations and, in early August, alerted the United States. Although the South Africans were trying to conceal their activities at the test site, they admitted later that certain aspects were distinctive to a nuclear test and could not be camouflaged.[4] US intelligence quickly confirmed the existence of the test site. The *Washington Post* quoted a US official: "I'd say we were 99 percent certain that the construction was preparation for an atomic test."[5] All the major powers assumed that South Africa was preparing for a full-scale nuclear test, evidently unaware that it still did not have enough HEU.

During August 1977, the Western nations pressed South Africa not to test. The United States presented some of its evidence about the test site to the South African government. An August 19, 1977 letter from the Secretary of State Cyrus Vance to R.F. Botha, Minister of Foreign Affairs, provided the geographic coordinates of the test site and key features of the test site, based on imagery.[6] According to the letter, the site consisted of:

- A drill rig and associated facilities;
- A square lattice tower in a cleared area enclosed by a wall, about one kilometer from the drill rig;
- An area, about 3 kilometers from the square tower, containing a pad; this area is connected to the tower area by power or communications lines;

- A secured housing area 15 kilometers from the tower area, containing approximately ten buildings; and
- A hard-surface airstrip approximately 1,600 meters long and three kilometers from the housing area. In addition, the entire area is surrounded by an outer patrol road.

The French foreign minister warned on August 22 of grave consequences for French-South African relations. Although he did not elaborate, his statement implied that France was willing to cancel its recent contract to provide South Africa with the Koeberg nuclear power reactors.

The international reaction startled the South African government. It had led itself to believe that its testing program would not "lead to excessive international reaction," according to J. W. de Villiers, the past President and Chairman of the Board of the AEB.[7] This belief was based on the muted reaction to India's 1974 nuclear explosive test.

One of the biggest surprises was that the United States insisted on inspecting the Kalahari site, causing panic in the PNE program.[8] To prevent such an inspection revealing the activities at the site, the program launched "a crash program to dismount and remove critical equipment that could not be explained for military use."[9] The site was cleared within a few days and the two test shafts sealed. Ironically, an inspection did not take place. However, according to three former leaders of the nuclear weapons program mentioned earlier, Hannes Steyn, Richardt van der Walt, and Jan van Loggerenberg, "It was now obvious that the testing of nuclear devices for civil applications could no longer be executed even in secret." [10] Any hope for a civil PNE program ended that August. By this time, however, the PNE program had gained enough knowledge to realize that a full-scale test was not necessary to prove the design, as it had believed in 1970.

GROWING MILITARY INTEREST AND PERCEIVED THREAT

In parallel to the test site preparations, the mid-1970s witnessed the military's increased interest in the nuclear program. As discussed, P.W. Botha, the then Defense Minister, said that he started secret discussions about obtaining nuclear weapons in 1975 and had further conversations in 1976, during which the need for tactical weapons came to the forefront."[11] In 1976 the South African air force publicly announced that Buccaneer bombers had practiced nuclear weapon delivery techniques, characterizing one exercise as employing "computerized techniques to deliver nuclear bombs and escape the effect of the resulting explosion."[12] In July 1977, right before the discovery of the test site, Botha ordered the development of national strategic guidelines for nuclear weapons.[13]

A number of factors appear to have motivated this increased military interest, including the government's growing perceived threat to apartheid South Africa posed by Angola and Mozambique, which were receiving Soviet backing; pressure on Namibia (which was then controlled by South Africa) by black African nationalists; and diminishing military confidence in the Atomic Energy Board's handling of the PNE program.

The South African government's security situation was seriously aggravated following Portugal's hasty departure from Mozambique and Angola in 1974-1975.[14] In 1975 the Russian and Cuban militaries intervened in Angola and helped to install a Marxist-oriented regime with close ties to Mozambique, Zambia, and two anti-apartheid movements, the South West African People's Organization (SWAPO) and the ANC. Pretoria feared that these former colonies would become staging areas for a direct Soviet-backed invasion, perhaps involving both Cuban and black African military forces. The stage was set for military clashes across southern Africa that would last until 1988.

Regardless of the merits of South Africa's position at the time, South African government officials often expressed bitterness and disillusionment with the actions of the US government following the withdrawal of Portugal from Angola. At the time, South Africa saw itself as aligned with the West against what it perceived to be communist expansion in southern Africa, and in 1975, had intervened militarily in Angola with covert support from the US Central Intelligence Agency (CIA). Meanwhile, the US Senate, in the wake of investigations into controversial CIA activities and critical media reports revealing the covert Angolan aid, voted to ban US military aid to any Angolan party.[15]

South African leaders felt betrayed. According to Chester Crocker, former Assistant Secretary of State for African Affairs, "Pretoria blasted what it saw to be Western flakiness, if not perfidy, and pulled out of Angola [in 1976] after cutting a side deal" with Angola.[16] The Angolan episode, according to Crocker, had a traumatic effect in South Africa, prompting a "sentiment of revenge for past humiliation and an abiding suspicion of Western diplomacy."[17]

The South African military, in particular, reportedly felt strongly betrayed by the sudden halting of US covert assistance during the Angolan crisis.[18] The shift in US policy against what South Africa viewed as a well-orchestrated communist threat, strengthened the hand of those who believed that South Africa needed nuclear weapons to protect its security. To Pretoria, South Africa was standing virtually alone against a "total onslaught" by black insurgents and radical black African states supported by the Soviet Union and its allies.[19]

The hostile international reaction to the August 1977 disclosure by the Soviet Union and the United States that South Africa was preparing to conduct a nuclear explosive test in the Kalahari Desert shifted the focus of the PNE program and further contributed to the push for a military nuclear program. Although members of the PNE program worried that the discovery of the test site would lead to the cancellation of the entire program, the government decided to delay the test for an undetermined period and continue the refinement, miniaturization, and transportability of the existing nuclear device.[20] It began to see a nuclear test as a way to demonstrate a political and military message to further South Africa's national security goals. South Africa's political leadership tended to have a confrontational attitude to resolving political conflicts, according to a former senior member of the nuclear weapons program.

Soon after the test site was closed, Johan Slabber, the leader of the nuclear explosive program, was ordered to design a smaller, lighter device.[21] According to Slabber, he and his colleagues received an order to develop a device that could be tested in 24 hours after receiving notice.[22] The implication was that a redesigned device would be small enough to be weaponized. Despite not knowing the exact intentions of the leadership, the team was reportedly energized by this order and stopped thinking just in terms of a peaceful nuclear explosive program [23] The team finished a smaller device in 1978 that was about half the size and weighed about one-fifth of the first device (see figure 4.1).

The initial rationale for a smaller device was to allow for its rapid transportation to the test site and its detonation underground. Thus, the reaction to the international pressure was not to con-vince South Africa to forgo testing, but to be able to test successfully before the international community could intervene to stop it. In essence, the government wanted to control the initial military and political message of a test.

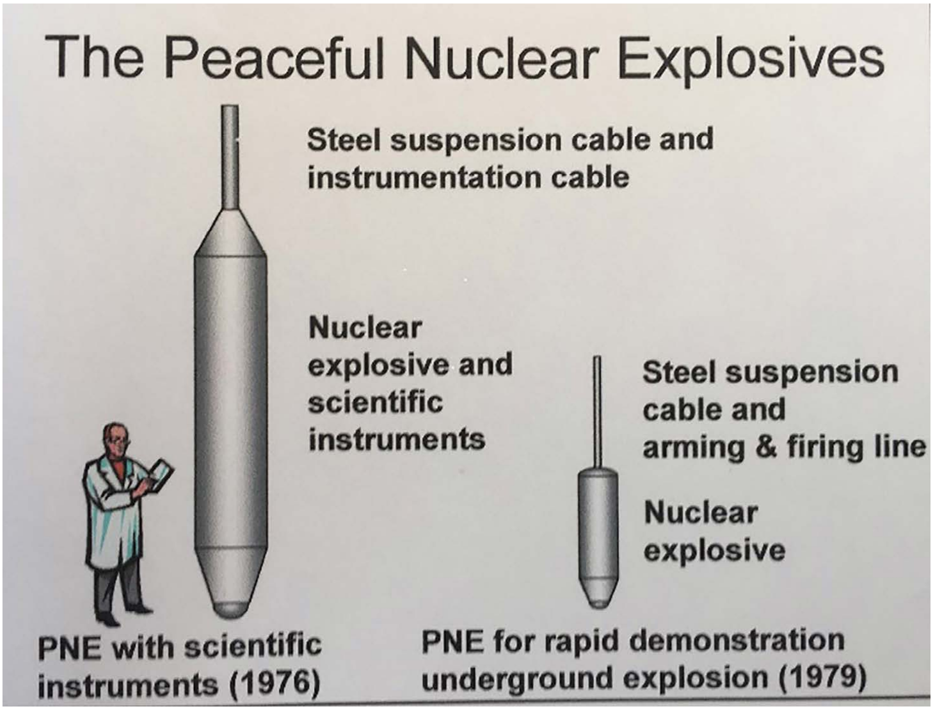


Figure 4.1 Comparison of the relative size of the two nuclear test devices developed by South Africa in the 1970s. Source: André Buys

The only data collected from the test would be the device's explosive yield and radioactive releases.[24] The heavy gear over the shafts, the instrumentation cable trenches, and the instrumentation site were eliminated.[25]

The yield of the second device was lower than the first one.[26] This reduction in yield may have resulted from its miniaturization.

If a test had occurred in the 1970s (and 1980s), it may have released a substantial amount of radiation into the atmosphere, based on a recently declassified South African document. This document uses the codename Gardenia for the combination of this first device and the placement and control systems, characterizing the test as "dirty."[27] What this means is not clear in the document, although the document discusses that backfilling the shafts was not possible, implying that the radioactive material would be blown out the top of a shaft. Moreover, the South African decision makers in 1987 wanted to replace this device with a new one and a renovated test shaft that would be "capable of being used for a refilled clean underground demonstration test." Moreover, the document states: "The Gardenia system was engineered for an OPEN (caps in original) underground test explosion. This means that there would be a considerable radioactive release into the atmosphere during such a test." The level of expected radioactive releases is not quantified in the document, and may have been relatively small. By the 1980s, when the document was prepared, any venting from the test site would likely be viewed as worrisome. However, the document appears to contradict that benign assessment.

Looking back, it would not be surprising to conclude that the PNE program was less sensitive about potential radioactive fallout from its use of nuclear explosives than nuclear programs today, or even a decade later. After all, if the program had ever deployed a nuclear explosive to make, for example, a mine, the ensuing blasts would have released a large amount of radioactive materials into the environment. In fact, such expected releases were a key reason PNE programs were cancelled worldwide.

GROWING PUBLIC AWARENESS OF NUCLEAR WEAPONS CAPABILITY

The revelations about the test site exposed to the South African public and the rest of the world what was thought to be a secret program. This awareness led to widespread debate about what was generally perceived as a South African nuclear weapons program, although the government publicly and diplomatically denied the existence of any such program. This public and international debate served the purpose of creating ambiguity, and this ambiguity became one of the nuclear weapon program's cornerstones.

In South Africa, the exposure led to increased public and academic discussions about the potential role of South African nuclear weapons, albeit with disclaimers that the exact status of the nuclear weapons program was unknown. For example, analyses of the relative pros and cons of building nuclear weapons by M. Hough and Denis Venter, two South African political scientists, tended to conclude that nuclear weapons offered limited strategic and few political advantages.[28] In their view, the possession of nuclear weapons could provoke a strong Russian reaction. On the other hand, if South Africa's conventional superiority eroded and the military situation on South Africa's borders intensified, a South African bomb could help equalize any conventional imbalance against South Africa. Because such a possibility appeared unlikely in the foreseeable future, however, these authors opposed a South African nuclear weapon. Nevertheless, they also argued that South Africa should keep its options open and not sign the Nuclear Non-Proliferation Treaty.[29]

In one of the best known articles of that time, Dr. Lukas Daniel Barnard, then a professor at the University of the Orange Free State and later head of the National Intelligence Service argued that South Africa should acquire nuclear weapons.[30] Barnard concluded that South Africa could no longer depend on the West for its security. Citing Western opposition to apartheid and weak leadership, he said that it would be wise to obtain nuclear weapons. Nuclear weapons would not add significantly to South Africa's international isolation but could bolster its security, both as a back up to the country's conventional forces and as a deterrent to invasion. Because the deterrence value of nuclear weapons depended on the perception of that capability, Barnard advocated that South Africa build nuclear weapons and ensure that the world knew that it had them. Moreover, since South Africa could be expected to face a growing threat to its security, it should build the weapons immediately, because it probably would be too late to build them when a "nuclear crisis really lands on our doorstep." Even a small nuclear arsenal would suffice, as the French "force de frappe" demonstrated: "Even mighty nuclear powers are only too aware of the phenomenal destructive power of a single nuclear warhead in industrial heartlands or urban centers." While key officials may have shared Barnard's views of the need for nuclear weapons, Botha in particular did not believe openness would serve South Africa's interests.

As support for nuclear weapons was growing among South Africa's white elite and military, the international community was becoming increasingly alarmed by the revelations. In response, the United Nations took additional steps to impose sanctions on South Africa.

In November 1977, the UN Security Council approved unanimously a resolution to make mandatory a military arms embargo on South Africa that had been voluntary since 1963.[31] While citing apartheid as a reason for this action, this resolution also expressed "grave concern that South Africa is at the threshold of producing nuclear weapons" and declared that all states "shall refrain from any cooperation with South Africa in the manufacture and development of nuclear weapons." One year later, the UN General Assembly recommended that the Security Council impose an oil embargo on South Africa, which depends heavily on oil imports. Although the Security Council refused, the General Assembly endorsed a voluntary oil embargo in 1979.

Despite opposition from many nations, including the United States, Japan, and Canada, the IAEA Board of Governors in June 1977 voted to remove South Africa from the list of candidates for the Board and replace it with Egypt. Two years later, South Africa was denied participation in the International Atomic Energy Agency's (IAEA's) General Assembly. Both actions resulted from South Africa's apartheid policies and its refusal to submit all of its nuclear facilities to IAEA inspection.

There were a range of efforts in the mid-to-late 1970s to deny South Africa sensitive nuclear goods. Most significantly, the United States cut off nuclear assistance for the Safari-1 research reactor in 1976 and enrichment services for the Koeberg nuclear power reactors in 1978 [32]

According to Waldo Stumpf, the former head of the Atomic Energy Corporation (the successor organization to the AEB), the cutoff of US nuclear assistance in the 1970s was viewed very negatively since these specific reactors already were subject to IAEA safeguards.[33] The cutoff of US and other countries' nuclear aid did not disrupt the nuclear explosive effort, however. These actions were perceived within the South African government as motivated primarily by opposition to apartheid, reinforcing the view within the government that South Africa had little to gain from stopping its nuclear weapons program or joining the NPT, unless it first ended apartheid and made other fundamental domestic changes. More importantly, according to Tielman de Waal, former managing director of Armscor, "These circumstances led to the conviction that in the event of a direct threat to its territorial integrity, the Government would not be able to rely on international assistance. The option of developing a nuclear deterrent became increasingly attractive."[34] The military embargo also empowered those in South Africa that wanted to intensify indigenous military industries and couple those efforts with an active sanctions busting program to acquire necessary goods aboard.

THE DECISION TO CREATE A NUCLEAR WEAPONS PROGRAM

The South African government's shift to a more formal military emphasis occurred in 1977 and 1978. In 1977 the government ordered the creation of national strategic guidelines, as mentioned above, which were first discussed by the government in August 1977; however, they were not approved formally until April 1978.[35]

The growing militarization of the nuclear device coincided with a change in government. In September 1978, Prime Minister Vorster resigned because of a financial scandal, and he was replaced by P.W. (Pieter Willem) Botha, who had been Defense Minister since

1966, a portfolio he maintained for two years after becoming head of government. Botha was a proud nationalist who had presided over the build-up and modernization of the South African Defense Forces and the growing Armscor military-industrial complex that supported it.

According to a declassified 1979 CIA assessment, he had:

> Advocated more than any other Cabinet officer the military components of South Africa's strategy for coping with possible external threats. He has regarded the West as unwilling to support South Africa against foreign threats that he has perceived to be growing. Moreover, he has probably sympathized with views that nuclear weapons might ultimately be needed. However, he probably has not foreseen any imminent military requirement for nuclear weapons or any political advantages to disclosing particular elements of South African nuclear weapons capabilities at this time [1979].[36]

Botha was a strong supporter of building nuclear weapons but also of not revealing them. In October 1978, one month after taking office, Botha appointed a cabinet committee to oversee the military aspects of nuclear devices that quickly decided that Armscor, the Defense Force, and the AEB should work together and prepare a program to start a nuclear weapons program.[37] Armscor officials state that the resulting "Action Committee," chaired by a senior defense official and composed of Armscor, the Defense Force, and the AEB, recommended future plans for producing nuclear weapons, based on the AEB designs.[38]

Faced with an enormous challenge, the Action Committee established several working groups to evaluate in detail the needs of a military nuclear program. One group developed a national nuclear strategy, which is discussed in chapter 6. Other working groups focused on:[39]

- The test site and possible tests;
- Security;
- The integration of the work forces of the three different institutions;

- Safety issues; and
- Possible delivery systems for the nuclear devices.

Botha approved the Action Committee's proposal of the intended weapons and facilities on July 4, 1979.[40] The nuclear weapons program was codenamed Project Festival.

Armscor believed it could do this task more effectively and economically than the AEB. Armscor officials viewed the AEB program as essentially a scientific exercise. The AEB for its part did not believe it had a mandate to weaponize the devices, the critical new mandate. As a result, the government assigned Armscor the task of turning the device into weapon systems.[41] Its subsidiary Kentron, which made advanced weapons and missiles, took responsibility for building the nuclear weapons.

Significantly, Armscor believed that a nuclear weapon was a combination of the nuclear device and a delivery system. According to senior Armscor officials, they did not refer to the nuclear device as a nuclear weapon.

The decision to make nuclear weapons required the three groups to coordinate, and fulfill specific responsibilities:

- Armscor would make the deliverable nuclear devices, focusing initially on the development and production of a number of deliverable gun-type devices. It also conducted studies of implosion and thermonuclear technology, including "boosted" devices.
- The Atomic Energy Board would provide the nuclear explosive materials health physics support, theoretical studies, and contribute to the development of more advanced nuclear weapons technologies. The AEB was also given the new responsibility for evaluating methods to produce and recover plutonium and tritium and produce lithium used in making tritium and in thermonuclear weapons. The Atomic Energy Corporation focused on the design of a 150-megawatt pressurized-water research and development reactor to be built at Gouriqua, near Mosselbay in the Cape Province, to make plutonium and tritium.

It also planned to build a facility at Pelindaba to handle tritium, a difficult to handle radioactive material. In essence, the Reactor Development Division returned to its original mandate of building a reactor. Only this time, it was to support a nuclear weapons effort.

- The South African Defense Force was responsible for providing the delivery vehicles, logistical arrangements, communications, and the deployment of the nuclear weapons. In practice, this task went to the Air Force, which was developing a television-guided long-range glide bomb, called the h3 and later the Raptor, which would become the delivery system for the nuclear device. The Air Force developed special logistics facilities at its bases for the storage, handling, maintenance, and support of nuclear weapons.[42]

Representatives of the SADF, AEB, and Armscor coordinated their efforts through a senior level management committee, most likely the Action Committee or its successor. The government controlled the entire nuclear weapons program through a special Committee of Ministers, chaired by the Prime Minister and later the State President.

This shift to Armscor's making of the nuclear devices saw the phase out of the AEB's PNE program and the closure of most of its buildings and activities. Most of the PNE personnel went back to civil nuclear pursuits at the main Pelindaba site or joined the new reactor project. One exception was that building 5100 continued to house the nuclear weapons program's small theoretical group until 1988 or 1989.

The transfer of the program to Armscor in essence "froze" the design of the nuclear core of the gun-type device. Armscor concentrated on turning the device into a qualified military weapon at a new facility to be called Circle, the name perhaps signifying South Africa "circling the wagons."

NOTES

1. Hannes Steyn, Richardt van der Walt, and Jan van Loggerenberg, *Armament and Disarmament: South Africa's Nuclear Weapons Experience* (Pretoria: Network Publishers, 2003), p. 41.

2. *Armament and Disarmament*, op. cit., p. 41.

3. Interview with Dieter Gerhardt, March 9, 1994.

4. *Armament and Disarmament*, op. cit., p. 42.

5. Murray Marder and Don Oberdorfer, "How West, Soviets Acted to Defuse S. African A-Test," *The Washington Post*, August 28, 1977, p. Al.

6. Letter from US Secretary of State Cyrus Vance to South African Minister of Foreign Affairs R.F. Botha, August 19, 1977. Letter available in Nic von Wielligh and Lydia von Wielligh-Steyn, The Bomb (Pretoria: Litera Publications, 2015) and at http://digitalarchive.wilsoncenter.org/document/114153

7. Quoted in Mitchell Reiss, *Bridled Ambition: Why Countries Constrain Their Nuclear Capabilities* (Washington, D.C.: The Wilson Center, 1995), pp. 9-10.

8. *Armament and Disarmament*, op. cit., p. 42. For the US request to inspect the site, see August 19th letter from Vance to Botha, op. cit.

9. *Armament and Disarmament*, op. cit., p. 42.

10. *Armament and Disarmament*, op. cit., p. 42.

11. Prime Minister P.W. Botha, *Draft Speech for the Opening of Kentron Circle*, May 4, 1981, in Afrikaans. Original in Nic von Wielligh and Lydia von Wielligh-Steyn, *Die Bom* (South Africa: Litera Puasies, 2014), Appendix, translated by Schreiber Translations, Inc. for Institute for Science and International Security, July 7, 2015.

12. Quoted in Director of Central Intelligence, *Trends in South Africa's Nuclear Security Policies and Programs*, National Intelligence Estimate, October 5, 1984, declassified version.

13. *Draft Speech for the Opening of Kentron Circle,* op. cit.

14. The Portuguese military seized power in Lisbon in April 1974 and decided to abandon Portugal's colonies, Angola and Mozambique, after more than a decade of failing to subdue indigenous nationalist forces.

15. Christopher Andrew, *For the President's Eyes Only* (New York: HarperCollins Publishers, 1995), p. 417.

16. Chester Crocker, *High Noon in Southern Africa* (New York: W. W. Norton & Company, 1992), p. 50.

17. Crocker, *High Noon in Southern Africa*, op. cit., p. 56.

18. Interviews with former members of the South African nuclear weapons program, February 1994.

19. Director of Central Intelligence, *Trends in South Africa's Nuclear Security Policies*, op. cit.

20. *Draft Speech for the Opening of Kentron Circle,* op. cit.

21. Interview with a senior official close to the IAEA knowledgeable about Slabber's and other South Africans statements to the IAEA in 1993 following President de Klerk's announcement.

22. Timothy McDonnell, "International Conference: the Historical Dimensions of South Africa's Nuclear Weapons Program" (Washington, D.C.: The Wilson Center, January 4, 2013). https://www.wilsoncenter.org/article/international-conference-the-historical-dimensions-south-africas-nuclear-weapons-program

23. Interview with a senior official close to the IAEA knowledgeable about Slabber's and other South Africans statements, op. cit.

24. *Armament and Disarmament*, op. cit., p. 43.

25. *Armament and Disarmament*, op. cit., p. 42

26. *Armament and Disarmament*, op. cit., p. 41.

27. *Presentation to Witvlei Committee: Kramat Capability: Current Status and Further Developments, by Lt. Gen. F.E.C. van den Berg, Chairman, Coordinating Sub-Committee,* September 3, 1987, in Afrikaans, Original in *Die Bom,* op. cit.

28. Denis Venter, "South Africa and the International Controversy Surrounding its Nuclear Capability," *Politikon*, Vol. 5, No. 1, June 1978; and M. Hough, "Deterrence and Deterrence Interaction with Reference to the South African Situation," *Politikon*, Vol. 5, No. 1, June 1978.

29. This type of opposition to signing the NPT was also expressed in a secret May 14, 1981 memorandum from the South African embassy in Washington, D.C., which was leaked to the US-based non-governmental organization Trans Africa: "It must be realized that South Africa is threatened by the USSR and its associates and by certain African countries with Soviet support and encouragement. South Africa has no hope of any assistance from the UN in case of attack. On the contrary, it is continually being threatened with action under Chapter VII of the Charter of the United Nations. While this state of affairs continues, South Africa cannot in the interest of its own security sign the NPT and thus set the minds of its would-be attackers at rest, allowing them to proceed freely with their plans against us."

30. Lukas Daniel Barnard, "Die Afskrikkingstrategie van Kernwapens" ("The Deterrent Strategy of Nuclear Weapons"), *Journal for Contemporary History and International Relations*, Vol. 2, No. 2, Sept 1977, pp. 74-97 (translated into English).

31. UN Security Council, "The Question of South Africa," S/RES/418 (1977), November 7, 1977.

32. During the Reagan administration, certain limited nuclear assistance occurred.

33. Waldo Stumpf, "South Africa's Nuclear Weapons Program," undated, p. 9. An edited version of this paper is in Kathleen C. Bailey, *Weapons of Mass Destruction: Costs versus Benefits* (New Delhi: Manohar Publishers and Distributers, 1994), pp. 63-81.

34. Tielman de Waal, "South Africa's Past Nuclear Program" (paper presented at a press briefing in South Africa, April 6, 1995).

35. Stumpf, "South Africa's Nuclear Weapons Program," op. cit.; and Interviews with former members of the nuclear weapons program.

36. Director of Central Intelligence, *The 22 September 1979 Event*, Interagency Intelligence Memorandum, December 1979, Declassified version obtained through Freedom of Information Act by Natural Resources Defense Council and released July 10, 1990.

37. *Armaments and Disarmament*, op. cit., p. 43.

38. Armscor officials, personal interviews 1994 and 1995; and Reiss, *Bridled Ambition*, op. cit., p. 9. These discussions involved only senior officials. The AEB personnel involved in the nuclear explosive program were told of the formal shift to a military emphasis in November 1978. See also *Draft Speech for the Opening of Kentron Circle,* op. cit. *Armament and Disarmament*, op. cit., p. 43.

39. Armscor officials, personal interviews 1994 and 1995; and Reiss, *Bridled Ambition*, op. cit., p. 9. These discussions involved only senior officials. The AEB personnel involved in the nuclear explosive program were told of the formal shift to a military emphasis in November 1978. See also *Draft Speech for the Opening of Kentron Circle,* op. cit. *Armament and Disarmament*, op. cit., p. 43.

40. *Draft Speech for the Opening of Kentron Circle,* op. cit.

41. Interview with a former member of nuclear weapons program, Spring 1994.

42. *Armament and Disarmament*, op. cit., pp. 74-80. The authors describe the South African nuclear weapons program more broadly and include other SADF units, in particular the ballistic missile units. As will be discussed later, South Africa planned on building nuclear warheads for a ballistic missile.

CHAPTER 5
KENTRON CIRCLE FACILITY

At the commissioning of the Kentron Circle facility on May 4, 1981, Prime Minister P.W. Botha told the highly secretive and selective crowd: “The time has come when the South African “Plowshare” must be forged into a sword, for the battle that awaits.”[1] Circle was to be South Africa’s own nuclear weapons research, development, and manufacturing facility dedicated to the creation of nuclear weapon systems. The facility was under the control of the defense establishment, which wanted fully weaponized, deliverable nuclear weapons.

Botha delivered his speech by the new high security vault inside the Circle building, designed to securely store nuclear weapons. According to a senior official present at the commissioning, in front of him was arrayed nuclear weapons components and a prototype mock-up of a warhead for a sophisticated glide bomb under development by Armscor.

Botha likened Circle to Los Alamos and Livermore National Laboratories, centers of US nuclear weapons research and development. In practical terms, however, Circle functioned more like Sandia National Laboratories. It concentrated on refining the parts of the nuclear weapon that are outside the central nuclear core or pit, and ensured warhead reliability, safety, and security.

Botha told the audience that a nuclear weapon is "primarily a political weapons system, not a military system." It is a weapon of "inducement, persuasion, and compulsion in the hands of the leaders of the world," he added. "This political weapon opens a new possibility," namely "the option for the RSA to stipulate its birthright at the negotiating table of the Greats, with nuclear deterrence strategy as its foundation."[2] At the end of his speech, Botha presented a commemorative plaque which reportedly read: "For all South Africans."[3]

Botha was followed by André Buys, Circle's first Plant Manager. Buys' task was to describe all the sensitive items in front of the esteemed audience, which included several cabinet ministers. Off-script for such a momentous occasion, he also raised doubts about whether South Africa's nuclear program had an adequate nuclear strategy. Implicit in his comments was the need for more thorough guidance on the type and number of nuclear weapons that needed to be built and how they would be used in a crisis. Afterwards, at the reception, Buys said that Botha ignored him but F.W. de Klerk, who attended as Minister of Mineral and Energy Affairs, came up to him and said that he liked what Buys had said. Buys was struck with a suspicion that there could be a split at the highest level of government about the nuclear weapons program.

THE CIRCLE FACILITY

Armscor built the Kentron Circle facility utilizing a design by a leader of the AEB PNE team. The Circle facility, located about 15 kilometers east of Pelindaba, essentially duplicated under one roof, most of the development and manufacturing capabilities in the valley below Pelindaba. However, Armscor did not duplicate the AEB's facilities to conduct criticality or dragon experiments. The focus was on making deliverable nuclear weapons utilizing a core developed at the AEB in the late 1970s.

Circle was built in 1980 and occupied in 1981. The facility comprised the Circle building itself, a nearby environmental test facility that was involved in ensuring that nuclear weapons could withstand deployment on aircraft and delivery to the target, and a magazine for storing high explosives and propellants that had been disguised externally to hide its purpose, according to a former senior leader of the nuclear weapons program. Figure 5.1 shows the Circle complex in a commercial satellite image. Figure 5.2 shows the Circle building, as it appeared after the program was cancelled. Standing in the main entrance, figure 5.3 shows a central bay of the building.

Figure 5.1 Commercial satellite image of the Circle Complex. Visible is the main building, the environmental test building, and a magazine for storing high explosives and propellants.

Figure 5.2 Main Circle building, with its main entrance visible.

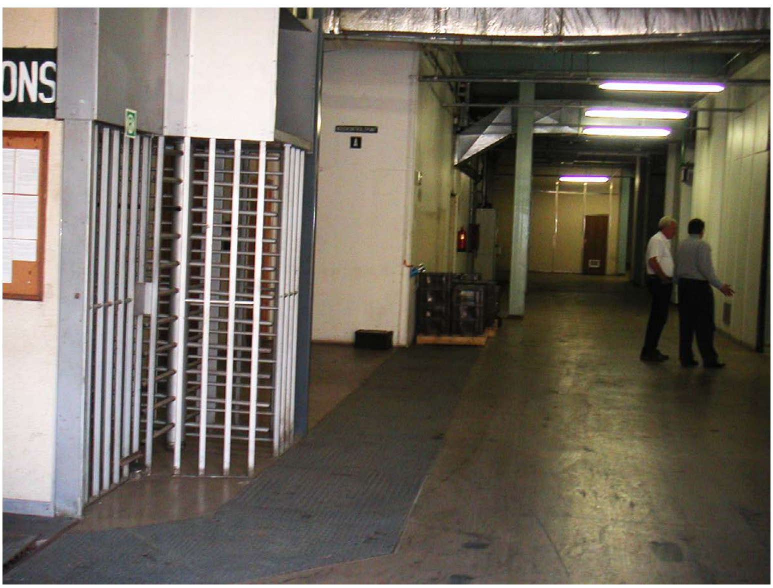


Figure 5.3 Looking from the main entrance into the central bay of the Circle building in 2002 after building renovations following end of nuclear weapons program. The original personnel portal for the facility is on left.

Circle facility was built deep within Armscor's Gerotek site, which was being built at the same time (see figure 5.4). This site was designed to test vehicles at high speeds and on various types of road surfaces and grades.

A high priority was maintaining the secrecy of the nuclear weapons program, particularly the existence of the Circle complex. According to a former senior member of the program, officials thought it too risky to build Circle at a nuclear or armaments manufacturing site. They concluded that it must be sited on its own and that it should not be easily accessible to outsiders. Upon reflection, Gerotek seemed like a good choice. If someone asked about the Circle buildings, they could be identified as defense industries workshops. Such a question did arise in fact in the mid-1980s, when an American was in a test vehicle on the high speed track and asked about the Circle building.

Figure 5.4 The Gerotek site where the Circle facility was located. A high speed test track can be seen in the center of the photo. The Circle facility is on the hillside above the track.

The turn-off to the Circle facility, marked only with a sign that said "Workshop," is several minutes' drive inside Gerotek's main gate. Figure 5.5 shows the non-descript turnoff to Circle taken in 2002. (The workshop sign had been removed by the time this picture was taken.) The entire site is hilly. On the hillsides can be seen graded tracks for testing military vehicles.

Initially, Circle was to be an underground facility. An embankment was constructed around part of the facility, according to a former leader of the program. The satellite image in figure 5.1 and figure 5.6 show the berm and how the facility was dug into the hillside. However, this plan was quickly abandoned as too expensive.

Nonetheless, the berm remained as the only external clue to the potential importance of the building and blocked prying eyes from seeing the building from a nearby road deep within the Gerotek compound. Figure 5.7 shows a view of the Circle building from the bridge over the test track; only the top portion is visible.

Figure 5.5 Road inside Gerotek right before the turnoff to the Circle facility (first left). Test tracks can be seen in the distance on the hillside.

Figure 5.6 Main entrance of the Circle building, as viewed from the top of a berm. Photo credit: Armscor

Figure 5.7 Top of Circle building visible in the distance from the oval race track at Gerotek

The exterior of the Circle building is nondescript. Advena's managers blocked proposals to place sophisticated communications on the roof to avoid a "signature" that might attract the attention of intelligence agencies.

Armscor imposed a more stringent security regime on the personnel in the program than the AEB had exercised in the 1970s. Circle employees acted as if they could be observed by satellites. Employees going between Circle and Pelindaba took special precautions to prevent anyone from following them or uncleared Pelindaba employees from seeing them enter or leave the road from the military vehicle testing facility.[4]

A number of AEB personnel were transferred to Circle along with key manufacturing equipment. According to a leader of the Armscor program, others at the AEB, such as the leader of the PNE program and designer of Circle, remained active in providing technical advice for several years after the transfer of the program to Armscor. Armscor also had to recruit new engineering talent. According to a leader of the Armscor nuclear program, technical capabilities were of critical importance; however, so was recruiting people who were responsible and mild-mannered. He said that they wanted to avoid fanatics.

The AEB remained responsible for supplying highly enriched uranium. It also continued theoretical nuclear weapons work.[5]

The nuclear weapons program's main office was at the Kentron headquarters, near Pretoria and staffed jointly by Armscor and Air Force personnel.[6] It was under high security and access was carefully controlled. To prevent eavesdropping, a wire mesh was put around the office during one weekend when everyone was gone. The purpose of the office was unknown to others in the building; they just knew it was a cover for something. Given the extensive overseas smuggling and other secret activities undertaken by Armscor, the office did not create any undue suspicion in the building.

INSIDE CIRCLE

Inside the Circle building are two floors with a total of 8,000 square meters of floor space. The lower floor was dedicated to developing and making nuclear devices. Offices and conference rooms were located on the second floor.

The site was designed in particular to carry out further development and routine manufacturing of gun-type nuclear weapons. The building was also capable of conducting research and development of implosion-type nuclear weapons.

The first floor of the Circle building had conventional workshops for making mechanical and electrical equipment for a gun-type weapon; storage rooms; uranium casting and machining workshops for gun-type weapons; a large vault; integration rooms where portions of the devices were assembled; and eight thick-walled “cells” for testing internal ballistics, propellants, igniters, and small quantities of high explosives for self-destruct mechanisms. An explosive test chamber located in one of the cells could handle up to 2.5 kilograms of high explosive. It was used to conduct many plane-wave high explosive tests and detonator experiments with shaped charges related to implosion designs and to develop high-speed instrumentation necessary for developing these designs. Another cell contained the “pig sty,” a wooden enclosure where projectile tests were done for the gun-type device.

In anticipation of an accident with high explosives, which in the worst case risked blowing off the roof and exposing the facility, the designers put a “plenum” or large room above the high explosive cells on the second floor. In an accident, this room would serve to dissipate the overpressure from an explosion, preventing the collapse of the roof or the walls. Holes at one end of the room would allow the explosion to vent. From the outside, the holes were disguised as ventilation ducts (see figure 5.8).

In the early 1980s, the program employed about 100 people, of which only about 40 were directly involved in the weapons program. Only 20 actually built the devices. The rest were involved in administrative support and security. Figure 5.9 shows Circle’s organizational structure. By the time the program was canceled in 1989, the work force had risen to 300, with about half directly involved in weapons work.

Figure 5.8 Fake ventilation ducts (left) hid holes in the walls of the second story plenum (right photo at back; light can be seen through these holes) designed to minimize damage in an accidental explosion in internal high explosive test cell. The holes would have served to dissipate any overpressure from an accident in an indoors high explosive facility. In photo on right, one of the orange blast covers over an explosive cell has been removed. These blast covers are secured by special bolts that are designed to break in an explosion and also reduce the destructive force of an accidental blast.

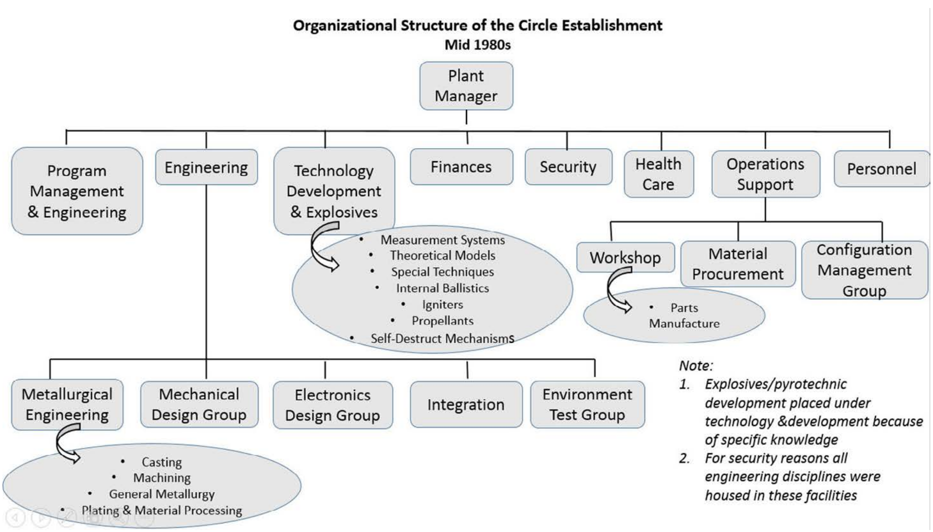


Figure 5.9 Organizational structure of the Circle facility. Source: Armscor

THE ARMSCOR APPROACH

Armscor approached the problem of building nuclear weapons very differently than the AEB, which was reorganized as the Atomic Energy Corporation (AEC) in 1982. Comprised principally of engineers and employed by the military, Armscor's philosophy differed from that of the AEC, which was essentially a civilian scientific organization.

Armscor considered the AEB's November 1979 device to be an unqualified design that could not meet the rigid safety, security, and reliability specifications then under development by Circle engineers. Moreover, the first device was not deliverable.

The AEB device was transferred to Circle. Prior to the move, it had been temporarily stored in an abandoned coal mine at Witbank, a former military ammunitions depot. Armscor modified the device slightly, including re-plating the metal HEU components in 1982, according to South Africa's declaration to the IAEA. The device was renamed Melba, and it lacked many of the safety measures of later devices.

Armscor implemented a capability to conduct a nuclear explosive test more rapidly than the period of time required for the 1977 test. It developed methods for quickly transporting the device to the Kalahari test site and placing it down the hole. The latter involved special trucks with winch equipment rather than stationary equipment of the type used in 1977. Necessary equipment was kept ready at the Circle complex. According to an Armscor official, even the explosive yield would have been estimated only through seismic methods. Instrumentation would mainly be limited to that necessary for assessing any radioactive fallout risks to the public from the possible accidental release of material during the explosion. Although speed was desired, the time required to prepare the Melba test device and conduct a test would likely have been measured in days. Although a 24 hour deployment was the goal, Armscor officials cast doubt on its ability to test so quickly.

To establish an initial credible deterrent, Armscor manufactured its first device in 1981 and 1982, which it considered a "pre-qualification" model. The HEU components had been made at the AEC, however. The yield was six kilotons, implying that, like

Melba, it contained 80 percent HEU.[7] According to an Armscor official, it was capable of being dropped from a plane. This device gave South Africa a way to carry out its initial nuclear strategy, which required deliverability, albeit primitive at this stage. It was initially named Hobo, but later renamed Cabot.

Armscor's goal was to produce warheads for delivery by stand-off weapons launched from Buccaneer bombers. The stand-off weapon was the video-controlled Raptor, or h3, glide bomb with flip-out wings (figures 5.10 and 5.11). This highly accurate weapon was developed as a smart weapon for conventional use at the Kentron facility at Irene, Pretoria. The range was about 60 kilometers, and it could be delivered with one meter accuracy.

In a nuclear mode, one or two Raptors would be mounted on the innermost pilings under the Buccaneer's wing. The two outer pilings were for a control pod for the weapon and an anti-electronic warfare pod.

After firing a Raptor, the aircraft pilot and navigator would continuously communicate with the warhead (figure 5.12). The Raptor would travel to the target and then dive in its final approach. A height sensor would detonate the warhead above ground as an airburst to reduce the amount of radioactive fallout. However, the warhead was not armed when it started its dive. The pilot had to send a signal to arm the device before the pre-determined height of

Figure 5.10 South Africa's 1980s nuclear delivery system, the Raptor 1, or h3, Glide Bomb with inertial and optical guidance. Source: Armscor

Figure 5.11 Buccaneer with the non-nuclear Raptor 1 (h3) on the inner pylons (wings folded in). The h3-Comms Pod is on the starboard outer pylon and an ECM pod is on the port outer pylon. In nuclear strike mode, the outer pylons would have a control pod for the nuclear weapons and an electronic warfare pod. Source: Armscor, Marais

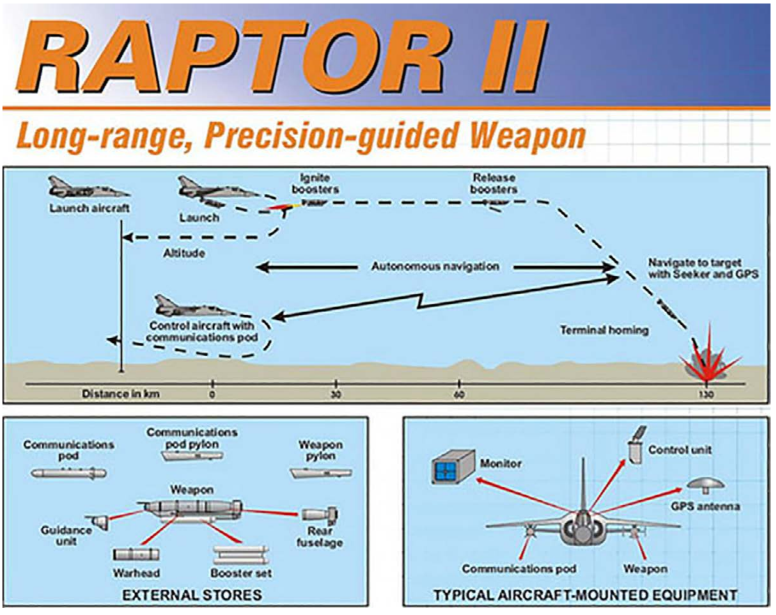


Figure 5.12 Raptor II firing procedure, which is more advanced than Raptor 1 but similar, showing how glide bomb is delivered to a target. Source: Armscor

detonation was reached. If no signal were received by then, the warhead would self-destruct.

Key to Armscor's development of nuclear weapons was reliability, safety, and security.[8] The system engineering department at Circle developed very strict qualification specifications. In addition, extraordinary secrecy requirements forced Circle to make many items in-house. As a result, according to Armscor, design refinement and re-qualification of the hardware took several years.

Many difficulties were encountered in the early years at Circle. Some of the development and production problems concerned the density of the neutron reflectors and the plating of uranium components with nickel. The latter was solved only after trying many approaches. The neutron reflector was made using tungsten-copper, and many problems were confronted in building this part, which required a high density. Density affects the explosive yield of a nuclear device, according to a former senior official close to the IAEA knowledgeable about the South African program. In addition, much effort was invested in the reliability of arming and safing devices.

Ultimately, however, Armscor's production models were highly reliable – they had redundancy built into the system whenever possible, and they were thoroughly qualified in terms of their internal ballistics and mechanical arming and safing operations.

Each nuclear device was divided into two sections, a front and back. With the HEU distributed between the two halves in subcritical quantities, the design minimized the possibility of accidental detonation or unauthorized use. Both halves had to be assembled together to have a nuclear explosion. In essence, the separation of the halves was South Africa's key control philosophy.

The front end contained the bulk of the HEU, the neutron tamper, and the heavy steel mechanism to catch the projectile and ensure it was properly seated. It did not contain electronics or safety systems in order to avoid the need for periodic maintenance. The front end also did not have any components typically associated with starting the chain reaction in the supercritical material. A unique feature of South Africa's gun-type design was that it did not use a neutron initiator. The devices were designed to use background, or stray, neutrons to initiate the chain reaction. Calculations showed that the chain reaction would start within a few milliseconds after the HEU projectile hit the fixed HEU component. However, a downside is that the front end had to catch and hold the HEU projectile long enough for a stray neutron to start the chain reaction. Ensuring that one piece would fit into another and stay put required careful design. The front end had a relatively heavy damping component and a way to stop the projectile from bouncing back. With these design features, once a front end was built and tested, it required no maintenance and could remain stored in the vault. The ability to permanently store the front end was an important part of South Africa's control philosophy to ensure that a weapon could not be assembled unless authorized by the State President.

The back end contained the HEU plug, the propellant, the ignitors, the fusing and firing circuits, and self-destruct mechanisms. The back section needed maintenance by Circle personnel, requiring its periodic removal from the vault.

According to an Armscor official, a front and back end were never worked on simultaneously. Each section was kept in a separate vault inside the main vault. Moreover, a single person could not open a vault where each half was stored.

Figure 5.13 shows the outer doors of the vault at Circle, as they appeared after the program had ended and the area had been modified. Inside the main vault are ten separate vaults on two levels (figure 5.14). A back and front half would not be stored in the same vault.

The inner and outer vault doors were equipped with a range of locks and control panels restricting access. Figure 5.15 shows the outer vault doors closed.

The vault had an inner control panel that controls the ten inner doors (figure 5.16). A keypad can be seen. A control panel was also in the plant manager's office on the second floor of Circle. He had video surveillance of the vault and had to approve access to the vault. The doors of the inner vault had two locks (figure 5.17).

To prevent an unauthorized assembly of a whole weapon, while allowing periodic maintenance of the back half, the removal of the front end from an inner vault was tightly controlled under the authority of the State President. The front half could not be removed

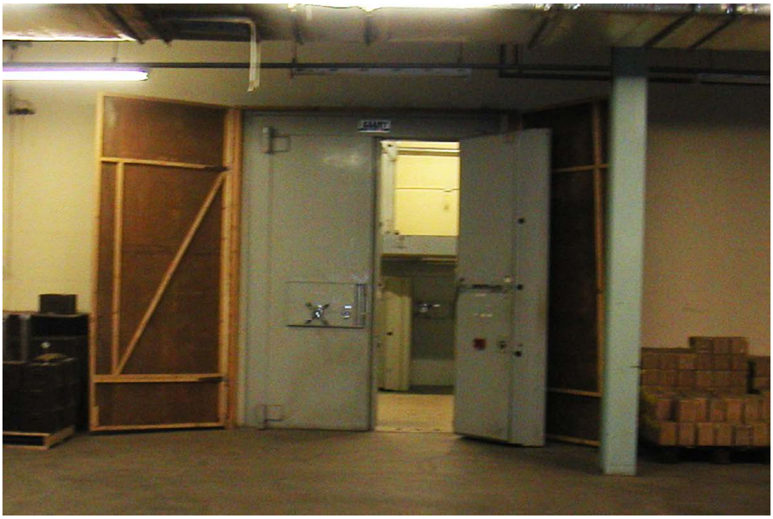


Figure 5.13 Outer doors of the high security vault at Circle, showing the inner vaults as they appeared on a visit by one of the authors in August 2002. The outer wooden doors were added after the end of the nuclear weapons program as part of a strategy (later abandoned) to deny the existence of the nuclear weapons program (see chapter 9).

Figure 5.14 The inner vaults. Source: Armscor

Figure 5.15 Closed outer vault door and close up

Figure 5.16 Control panel inside the main vault for the inner vault doors.

Figure 5.17 A closed inner vault door that shows two locks

from the vault without specific orders from the President, via two separate military and civilian chains of command.[9] Wide representation helped ensure that no one government entity could assemble the weapons itself. For removal, the President would give an order to both the Minister of Defense and Minister of Minerals and Energy Affairs, who in turn would order the Chairperson of the AEC and the Chief of South African Defense Force to delegate their representatives, who would each possess a code. Both codes would be necessary to insert into an inner vault to retrieve a front end.

The removal of the back end was easier but still required four people with different codes, according to a senior Armscor official. All four would have to be on-site. No one person had all four necessary codes. The four people had to include a military representative, someone from the Atomic Energy Corporation, and a senior Armscor official.

The President exercised one additional positive control prior to the delivery of an assembled weapon by the South African Air Force (or its detonation at the Kalahari test site), according to a former leader of the nuclear weapons program. Air force bases were well equipped to handle the nuclear weapons. They had special logistics facilities and equipment for the storage, control, handling, maintenance, and support of nuclear weapons.[10] The warhead halves would be bolted together only on the "flight line."[11] To allow the assembling of a front and back half in the field, Circle built and stored a special portable assembly jig; however prior to the warhead's delivery, the President had to send an affirmative instruction to the air force base in possession of the weapon.

The HEU was also tightly controlled. At the beginning of each work day, the HEU scheduled for use in a manufacturing area was carefully weighed to the nearest 0.1 gram before being checked out of the vault. At the end of each day, the material was removed from the processing and manufacturing areas and weighed to a similar precision before being returned to the vault. HEU was not stored in process lines.

Circle personnel needed top secret security clearances. Only native-born South African citizens with no other citizenship could receive the necessary security clearance. Contact with people outside the program was tightly controlled and movement into and from the Circle complex was carefully orchestrated to avoid program personnel being seen.

SAFETY

Circle engineers carefully studied failure modes and effects and conducted theoretical nuclear criticality analysis under a range of postulated storage, delivery, and accident scenarios. According to Armscor, the devices exceeded safety requirements for this type of device, and "subsystems were subjected to strenuous tests to insure that reliability and safety criteria were met." Some of this care was dictated by the reliance of the design on a relatively large amount of HEU. The devices had enough HEU so that they were near critical if fully assembled. One former senior member of the program said that a wet hand inserted between the two parts of an assembled device could cause a criticality accident. This design limitation required extra care.

A common safety concern with gun-type devices is that the propellant will accidentally fire, sending the projectile into the fixed end, causing a nuclear explosion. Another danger is that the projectile will accidentally slide down the barrel. At a minimum, this would ensure a criticality accident, risking workers and contaminating the adjacent area.

To prevent such accidents, each device had mechanical safing mechanisms. One blocked the projectile from reaching the other end. The first attempt did not work adequately; in the mid-1980s, one model was tested by dropping it and igniting the propellant, but the safety system did not prevent the projectile from reaching the core. It took a year and a half to fix the problem, and later versions performed well. The basic idea of the safety system was that when the device was disarmed, the barrel opening did not line up with the opening of the stationary HEU target in the front part of the device. When the device was armed for detonation, the barrel would rotate so that the openings would line up.

Another related safety system dissipated the pressure caused by the propellant firing, reducing the speed of the projectile. Holes in the barrel were left open to disperse the pressure generated by the propellant's accidental firing. The holes were closed only after the device was armed.

As a fail-safe, the devices were outfitted with a non-nuclear self-destruct mechanism. This mechanism was located in the back end.

Arming of the device would have occurred only seconds before detonation. If a positive signal to arm the device was not received from the Buccaneer aircraft, the warhead would have automatically self-destructed.

Transport containers were carefully constructed with safety in mind. Air-transport containers, such as those used to transport a device to the Kalahari test site, were designed to survive an aircraft crash and fire, according to a former senior official of the program.

1985 GOVERNMENT DECISION TO LIMIT PROGRAM

As Armscor was developing its ability to build deliverable warheads for the Raptor in the early 1980s, the South African government decided to put limits on the nuclear weapons program in September 1985. According to a then-senior nuclear official, President Botha recognized that the cost of the weapons program could escalate significantly. The government's rationale for limiting the program was a worsening economic crisis. However, the cost and effort to maintain South Africa's conventional military capabilities and to procure advanced weaponry in the mid-1980s, according to a declassified CIA National Intelligence Estimate, "strongly suggest that [in the mid-1980s] a nuclear weapon is far down on the military's shopping list."[12] One Armscor official said that the nuclear weapons program was "always very poor."[13]

The government decided to take ten steps:[14]

- Order the manufacture of a maximum of only seven gun-type, type A, warheads with a yield of 5-20 kilotons;
- Carry out engineering development of implosion type warheads;
- Carry out limited research and development of boosted gun-type warheads (type A*) with a yield of about 100 kilotons;
- Continue theoretical work on all other types of nuclear explosives including thermonuclear designs (B types);
- Continue efforts to integrate the payload to the long-distance carrier, a phrase for a ballistic missile.
- The production of plutonium warheads to be discontinued, but expertise developed with lab-scale production must be preserved, with the emphasis on fission element and transuranium element research. Only a limited program is envisioned;
- Limit the production of lithium 6 to a fixed quantity (about 40 kilograms), which must be stored for future use;
- Stop work on plutonium-based nuclear weapons, but maintain existing know-how.

- The Gouriqua reactor project is continued for civil purposes and to keep open option for the future production of plutonium and tritium, if necessary. However, the AEC was unable to sustain the program with its own funds. The AEC tried unsuccessfully to turn the reactor into a test facility for pressurized-water reactor fuel, but the program ended in 1989 or 1990. The Gouriqua site was never developed beyond some rudimentary civil engineering preparations;
- With a view of cost savings, limit production of HEU in the Y Plant to enough for seven weapons and a prudent reserve stock.

PRODUCING MORE DEVICES

However, these 1985 limits did not have much impact on the day-to-day operations then on-going at Circle. With such stringent reliability, safety, and security specifications, weapon production had been slow and only two nuclear devices weapons had been made by the time the program was limited to a total of seven devices.

In 1985, the Circle engineers were mainly focused on developing pre-production gun-type models, referred to as the 300 series. They were built to test the reliability of various components, to integrate the nuclear core into a bomb casing, and to conduct tests with delivery systems. A total of six devices in this series were built. Most were used for testing. Only two in this series were eventually armed with HEU.

- Model 301 was incomplete and used for flame tests
- Model 302 was complete and used for practicing the integration of the full device and for several firing tests
- Models 303 and 304 were used for flight tests
- Model 305 was a complete device built as a spare device for flight tests. However, its quality was sufficient to allow it be provided with HEU. Later, the HEU was removed and transferred to Model 502 in 1988. Afterwards, model 305 was used for training.

- Model 306 was the final one built in the 300 series; its quality was sufficient to upgrade to an active device in 1988 and 1989.

There exists evidence of model numbers greater than 306, such as 308 and 309, but these models were not completed, according to South Africa's declarations to the IAEA. They refer to subsystems that were at different stages of development.

Model 305 was fitted with HEU in the fall of 1986, bringing the number of nuclear devices to three. Later, HEU was put in model 306. Only model 306 remained fitted with HEU at the end of the program in 1989. Model 305's HEU had been moved to a production model, and the model minus HEU was being used as a training model.

Circle started to finally produce production models, named the 500 series, in 1987 and 1988. These were originally codenamed Bakker but later called Hamerkop, or hammerhead in English. Like the 300 series models, they were all guided glide bombs for the Raptor long range weapon. They had a yield of 20 kilotons and used about 56 kilograms of weapons-grade uranium in their cores. Table 5.1 shows the schedule of builds into 1989, when the program was cancelled.

By 1989 Armscor had mastered the routine manufacture of gun-type nuclear weapons able to meet Armscor's rigorous safety, security, and reliability specifications.[15] Most of the weapons were manufactured after 1987. One Circle employee said that 1987-1989 was a period of considerable stress for employees at Circle.

Up until the program was cancelled in 1989, a total of eight nuclear devices with HEU were made, and two were retired. At the end, there were four 500 series devices. As mentioned above, another device was incomplete at the end of the program; the core and some non-nuclear components for this device were finished. This was to be a production model.

By 1989 according to an Armscor official, the annual operating expenditures were about 20 to 25 million rand, or approximately 125-160 million rand in April 2016.[16] The latter is equivalent to about

$8.5 to 11 million at an April 1, 2016 exchange rate. In the early 1980s, the annual budget was about 10 million rand, or several million dollars a year.

TABLE 5.1 PRODUCTION SCHEDULE OF SOUTH AFRICAN NUCLEAR EXPLOSIVE DEVICES(1)

Name of Device	Rear or Front Part	Production Date of Part or Device	Comments
Video/ Melba	?(2)	Novermber 1979	Manufactured at Pelindaba, moved to Circle in 1982 and HEU core was replated; afterwards renamed Melba. A test device.
Hobo/ Cabot	N.A.(2)	December 1982	Shaped HEU components made at Pelindaba, but rest of device made at Circle; Unknown when device renamed.
305	Rear	September 1986	Upgraded pre-production model; HEU removed and reused in 502(3)
	Front	November 1986	
306	Rear	June 1988	Upgraded, pre-production model
	Front	June 1989	
501	Rear	August 1987	Production model
	Front	June 1988	
502	Rear	November 1988	Production model; HEU from 305
	Front	October 1988	
503	Rear	November 1988	Production model
	Front	March 1989	
504	Rear	March 1989	Production model; HEU from Cabot
	Front	March 1989	
Set 7		Not completed	Production model

NOTES AND COMMENTS

1. Unless otherwise noted, devices were made at Circle and were deliverable by aircraft.
2. Information not available on whether it had a front and back end.
3. Model 305 continued to exist as a training model without HEU.
4. A total of eight active devices were built. One device was dismantled and the other placed on an inactive status as a training model. Thus, at end of program, there were six active devices, one active device under construction, and at least one device that was, at least, originally qualified to be armed with HEU.

MAKING THE DEVICES

Armscor developed a sophisticated manufacturing system to make gun-type nuclear weapons. Despite its sophistication, most of the manufacturing steps were straightforward. As can be seen in figure 5.9, the manufacturing operations were under the engineering, technology development, and operations sections, which reported directly to the plant manager.

A former senior nuclear weapons official stated in 1994 that South Africa realized that it could develop a nuclear arsenal without significantly running afoul of international export control efforts, which were considerably weaker than today. In the 1980s, much of the equipment could be bought on the open market without much scrutiny. Once bought, it was sometimes copied as necessary.

The process of making a nuclear weapon started with the receipt of HEU metal billets from the AEC (formerly the AEB). After measuring its mass and enrichment level, the HEU was placed in the high security vault.

The first manufacturing step was to cast the HEU metal into the rough shape of a nuclear weapons component. The South African design did not cast HEU hemispheres but several sections that were later joined together to make the final HEU pieces, or apparently rings, for the gun-type design. A mold was prepared and on the day of the casting, the necessary amount of HEU was carefully checked out of the vault. The operators melted the HEU in a German-made Degussa vacuum furnace and poured it into the mold. Circle depended on two vacuum furnaces. The first was bought abroad in the 1970s. The second was made by South Africa. The latter was a backup that could be used if the first furnace broke. The backup furnace had not been used by the end of the program.

The casting operations occurred in the metallurgy room. Figures 5.18 and 5.19 show different views of this area as it appeared in 2002 after the room had been emptied, the walls and original floor removed, and the area thoroughly decontaminated following the end of the program in 1989. After inspection and material accounting, the molded metal was placed back in the vault. The casting area was also decontaminated.

The next step in the process was to machine a casted piece or section of the HEU core. Lathes outfitted with special fittings machined each uranium casting. One lathe was used to machine

Figure 5.18 A view of the metallurgy or "uranium" area in Circle, after the removal of the walls and equipment. The outer vault doors are visible in the background.

Figure 5.19 A view of the metallurgy or "uranium" area in Circle, after the removal of the equipment and walls. The barrels and boxes are unrelated to the nuclear weapons program.

the HEU components and another one machined the depleted uranium components. The latter were not used in actual weapons but in models. Easing their manufacture, the components were in segments that were alloyed together later into the final HEU core component. The lathes were in inert cabinets with hoods. The room that contained this equipment can be seen in figure 5.20. These lathes were not sophisticated, lacking numerical control. The weapon program depended on using a clever design for the HEU components and good machinists to compensate for the simplicity of the lathes. The machining areas were well filtered and any liquid material was collected in a pit and pumped into a cart. Material containing HEU, including in liquid solvents, cut-offs, and shavings, was carefully collected. The finished piece was placed in the vault and the area was decontaminated.

Figure 5.20 Two views of the machining area of the Circle plant in 2002. On right photo, boxes are unrelated to nuclear weapons program. Photo on the right is from inside the machining room looking into the metallurgy area.

The machining area was in a closed room adjacent to the metallurgy room (see figure 5.20). It contained two lathes, hoods, and ventilation equipment.

After retrieval from the vault, each HEU section was plated with nickel to protect it against oxidation or corrosion. Afterwards, each section was returned to the vault.

The casting and machining operations generated scrap and nuclear waste, which were sent to the Atomic Energy Corporation for recovery or disposal. The shipments were sent at night to minimize detection.

There were many non-nuclear parts that had to be procured from outside suppliers or made on-site. A Master Record Index (MRI) contained all the necessary drawings and specifications. Many non-sensitive parts were procured from outside the organization. These electronic and standard parts and components were purchased externally through an open tender system.

Sensitive parts were manufactured at Circle. It made certain electronic parts, including firing circuits, PC boards, and certain electrical devices that initiate a mechanical action ("electro-mechanical devices"); the barrels; the tampers; the metal damper or stopper pieces; and stainless steel sleeves or shields surrounding the tamper. In addition, it made the ignitors for the propellant and the propellants. Some of these items were made in a workshop (see figure 5.21) that was right off the center bay of the building. Equipment included two and three dimensional milling machine tools, inspection equipment, ball mills, lathes, and furnaces. At the end of the program, a five-axis Takisawa MAC-V2 milling machine had been procured for Circle, although its purpose is unknown. There was also a gauging shop in Circle that could provide accurate instrumentation for measuring weapon components and produce shapes or reference components used to check manufactured items. When entering the building, a large store room was directly left of the central bay of Circle (western side) for raw materials and spare parts (see figure 5.3).

The tamper of the device, made from tungsten, was sensitive and difficult to make. It was composed of orange peel shapes glued together into a shell. The raw material was tungsten powder, which was ground in a ball mill, placed in a rubber bag, and pressed in a cold isotopic press (CIP). The CIP was made in South Africa. After inspection, the solidified powder was heated, or sintered, in a special oven that had been purchased from Degussa-Durferrit. Afterwards, the pieces were machined and glued together. Tamper (and steel

Figure 5.21 The former workshop in 2002 after it was emptied of equipment following the end of the nuclear weapons program.

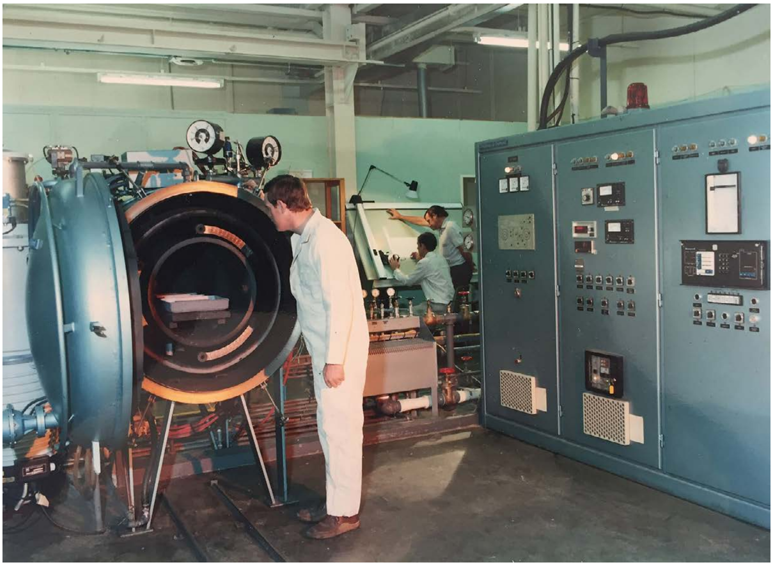


Figure 5.22 Vacuum induction furnace in Circle workshop that had earlier been used to sinter the tamper subcomponents. The furnace was manufactured by Degussa-Durferrit and has Honeywell control equipment. Photo source: Armscor

shield) elements were made for the HEU plug as well. Figure 5.22 shows the oven and control panel.

The parts and subcomponents had to be integrated, or assembled into a front or rear section of the nuclear device. To ensure adequate security, a front and rear end were never integrated simultaneously. Figure 5.23 is a simplified schematic of the integration process.

A special part of the integration process was called the "burn-in" which was done at the nearby environment test facility. Testing at this facility was necessary to ensure that the nuclear weapons could withstand being transported and launched.

Figure 5.24 and 5.25 show opposite ends of the environmental test facility, which was built into the hillside. It had doors on each end to allow vehicles to drive through the building. Figure 5.26 shows the facility from the bridge over the oval high speed test track. The facility was made out of concrete since it was designed to handle high explosives (up to 30 kilograms).

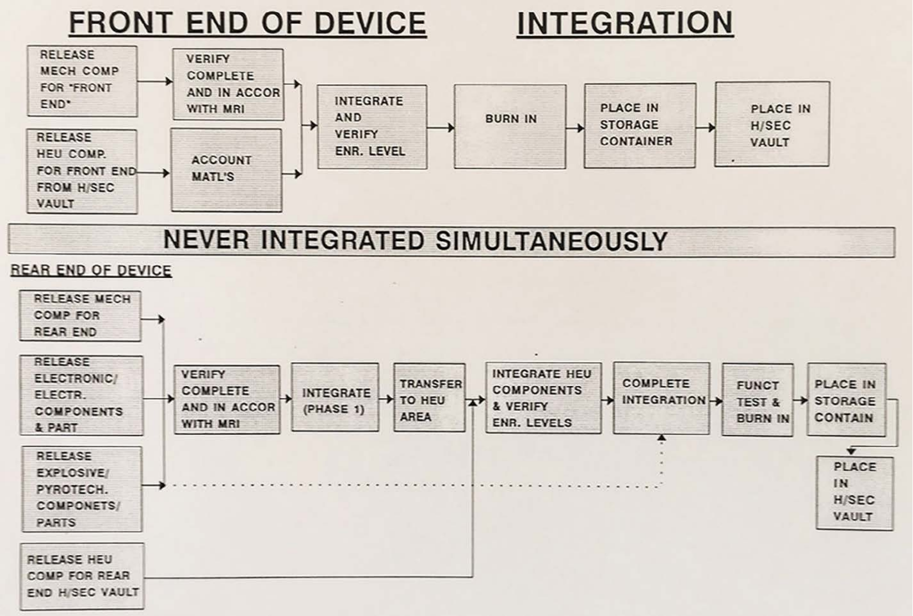


Figure 5.23 Schematic of steps in assembling a front or rear end of a nuclear device, where enr. is enrichment, H/Sec is high security, MRI is Master Record Index, and accor is accordance. Source: Armscor

Figure 5.24 Environmental test building from side opposite the Circle building.

Figure 5.25 Environmental test building, the end closest to the Circle building.

After manufacturing in the Circle facility, a front or back end would be sent to the environmental testing facility for burn in (figure 5.27). It would be shaken, and put in a humidity cabinet and an environmental oven. The testing evaluated the effect on the weapon as it was cycled through temperatures and changes in air pressure.

Inside the test facility, one set of tests ensured that the warhead would survive the considerable vibrations encountered on take-off, particularly when it is mounted under an aircraft wing. For such

Figure 5.26 Environmental test building in the distance as viewed from the bridge over the oval test track (see figure 5.4). The Circle building (not visible) is to its left.

tests, the facility had both a large and small vibration table. They were capable of generating random and large periodic vibrations. The vibration table needed cooling so cooling towers were built behind the building. Armscor had difficulty buying the vibrators, especially the large one, according to a former senior Armscor official, since they are only used by the military. According to a former senior member of the program, "Their purchase was quite a headache."

The building was also equipped with a 200g centrifuge. It also had two climate testing chambers, at least one of which could simulate humidity and altitude up to 50,000 feet, at 99 percent relative humidity, and achieve temperatures from -60 to +130 degrees centigrade.

After the testing was complete, the half would be returned to the vault at the Circle building. In the case of the front ends, once burn in had occurred, they would not come out again for maintenance.

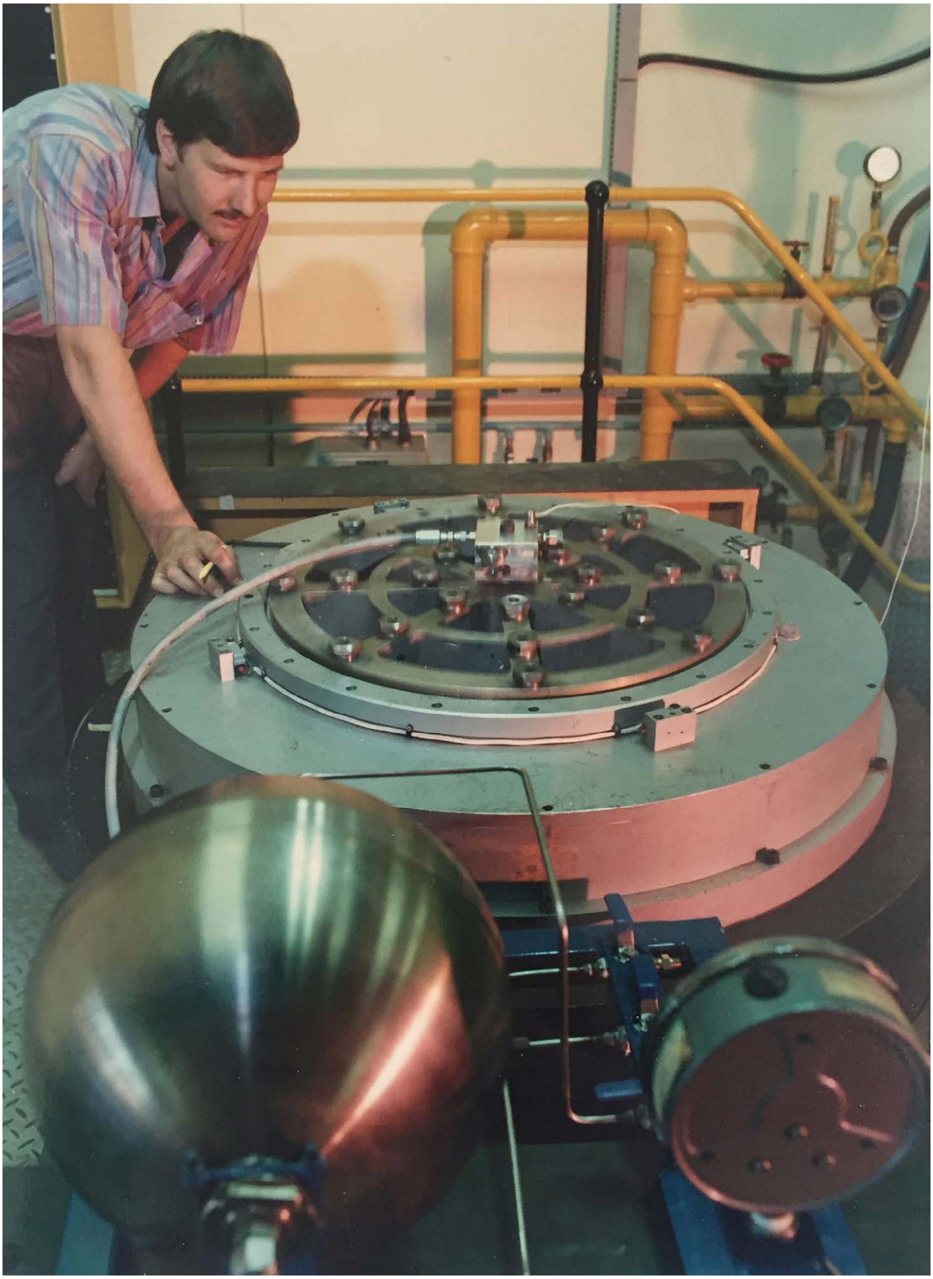


Figure 5.27 Testing equipment at the environmental test facility. Source: Armscor

TAKING STOCK

Overall, Armscor was creating a small but formidable nuclear weapons arsenal at Circle. The weapons program had benefited from Armscor's independent development of a highly accurate standoff weapon to build a credible nuclear weapon system. Its emphasis on reliability and safety ensured that the South African defense forces would have confidence in this weapon system, if it ever had to be deployed. South Africa's development of a ballistic missile in the late 1980s would motivate the next phase of its nuclear weapons production ambitions.

However, key personnel in the nuclear weapons program believed that the nuclear strategy needed further refinement. André Buys, who had risen in stature in the weapons complex, obtained a mandate in the early 1980s to lead a team in creating a more sophisticated strategy that would help guide the next stage of South Africa's nuclear weapons.

NOTES

1. Prime Minister P.W. Botha, *Draft Speech for the Opening of Kentron Circle,* May 4, 1981, in Afrikaans. Original in Nic von Wielligh and Lydia von Wielligh-Steyn, *Die Bom* (South Africa: Litera Puasies, 2014), Appendix, translated by Schreiber Translations, Inc. for Institute for Science and International Security, July 7, 2015.

2. *Draft Speech for the Opening of Kentron Circle,* op. cit.

3. Interview with André Buys, July 31, 2002.

4. South Africa's nuclear explosive program in the 1970s was widely known about. In 1984, the CIA wrote: "Evidence that South Africa has developed a significant nuclear explosives capability is substantial and compelling." [Director of Central Intelligence, *Trends in South Africa's Nuclear Security Policies and Programs*, National Intelligence Estimate, October 5, 1984, declassified version]. However, this report recognized that South Africa imposed tighter security over its nuclear explosives program after the 1977 Kalahari incident. In particular, the authors of the report appeared not to know that South Africa had embarked on a program to produce deliverable nuclear weapons, although they recognized correctly that it possibly could have done so. A related issue is when Western intelligence agencies discovered the true purpose of the Circle building. US satellites likely picked up the construction of Circle, but one official said that the US intelligence agencies had misunderstood Circle's true purpose, perhaps for the first five or six years of its operation. Certainly, by 1988 or 1989, the true purpose of Circle was known, he added.

5. Johann Viljoen and Deon Smith, *The Birth, Life, and Death of South Africa's Nuclear Weapons Program*, Unpublished manuscript commissioned by the Institute for Science and International Security, 1999.

6. Hannes Steyn, Richardt van der Walt, and Jan van Loggerenberg, *Armament and Disarmament: South Africa's Nuclear Weapons Experience* (Pretoria: Network Publishers, 2003), p. 75.

7. *Kramat Capability: Current Status and Further Development,* part of September 3 1987 submission to the Witvlei Control Committee (WBK), in Afrikaans. Original in *Die Bom*, op. cit. See also the English version in *The Bomb* (Pretoria: Litera Publications, 2015), Appendix.

8. See for example, *Armament and Disarmament*, op. cit., pp. 83-87.

9. Nic von Wielligh and Lydia von Wielligh-Steyn, *The Bomb* (Pretoria: Litera Publications, 2015), pp. 172-173.

10. *Armament and Disarmament*, op. cit., pp. 75 and 88.

11. *Armament and Disarmament*, op. cit., p. 88.

12. Director of Central Intelligence, *Trends in South Africa's Nuclear Security Policies and Programs*, National Intelligence Estimate, October 5, 1984, declassified version.

13. Interview by one of the authors, October 31, 1994.

14. *Meeting of Ad Hoc Cabinet Committee Under the Chairmanship of the Honourable State President on Tuesday 3 September 1985 at 15H00*, in *The Bomb*, op. cit., pp. 480-483.

15. Interview with Armscor officials, Circle building, February 1994.

16. Inflation Calculator: http://fxtop.com/en/inflation-calculator.php

CHAPTER 6
NUCLEAR STRATEGY AND ARSENAL EXPANSION

South Africa's formal nuclear strategy evolved throughout the late 1970s and early 1980s. According to a former member of the nuclear weapons program, an adequate strategy was not formulated when Armscor took over the program. Although the basic strategy was approved in 1978, he said that this strategy was only sufficient to support the decision to develop a nuclear deterrent. By 1986 however, a policy document approved by the then Minister of Defense Magnus Malan laid out South Africa's detailed strategy for nuclear weapons.

The strategy was not based on war-fighting, but rather was intended as a political strategy designed to force Western powers, particularly the United States, to assist South Africa against an overwhelming military threat to its territory, or what was referred to in strategy documents as finding itself with "its back against the wall." The most widely feared threat envisioned Soviet-backed forces overrunning South African forces in Angola and invading South Africa itself. If South Africa possessed nuclear weapons, planners reasoned the United States and its allies would step in between the two warring sides and end the conflict.[1] This strategy, sometimes referred to as a catalytic strategy, assumed that the United States would not allow a nuclear war to occur, or allow any country to detonate a single nuclear weapon. The assumption was based on a US fear that the use of a nuclear weapon would set a precedent, and make it easier for the next country to decide to build or use nuclear weapons. South Africa may also have reasoned that any demonstration of its nuclear weapons could cause the Soviet Union to threaten the United States with a nuclear confrontation unless South Africa was adequately constrained, which in turn would motivate the United States to seek an end to the conflict.

In addition, nuclear weapons, according to Prime Minister P.W. Botha in his 1981 speech opening the Circle facility, would "give the RSA [Republic of South Africa] the capability to manage the (superpower) conflict from a power base of nuclear strategy, rather than a power base of black politics." This statement also indicated the resentment held by the political leadership against Western sanctions over its apartheid policies and a desire to change those negotiating and power dynamics. Nuclear weapons would allow South Africa to shift the conversation from its internal affairs to security interests if needed. Botha stated: "Nuclear is primarily a political weapons system, not a military system."[2]

Unlike any other nuclear strategy, South Africa's strategy envisioned no actual operational use of nuclear weapons. It was designed to be a bluff. However, the challenge was to ensure that if the strategy was exercised, South Africa was perceived as having the means and resolve to use nuclear weapons militarily. The goal was to deter aggression, not to be involved in a nuclear war that South Africa could not survive.

1978 BASIC STRATEGY

In his 1981 Kentron Circle speech, Prime Minister Botha announced that he first ordered the development of the nation's nuclear strategy in July 1977 when he was Defense Minister.[3] He and the State Security Council approved the basic strategy, or "national strategic guidelines for nuclear weapons," in April 1978. Within one month after Botha become prime minister in late September 1978, he authorized the creation of a high-level action committee to further develop guidance for the planning of the nuclear weapons program, as discussed in Chapter 4. This group oversaw the production of the first nuclear strategy.

The April 1978 strategy document has never been publicly released or published. The American political scientist Peter Liberman, however, details its initial development. He cites interviews with André Buys, who after being the Plant Manager at Circle moved to a more senior position in Armscor. Buys stated that under Botha's Defense Minister title, which he held simultaneously until 1980 after becoming Prime Minister, Botha asked close advisor and South African Defense Force chief of staff for planning, Army Brig. John Huyser, to prepare a memorandum laying out the potential elements of a nuclear strategy. Huyser returned a six to eight page discussion memo laying out the following options: 1) secret development, 2) covert disclosure, and 3) overt disclosure. Huyser recommended the third option, "openly joining the nuclear club." Botha approved the document but wrote on the memo that "any disclosure should be delayed "until we are ready" and it required government approval. Liberman states that Buys told him the document "did not specify numbers or types of weapons, which left the AEB still uncertain about whether a demonstration capability was sufficient."[4]

The government eventually approved sometime around 1978 an actual range of nuclear weapons to be developed along with turning Huyser's options memo into a linear, three-phase strategy:[5]

- Five to six nuclear weapons would be "kept on the shelf," or developed;
- Should the RSA find itself in a "back against the wall" situation:
    - the existence of the RSA's nuclear weapons would be conveyed to Western countries (primarily the USA) in a covert manner; if this does not alleviate affairs,
    - an underground test will be performed to demonstrate the RSA's capability, and
    - finally, an above-ground test, if the threat persists.

Armscor would have overall responsibility for the nuclear deterrent's development, and the South African Defense Force and AEB would cooperate, according to Botha, on:

> *…Identify[ing] in which manner the production of suitable nuclear weapons can be brought about for SA [South Africa] – this with consideration for the developments made by the AEB concerning peaceful use of explosive nuclear material, and, after approval of said proposal, to truly implement the suggestions. This Committee proceeded to their task…in such a way that I was able to approve the proposed outline of the intended weapon and establishment of certain facilities, the so-called Project Festival, already on July 4, 1979.*[6]

An important aspect of the nuclear strategy was to maintain uncertainty about the program. Protecting uncertainty required the government to ensure that nuclear weapons activities remained secret. As a result, Armscor imposed a more stringent security regime on the program than the AEB had exercised in the 1970s.

Tasked with planning in the early 1980s, key Armscor officials felt they lacked adequate guidance about the circumstances in which the strategy would be implemented and the number and type of nuclear weapons required. For example, the original 1978 decision that talked about five to six gun-type devices on the shelf had little justification. Moreover, from an engineering standpoint, Armscor needed to know whether to actually make five or six weapons. Buys complained that Huyser's memo, for example, "was not very concise" and they "often had difficulties in interpreting it."[7] To Buys, the existing strategy was inadequate.

In 1983, while still Plant Manager of Circle, Buys received approval to chair a working group of eight to ten people based at Armscor to develop more detailed guidance on when to move from one phase of the strategy to the next. Since the three-phase strategy moved linearly from disclosure of the bomb's existence to demonstration, Armscor officials were concerned that the guidance was too vague and needed to show prescriptively what had to occur before moving to the next phase. They did not want the phase three testing of nuclear weapons to take place, for example, quickly or without considering the consequences of moving past earlier stages. Nor did they want an irrational politician to be in control of hasty or ad hoc decision making in a crisis situation. It was unclear what Botha's plan for overt disclosure "when ready" meant and whether that needed to happen.

Each escalatory step should be small, according to Buys, starting with low-key steps.[8] The aim should be to stop as early in the escalatory process as possible, he added.

Buys' working group contacted many people, read many nuclear strategy references, and studied the strategies of other countries. The group "met monthly for a year, conducting war games, reviewing the nuclear strategy literature, and selectively consulting experts, politicians, and even a leading South African theologian."[9] In the end, by 1985, the working group believed that their strategy, summarized into a 10-20 page document, was different from other nuclear weapon states in that it did not envision the use of nuclear weapons in an offensive mode.

While the working group was developing its more detailed strategy, an Ad Hoc Cabinet Committee, chaired by then-retitled State President Botha[10] and attended by Armscor Chairman Commander P.G. Marais, Minister of Defense General M.A. Malan, Director General of the Mineral and Energy Affairs Ministry Dr. L. Alberts, and Chairman of the Atomic Energy Corporation Dr. J.W.L. de Villiers, reconfirmed the 1978 three phase strategy. South Africa's nuclear weapons would be made known to Western countries, primarily the United States, and then if needed, escalated to conveying their presence via underground or above ground nuclear tests.[11] The document stated that the strategy specifically excluded the "operational application of nuclear weapons." We were unable to determine if the 1978 document had a similar statement. Moreover, the document also said that any decision to implement the strategy will be authorized solely by the State President.

The main purpose of the 1985 Cabinet meeting was to limit the size of South Africa's nuclear weapons program. It ordered the manufacture of a maximum of seven gun-type devices. However, this represents an increase from the numbers in the 1978 strategy document. Rather than build five or six gun-type devices, as was ordered in 1978, the Committee decided to build seven of them, while committing to developing more advanced weapons, as discussed earlier in the Circle chapter. The main cutbacks were in the production of nuclear materials, which tend to be the most costly part of producing nuclear weapons.

The more detailed, Armscor-developed South African "deterrent" strategy was adopted in November 1986 and was still based on three escalating, step-wise phases but with additional guidance. The updated strategy document, in essence, provided a roadmap for identifying the requirements for progressing through successive phases. Because South Africa could not return to an earlier phase, the document described more criteria and the factors that would lead South Africa to enter the next phase. The document, Buys said, also contained specific language that any actual use of nuclear weapons should never happen. It would be suicidal, given the Soviet Union's vast ability to strike with nuclear weapons.

According to the strategy document, the first phase, "strategic uncertainty," would include the South African nuclear capability neither being acknowledged nor denied "as long as the military threat remained remote."[12] The intention, according to Buys, was to create worry in the world.[13] South African politicians, with their periodic leaks, he added, created that uncertainty without any guidance.

Phase two, or "the covert condition phase," applied if the country were threatened militarily by Soviet or Soviet-backed forces. At that time, the government would covertly acknowledge the existence of its nuclear weapons to leading Western governments, particularly to the United States and perhaps Britain, and ask for their intervention to end the war. For example, it would state that it has a few nuclear weapons and cannot stand up to the Soviet Union's conventional forces. In interviews, Buys called this phase "arm twisting" of the major powers. Moving to this phase required South Africa to possess deliverable nuclear weapons so that the powers would believe that the implied threat was credible.

If phase two failed to persuade the international community to provide assistance against a military attack and South Africa was starting to lose a war, the government would move to phase three, or the "overt deterrent phase." This phase, which included a series of successive steps, intended to force the intervention of the United States and others to stop a war. The first step would be the public announcement of having nuclear weapons and an appeal for Western government aid. If that failed, South Africa would demonstrate its capability with an underground test. Next, South Africa could invite outside experts to look at the arsenal. The next step would be to demonstrate long-range delivery capability. Others have said that such a demonstration could have involved flying a Buccaneer bomber 1,000 kilometers south of South Africa and launching a nuclear weapon on a Raptor that detonated in the atmosphere.[14] If nothing had worked, the last step threatened "application on the battlefield," which could be employed as self-defense against an impending conventional military attack.[15]

According to Buys as cited by Liberman, actual battlefield use was hotly debated internally. Many members of the committee, including Buys, felt it would have been suicidal to threaten use of nuclear weapons even if South Africa were on the verge of being defeated militarily by the Soviet Union.[16] Buys noted: "Others would argue differently, they would say fight to the bitter end…But there was no strategy for that."[17] Moreover, some officials who were concerned about the battlefield use provision worried in particular that the leadership may be unpredictable enough to use nuclear weapons even without a clear, imminent military threat. In the end, no operational use remained fundamental to the strategy.

Buys' strategy document has not survived. All copies were destroyed as part of South Africa's dismantlement of its nuclear weapons program. Buys said in an interview that security officials even came to his office and took his copy. However, a declassified September 1987 document contains an outline of the new strategy that confirms what Buys has said. In this document, "Kramat [nuclear weapons] Capability: Current Status and Further Developments," a subcommittee called the Weapons System Working Group (WSWG) submitted a set of nuclear weapons recommendations to the Witvlei Control Committee (known by its Afrikaans acronym WBK), which was a senior coordinating body for the nuclear weapons program.[18] The exact role and membership of the Witvlei Committee, which also translates as a strategy council, remains unclear. Buys called it a committee that dealt with budgets and coordination. The chair of the Witvlei Committee also briefed the Ad Hoc Cabinet Committee chaired by the State President prior to its 1985 decision to limit the nuclear weapons program.[19] Therefore, its role appears critical in the decision making about nuclear weapons.

The recommendations in the "Kramat Capability" document will be discussed soon, but the memo contained a summary of the new strategy. Kramat is a code word for nuclear weapons. The memo specifically states that the updated nuclear strategy was "approved by the Minister of Defense on November 24, 1986."[20] According to Buys, he briefed President Botha on the new strategy. In the meeting, Buys recommended never to use nuclear weapons, and he said that Botha did not object. He was not aware of whether Botha or the Cabinet approved the new strategy document, which had the status of a defense policy document.[21]

According to this Kramat Capability document, the South African escalating, three-phase "deterrent" strategy included:

- During the **strategic uncertainty phase**, the existence of the KRAMAT [nuclear] capability will be denied.
- During the **covert condition phase**, the KRAMAT capability will be covertly revealed as a means of inducement, persuasion, and coercion.
- During the **overt deterrent phase**, the following actions will be considered:
  - Overt announcement.
  - Display of force.
  - Demonstration (underground or atmospheric test explosion).
  - Threatened use.
  - Battlefield application as DETERRENT *(caps in original)* against conventional assault forces.
  - No strategic application foreseen, only the threat of use.

The document continued, "In order to carry out this strategy with credibility, the following weapon systems are required":

- Air-launched weapon for atmospheric demonstration test and use in battle.
- Explosive device for underground demonstration test.
- Long-range ballistic missile for threat of strategic use.

By this time, the air-launched weapon, namely the Raptor discussed in chapter 5, was fully developed and being outfitted with nuclear warheads. However, the nuclear test site had not been visited since 1977, when it was hastily shutdown, and the two deep shafts were sealed. Ensuring that a test was possible became an urgent priority. Moreover, although the ballistic missile was still many years from deployment, it was envisioned by 1987 as a critical nuclear weapons system that would require new warheads. The 500 series production gun-type models were not suitable for use on ballistic missiles, in part because of the safing mechanisms.

NUCLEAR TEST SITE

According to Buys, in late 1986 or early 1987, Armscor was told to "make sure that the capability to actually execute the strategy is in place."[22] The most urgent priority was ensuring that an underground nuclear test could be carried out.

The Weapons System Working Group report mentioned above offers some insight into the thinking about the nuclear test. Although the request for the inspection of the test shafts had occurred prior to the working group's Kramat report, the working group included this issue in its nuclear weapons assessment and made recommendations about how to proceed. The concern was that the deeper of the shafts may have become blocked by an obstruction and that the Melba test device, built in 1979, was obsolete. The group was also worried that the combined system, codenamed Gardenia/Melba and composed of the Melba device with placement and control systems, while in working order, was no longer reliable and would take 21 days to prepare for deployment. A test under the then existing conditions was also considered as an "open" underground test explosion that would discharge a considerable amount of radioactive material into the atmosphere, apparently because the shafts could not be backfilled after placement of the device deep in the shaft (see also chapter 4). The Group recommended the development of a new test device, codenamed Modulus, accompanied with new placement and control equipment to be finished by about 1991. The group said, “It must be possible to use the Modulus device for a back-filled “clean” underground demonstration test.” In addition, it recommended an inspection of the test shafts to determine their condition. However, it said that the inspection should happen “in a manner that will not attract international attention to the test site.” If this is not possible, the group was so worried about renewed detection of activity at the site that it recommended that “an alternative test site must be sought.”

Armscor visited the site in 1988, according to a former senior member of the nuclear weapons program. The lag time between the timing of the decision to reopen the shaft and the actual reopening resulted from the time to draw up plans, conduct trials at Circle, and obtain the necessary equipment and supplies.

With no intention to send a signal to the United States or the Soviet Union that they were reopening a shaft, possibly triggering worry about an impending nuclear test, Armscor investigated the test shafts clandestinely. To that end Armscor built a hangar, which it called a “shade,” over a test shaft, placed dummy military vehicles near around the site, and conducted target shooting during construction to provide a plausible cover for the operation. They opened the shaft, emptied the water within, and tested the shaft’s integrity. As will be discussed later, despite all these precautions, this activity was likely noticed by the United States.

BALLISTIC MISSILES

The most dramatic shift in carrying out the new strategy was the decision to arm ballistic missiles with nuclear warheads. The plans for building a nuclear warhead for a ballistic missile grew out of South Africa’s evolving security situation and its cooperation with Israel on rocket technology. South Africa’s space program had the lead in developing a space launch vehicle in cooperation with Israel. The main purpose of the program was to contribute to South Africa’s overall industrial development and launch low orbit reconnaissance satellites. South Africa's military viewed its lack of strategic reconnaissance as a major weakness in confronting the front line states militarily. That the launching rocket could be adapted to carry conventional and nuclear warheads was an added benefit and an opportunity. There is very little difference between a satellite launch rocket and a surface-to-surface rocket.[23]

Compared to aircraft, ballistic missiles offered South Africa a more reliable nuclear weapons delivery system able to deeply pen-etrate into Southern Africa. According to a former leader of the nuclear weapons program, South Africa wanted a missile with a range of 2,500-3,000 kilometers, longer than the range of the Israeli rockets that formed the basis of the cooperation. The goal was to be able to strike Luanda, the capitol of Angola, and points further north. Another motivation for a nuclear- tipped ballistic missile is that the Buccaneer bombers, which had been procured from Brit-ain in 1965, were nearing the end of their operational lifetime. Only three were licensed to carry nuclear weapons by the late 1980s, ac-cording to this same official. The French- supplied Mirage aircraft could also be modified to carry nuclear weapons, but it did not have the range needed to carry out South Africa's nuclear strategy. There were also increasing concerns about the ability of South Africa's air-craft to penetrate enemy airspace in the future. With international sanctions in place, South Africa was unlikely to be able to buy a long-range, modern bomber or afford the domestic development of one. Thus, the development of a nuclear- tipped ballistic missile emerged as a feasible South African priority, given Israel's willing-ness to supply rockets.

The rocket of choice to carry a nuclear payload was the RSA-3 missile, which was a three-stage rocket under development by the late 1980s. By then South Africa had constructed a range of facilities to develop, build, and test this and other rockets.[24]

The new strategy emphasized the need for credible nuclear weapons, which led to the choice of the Raptor and ballistic missiles as the delivery systems of choice. It also led the military to conduct a reevaluation of the number and type of nuclear weapons that would be built.

PLANS FOR INCREASING THE NUMBER OF WARHEADS

The 1985 Cabinet decision discussed in chapter 5 set a limit of seven nuclear weapons and called for a feasibility study in respect to implosion-type warheads. However, the new nuclear strategy stimulated a new discussion of this limit. Moreover, in April 1986, the SADF's Air Force was appointed as "user of the nuclear and missile programme and went through several processes in the course" of 1986 and 1987 to determine the needs of the SADF.[25] Its plans called for doubling the number of nuclear weapons needed.

Again the Weapons System Working Group document offers insight into this decision. This group was instructed by the Witvlei Control Committee in April 1987 to determine a desired number of missiles and nuclear warheads from a strategic and operational point of view. It reported under the recommendation section that the view of the SADF was that a minimum of 14 Kramat payloads would be required, after taking into account the strategic and operational requirements and financial constraints.[26] The specific recommendations were:

- One Modulus device
- Ten gun-type warheads that will be operationally interchangeable between aircraft- deliverable and intermediate range missile-deliverable weaponry.
- Three boosted (A*) for the same type of missiles. ("This choice results in a better balance between circular error probabilities of ballistic missiles and payload yield.").

The working group also had a series of technological development recommendations, including:

- Continuing the development of the implosion technology and do theoretical studies on the other nuclear technologies.
- Implosion technology is still at an early stage of development and the switch to implosion-type warheads will be possible only after year 2000, if the user [Air Force] decided to update the missiles with these warheads. (Implosion and other types of warheads may be better suited to new

generation of lighter and smaller weapon systems that may become available in the future.)

TABLE 6.1 1987 CODENAMES FOR NUCLEAR WEAPONS

Kramat	Nuclear Warhead
Modulus	"Clean" underground test device
Gardenia	System of placement shafts and "dirty" underground test device
Melba	"Dirty underground test device
Cabot	Formerly Hobo (dumb weapon), see chapter 5
Hamerkop	Formerly Bakker or 500 series (smart weapon), see chapter 5
Husky	Intermediate range ballistic missile system
Ostra	Warhead on Husky

Another recommendation was to keep the Y Plant in operation longer than envisioned in the 1985 Ad Hoc Cabinet Committee decision. The group notes, however, that if there was a need for more warheads, switching to implosion warheads could be used to double the number of warheads with existing amounts of highly enriched uranium. (An implosion-type warhead needs about half the amount of HEU as a gun-type device.)

The total projected cost of all these recommendations was about 800 million rand from 1981 to 2006, of which about 265 million rand had been spent by 1986. Most of the monies already spent had been allocated to make HEU. During the next 20 years, annual average nuclear weaponization costs, excluding missile costs, were estimated at about 20 million rand per year. The average annual cost to make HEU and thermonuclear materials was estimated at almost 7 million rand per year. The latter average is misleading because in all likelihood most, if not all, of the HEU would be produced during the first several years of this 20 year period.

The level of government approval for these plans is not clear in the declassified documents. However, an April 1988 declassified document regarding the Air Force's "Dunhill Program" produced by the SADF's Air Force planning division shows that these recommendations were approved by the Minister of Defense in August 1987.[27] The recommendations were sent to the Witvlei Control Committee in September 1987. It is unclear if the WBK committee approved them, or if the President or the Ad Hoc Cabinet Committee approved them. However, what was called a Reduced Witvlei Committee approved them in June 1987, under what was called "Program Olympic."[28]

The 1988 Dunhill document implies that the AEC may have resisted some of the recommendations. De Villiers, the Chair of the Atomic Energy Corporation, did not want to make the nuclear materials without explicit orders from the Minister of Economic Affairs and Technology.[29] By implication, this action may have required Cabinet level approval for this recommendation, instead of just that of the Minister of Defense.

At the time, the AEC was focusing on producing low enriched uranium for the Koeberg nuclear power reactors. Once the Z Plant was finished, it would have taken over this responsibility. The AEC viewed the production of LEU as a national security priority, however, so until that plant was running, it had started using the Y Plant to make LEU and blending down stocks of weapons-grade uranium to LEU for the Koeberg reactors. There could have been another, more mundane reason. The budgets for the military and the AEC were separate, possibly leading de Villiers to want to ensure that the necessary funds would be there to make the additional weapons-grade uranium.

Overall, however, these decisions shaped South Africa's plans for nuclear weapons. It is natural to ask what had happened in the years 1986 and 1987 that motivated this push for an improved, more threatening nuclear arsenal.

TENSIONS MOUNT

By 1987 the war in Angola, which had raged for almost a generation, had become South Africa's equivalent of the Vietnam War. The South Africa Defense Force and its ally UNITA were not able to win the war, although they achieved significant battlefield victories over their enemy. Out of fear of sparking direct Soviet intervention, the South African government was constrained from outright defeating its enemies and seize Angola, assuming that such a victory was indeed possible.

After the late 1987 defeat of a major Soviet-Angolan offensive, Cuba decided to escalate its own involvement in the civil war and send an additional 15,000 troops to Angola, bringing the total to about 50,000.[30] By early 1988, the Cuban and Angolan forces had started to advance into southwestern Angola near the Namibian border. By late May they had created a new southern front that ran approximately 250 miles and was heavily defended with tanks and artillery, late-model fighter aircraft, and sophisticated air defenses.[31] According to Chester Crocker, former Assistant Secretary of State for African Affairs who had a major hand in ultimately resolving the tense standoff, although international peace talks had started in London, Fidel Castro "spoke mainly the language of war and military intimidation."[32] In Crocker's view, Castro "publicly dared the South African leadership to run the risk of a 'serious defeat' if they tangled with him, and claimed that he had refused to give Pretoria a guarantee that he would not cross into Namibian territory."[33] Yet, interpreting Castro's true intentions during the first half of 1988 was difficult for South Africa and the Western negotiators. Was he headed for a military invasion of Namibia or was he seeking a way to negotiate an honorable exit from Angola?

Although hindsight has shown that Castro indeed was trying to drive South Africa to the negotiating table and never intended to invade Namibia, at the time South Africa was not so sure of Cuba's intention and took several military counteractions that only escalated the crisis. By late May 1988, heavier military units had been deployed in northern Namibia. In early June, the South African government called up its 140,000-man Citizen Force, the backbone of its conventional forces.[34] Tensions along the Angolan/Namibian border escalated throughout June, finally resulting in heavy exchanges on June 27. Rarely since 1975 had South African and Cuban forces confronted each other so directly.

Against this background, it is not surprising that the nuclear test site was being readied and the South African air force was interested in upgrading its nuclear forces. In the minds of the South African leadership, Buys recalled, the war was reaching a "semi-conventional state," implying in his statement that South African nuclear weapons could be needed. A common interpretation of the military situation had concluded that if the Soviet Union decided to win the war in Angola, South Africa could not have stopped it with conventional military forces. Another senior official in the nuclear weapons program similarly recalled that during the "Cuban crisis," Circle employees were "under a lot of stress" to produce nuclear weapons.

There is also a question whether in light of the increased threat, the leadership of South Africa was also thinking of escalating its nuclear posture. Buys said in an interview in February 1994 that the decision to reopen a shaft in the Kalahari Desert was a consequence of developments in Angola, although the intent was to do so without being discovered by foreign intelligence services. Despite Armscor's precautions, however, was this activity noticed by foreign intelligence services, and did South African political leaders exploit any such detection to send a signal to the world's powers?

Frank Pabian, a leading expert on South Africa's nuclear program, thinks South Africa did so.[35] He believes that the United States and probably Russia detected renewed activity at the site. In a recent report, Pabian states that South Africa's Foreign Minister Pik Botha told an interviewer that he was approached about the test site by the US ambassador, who showed him images of the shade over the test shaft.[36] In Pabian's view, the building activity over the test shaft had "intentionally or not, provided a means for South Africa to send a signal that a nuclear test was possible."[37] That signal may have been exploited by Pik Botha, according to Pabian, to demonstrate a nuclear deterrent capability in the event that Cuba and Angola attempted a surprise conventional military assault against Namibia after South Africa's withdrawal from Angola by September 1, 1988.[38]

To support his interpretation, Pabian points out that eight days after South Africa agreed to withdraw its troops, Pik Botha suddenly announced at a press conference in Vienna that South Africa had the "capability to make" a nuclear weapon "should [it] want to," but he refused to elaborate on that statement.[39] The Foreign Minister may have intended, perhaps on his own, to send a strong signal about South Africa's nuclear capabilities to Russia and the United States, figuring they were already worried about the test site activity.

Although tensions were decreasing by August 1988, the government had already made decisions to improve its nuclear weapons and possibly increase their number in parallel to the development of a more sophisticated nuclear strategy. To develop the capability to build these new weapons, the government decided to build a new facility close to the Circle facility that would make the advanced warhead for ballistic missiles.

NOTES

1. Interview with a former member of the nuclear weapons program, October 1995.

2. Prime Minister P.W. Botha, *Draft Speech of Prime Minister P.W. Botha for the Opening of Kentron Circle,* File No. 13/2/8/C, May 4, 1981, in Afrikaans, Original in Nic von Wielligh and Lydia von Wielligh-Steyn, *Die Bom* (Pretoria: Litera Puasies, 2014), Appendix, translated by Schreiber Translations, Inc. for Institute for Science and International Security, July 7, 2015.

3. *Draft Speech of Prime Minister P.W. Botha for the Opening of Kentron Circle,* op. cit.

4. Peter Liberman, "The Rise and Fall of the South African Bomb," *International Security,* Vol. 26, No. 2, Fall 2001, p. 53.

5. This plan was reiterated in a 1985 meeting and referred to as the 1978 plan. See *Meeting of Ad Hoc Cabinet Committee Chaired by Honorable State President,* September 3, 1985, *Die Bom,* op. cit., or the English version: Nic von Wielligh and Lydia von Wielligh-Steyn, *The Bomb* (Pretoria: Litera Publications, 2015).

6. *Draft Speech of Prime Minister P.W. Botha for the Opening of Kentron Circle*, op. cit.

7. Liberman, "The Rise and Fall of the South African Bomb," op. cit., p. 55.

8. Interview with Buys, April 5, 2001.

9. Liberman, "The Rise and Fall of the South African Bomb," op. cit., p. 56.

10. By 1984 the prime minister title was changed to State President.

11. *Meeting of Ad Hoc Cabinet Committee, The Bomb*, op. cit.

12. Liberman, "The Rise and Fall of the South African Bomb," op. cit., p. 56.

13. Interview with Buys, April 4, 2003.

14. Mitchell Reiss, *Bridled Ambition: Why Countries Constrain Their Nuclear Capabilities* (Washington, D.C.: The Wilson Center, 1995), pp. 15-16; and Interview with Buys, April 4, 2003.

15. *Presentation to Witvlei Committee: Kramat Capability: Current Status and Further Developments*, *The Bomb*, Appendix, op. cit., pp 486-496.

16. Liberman, "The Rise and Fall of the South African Bomb," op. cit., pp. 56-57.

17. Liberman, "The Rise and Fall of the South African Bomb," op. cit., pp. 56-57.

18. Witvlei means White Marsh in English. The word's origin in unknown.

19. *Meeting of Ad Hoc Cabinet Committee, The Bomb*, op. cit.

20. *Presentation to Witvlei Committee: Kramat Capability: Current Status and Further Developments, The Bomb,* op. cit.

21. Interviews with Buys, April 4 and July 31, 2003.

22. "The Rise and Fall of the South African Bomb," op. cit., pp. 57-58.

23. When the rocket has a satellite payload, an apogee kick motor is affixed to the top of rocket so as to propel the satellite into low earth orbit at the top of the rocket's parabolic trajectory. When the rocket has a warhead, it is topped by a re-entry vehicle that protects the warhead as it reenters the atmosphere on the downward portion of the parabolic trajectory.

24. For more details about these sites, see Hannes Steyn, Richardt van der Walt, and Jan van Loggerenberg, *Armament and Disarmament: South Africa's Nuclear Weapons Experience* (Pretoria: Network Publishers, 2003), pp. 75-82.

25. *Programme Dunhill: Development of a Nuclear Capability for the SADF, Decision of the Ad Hoc Cabinet Committee,* April 18, 1988, *The Bomb,* op. cit., p. 497.

26. *Presentation to Witvlei Committee: Kramat Capability: Current Status and Further Developments,* op. cit.

27. *Programme Dunhill: Development of a Nuclear Capability for the SADF, Decision of the Ad Hoc Cabinet Committee, The Bomb,* op. cit., pp. 497-498.

28. *Program Olympic: Corroborative Notes following the briefing of the Minister of Defence in Cape Town on 27 July 1987,* July 30, 1987, *The Bomb*, op. cit., pp. 484-5.

29. *Programme Dunhill: Development of a Nuclear Capability for the SADF, Decision of the Ad Hoc Cabinet Committee,* op. cit.

30. Chester Crocker, *High Noon in Southern Africa* (New York: W.W. Norton & Company, 1992), pp. 365-366.

31. Crocker, *High Noon in Southern Africa*, op. cit., p. 367.

32. *High Noon in Southern Africa*, op. cit., p. 367.

33. *High Noon in Southern Africa*, op. cit., p. 367.

34. *High Noon in Southern Africa*, op. cit., p. 372.

35. Frank Pabian, "South Africa's Nuclear Weapon Program: Lessons for US Nonproliferation Policy," *Nonproliferation Review*, Fall 1995, p. 28. https://www.nonproliferation.org/wp-content/uploads/npr/31pabian.pdf

36. Frank V. Pabian, "The South African Denuclearization Exemplar," *Nonproliferation Review,* 2015, Vol. 22, No. 1, pp. 27-52. http://dx.doi.org/10.1080/10736700.2015.1071969. Pabian cites a discussion at an international conference on South Africa's nuclear weapons program held in Pretoria on December 9-12, 2012, titled "The Historical Dimensions of South Africa's Nuclear Weapons Program." The conference is discussed, although not this information from Pik Botha, at https://www.wilsoncenter.org/article/international-conference-the-historical-dimensions-south-africas-nuclear-weapons-program

37. "The South African Denuclearization Exemplar," op. cit.

38. "South Africa's Nuclear Weapon Program," op. cit.

39. "Pretoria Says It Can Build A Arms," Reuters. August 13, 1988.

CHAPTER 7
ADVENA CENTRAL LABORATORIES

The 1987 decision to improve the quality and possibly the quantity of nuclear weapons opened the next phase of South Africa's nuclear weapons program. In a difficult economic time, monies were found to renovate and expand South Africa's capability to make nuclear weapons. The new complex was more spacious and capable, and a far nicer work environment than the Circle facility. The Circle building, located about five minutes from the new complex by car, became known as the "old building." As the inhabitants of Circle did not like this name for the old building, they decided to call it the "Castle," since its physical appearance to a certain extent resembled a castle.

The new facility cost about 36 million rand (about $15 million in 2016 dollars). Its codename was Advena Central Laboratories. The name's genesis is unknown, but Advena in Latin means the foreigner or stranger. Figure 7.1 shows two of the site's main buildings. Figure 7.2 is a commercial satellite image of the site taken after the nuclear weapons program ended.

The occupation of the new Advena facilities started during 1988, and the process of commissioning was still underway when the nuclear weapons program was terminated in the fall of 1989. Once Advena was completed, the Circle building would have been used for the maintenance of the existing gun-type nuclear weapons.

Advena would have concentrated on new types of weapons. After the program was cancelled, Armscor commercialized the facility, as will be discussed later.

Figure 7.1 The entrance to the main building of Advena Central Laboratories. On right image, the integration building is in the foreground and the main building is behind. The wide wing of the main building on the left of the main building holds the clean room. A double fence is visible on right of the photo. Photo Credit: Armscor and Albright

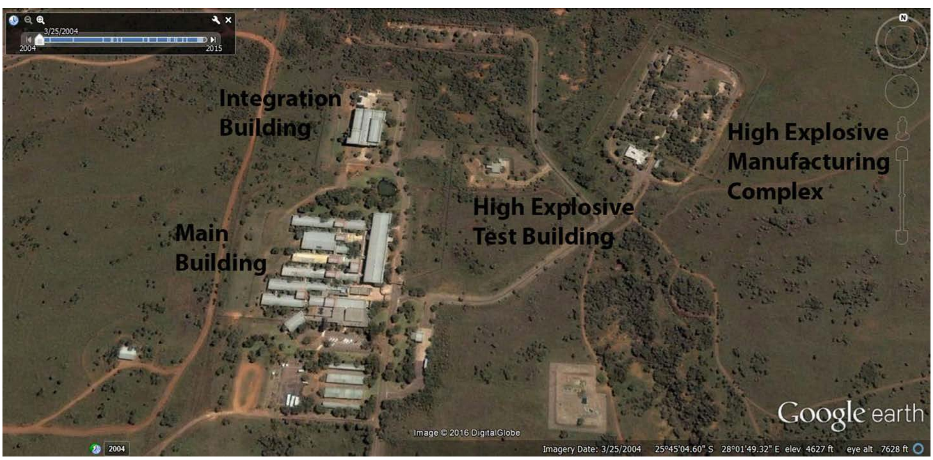


Figure 7.2 Google Earth commercial satellite image of Advena Central Laboratories taken in 2004.

WHY ADVENA?

The decision to build new facilities was motivated first by the decision to build the next generation of nuclear weapons. The government had mandated the development of implosion-type warheads, the continuation of theoretical work on all types of nuclear explosives including boosted and thermonuclear designs, and most importantly, the integration of a nuclear warhead onto a ballistic missile. The new site was designed by Armscor to be able to carry out these missions.

The development of a nuclear-tipped ballistic missile had emerged in the late 1980s as a feasible South African priority—one that was expected to drive Advena's first decade of operation. For ballistic missile warheads, Armscor planned to upgrade the 500-series gun-type nuclear weapons. Armscor said it planned to "replace the seven cannon-type devices with seven up graded devices, when they reached the end of their estimated life by the year 2000."[1] To that end, Advena planned to conduct nuclear-weapons development work on advanced gun-type and implosion-type devices able to fit on a ballistic missile. The site was designed with sophisticated capabilities in high explosives, ultra-high-speed diagnostics, theoretical calculations, metallurgy, high-speed electronics, and environmental and reliability testing.

Although Advena had many capabilities for advanced nuclear weapons work, its rate of weapons production would have been modest. Each year, it could have produced no more than about two to three weapons.

Advena Central Laboratories was built so that it could both develop and produce implosion-type devices. A key part of that effort was mastering high explosives. The new facilities could test larger amounts of high explosives than Circle, and these new capabilities allowed for an expansion of its development and evaluation of implosion technologies.

Moreover, Advena was also embedded with other capabilities to support the missile program. It was diversifying into conventional military pyrotechnics and missile control components, such as "jet vanes."

Despite the commitment to boosted and thermonuclear weapons development, Advena did not have a capability to handle tritium. Although South Africa had acquired tritium from Israel in the 1970s, and the AEC made lithium 6, Advena's lack of tritium capability suggests that boosted and thermonuclear weapons were not an Armscor priority beyond theoretical studies, as will be discussed below.

In addition, the new complex could house a larger staff. The nuclear weapons program had outgrown the Circle building. The labor force had increased from 100 to 300, and more space was needed. Workers expressed frustration with the small spaces in the Circle building. They expressed relief that the new buildings were better lighted than Circle, which had no windows and felt claustrophobic. Although cognizant of the risk of observation from satellites or other methods, the designers of the main building created a design with many windows and views of gardens (see figure 7.3).

Figure 7.3 Landscaped areas between two of the wings of the main building.

In addition, the Circle building was designed so that only project participants could enter the building. The new site, however, allowed visitors without divulging the true purpose of the program.

The site also had a more modern feel. Inside the entrance was a mural (see figure 7.4) containing many South African symbols with the phrase “Explore future technology today” written in Afrikaans on the top and English on the bottom. The symbols are far more relevant to aerospace engineers than nuclear engineers, which may reflect that the former dominated this nuclear weapons program and were increasingly comfortable in that role.

Figure 7.4 Mural in the lobby near the entrance to the main Advena building. Artist unknown

INTEGRATION BUILDING

The most notable new building at Advena was the integration and test facility (see figures 7.1 and 7.5). Finished in June 1989, it was designed for advanced weapons assembly and integration with delivery systems, in particular ballistic missiles. Its significance to those at the site is revealed in its nickname. This building was known as "Ararat," a Biblical reference to the sacred land or mountain where Noah's ark rested after the Great Flood subsided.

Figure 7.5 The integration building as viewed from the main building.

It had a long central bay with a large door at each end and rooms on either side of the bay. Its design allowed for a ballistic missile on a TEL to be driven into the building. Rooms on the side of the central bay were to produce reentry vehicles, balance warheads, cast and machine HEU, and store HEU, warheads, and reentry vehicles. Figure 7.6 shows the large central bay and a side room as it appeared in 2002, after the program ended. One of the large doors is visible in the background.

Figure 7.6 On left, the large central bay where a ballistic missile could enter and be loaded with a nuclear warhead. On right, one of several adjacent rooms for warhead manufacturing. The high security storage vaults were on the right side of the bay and near the far outer door. The CNC machines in the photos are not associated with the nuclear weapons program.

Figure 7.7(a) The outer high security vault doors in the Integration Building, with a view of the inner vaults.

The high security storage vaults were located near one end of the central bay at the end of a series of production rooms (see figures 7.7 (a) and (b). The new storage vaults contained space suitable for one small reentry body, according to Armscor.

A critical part of developing a nuclear-tipped ballistic missile is the re-entry vehicle, which holds the warhead. It must be able to withstand re-entry to the earth's atmosphere and is challenging to build. This task became more challenging because Armscor decided that the reentry vehicle would need to reenter the atmosphere at a high speed in order to thwart possible countermeasures against the warhead. The integration building was being outfitted with

Figure 7.7(b) Inner vaults. Each vault appears to require two codes or keys to enter.

the necessary equipment, including balancing and mass property machines.

Work was progressing on learning how to balance warheads. The task was further complicated because Armscor decided to avoid buying sophisticated balancing equipment abroad out of fear that seeking such goods would tip off foreign intelligence agencies that South Africa was trying to mate nuclear warheads to a ballistic missile. The domestic production of adequate equipment proved difficult. Moreover, Advena had little knowledge about what would constitute adequate balancing of a warhead or a reentry vehicle. It thus expected to spend a considerable amount of time developing both the necessary theoretical and practical expertise.

Seeking foreign help was not completely avoided, however. Personnel in the nuclear weapons program developed questions about the re-entry vehicle that South Africa' space launch experts could not answer. One of the South African nuclear weapons personnel went to Israel and got the answer from unwitting Israeli experts by couching the questions in a satellite discussion. Based on an agreement at the head of government level, South Africa and Israel had agreed not to discuss nuclear weapons, only space launch-related issues. Whether this particular visit was sanctioned by Armscor is unknown.

MAIN BUILDING

The main building had offices, labs, and a variety of support facilities, including a library, cafeteria, and an auditorium. Completed in February 1989, the main building had about 100 offices or rooms. The main building was known as Uitsig, or good view, in Afrikaans.

The building had a range of laboratory and small-scale industrial capabilities. Unlike the Circle building, it had a "clean room" for more advanced manufacturing, including more sophisticated electronics manufacturing. Figure 7.8 shows the clean room a few years after the program ended. This facility is the long, wide wing of the main building visible in figures 7.1 and 7.2. Figure 7.9 shows the entrance to the electro-mechanical area in the main building.

The main building, like Circle, contained a range of equipment related to making nuclear weapons components. For example, in one room in the early 1990s (see figure 7.10) there was an Italian-supplied precision coordinate measurement machine used to ensure

Figure 7.8 Clean room in main building in early 1990s. Photo source: Armscor

Figure 7.9 Entrance to the electro-mechanical area in the main building, with a high security vault inside the room in left image.

that manufactured items met specifications. This same type of machine, the DEA Iota 2204, can be seen in operation an online video.[2] International Atomic Energy Agency inspectors reported finding nuclear weapons component gauges near this machine when they inspected Advena in 1993. These are essentially exact models of a nuclear weapons component, and they asked South Africa to destroy them. Earlier, this DEA machine may have been in one of the bunkers in the high explosive manufacturing area, according to a former member of the nuclear weapons program who saw a coordinate measuring machine there (see below).

Armscor decided to create its own nuclear weapons theoretical group at Advena. Some of its members moved to Advena from the AEC's program still housed in building 5100 below the main site at Pelindaba. By the late 1980s, four or five people remained in the AEC theoretical group and were involved in nuclear weapon simulations and investigations of basis processes in a nuclear explosion, including neutronics and nuclear physics. However, they were not involved in designing nuclear devices. After the opening of Advena and the creation of an in-house theoretical group in 1989, the AEC ended its theoretical work on nuclear weapons, in essence ending the last vestiges of the Reactor Development Division. Figure 7.11 shows some of their offices at Advena, as they appeared during a visit in 2002. Those who moved from the AEC to Advena believed they had moved nearer to the center of the weapons program.

Figure 7.10 A DEA machine in Advena main building in early 1990s. Right image, as the area appeared in 2002 after machine removed. Source: Advena Central Laboratories advertising brochure from the early 1990s and Albright.

Figure 7.11 Wing that housed the nuclear weapons theoretical group. The partitions had been removed and the room converted to another purpose. A large vault was at the other end of this wing (not shown).

Armscor and the AEC acquired various computer codes abroad and then applied them to the weapons program. These included codes for calculating two dimensional shaped charges. However, the weapons program in general was satisfied with one dimensional integrated neutron and hydrodynamic codes. The weapons-specific computer codes, which had been created over many years, were at the AEC until May 1988, when they were transferred to Advena with the closure of the Reactor Development Division.

HIGH EXPLOSIVE TEST FACILITY

The high explosive test facility, which was completed in July 1991, was a small building licensed to withstand the blast of up to 10 kilograms of TNT while measuring blast phenomena (see figure 7.12). It was intended to develop the shaped charges of an implosion-type nuclear device. It was known as Toiings, or tatters, in Afrikaans.

The core of the building is a test chamber with thick concrete walls lined with wooden beams that prevented shrapnel from chipping the concrete walls. Figures 7.13 (a) and (b) show the inside of the blast chamber, where shaped charges were tested, and the three-tonne blast door. Portals are visible through which flash x-ray machines and fast cameras record the blast. Figure 7.14 shows the room with the pedestals that held this equipment and the portals. The facility housed a 450 keV flash x-ray, possibly of U.S.-origin, and a streak camera (100-1000 ns/mm).

Figure 7.12 The high explosive test facility, with integration building in background. Lightening arresters are visible.

Figure 7.13(a) The inside of the high explosive test cell, able to conduct tests of up to 10 kilograms of high explosives. The tests would be conducted in the sand pit. Open and closed portals are visible.

Figure 7.13(b) The high explosive test cell was sealed by a three-tonne door that was closed hydraulically.

Figure 7.14 The inside of the high explosive test facility showing where the flash x-ray and streak camera had been positioned on pedestals behind the portals. The photo was taken in 2002 after the facility had been repurposed to a classroom on nature conservation for former South African military personnel.

In contrast, the indoor high explosive test cells in the Circle building could handle only 2.5 kilograms of high explosives. Figure 7.15 shows the blast door to Circle's ballistic testing area, which had eight small cells, each of which had a blast cover on top of it. Based on looking at the circular blast cover of a single cell in figure 7.15, Circle's blast cells appear significantly smaller than the test chamber at the Advena site.

To successfully import high speed cameras for implosion-related testing, Armscor knew that it would need to deceive a foreign supplier, which would never approve an export to South Africa's nuclear weapons program.[3] At the time, South Africa could buy such cameras for a civil industry. So, in at least one case, Armscor used a mining company as a front. Armscor invested funds to create a high explosive facility at the mining company so that this facility could plausibly argue that it needed a fast camera. The camera was bought using a false end user certificate of this mining company. Once received, it was diverted to Armscor. At some point, the exporter visited


Figure 7.15 In left image, the heavy, electrically controlled sliding blast door to the test cell area at the Circle building (closed). On right image, orange blast covers cover the high explosive test cells in the western end of the Circle building. Each cell was considerably smaller than the blast test cell at Advena.

the mining company to check that the camera was there. However, the exporter gave the mining company typically two weeks advance notice of their visit, reflecting the time needed to receive a visa. Two weeks was more than enough time to move the camera back to the mining company, so that it could be seen by the supplier. After the supplier left, it was moved back to Armscor.

HIGH EXPLOSIVE PROCESSING FACILITY

The high explosive manufacturing facility, finished in September 1989, was composed of six bunkers, a control building, and an administrative office involved in high explosives processing, storing, testing, and manufacture. The general assembly bunker (G6) was licensed to handle up to 200 kilograms of high explosives. The facility was known among the workers as Knopppiesaagte, or valley with bulges, in Afrikaans (figures 7.16-7.20).

Just before the end of the program, Advena illicitly acquired an explosion-proof five axis computer-numerically controlled milling machine from Japan (Ikegai) to machine precisely high explosive lens in the manufacturing bunkers. The precise shaping was judged necessary for the small implosion device Armscor was developing for its ballistic missiles.

Figure 7.16 High Explosive Manufacturing Site

Figure 7.16 High Explosive Manufacturing Site

Figure 7.18 Entrance to bunker G2 from outer perimeter road.

Figure 7.19 Top photo, bunker G6 looking in direction of G2. Lightening arresters are visible. Bottom photo, inside bunker G6. The cars are unrelated to the former nuclear weapons program.

Figure 7.20 Inside the control building at center of site. Original panels from time of nuclear weapons program.

ADVANCED NUCLEAR WEAPONS

The South African nuclear weapons program remained focused on developing and then improving deliverable gun-type devices. Since its start, however, members of the program had studied and developed advanced nuclear weapons, and South Africa had a long list of them in which it expressed interest. Nevertheless, as the program evolved, implosion-type nuclear devices received the most attention followed by the use of thermonuclear materials to "boost" the explosive yield of a fission weapon. Several advanced weapons concepts were barely studied, discarded, or postponed until some distant future.

Further, questions have been raised about whether South Africa received nuclear weapons assistance from other countries. China and Israel in particular are mentioned. South African officials have maintained that South Africa did not receive nuclear weapons designs or devices from any other country.

ADVENA CENTRAL LABORATORIES

Building	Completion date	Comments
Offices and labs	February 1989	The main building had about 100 offices and a “clean room” for more advanced manufacturing, including more sophisticated electronics manufacturing. The main building was known as Uitsig (good view in Afrikaans)
Integration and test facility	June 1989	Designed for advanced weapons assembly and integration with delivery systems. It had a long central bay with a large door at each end and rooms on either side of the bay. These rooms were to make and balance reentry vehicles, to cast and machine HEU, and store HEU, warheads, and reentry vehicle. The central bay was large enough to drive in a ballistic missile. This building was known as Ararat.
High explosive processing facility	September 1989	Composed of six bunkers and a control building for explosives processing, storing, testing, and manufacture. The general assembly bunker was licensed to handle up to 200 kilograms of high explosives. Facility known as Knopppiesaagte (or valley with bulges);
High explosive test facility	July 1991	A small building licensed to withstand the blast of up to 10 kilograms of TNT while measuring blast phenomena. Intended to develop the shaped charges of an implosion-type nuclear device. It was known as Toiings (tatters)
High explosives magazine	September 1989	
High explosives demolition facility	September 1989	Called Brandlaagte in Afrikaans.

ADVANCED GUN-TYPE NUCLEAR DEVICES

Armscor intended to develop a more advanced gun-type nuclear device. The target date for completing this device was 1996. The modified device would have used a more modern propellant and improved electronics. Armscor officials have made clear that if a missile warhead were developed, it may have carried an advanced gun-type warhead and not an implosion-type warhead. To that end, it needed to modify the series 500 warheads' safety mechanism that prevented the HEU projectile from entering the HEU core when the barrel and sleeve mechanism were not aligned. This system was asymmetrical about the warhead's central axis and thus not usable on a ballistic missile where symmetry is required for a successful flight. It was just starting to develop an acceptable new safety mechanism.

One loose end when the program ended was creating a new gun-type device for use in an underground test. The original Melba device was to be replaced by an updated device in 1991, codenamed Modulus; how much work was accomplished on this new device is unknown.[4] This device would be expected to incorporate the latest safety mechanisms of the 500 series of devices. It would also likely have been designed for more rapid deployment at the test site than was possible with Melba, requiring additional or upgraded placement and control equipment.

IMPLOSION-TYPE NUCLEAR DEVICES

Although research on implosion-type devices had occurred since the beginning of the nuclear explosive program in the early 1970s, implosion research did not become a priority until the mid-1980s. One reason cited by former members of the program, is that the leaders of the program did not believe that an implosion weapon was really needed, given the focus on building gun-type nuclear devices.

By the 1980s, however, little work was being done at the AEC. Even its theoretical nuclear weapons work was not specific to an implosion design, although some of the basic physics research done in building 5100 could be applied to implosion designs.

The implosion work was taken over by Armscor. In the mid-to-late 1980s, its motivation was not strictly the development of an implosion design.[5] Armscor was interested in developing a method to use about half as much HEU per device, allowing the recycling of HEU in seven gun-type devices into 14 implosion-type devices. Another motivation was that lighter, smaller weapon systems could become available in the future, and implosion weapons could be miniaturized more easily than the gun-type devices. Another more immediate purpose, which applied to other advanced weapon designs as well, was to help maintain the interests of the scientists and engineers who were involved in the design of the gun-type devices. The goal was to keep weapons scientists and engineers engaged by working on more challenging problems. This plan had the immediate spin-off of helping maintain the technology base for the maintenance of gun-type systems.

Armscor's implosion effort focused on developing, maintaining, and demonstrating a technical level of sophistication. Although implosion development had always been present in South Africa's nuclear explosive efforts, Advena's capabilities were far more extensive and reflected a stronger commitment to the development of a small implosion device.

Circle engineers correctly realized that a major stumbling block in developing an implosion system would be determining that a design would work satisfactorily. This problem was considerably simpler in the case of a gun-type device. The implosion program recognized that understanding compression during the detonation of the high explosives would be key to success, and decided to focus on developing good diagnostic capabilities to understand this phenomenon. The primary focus of the implosion effort during the late 1980s, according to Armscor, "was on the development of measurement systems which could be used during the 1990s." These included the development of diagnostic capabilities with flash x-rays, streak cameras, and flyer plates with pins that would allow for high explosive experiments where progress could be carefully documented.

By the end of the program, a number of implosion technologies were being developed.[6] They included:

- High explosive charge design;
- Ignition mechanisms;
- Detonic measuring techniques;
- Neutron triggering;
- Computer simulation and analyses;
- Plane wave lenses;
- Flyer plate acceleration (study on high explosive compaction);
- Casting experiments (TNT, HMS, Mixtures but not TATB);
- Isostatic pressing experiments (PBXs); and
- Machining experiments on simulants (plastics).

Safety considerations were being factored into future implosion designs. An implosion device poses a risk that an accidental detonation of high explosives will trigger a nuclear explosion. To reduce this risk, Circle engineers began producing small quantities of TATB, an "insensitive" high explosive, in 1988. Insensitive explosives ignite at higher temperatures than ordinary explosives. Firing a bullet into TATB will not cause it to detonate.

The program imposed very strict criteria on the implosion design. By the end of it, there was still no agreement on the specifications of a design, but the high explosive lens design had received most of the attention, according to a former member of the program who worked on the implosion effort.

According to Armscor leaders and members, the implosion device was to have a diameter of no more than about 50 centimeters, a size likely dictated by the RSA-3 missile re-entry vehicle. It would utilize about half the amount of HEU as the gun-type device, or 28 kilograms of weapon-grade uranium. The actual amount would have depended on the design ultimately developed, but would have likely been in the range of 20-30 kilograms of weapon-grade uranium in a solid ball. This relatively small diameter, according to another former senior Armscor member, placed a "tremendous constraint on the implosion system."

Although no full-scale prototypes had been built, nor any designs developed in detail, the program did have a cut-away scale wooden implosion model. One participant remembered that it was of the high explosive system.

Unlike South Africa's gun-type design, an implosion device would require a neutron initiator able to start the chain reaction at a precise moment. Armscor turned to the AEC to develop a miniaturized neutron generator based on accelerating deuterium into a tritium target. However, by the time the weapons program was cancelled, the AEC had built only a large laboratory model about 60 centimeters long. They were able to get pulses of neutrons but had not yet miniaturized it. The then implosion design required a neutron initiator that was no longer than about 15 centimeters, or one fourth as long as the lab model.

To develop implosion technologies, South Africa acquired a range of diagnostic and manufacturing equipment overseas. As discussed earlier, it had acquired flash x-rays and fast cameras. It also procured an isostatic press for pressing high explosives and a specialized five-axis computer controlled machine tool for precisely shaping the high explosives.

It was recognized that an implosion system would be easier to build with plutonium rather than HEU. However, without a source of plutonium, or the means to handle it safely, Armscor did little work on a plutonium-based implosion designs.

Armscor conducted at least one high explosive test of the spherical core using a surrogate material for the HEU. In 1987, the program conducted a six-point detonation test of a high explosive package with a steel ball at its center at the large Boskop high explosive test site several kilometers from Potchefshoom (southwest of Johannesburg). However, the test was unsuccessful; the steel ball was ejected and rolled down the hillside. Nonetheless, more tests were planned, using 12- and 20-point tests.

The Boskop site operated by Naschem had a high explosive detonics facility that was adequate to conduct large-scale implosion package tests. The site was comprised of a small high explosive test bunker, a flash x-ray machine of 300 KeV, and two streak cameras, one with a framing speed of half a million frames per second. Later, after the program ended, Armscor advertised this site as having a flash x-ray and an ultra-speed camera with a framing speed of up to 20 million frames per second.[7]

It is unknown whether Armscor would have ultimately built implosion devices as replacements for the gun-type devices. Armscor engineers have acknowledged that they would have faced many challenges producing an implosion weapon manufactured to the same level of demanding safety, security, and reliability specifications as the gun-type device. Nonetheless, Advena engineers appeared to be taking the right steps to build an implosion device, and they allowed for sufficient time. According to an Armscor official, a decision on building implosion weapons was still ten years away when the weapons program was canceled.

A senior Armscor official said that an implosion-weapon program would have required full-scale cold tests of the implosion system with a natural uranium core. Conducting such tests regularly, he said, "would have posed risks with regard to detection." One solution was to build a closed facility to conduct such tests. If Armscor had decided to build a closed arena large enough to contain the detonation of large quantities of high explosives in a cold test, the arena would have cost about 12 million rand. This sum, he said, was considerable for the Advena program.

According to a former senior leader of the program, it may have been difficult to convince people that an implosion design would work without full-scale testing. If a full-scale nuclear test was needed to certify the weapon, the nuclear strategy would have had to be modified, another major challenge. This possible need for a full scale test was another factor that could have discouraged a decision to build and deploy implosion-type nuclear weapons. At the least, developing methods to provide adequate safety, security, and reliability without full-scale testing would have likely delayed the program.

ARTILLERY SHELLS

For years rumors had abounded that South Africa made a warhead that could have been fired from its 155-mm artillery system, called the G-6. A major reason for this rumor was South Africa's announcement in 1982 that this system was capable of carrying a NATO nuclear warhead.[8] In fact, South Africa conducted paper studies of artillery shells armed with nuclear devices, according to its declaration to the IAEA. Nonetheless, this project did not advance beyond preliminary paper studies of nuclear-armed artillery shells, according to Armscor officials involved in the program. The studies, including at least one done in the late 1980s, included shells with a diameter of 155 millimeters. Artillery shells with a gun-type device were also worked on. Earlier, following the 1985 decision, work had stopped on an artillery shell containing an implosion system using plutonium, according to South Africa's declaration to the IAEA.

BOOSTED DEVICES

South Africa was interested in the idea of "boosting" the yield of its fission weapons by using a small amount of tritium and deuterium. The idea was to increase the explosive yield from 10-20 kilotons to 60-100 kilotons. Small-scale theoretical work on the basic principles of nuclear fusion had started.[9] Both a gaseous and solid form of the fusion fuel were considered. However, the gaseous form would have required the insertion of tritium and deuterium at high pressure into a capsule or reservoir, which the program judged as beyond South Africa's capability.[10] A solid pellet of lithium, tritium, and deuterium was selected instead.

For the gun-type device, the pellet would have been placed in the HEU projectile, according to South Africa's declaration to the IAEA. Such placement would have been consistent with South Africa's command and control philosophy because the tritium in the fusion pellet decays radioactively in a relatively short period of time. Thus, the pellet would require periodic replacement.

Armscor, however, had little interest in boosted devices. In the 1980s, its weapons effort was not ready for such an advanced concept and in any case not prepared to study the practicalities of boosting.

Moreover, Circle and Advena Central Laboratories did not have any facilities to handle tritium, which is very radioactive. In addition, Armscor officials said, if the purpose of the bomb program was to demonstrate capability, why would yield matter?

The work never moved to the point where tritium was used. In any case, the work was stopped in 1987, according to South Africa's declaration to the IAEA. However, theoretical work may have continued afterwards or could have been restarted eventually.

Whether an effort to make a boosted device would have materialized later is unknown. If it did, a new source of tritium would have been needed. Starting in 1987, the AEC started to sell the tritium that had been imported from Israel ten years earlier. Much of this tritium had already decayed radioactively since tritium has about a 12 year half-life.

The AEC decided to use its tritium handling laboratory, called the Gas Laboratory, at Pelindaba for making radio-luminescent light sources.[11] Of the initial quantity of about 19.9 grams of tritium, about 9.31 grams were withdrawn from the four cylinders through 1992 and about four grams were sold as light sources as of 1993.[12] By this date, the cylinders had been emptied and were then disposed as waste because small amounts of tritium remained on their inner walls. By 1992, over half of the tritium had been lost through radioactive decay. Some, less than a gram, was also lost through uncontrolled releases or retained on container walls and disposed. Over time, more of the unused tritium decayed or was sold.

THERMONUCLEAR WEAPONS

Although thermonuclear weapons were on a list of technologies to develop, little work was accomplished. The open literature was studied and some preliminary work was done by AEC or Armscor experts, but nothing concrete, according to a senior Armscor official. There were lectures for program personnel on the subject, but one official who attended found the presentation simplistic and more like a report on an open literature search.

FOREIGN ASSISTANCE ON NUCLEAR WEAPONS

There have been allegations that Israel provided or offered nuclear weapons to South Africa, particularly in the 1970s. One often discussed case involves a declassified document describing a secret 1975 meeting in Pretoria between Minister of Defense P.W. Botha and Israel's Defense Minister Shimon Peres. In this meeting Botha expressed interest in receiving a limited number of units of "Chalet," provided the correct payload could be provided.[13] The Israeli Defense Minister said that the correct payload was available in three sizes. Chalet was a codename for the Jericho missile, and some have concluded that one of the "sizes" must have been nuclear. In essence, according to this interpretation, Botha was expressing interest in buying nuclear weapons from Israel and a ballistic missile to deliver them. Although the declassified document summarizing this discussion does not mention a nuclear payload, it is plausible to assume that a nuclear warhead was one option, given the coded nature of the discussion. It would also be expected in such a delicate discussion that deniability of any such possibility would be preserved.

After the document was made public, Peres and South African officials denied that the discussions involved the sale of any nuclear weapons. However, their denials do not settle the issue, given that the nature of the payload has not been revealed.

Complicating matters, following an earlier meeting in 1975 where Israeli officials offered South Africa Jericho missiles,[14] the South African military chief of staff wrote in a secret memorandum that "in considering the merits" of the offer, "certain assumptions have been made: that the warhead will be armed with nuclear warheads manufactured in the RSA [Republic of South Africa] or acquired elsewhere."[15] This memorandum added credibility to the claims that Botha was considering buying nuclear weapons later that year. However, this memorandum does not state that South Africa asked Israel for nuclear weapons or that Israel offered them. It could as well be interpreted as the defense official expressing his own views about the growing need for South Africa to make a decision about obtaining nuclear weapons and reliable, credible delivery systems. Given concerns about the growing sophistication of enemy air defense systems, he mentions the need to consider acquiring "stand-off television-guided bombs or surface-to-surface missiles," noting that at that time South Africa possessed neither and would be advised to add these "very expensive but highly efficient weapons to our armoury." In 1975 the South African defense establishment, headed by Botha as Defense Minister, was just starting a discussion about acquiring nuclear weapons. At the time, South Africa was concentrating on its peaceful nuclear explosives (PNEs) in a program run by the Atomic Energy Board that envisioned an underground test rather than deliverable nuclear weapons. Yet the official's offhand mention of acquiring nuclear weapons elsewhere implies that he may have thought that in addition to indigenous production, Israel could also be a source for them.

Long before the declassification of the documents discussed above, the ex-Soviet spy Dieter Gerhardt said he had learned that in 1975 Israel had offered South Africa several Jericho missiles with six "special" warheads.[16] He correctly said that the project was codenamed Project Chalet. He said that the special warheads were nuclear, based on his asking a more senior South African military official. Gerhardt's information must be taken seriously; as a senior military official who spied for over twenty years, he had "access to some of the most sensitive information" in the South African Defense Force, according to former senior defense and nuclear officials.[17] At a minimum, Gerhardt's information would imply that some senior South African military officials believed that Israel was offering nuclear weapons to Pretoria or at least considering a request from South Africa for them.

In any case, Botha decided not to proceed with buying any Chalets at that time, and the Israeli prime minister may have been unwilling to approve a sale in any case. So, the nature of the payload was never established concretely in any deal.

Avner Cohen, a well-respected Israeli nuclear historian, makes a convincing argument that Israel did not make an actual offer to sell nuclear weapons to South Africa. He writes: "To the contrary, the conversation amounted to a probe by the South Africans, which ultimately went nowhere."[18] He added that he believes that both Israel's then Prime Minister and its head of the nuclear program would have "opposed the sale of nuclear weapons, technology, or even components—not just to South Africa, but to anyone." However, what remains unclear is whether Botha made a direct or veiled request to purchase them.

The answer to what Botha intended with respect to Chalet payloads may never be known. He was an intensely secretive leader. However, what is known is that Botha himself dates 1975 as when he "initiated discussions in respect of the possibility of creating nuclear weapons" for South Africa.[19] Perhaps these negotiations with Israel focused South Africa's defense establishment on the value of nuclear weapons and its perceived need to acquire advanced delivery systems. Until then, the South African military had expressed little interest in the PNE program run by the nuclear program. As discussed earlier, all of that would change in the late 1970s, as South Africa decided to build deliverable nuclear weapons. In parallel, it decided to build the stand-off television-guided bomb and later the capability to make surface-to-surface missiles in cooperation with Israel.

This episode highlights both countries' skittishness with regard to discussing nuclear weapons. Armscor officials interviewed by one of the authors were unaware of any discussions with Israel in the 1970s about nuclear weapons. However, they have stated often that during the 1980s, when Armscor controlled the nuclear weapons program, Armscor did not cooperate with Israel on nuclear weapons. One official added that the mere mention of cooperation on nuclear weapons was taboo.

As is well-known, there was extensive cooperation between the scientists and engineers of Armscor and Israel on rockets, which each side called space launch cooperation. However, both countries used or planned to use these rockets as ballistic missiles to carry nuclear weapons, even if in the case of South Africa the rockets would also place a satellite into orbit. Moreover, in the case of South Africa, there were Armscor experts who simultaneously worked on both the ballistic missile and nuclear weapons programs. Thus, the possibility for exchanges of sensitive nuclear weapons information cannot be excluded, despite both countries' officials stating that their countries maintained official policies banning such cooperation. However, like the case discussed earlier about a South

African engineer seeking data about re-entry vehicles from Israelis, Armscor engineers or scientists may have sought other sensitive nuclear-related information. They may have operated under general instructions to pick up sensitive information whenever they could; South African nuclear officials had such orders.[20] However, other than information about re-entry vehicles discussed earlier, no evidence was found that nuclear weapon information was obtained by South Africa from Israel.

The South Africans reported good cooperation with Israel on space launch vehicles but over time that cooperation suffered from the two countries having different operational requirements for their rockets, according to a former senior Armscor official. This official also said that Israel became worried about the cooperation during the mid-to-late 1980s, as international pressure against the apartheid government intensified. Despite their deteriorating relationship, by the late 1980s South Africa with Israeli assistance had created a robust rocket program expected to launch reconnaissance satellites and deploy nuclear-tipped intermediate range ballistic missiles.

SOUTH AFRICA'S NUCLEAR FUTURE

As the 1980s closed, South Africa's nuclear weapons and ballistic missile programs were poised to make significant, albeit rather slow, advancements. Advena's main objective was to develop the necessary capability by the year 1996 to support a government decision to deploy a nuclear warhead on a ballistic missile. A multi-year development effort was viewed as acceptable because of the number of obstacles that had to be overcome. As 1989 dawned and Advena became operational, however, the political winds in Southern Africa were shifting to greater regional accommodation and peace. The planned nuclear and missile future was not to be.

NOTES

1. Armscor, Written responses to queries by one of authors, Spring 1993.

2. DEA IOTA 2203, YouTube, February 24, 2014, https://www.youtube.com/watch?v=P3UyXfBumAk

3. Interview with former senior member of South Africa's nuclear weapons program, 2003.

4. *Program Olympic: Collaborative Notes Following a Briefing of the Minister of Defense in Kaapstad on July 27, 1987,* dated July 30, 1987, in Afrikaans, Original in Nic von Wielligh and Lydia von Wielligh-Steyn, *Die Bom* (South Africa: Litera Puasies, 2014), Appendix, translated by Schreiber Translations, Inc. for Institute for Science and International Security, July 7, 2015. See also English version, *The Bomb*, (Pretoria: Litera Publications, 2015).

5. Johann Viljoen and Deon Smith, *The Birth, Life, and Death of South Africa's Nuclear Weapons Program*, Unpublished manuscript commissioned by the Institute for Science and International Security, 1999.

6. Information sheet provided to the IAEA by South Africa, undated but in period immediately following President de Klerk March 1993 announcement of a prior nuclear weapons program.

7. "From Bomb-filling to Advanced R&D," *Engineering Week: ARMSCOR Annual Survey* (Johannesburg, 1989), p. 22, cited in Frank Pabian, "South Africa's Nuclear Weapon Program: Lessons for U.S. Nonproliferation Policy," *Nonproliferation Review*, Fall 1995. https://www.nonproliferation.org/wp-content/uploads/npr/31pabian.pdf

8. Jaap Boekkooi, "Whose Basements Have a Bomb?" *The Star*, Johannesburg, September 29, 1982, p. 29.

9. *The Birth, Life, and Death of South Africa's Nuclear Weapons Program*, op. cit.

10. Nic von Wielligh and Lydia von Wielligh-Steyn, *The Bomb*, op. cit., p. 175.

11. Atomic Energy Corporation, "Tritium Programme," undated (about 1993), unpublished.

12. "Tritium Programme," op. cit.

13. Sasha Polakow-Suransky, *The Unspoken Alliance* (New York: Pantheon Books, 2010). See also, *Die Bomb* op. cit., which contains some of the documents in its appendix.

14. *The Unspoken Alliance*, op. cit.

15. "The Jericho Weapon System," from CS [Lt. General R.F. Armstrong] to C SADF, date March 31, 1975, stamped top secret. The declassified document was obtained by Peter Liberman. See Liberman, "Israel and the South African Bomb," *Nonproliferation Review*, Summer 2004.

16. Interview of Dieter Gerhardt, March 9, 1994.

17. Hannes Steyn, Richardt van der Walt, and Jan van Loggerenberg, *Armament and Disarmament: South Africa's Nuclear Weapons Experience* (Pretoria: Network Publishers, 2003), p. 91.

18. "Avner Cohen on Israel and South Africa," *ArmsControlWonk.com*, May 24, 2010 under Israel, media-criticism by Joshua Pollack.

19. Prime Minister P.W. Botha, *Draft Speech of Prime Minister P.W. Botha for the Opening of Kentron Circle,* File No. 13/2/8/C, May 4, 1981, *Die Bom,* op. cit.

20. Albright, *Peddling Peril* (New York: Free Press, 2010), p. 105; and Interview with former leader of gas centrifuge program.

CHAPTER 8
NUCLEAR ROLLBACK

By the 1980's, several events were significantly changing the fundamental security situation in Southern Africa and increasing political support among white South Africans for an end to apartheid. These changes created the preconditions for denuclearization, even while support for nuclear weapons was growing in the South African military.

The June 1988 military exchanges between South African and Cuban troops along the Angolan/Namibian border appeared to shock both sides into finalizing a negotiated settlement. The US government was brokering a comprehensive peace settlement in Southern Africa in an effort led by Chester Crocker, then Assistant Secretary of State for African Affairs.[1]

On August 5, 1988, South Africa, Cuba, and Angola established a *de facto* cease fire, followed by the complete withdrawal of South African troops from Angola by September 1, 1988.[2] The agreement, called the "Geneva Protocol," was followed on December 22, 1988 with a tripartite agreement, signed at the United Nations by Cuba, South Africa, and Angola, which provided for Namibia's independence, the redeployment of Angolan and Cuban troops to northern Angola, and the withdrawal of 50,000 Cuban troops from Angola.[3]

The settlement of these long-standing issues in Angola and Namibia removed the major external security threat to South

Africa. The withdrawal of South African forces from Namibia went smoothly, and its old enemy, SWAPO, won the independence elections. The process demonstrated to white South Africans that major change could occur without catastrophic results. It also opened the door to a new set of expectations, namely that South Africa might move away from a confrontational relationship with the international community to one of cooperation and development. The idea of South Africa as a regional leader for peace and prosperity started to emerge.

Parallel to achieving a settlement in Angola and Namibia, the leadership of Soviet President Mikhail Gorbachev fostered the perception in the South African government that the Soviet Union was no longer the threat it used to be. In particular, Gorbachev reduced the impression among white South Africans that Moscow was behind all the imperialist ventures in southern Africa, and thus a major threat to its security. Since the African National Congress was viewed by Afrikaaners as a stalking horse for Moscow, this shift in belief meant that the government could now begin a more realistic reevaluation of South Africa's domestic situation. Direct governmental negotiations with the ANC need not be seen by white South Africans as tantamount to national suicide. The collapse of the Berlin Wall in late 1989 brought an end to the Cold War and signaled the end of the Soviet threat in Southern Africa.

A growing desire to end apartheid may also have contributed indirectly to a reevaluation of the South African nuclear weapons program. By the late 1980s, economic sanctions and the withdrawal of investments from South Africa, combined with racial unrest, had left South Africa in its deepest financial crisis ever. In light of South Africa's worsening economic situation, many important members of the ruling National Party had come to believe that apartheid was unworkable and that a political solution was needed to dismantle the system. Several years of secret discussions between key Afrikaaner leaders, Nelson Mandela, and other ANC leaders in the mid-to-late 1980s had convinced much of the white leadership of the ANC's moderation and its willingness to negotiate if all restrictions were lifted. It also convinced them that its rise in power within

South Africa was inevitable,[4] or at the very least, many members of the National Party realized that the ANC and its political allies could not be defeated.

Although the above changes were necessary for a nuclear rollback, they may not have been sufficient. In 1988 and 1989, Armscor was finishing a new set of nuclear weapon production facilities and was initiating a long-term modernization program of South Africa's nuclear arsenal. This included developing nuclear-tipped ballistic missiles and possibly increasing the total number of nuclear weapons. A change in political leadership appears to have been necessary as well.

The most important patron of this weapons program, and opponent of ending apartheid, was President Botha, whose well-known explosive temper and authoritarian manner earned him the nickname the "old crocodile." Although Botha was committed to reforming the apartheid system, he was unwilling to sacrifice Afrikaaner power in the process. For example, in the early 1980s, he created the powerful new office of State President and a tri-cameral Parliament. It gave separate houses to the Colored and Indian communities, a controversial action that split the National Party. This led to the creation of the Conservative Party, whose members saw even these modest reforms as going too far.

Despite the controversy over his policies, Botha's changes were seen by blacks as token reforms at best and served mainly to inflame them. His efforts to suppress the black rebellion were ruthless and intensified throughout the second half of the 1980s. It left him increasingly isolated in his efforts to defeat the rebellion before allowing any negotiations with black leaders, which, according to Botha's vision, would proceed only with "moderates" and not with the ANC.

Further serving to undermine reforms, Botha had created a parallel governing structure dominated by security elements. When he came to power in 1978, Botha launched basic changes in the governmental structures for decision-making and implementation that led to the concentration of security issues in the hands of a revived State Security Council. This council was composed of the so-called "securocrats"—mostly military, intelligence, and security officials, and a few of his closest ministers. The State Security Council, which was highly conservative, became the central instrument of control of the country, bypassing Botha's own National Party and the Parliament, a fact increasingly resented by the members of the National Party.

Botha went further in concentrating power on certain secret projects, such as the nuclear weapons program. This project was never discussed in the State Security Council and only with those ministers who had a strict need to know.[5] Cabinet level decisions on nuclear weapons, such as limiting the program in 1985, appear to have been made by an ad hoc group of ministers, including Defense, Foreign Affairs, Finance, and Mineral and Energy Affairs (see chapter 5).

In early 1989, an opportunity for significant political change appeared. Despite both the untenable domestic and international situation, Botha exhibited no intention to step aside. In January 1989, he suffered a stroke and then unexpectedly resigned as leader of the National Party. Botha retained his position as State President, however, which sparked a political crisis since South Africa's constitution provided that the leader of the strongest party is also head of government. Although the desire for change was mounting within the National Party, few expected significant change when, in February 1989, F. W. de Klerk won the party leader position over several candidates who were considered "reformists" but were too closely linked to the securocrat faction.[6] The stage was now set for de Klerk to oust Botha and claim the Presidency. Following a dramatic confrontation with his cabinet ministers in August 1989, Botha resigned as president on August 14, 1989.[7] De Klerk became acting president the next day, and won the whites'-only election held in September, ushering in a new era for South Africa.

As has been extensively documented elsewhere, the political rise of F. W. de Klerk led to a fundamental transformation in South Africa. This included the freeing of Nelson Mandela and hundreds of other political prisoners, the lifting of a ban on the ANC, the demilitarization of the government's decision-making processes, and the starting of negotiations with the ANC and other opposition parties to work out a new national constitution. Unseen and in parallel to these profound changes, de Klerk decided to secretly terminate South Africa's nuclear weapons program and dismantle the existing nuclear weapons.

DE KLERK'S DECISION

Because he had been the Minister in charge of the Atomic Energy Corporation, namely Minister of Minerals and Energy Affairs several years earlier, de Klerk already knew about the nuclear weapons program. He had even attended the opening of the Kentron Circle Building in 1981 (see chapter 5). However, he had never been in Botha's "inner circle," so he never had an impact on the program or much to do with decisions about it. De Klerk said that by the time he became President in September 1989, "it was already evident to me, and also to my colleagues who were also informed, that it was in our national interest that a total reverse—also in respect to our nuclear policy—was called for."[8] Given the international and domestic changes that had occurred, President de Klerk believed that "a nuclear deterrent had become, not only superfluous, but in fact an obstacle to the development of South Africa's international relations."[9] The desire to rejoin the international community was a primary motivation for many of his subsequent actions.

Waldo Stumpf, the head of the Atomic Energy Corporation at the time, tells an anecdote that sheds some light on de Klerk's thinking. One or two weeks after assuming office, de Klerk called a meeting of a few key Ministers and experts, including Stumpf. According to Stumpf, President de Klerk said that he wanted to make South Africa a "respected member of the international community, and we'll have to turn around the politics and we'll have to terminate this program, turn it around and accede to the Nuclear Non-Proliferation Treaty."[10] The termination process, Stumpf says, started then.

De Klerk believed that world opinion had become increasingly opposed to nuclear weapons. He also thought that South Africa would acquire significant advantages if it acceded to the NPT, which would include international exchanges of nuclear technology beneficial to South Africa's future. When South Africa did so in the summer of 1991, de Klerk expressed his hope that joining the treaty "[would] facilitate the international exchange of nuclear technology, which is not only important for the maintenance and further development of South Africa's own nuclear program, but [would] also be to the benefit of its neighboring states and the international nuclear community."[11] Nuclear weapons would have spoiled any such cooperation.

At home, opposition to the nuclear weapons program had been growing within portions of the top leadership, particularly after South Africa's security situation eased in 1988 and the Soviet Union and the Warsaw Pact showed increasing signs of disintegration. Some of de Klerk's colleagues who knew about the weapons program had lost their faith in the potential usefulness of the arsenal. For example, Jeremy Shearer, then a senior member of the Department of Foreign Affairs (DFA) who had been responsible for nuclear matters, recalled that he and others in the government had begun to wonder what might actually occur if South Africa exercised its nuclear option in a military crisis with front-line states and their Warsaw pact allies.[12] He had come to believe that if South Africa implemented this strategy, the actual effect might be to invite the combined wrath of both the United States and Russia. The unintended result could be the end of the South African government, rather than its preservation.

Initial opposition appears to have been mainly centered in the Department of Foreign Affairs. A DFA memorandum from 1988 shows strong opposition to the AEC and Armscor's positions of maintaining the then nuclear weapons strategy and not signing the Nuclear Non-Proliferation Treaty. DFA's argument, which is in a response to a document circulated by the AEC and Armscor, centered on the point Shearer mentioned above. It also included a range of concerns that the policy of strategic nuclear uncertainty was not deterring South Africa's enemies, but rather leading to greater international condemnation, all at a time when South Africa needed greater international integration to solve its political, energy, and social problems.[13]

Among those that believed the strategy had worked to deter Cuba and the Soviet Union, many of them agreed in general that regional and international changes had made the program unnecessary. Even Armscor's leadership, according to former leaders of the program, had started to recognize the impact of these changes; at least they were not surprised by de Klerk's actions.

Questions have been raised regarding why de Klerk acted so quickly on the nuclear issue after becoming State President. Mitchell Reiss, who studied the South African nuclear program in the early 1990s, believes that de Klerk needed to seize the opening produced by his election victory to dismantle the program.[14] He quotes a senior South African official: "If [de Klerk] had waited, he never would have gotten cabinet approval, since opposition to giving up the program in the defense community was great."[15]

Significantly, many senior Armscor officials, who could have been strong advocates of continuing the nuclear weapons program, did not oppose ending it.[16] Although the program had considerable momentum, the growing consensus among key Armscor leaders was that it was no longer needed because of the dramatic changes occurring in Southern Africa and the former Soviet Union.

Moreover, at the time of the dismantlement decision, Armscor understood that its space launch program would survive. This high-tech program was considerably larger than the nuclear weapons program in terms of personnel, infrastructure, and funding. To Armscor, the demise of the nuclear weapons program had little institutional impact, although it had major strategic consequences and required careful consideration of how to end the program safely and securely. To Armscor's great disappointment however, a few years later it was forced to abandon its space launch vehicle program as well. This decision was much harder to swallow for Armscor officials.[17]

Members of de Klerk's government have consistently denied that the dismantlement decision was motivated by a desire to prevent nuclear weapons or unsafeguarded materials from falling into the hands of an ANC-led government, i.e. to prevent a "black bomb." In 1989 Stumpf reports that de Klerk was not really worried about the ANC getting the bomb; at least the discussion did not surface when he was present in meetings.[18] Another former member of the program, who was also involved in implementing the dismantlement decision, similarly does not believe the question of inheritance was a major consideration of de Klerk.

However, according to André Buys, who in 1990 had become General Manager in charge of planning for Armscor, many in the program thought that a debate on the future of nuclear weapons would be harmful at that critical point in the transformation of South Africa.[19] In addition, it is believable that de Klerk and his advisors did worry about whether a future multi-party government could successfully share control over the nuclear arsenal. Eliminating the arsenal before launching major reforms of the government, in this view, prevented potential conflict among the major parties and created a regional and international policy against nuclear weapons. Because the ANC had opposed the South African nuclear weapons program, it would find it hard to oppose what de Klerk had done.

Although there is little evidence that de Klerk's thinking was dominated by concerns about a future ANC-led government inheriting nuclear weapons, Western intelligence agencies and right-wing military officials apparently worried a great deal about this possibility. To these groups, the prospect of an ANC-controlled nuclear program that might have included stocks of nuclear weapons or highly-enriched uranium was a major concern up to the time of the first democratic elections in April 1994. According to a 1993 article in the London *Sunday Times,* Western intelligence officials were concerned about the "unstable security situation in South Africa," and had expressed "deep disquiet that a future ANC government might be tempted to start its own weapons-making program, or to sell the [highly enriched] uranium either to Libya, Iran, or the Palestine Liberation Organization, all of which gave the movement support during the years in exile."[20]

Much later, after de Klerk publicly revealed the existence of the nuclear weapons program, South African and US officials expressed surprise to one of the authors at the support for nuclear weapons they heard from a few important members of the ANC. Individual members of the ANC, some of whom were destined for high office, expressed their opposition to the de Klerk government's decision to abandon nuclear weapons.[21] These opinions, however, were never the mainstream opinion of the ANC leadership, and in particular not those of Nelson Mandela.

As an informal advisor in 1993 and 1994 to the ANC nuclear policy group chaired by Roger Jardine, one of the authors (Albright) was struck by the ease with which Mandela publicly supported the NPT well before his election to the Presidency. Albright had raised the issue with Jardine of Mandela endorsing the NPT one day in the summer of 1993. Jardine approached Mandela. Within a few days, Mandela in a public statement on August 30, 1993 pledged: "The ANC will abide by the Nuclear Non-Proliferation Treaty, and we fully support the declaration by the Organization of African Unity calling for the establishment of the African continent as a nuclear weapons-free zone."[22] Despite many differences over the timing and details of past government announcements about the nuclear weapons program, Mandela unambiguously agreed that nuclear weapons would not be a part of South Africa's future.

NOTES

1. Chester Crocker, *High Noon in Southern Africa* (New York: W.W. Norton & Company, 1992).

2. “The Geneva Protocol, 5 August 1988,” in Appendix 3, *High Noon in Southern Africa*, op. cit.

3. “Tripartite Agreement, 22 December 1988, in Appendix 6, *High Noon in Southern Africa*, op. cit. See also “Bilateral Agreement, 22 December 1988,” in Appendix 5, *High Noon in Southern Africa*, op. cit.

4. For a more complete discussion of these changes see Alister Sparks, *Tomorrow is Another Country* (New York: Hall and Wang, 1995).

5. F.W. de Klerk, *The Autobiography: The Last Trek, A New Beginning* (London: Macmillan, 1998), p. 273. See also Nic von Wielligh and Lydia von Wielligh-Steyn, *The Bomb* (Pretoria: Litera Publications, 2015), Appendix.

6. *Tomorrow is Another Country*, op. cit., p. 88.

7. For a detailed description of this showdown between Botha and de Klerk see, Sparks, *Tomorrow is Another Country*, op. cit., pp. 88-90.

8. State President F. W. de Klerk, “Speech by the State President, Mr. F. W. de Klerk, to a Joint Session of Parliament, 24 March 1993,” Transcript of speech given in Cape Town. See also “De Klerk Discloses Nuclear Capability to Parliament,” FBIS-AFR-93-056, March 25, 1993, pp. 5-9.

9. State President F. W. de Klerk, “Speech by the State President, Mr. F. W. de Klerk, to a Joint Session of Parliament, 24 March 1993,” op. cit.; “De Klerk Discloses Nuclear Capability to Parliament,” op. cit.

10. Transcript of speech by Waldo Stumpf, South African Embassy, Washington, D.C., July 23, 1993.

11. David Ottaway, “South Africa Agrees to Treaty Curbing Nuclear Weapons,” *The Washington Post*, June 28, 1991, p. A25.

12. Interview with one of the authors, Vienna, September 1993.

13. “Report, South African Department of Foreign Affairs, 'A Balanced Approach to the NPT: Armscor/AEC Concerns Viewed from a DFA Standpoint,'” September 1, 1988, History and Public Policy Program Digital Archive, South African Foreign Affairs Archives, NPT-IAEA Agreement/Negotiations on full-scope safeguards. Obtained and contributed by Anna-Mart van Wyk, Monash South Africa. >http://digitalarchive.wilsoncenter.org/document/114185 or http://digitalarchive.wilsoncenter.org/assets/media_files/000/001/671/1671.pdf

14. Mitchell Reiss, *Bridled Ambition: Why Countries Constrain Their Nuclear Capabilities* (Washington, D.C.: The Wilson Center, 1995), p. 22.

15. Mark Hibbs, "South Africa's Secret Nuclear Program: The Dismantling," *Nuclear Fuel*, May 24, 1993, quoted in Reiss, *Bridled Ambition*, op. cit., p. 22.

16. Interview of Armscor officials by one of the authors, 1995.

17. Hannes Steyn, Richardt van der Walt, and Jan van Loggerenberg, *Armament and Disarmament: South Africa's Nuclear Weapons Experience* (Pretoria: Network Publishers, 2003), pp. 98-103.

18. Interview with one of the authors, Pelindaba, February 1994.

19. Interview with André Buys, January 23, 2003.

20. Richard Ellis, "Pretoria Seeks Haven for its Nuclear Stocks," *The Sunday Times*, August 15, 1993.

21. See also *Die Bomb*, op. cit., p. 277.

22. Shirley Woodgate, "Science Must Serve Democracy — Mandela," *The Star*, August 31, 1993.

CHAPTER 9
DISMANTLING THE NUCLEAR WEAPONS

The end of the nuclear weapons program was an emotional experience for those who had labored tirelessly in secret to build the deliverable nuclear weapons. The previous few years had been particularly stressful, when most of the production quality nuclear weapons were built and tensions escalated in Angola.

Those in the program had to be told what President de Klerk had decided. After all, they would be the ones actually carrying out the dismantlement of the nuclear weapons. Armscor gathered those in the program into the new cafeteria at Advena Central Laboratories to tell them of their fate soon after President de Klerk had publicly announced the end of apartheid in February 1990 (see figure 9.1).

After that dramatic speech, heralding a far different South Africa, most of the employees were not surprised by the decision to dismantle the nuclear weapons, according to one of the leaders of the Armscor nuclear weapons program.[1] They understood the lack of need for these dangerous weapons. Nevertheless, the announcement was an emotional blow to many of the workers, who had become like family. There was some relief that the government had decided to convert Advena to commercial purposes, ensuring that their jobs were secure, at least for a while.

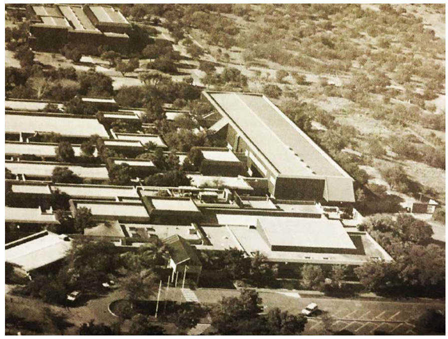


Figure 9.1 Cafeteria in Advena's main building near the front entrance, as it appeared in 2002. Here in early 1990, members of the nuclear weapons program heard that the nuclear weapons were to be dismantled. In the aerial image on right, the cafeteria appears on the bottom right of the building, with the sloped roof. The long building behind the cafeteria is where the clean rooms were located. Photo Credit: Albright (left) and Al Venter, *How South Africa Built Six Atom Bombs* (right).

ORGANIZING AND IMPLEMENTING NUCLEAR DISARMAMENT

Soon after taking office in the fall of 1989, President de Klerk ordered the creation of an Experts' Committee to investigate various ways to dismantle the nuclear arsenal and to draw up a schedule for dismantlement and accession to the Nuclear Non-Proliferation Treaty as a non-nuclear weapon state.[2] This committee, which included senior officials of the AEC, Armscor, and the South African Air Force, examined the entire dismantlement process over the next several weeks.[3]

Committee members were in consensus in their recommendations to de Klerk, but that did not mean that there had not been disagreements along the way. Should the arsenal be dismantled before announcing the existence of the program? Who outside the program should witness the dismantlement process? Some advocated that the weapons should be dismantled in exchange for something tangible from the international community.[4] However, this committee ruled out the IAEA as a body to verify the actual dismantlement process. The dismantlement would occur in secret and a nuclear weapons program would be denied, which would make it impossible to trade dismantlement for concrete benefits.

This committee gave its report to de Klerk in November 1989 with a formal recommendation to dismantle the arsenal and an outline of the dismantlement procedures.[5] According to Waldo Stumpf, then head of the Atomic Energy Corporation and a leader of the dismantlement effort, de Klerk approved the plan in principle.[6] He issued an instruction to stop the production of further nuclear devices, to shut down the Y Plant, and to dismantle South Africa's nuclear capability before accession to the NPT.

A few more months would pass before the formal dismantlement process was established. Many details needed to be worked out first.

Several recently declassified and translated documents shed light on the dismantlement decisions.[7] Codenamed the Mantel Project, the plan was intended for final review and approval by de Klerk. Outlined in a document dated February 8, 1990, it called for dismantling all the nuclear weapons and half-completed devices, components, and material in a tightly controlled manner along with melting down the HEU components.[8] In keeping with the decision to keep the nuclear weapons program secret, the plan stated: “Perform the necessary cleaning operations to attach credibility to the statement that the RSA [South Africa] did manufacture highly enriched uranium but did not undertake the final step of manufacturing nuclear weapons.”[9] Thus, the existence of the weapons would be denied but not the production of HEU. Because of the ability of the IAEA to detect traces of HEU at the Y Plant and in the surrounding area, which had also been contaminated with HEU, hiding the AEC’s production of HEU was assessed as impossible.[10] However, as will be discussed later, an effort was made to hide the presence of HEU at the Circle complex.

On February 26, 1990, de Klerk issued a written authorization to (1) release from the storage vault at Circle all existing nuclear devices and components, both complete and incomplete, (2) dismantle all existing nuclear devices, and (3) to transfer the HEU in a safe and secure manner to the AEC for storage. He ordered that the dismantling and cleaning up process take place under the supervision of a steering committee composed of senior members of the South African Defense Force, AEC, and Armscor. (Stumpf eventually became the head of steering committee).[11] De Klerk also appointed an independent expert to audit the entire process and to report independently to him.[12]

The President in the February 26th document also charged the steering committee to evaluate and approve the plan for dismantling the weapons and decontaminating the related facilities, to approve the dismantling process step-by-step, and to report regularly to the State President.

The steering committee's full set of specific responsibilities are not mentioned in the documents released by von Wielligh. However, key participants on the Steering Committee and its subsidiary working group charged with carrying out the dismantlement, have discussed these responsibilities. The following list was compiled mainly from a report by Stumpf.[13] Other responsibilities are added below this list and their sources cited.

- Dismantle the six completed gun-type devices and the pre-production "cold devices" at Advena under controlled and safe conditions;
- Melt and recast the HEU from these six devices, as well as from the partially completed seventh device, and to return it to the AEC for safe-keeping. Careful accountability measures must be followed;
- Decontaminate the Armscor facilities fully and return severely contaminated equipment to the AEC, such as the melting furnace;
- Convert the Advena/Circle facilities to conventional weapon and non-weapon commercial activities;
- Destroy/dispose non-nuclear components of the devices as well as technical design and manufacturing information. (Many components were recycled or left at Circle);
- Advise the de Klerk government of a suitable time-table for accession to the NPT, signature of a comprehensive safeguards agreement with the IAEA, and submission of a full and complete national initial inventory of nuclear material and facilities, as required by the safeguards agreement; and
- Close down the Y Plant at the earliest moment.[14]

Additional responsibilities of the steering committee included:[15]

- Maintain security and safety during the dismantlement process;
- Carefully and sympathetically handle personnel through alternative employment, early retirement, and retraining. Before leaving employment, every member was to be debriefed and re-motivated for the changed circumstances. "Security (and motivation) follow-ups were arranged in those cases where it was known that the decision caused financial hardship or moral backlash;"[16] and
- Conduct an internal audit of the nuclear weapons program by a combined South African Defense Force, Atomic Energy Corporation, and Armscor internal audit team.

According to Stumpf, before actual dismantling of the nuclear devices could occur, the steering committee in conjunction with the working group had to create extensive operational procedures to fulfill the safety and security requirements associated with the dismantling process. The committee had to develop procedures on destroying equipment and documents and on handling the nuclear material. The dismantlement process also involved many security risks because disgruntled employees could decide to reveal the program's existence or steal materials or documents. As a result, procedures to inform program personnel about the dismantlement procedure needed to be established.

The steering committee also developed two options for dismantling the arsenal.[17] One option called for first dismantling one-half of each device, for example, the front end of each device, before destroying the remaining halves. This option would be the quickest way to eliminate the arsenal. The other option involved dismantling one device at a time, allowing South Africa to preserve a nuclear capability until the last weapon was dismantled. De Klerk chose the slower option and approved the rest of the Steering Committee's procedures in July 1990. Dismantling then started. Table 9.1 shows the dismantlement schedule of the seven devices with HEU, in particular when HEU was removed from the front sections of the devices and when the rest of the device was dismantled.

TABLE 9.1: DISMANTLEMENT SCHEDULE OF SOUTH AFRICAN NUCLEAR EXPLOSIVE DEVICES, AFTER PRESIDENT DE KLERK'S DECISION TO DISMANTLE THE NUCLEAR ARSENAL (ARRANGED CHRONOLOGICALLY WITH RESPECT TO REMOVAL OF HEU)

Name of Device	Rear or Front Part	Start of Dismantling (HEU removed)	Completion of Dismantling (Rest of Device)
Set 7(1)		July 16, 1990	July 26, 1990
504	Rear	July 1990	October 1991
	Front	August 1990	October 1991
503	Rear	October 1990	October 1991
	Front	November 1990	October 1991
Video/ Melba	Rear	January 1991	February 1991
	Front	February 1991	February 1991
502	Rear	March 1991	September 1991
	Front	April 1991	September 1991
501	Rear	May 1991	September 1991
	Front	July 1991	September 1991
306	Rear	August 1991	September 1991
	Front	August 1991	September 1991

NOTES AND COMMENTS

1. The HEU core was recast.
2. The source for this table is South Africa's 1993 declaration about its nuclear program.

The center of dismantlement activities was the Circle and Advena facilities, by then collectively referred to as Advena. During the dismantlement process, the devices were removed from the vault at the Circle building and HEU removed. The HEU was melted and recast into ingots of a few kilograms each and then returned to the vault. Special shelves were installed in one internal vault to safely store the recast HEU ingots without causing a criticality accident. The nonnuclear components were taken from a device and grouped according to their design sensitivity and fate. A quality control group kept a careful record of the origin (by device) of each component and its subsequent destination. Sensitive components were either dismantled into raw materials and non-sensitive parts or destroyed by cutting and melting. Sensitive pyrotechnical components were destroyed. Explosives from the device (and samples stored separately for life-expectancy testing) were destroyed by detonation. As much as possible, components from different devices were grouped together and then cut up or destroyed in only a few campaigns. Non-sensitive components were transferred to Circle's stores or disposed as scrap. The dismantlement process is outlined in the sidebar for what Armscor called a "cold device," which was a nuclear explosive device that did not contain HEU.

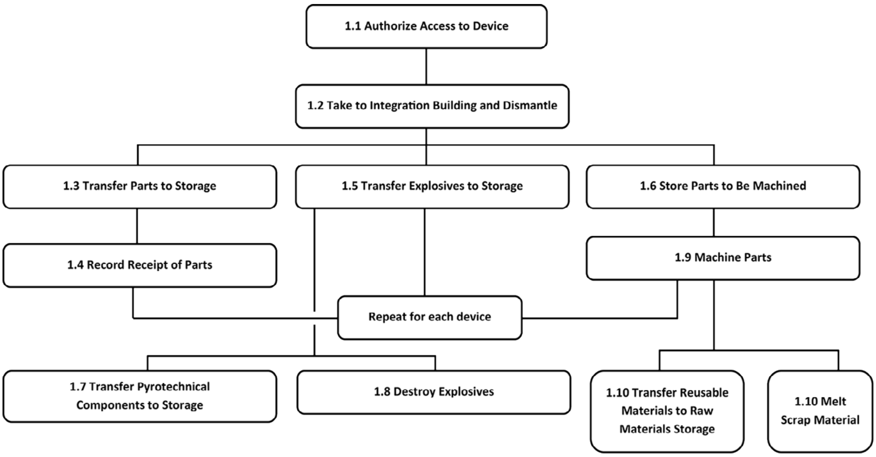
Before the last device was dismantled, de Klerk was asked if he was certain of his decision.[18] The President told Armscor and the AEC to finish the job.

To ensure secrecy, the HEU was sent from the Circle building back to Pelindaba at night in the trunks of Toyota sedans. For security reasons, Armscor initially had scheduled many military guards to patrol the road without informing them of the true purpose of their mission. Nevertheless, the increased activity attracted the attention of people living in the area. One curious neighbor of the site demanded to know what was happening. Subsequent shipments were done without arousing such curiosity, and involved far fewer guards. In total, about 20 shipments of HEU occurred over the four nights, March 12/13, March 14/15, September 3/4, and September 5/6, 1991.[19]

Soon after sending the last HEU to the AEC, the Circle building was completely decontaminated, and contaminated equipment that

DISMANTLING A COLD DEVICE

The following diagram is from a document preserved by South Africa and translated into English, titled "Rendering Harmless of Cold Device." Following the diagram is a description of each step in the diagram.



1.1 AUTHORIZE ACCESS TO DEVICE

The front and rear part of the device will be released simultaneously for dismantling. Concerned persons are:

ADVENA:	Integration Group	Mr ________
AIR FORCE:		Mr ________

The formal release for dismantling will be entered into the logbooks.

1.2 TAKE TO INTEGRATION BUILDING AND DISMANTLE

The device will be dismantled, and the individual parts will be grouped as indicated on the Parts List.

Dismantling will be done by ________ and ________ During dismantling the Quality Control Group will keep a record of the origin and destination of the various parts, and the record will be continuously updated. A device (front and rear parts) will be dismantled in the course of a week, but attempts will be made to speed up the process for subsequent devices.

1.3 TRANSFER PARTS TO STORAGE

Following the dismantling of the device, all parts deemed necessary for storage (ref. Parts List) will be transferred to raw materials storage. Storage staff will transfer components to the appropriate storage as soon as adequate numbers are available. The Quality Control Group will record the physical location of the transferred parts.

1.4 RECORD RECEIPT OF PARTS

The responsible storage staff will receive the parts at zero value. The parts will be stored separately. The storage staff may decide on the storage locations; however, it is important that the components can be traced.

1.5 TRANSFER EXPLOSIVES TO STORAGE

Following removal of the explosives from the device, they will immediately be placed in appropriate containers and transferred temporarily to explosives storage.

1.6 STORE PARTS TO BE MACHINED

Parts which need to be machined (ref. Parts List) will temporarily be transferred to storage so that they can later be machined in one campaign. It is recommend that the integration area be cleaned and used for this purpose.

1.7 TRANSFER PYROTECHNICAL COMPONENTS TO STORAGE

The pyrotechnical components which are not to be destroyed, such as detonators and cords, will be transferred to explosives storage and made available for later projects.

1.8 DESTROY EXPLOSIVES

The explosives from the device, as well as the separately stored samples used for life expectancy testing, will be destroyed in one major destruction campaign. The destruction will be carried out by ________ and ________ and be controlled by the Quality Control Group.

1.9 MACHINE PARTS

Sensitive parts that must be rendered harmless through machining must be stored in a location where they can be easily accessed. The machining must take place in the ADVENA workshop. The Quality Control Group must maintain records of the parts machined.

1.10 TRANSFER REUSABLE PARTS TO RAW MATERIALS STORAGE

Parts which are not classified as sensitive shall be transferred to raw materials storage and may be used for other projects.

1.11 MELT SCRAP MATERIAL

Parts which can no longer be used as raw material must be deformed in such a manner that they can be transferred to outside companies as scrap to be melted.

had been used for the re-melting and casting of HEU sent to the AEC. Most other machine tools and equipment were decontaminated, if necessary, but remained at Advena for commercial nonnuclear applications. Computerized testing equipment was rendered useless for the weapons program by destroying the specific software that controlled the equipment's operation. In addition, the main uranium processing section of Circle was carefully decontaminated. Walls were removed, and the concrete floor jacked out. Contamination was reduced to background levels. Special doors were built over the high security vault that would have served as part of an effort to hide the vaults from inspectors (see figures 9.2 (a) and (b)). As per ordered, the intent was to leave the room clean enough so that South Africa could plausibly deny the existence of the nuclear weapons program. Armscor officials stated that they personally did not believe that the program would ever be revealed.[20]

This portion of the dismantlement work was completed by September 6, 1991, approximately two months after South Africa acceded to the NPT on July 10, 1991, but prior to entry into force of the safeguards agreement on September 16, 1991.

By September 1991, not all of the major nonnuclear components of the weapons had been destroyed. In addition, detailed design drawings, computer software used in weapons design, documents, and photos of components remained. The retrieval of the classified records took time. The dismantlement team retrieved and indexed over 12,000 technical documents that described the design of the Y Plant and other nuclear weapon production facilities along with the methods for building nuclear weapons.[21] The documents were stored in a steel cage near the Circle building until they were burned in 1993.

Only on March 17, 1993 did President de Klerk order the destruction of the sensitive documents. The destruction orders were not limited only to technical documents; even the nuclear strategy and nuclear weapons policy documents were ordered destroyed before de Klerk announced the program.[22] By March 24, 1993, when President de Klerk announced the program's existence, sensitive weapon components had been destroyed or damaged beyond re-use.

Figure 9.2(**a**) High security storage vault in Circle that held nuclear weapons, as it appeared in 2002, with outer doors to hide vault, in open and shut position. If the IAEA had asked to visit the Circle building prior to March 1993, the outer doors could have been blended into a blank wall to hide the vault from the inspectors.

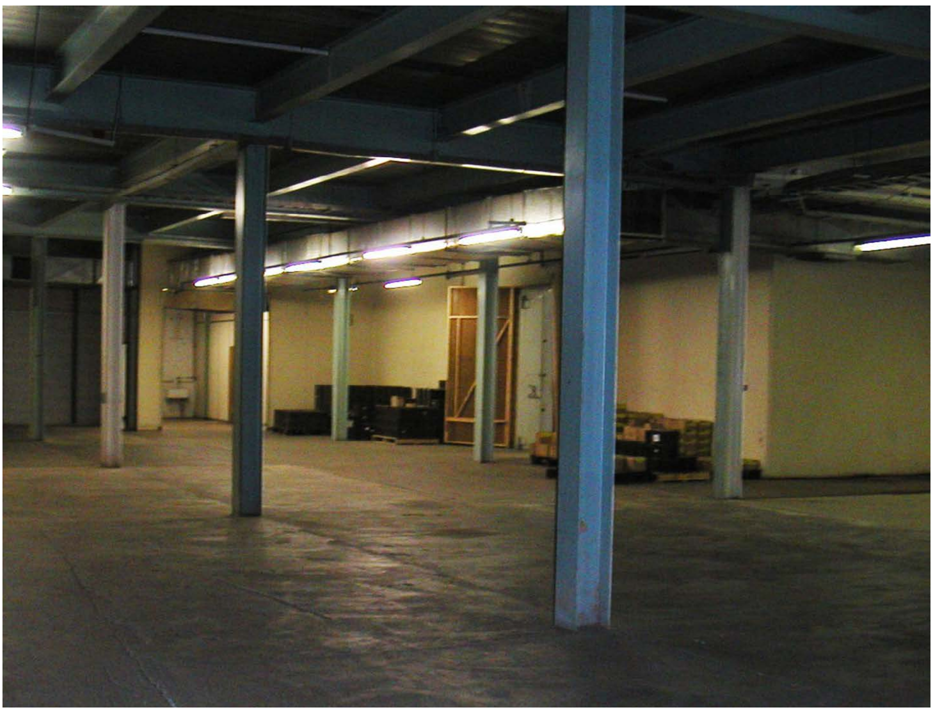


Figure 9.2(**b**) The uranium processing area after the removal of the original concrete floor and partition walls with the vault in the background.

De Klerk ordered certain documents to be preserved, mainly those needed to verify key decisions, the amount of HEU produced, the number of nuclear devices produced, and dismantlement operations. Because the production and material accountancy records of the Y Plant had been identified early in the process as critical to the verification that could be required under the NPT, the AEC had retained those records. South Africa also retained original documents relating to the initiation and termination of the project. By law, South Africa was required to keep medical and radiological records of all project personnel for 30 years.

Dismantlement records varied in their detail and thoroughness. Dismantling records involving HEU weapon components were detailed; however, records for natural and depleted uranium used in the pre-production devices were sparse and non-quantitative. The dismantling records for the non-nuclear components were brief and largely involved listings of component systems dismantled from the deliverable nuclear devices. Records were absent for the dismantling of the pre-production experimental devices or the Melba device. There were no destruction records for the components.

In the February 26, 1990 order to dismantle the program, President de Klerk nominated Professor Wynand L. Mouton, a well-known retired nuclear physicist and academic, to audit the dismantlement process. He was tasked with ensuring that it was done in a safe, secure, and responsible manner, along with regularly informing de Klerk personally about the progress of the dismantlement.[23] Mouton, in short, was de Klerk's representative during the dismantlement and clean-up process.[24] He attended all steering committee meetings both during the planning and execution stages, contributing ideas and suggestions and responding to requests for his advice.

Mouton's primary responsibility was to help ensure that nuclear materials and secrets were not diverted. Because he was an auditor and thus present at Advena only a fraction of the time, he first sought to determine if he could trust the people responsible for the dismantlement process. Many of them had been his students or colleagues during his long professional career, but he needed to ascertain if they "kept information away from him."[25] In general, Mouton later reported the personnel involved in the dismantlement process were both competent and trustworthy.

Although some people reportedly expressed unhappiness with the decision to give up the nuclear weapons program, their concerns had more to do with hesitancy to give up on something they had worked years to create.[26] Such concerns, however, influenced Mouton's recommendation to de Klerk to select the dismantlement option that would leave the country with a nuclear deterrent until the last weapon was dismantled. Mouton believed that this option was the "wiser one at that stage of the whole process"[27] and would help "acclimate the dismantlement team to the reality of the president's decision."[28]

Typically, Mouton would go to the Circle or Advena facilities two to three times a month, staying a day or more. He witnessed the dismantlement of the first device and returned later to see another weapon taken apart. In particular, he wanted to see the HEU components in the weapons. When the HEU ingots were sent back to the AEC, Mouton also accompanied the shipments in a separate car on two of the four nights. He also sampled the documents in the steel cage at Advena to ensure that the record keeping system was accurate, and he was present when the records were burned.[29]

Mouton reported personally to de Klerk, in most cases, briefing the president orally from his notes. On March 23, 1993, Mouton presented de Klerk with a final report that contained his judgments about the dismantlement process. He declared that the dismantlement objectives had been accomplished satisfactorily, namely that the nuclear devices were dismantled, all hardware for the nuclear devices in possession of Armscor was destroyed, no evidence was found that any documents ordered destroyed were deliberately withheld, and all of the highly-enriched uranium at Advena was sent back to the AEC.[30]

According to de Klerk, Mouton was charged "to satisfy himself that every gram of nuclear material had been accounted for and all the hardware and design information was destroyed."[31] However, despite Mouton's declaration, he could not accomplish such precise verification of the dismantlement process. For example, Mouton determined that the amount of HEU that was taken from the nuclear devices was "a few hundred grams" more than the amount subsequently returned to the AEC.[32] This amount, Mouton observed, was only a fraction of the amount needed for a nuclear weapon. He was not surprised by this small discrepancy, however, because the process of recovering the HEU involved steps such as removing the nickel coating that led to such losses of HEU.[33] More importantly, Mouton was unable to provide credible assurance to those outside the government, particularly the IAEA, that no weapons or HEU had been hidden away.

Because some employees in the nuclear weapons program were suspected of having far right-wing sympathies, Armscor had to ensure that the program was phased out in an orderly manner without leakage of fissile material or sensitive information. To minimize these risks, the government decided to commercialize Advena Central Laboratories and to gradually reduce the size of its operations. Its intent, according to Armscor officials, was "to reduce the risk of a security leak, or the even more serious risk of proliferation when persons with sensitive information [were] laid off." When the Advena employees were told in February 1990 of the end of the program, to soften the impact of the decision, management informed them that the site would be converted to the production of civilian products and that they were important to achieving this new goal. The commercialization decision allowed the program to shrink more slowly and thus provided time for members of the program to find other work. According to a former member of the program, this "cooling off period" enabled a more natural attrition in the workforce to occur. The workforce was reduced from about 300 to 100 during the first year.[34] Nonetheless, this rate of workforce reductions would be quite severe for any company.

Utilizing the remaining general and nonnuclear equipment, Advena sought to become a manufacturer of peaceful and commercial products during the first half of the 1990s.[35] Figure 9.3 shows the cover of Advena's commercial brochure that advertised its new products, which collectively looked like they were produced at a former nuclear weapons production site.

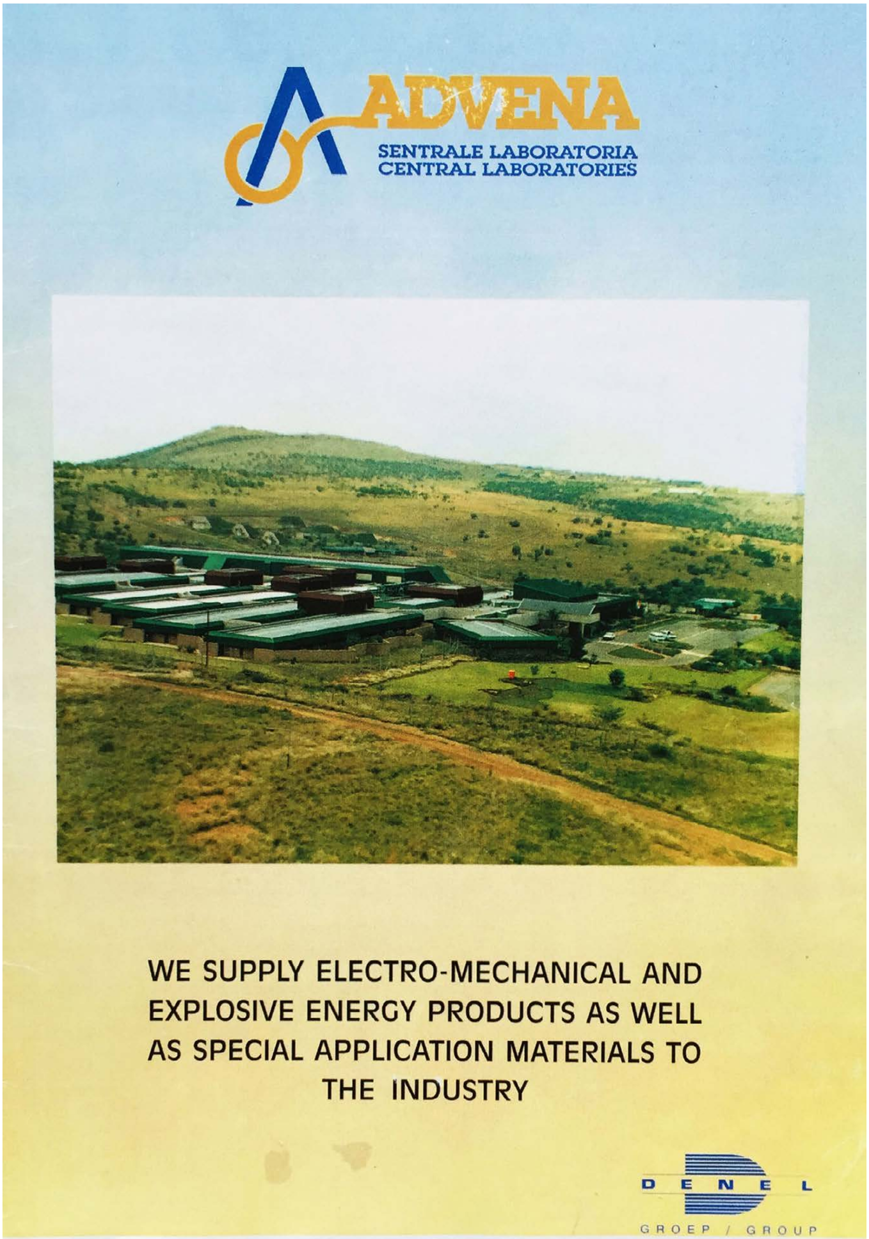


Figure 9.3 Cover of Advena Central Laboratories brochure, which advertised a rather unique set of products that suggested that Advena was a former nuclear weapons production site. The main building is visible with its entrance on right. The bunkers of the high explosive manufacturing complex are visible in the background.

However, this commercialization effort failed, and the site was formally closed. All the workers were gradually laid off or they took other positions within Armscor or Denel, a commercial entity created in 1992 to absorb all of Armscor's production divisions, including Advena.

After several years of remaining unused, Advena re-opened in about 2001 or 2002 as a site to re-train military personnel who were being discharged as part of downsizing South Africa's military. When it was re-opened, many of the items, signs, and infrastructure remained from the day it was originally closed.[36] One Armscor official who visited the site in 2002 felt like he was traveling back in time.

PUBLIC DISCLOSURE

All of the dismantlement activities were occurring in utmost secrecy. One of the first public signs to emerge that South Africa had given up its nuclear weapons was in September 1990, when then Foreign Minister Pik Botha announced in Pretoria that his government was "prepared to accede to the treaty in the context of an equal commitment by the other states in the southern African region." [37] Botha also announced Pretoria's support for a nuclear weapons free zone in southern Africa, in part as a way to remove suspicions and strengthen economic and geographical cohesion of the region. A regional nuclear weapon free zone also would be seen domestically as a clear positive achievement for de Klerk.

At the time, the announcement disappointed but did not surprise the IAEA members meeting at the annual General Conference in Vienna. Leading members of the IAEA initially had been optimistic that South Africa would announce an unconditioned pledge to join the treaty. However, the South African government wanted its neighbors to make nuclear non-proliferation commitments as well. Following Zambia's and Tanzania's decision to sign the NPT, South Africa announced on June 27, 1991 its intent to accede to the treaty.

In his 1990 announcement in Pretoria, Pik Botha had refused to confirm whether South Africa had built nuclear weapons, saying the question was "irrelevant" now that the country had agreed to sign the NPT. [38] Several governments, experts, and the ANC disagreed and pressed the South African government to come clean.

Shortly before the announcement that South Africa would join the NPT in the summer of 1991, the de Klerk government revisited the decision to keep secret the existence of the nuclear weapons program. President de Klerk, however, remained unwilling to reveal the program.

Stumpf has given several reasons for de Klerk's decision in the summer of 1991.[39] First, when South Africa acceded to the NPT, it was under no obligation to reveal the existence of its past nuclear weapons program. Under his interpretation, which was common at the time, the NPT essentially looks forward and requires extensive accounting of nuclear material and facilities that exist when the treaty takes effect. More importantly, de Klerk decided that the internal political situation, including forming a new constitution, was not conducive to revealing a nuclear weapons program. Lastly, if the government revealed a secret nuclear weapons program right when international attention was focused on highly intrusive and confrontational nuclear inspections in Iraq, South Africa could be easily branded in the eyes of the public and the press as a second Iraq. This was despite the fact that South Africa, unlike Iraq, had not violated the NPT since it never signed it. Officials worried that South Africa would end up subject to the same type of confrontational inspections as those being conducted in Iraq.

Although in mid-1992 officials again advised de Klerk to announce the program, he continued to reject this course of action until February 1993. By this time, however, the government's lack of candor about the nuclear weapons program had erupted into both a domestic and international political controversy. In his speech revealing the program, de Klerk said that some countries and the media had alleged that South Africa still had covert nuclear weapon aspirations and had not fully revealed its stockpile of highly enriched uranium. This suspicion, de Klerk observed, was hurting South Africa's efforts to commercialize its nuclear infrastructure, particularly its efforts to export high-technology products. Other South African officials have said that lack of candor was also interfering with South Africa's negotiations for an African nuclear weapons free zone and with its cooperation with other African countries. In retrospect, Stumpf has said that South Africa would have been "possibly more correct to have announced the past program at accession to the NPT."[40]

Within South Africa, the ANC intended to make the secret nuclear weapons program an election issue, and this obviously worried de Klerk's party. At a late December 1992 press conference in Johannesburg, the ANC demanded full disclosure of all present and past nuclear weapons activities, calling on the government to "admit the full extent of its nuclear weapons program and weapons-grade uranium stockpile now."[41] The ANC warned in its press release: "To continue to act clandestinely and give ambiguous answers on nuclear matters undermines the important process of building the confidence of all South Africans in the process of democratizing our country."[42]

US officials privately urged South African officials to fully reveal the country's nuclear weapons program in order to reestablish South Africa's international credibility.[43] Yet they were met with stubborn denials. One US official who met with Wynand de Villiers, then Chairman of the Atomic Energy Corporation, shortly before de Klerk's announcement, reported that de Villiers slammed his fist on his desk while vehemently denying South Africa had had a nuclear weapons program.[44] De Villiers said that South Africa had assessed a peaceful nuclear explosive but did not develop it.

To encourage greater South African candor, US officials "leaked" to the media information or, in most cases, worst-case suspicions, about the program. For example, on March 18, 1993, six days before de Klerk's announcement and coinciding with a visit of South Africa's Foreign Minister to Washington, a *Washington Post* article quoted US officials as saying that they "strongly suspect South Africa has not accounted fully for all the bomb-grade uranium it produced or the other nuclear weapons components it amassed and [it] may still be hiding some nuclear bomb-related items."[45]

Lacking an admission of past nuclear activities, the US government started seriously questioning South Africa's commitment to the NPT. On January 19, 1993, in the annual report by the President to Congress detailing the adherence of other nations to arms control, nonproliferation, and disarmament agreements, commonly called the "Pell Report," the Bush administration stated: "The United States has serious questions about South Africa's compliance with its Article II and III obligations" under the NPT.[46] Article II forbids the manufacture of nuclear weapons or explosives or their transfer to other countries, and Article III requires IAEA safeguards on all nuclear materials. The implication was that the United States had suspicions that South Africa had not declared all its HEU.

The Russian Foreign Intelligence Service expressed similar concerns. In early 1993, it reported that certain experts doubted that South Africa had declared all of its nuclear materials from nuclear explosive devices or weapons.[47]

Although President de Klerk had apparently already made his decision to reveal the program before the March 18th *Washington Post* story, he admitted that enough had leaked out that the government was getting press inquiries from "quite a number of sources."[48] Both countries and important commentators, he added, were expressing doubts that all the HEU had been disclosed, eroding trust in the government. However, suspicions remained even after de Klerk's March 1993 announcement.

The ANC, for instance, accused the government of hiding important information. "Despite his appeal, we cannot believe that 'South Africa's hands are clean' until we obtain full disclosure of all details of the weapons program and its alleged dismantling, the stockpile of weapons-grade uranium, and the full extent of international cooperation with Armscor and the Atomic Energy Corporation."[49] However, the worst of the suspicions would be laid to rest by a rigorous inspection effort by the IAEA. Although the inspections never became as confrontational as the ones then happening in Iraq, the inspections in South Africa were both intrusive and unprecedented in scope.

NOTES

1. Interview with senior Armscor official, October 10, 1995.

2. Waldo Stumpf, "South Africa's Nuclear Weapons Program," undated, p. 14. An edited version of this paper is in Kathleen C. Bailey, *Weapons of Mass Destruction: Costs versus Benefits* (New Delhi: Manohar Publishers and Distributers, 1994), pp. 63-81.

3. Mitchell Reiss, *Bridled Ambition: Why Countries Constrain Their Nuclear Capabilities* (Washington, D.C.: The Wilson Center, 1995), p. 17.

4. Following the 1994 agreement between the United States and North Korea, called the Agreed Framework, whereby North Korea would shut down its plutonium production facilities in exchange for two light water reactors worth many billions of dollars, an Armscor official expressed dismay to one of the authors that South Africa had not negotiated for something more concrete in exchange for abandoning its nuclear weapons program. A deal on the scale of the Agreed Framework would have paid a major share of the ANC government's reconstruction program. For regret about not doing so, see Hannes Steyn, Richardt van der Walt, and Jan van Loggerenberg, *Armament and Disarmament: South Africa's Nuclear Weapons Experience* (Pretoria: Network Publishers: 2003), p. 102.

5. Reiss, *Bridled Ambition*, op. cit., p. 17.

6. Transcript of talk by Waldo Stumpf, South African Embassy, Washington, D.C., July 23, 1993.

7. Nic von Wielligh and Lydia von Wielligh-Steyn, *The Bomb* (Pretoria: Litera Publications, 2015). See pp. 500-513.

8. *The 'Mantel' Project*, signed by W.E. Stumpf, CEO for the AEC and J.L. Steyn, Senior General Manager: R&D, Armscor, February 8, 1990, in *The Bomb*, op. cit., p. 507.

9. *The 'Mantel' Project*, op. cit.

10. Interviews with Armscor and AEC officials. See also, *The Bomb*, op. cit., p. 217 and document in appendix, pp. 500-501.

11. Stumpf, Transcript of talk at South African Embassy, op. cit.

12. *Dismantling of Nuclear Weapons,* from State President to Minister of Defense, February 26, 1990, *The Bomb,* op. cit., p. 512, Since the order controlled the release of the nuclear warheads from the Circle vaults, under warhead control procedures, there should have been an identical order to the Minister of Minerals and Energy Affairs.

13. Stumpf, "South Africa's Nuclear Weapons Program," op. cit., pp. 14-15.

14. The Y Plant was actually shut down on February 1, 1990, before the written instructions were received from de Klerk. Decommissioning and decontamination commenced immediately afterwards.

15. *Armament and Disarmament,* op. cit., pp. 99-100.

16. *Armament and Disarmament*, op. cit. p. 98.

17. Reiss, *Bridled Ambition*, op. cit., p. 18. This information was told to Reiss by Wynand Mouton, the expert who de Klerk hand-picked to audit the dismantlement process.

18. This episode was told to Reiss by Mouton, see *Bridled Ambition*, op. cit., p. 40, see footnote 66.

19. Reiss, *Bridled Ambition*, op. cit., p. 18; and IAEA, *The Denuclearization of Africa*, Annex 1, Attachment 1.

20. David Albright, "South Africa's Secret Nuclear Weapons" (Washington, D.C.: Institute for Science and International Security, May 1994), p. 16.

21. Reiss, *Bridled Ambition*, op. cit., pp. 18-19.

22. Reiss, *Bridled Ambition*, op. cit., p. 23; and Various interviews by one of the authors with Armscor officials in 1994 and 1995.

23. Interview with Mouton by telephone by one of the authors, October 13, 1995.

24. Interview with Mouton, op. cit.

25. Interview with Mouton, op. cit.

26. Interview with Mouton, op. cit.; and Reiss, *Bridled Ambition*, op. cit., p. 18. There have been media reports that two workers were removed from the dismantlement program and kept under continuous surveillance when they threatened to steal nuclear materials. Mouton said that he did not think this story was true. Armscor officials have also denied this particular story, although not the underlying concern.

27. Interview with Mouton, op. cit.

28. Quoted in Reiss, *Bridled Ambition*, op. cit., p. 18.

29. Reiss, *Bridled Ambition*, op. cit., pp. 18 and 40, footnote 69.

30. An irony of Mouton's involvement was that he lived within a kilometer of P. W. Botha in Wilderness, a retirement resort. Although they periodically saw each other, Mouton never talked to Botha about his role in dismantling the arsenal Botha played such a major role in creating.

31. State President F. W. de Klerk, "Speech by the State President, Mr. F. W. de Klerk to a Joint Session of Parliament, 24 March 1993," Transcript of speech given in Cape Town. See also "De Klerk Discloses Nuclear Capability to Parliament," FBIS-AFR-93-056, March 25, 1993, pp. 5-9.

32. The total amount of HEU unaccounted for, some of which was known to have been lost during processing, at Circle was higher, about 3.9 kilograms of uranium in total, containing 3.2 kilograms of uranium 235. Of this total, about 1.6 kilograms (and 1.3 kilograms of uranium 235) resulted from process losses during melting and casting operations at the Circle facility.

33. Interview with Mouton, op. cit.

34. Information supplied to one of the authors by Armscor officials, April and May 1993.

35. See for example, Andre Buys, "The Conversion of South Africa's Nuclear Weapons Facilities," *Bulletin of Arms Control*, Council for Arms Control and Center of Defense Studies at London University, No. 12, November 1993; and Albright, "A Curious Conversion," *Bulletin of the Atomic Scientists*, June 1993.

36. One of the authors took a tour of the site in August 2002 with a former Armscor official involved in the program. Many pictures in this book are from that visit.

37. Quoted in Ann MacLachlan and Mark Hibbs, "South Africa Ready to Sign NPT if Other States in Region Do So," *Nucleonics Week*, September 27, 1990.

38. David Ottaway, "South Africa Agrees to Treaty Curbing Nuclear Weapons," *The Washington Post*, June 28, 1991, p. A25.

39. Stumpf, "South Africa's Nuclear Weapons Program," op. cit., p. 16.

40. Stumpf, Transcript of talk at South African Embassy, op. cit.

41. Albright and Mark Hibbs, "The ANC and the Atom Bomb," *Bulletin of the Atomic Scientists,* April 1993.

42. "The ANC and the Atom Bomb," op. cit.

43. Interviews with US officials, 1994-96.

44. Interview of US official by one of the authors (Albright), 1997.

45. Steve Coll and Paul Taylor, "Tracking S. Africa's Elusive A-Program," *The Washington Post*, March 18, 1993. https://www.washingtonpost.com/archive/politics/1993/03/18/tracking-s-africas-elusive-a-program/41d5a61d-d12a-4ed7-9504-8973eb92898c/

46. For a report on the Pell Report, see R. Jeffrey Smith, "Pretoria's Candor on Nuclear Program Questioned," *The Washington Post*, March 18, 1993.

47. Senator John Glenn released the Russian intelligence report detailing global proliferation of weapons of mass destruction on February 24, 1993.

48. "De Klerk Holds News Conference on Speech," SABC TV 1 Network in English, 24 March 1993, Transcript published in FBIS-AFR-93-056, March 25, 1993.

49. "ANC Welcomes De Klerk Nuclear 'Admissions," Johannesburg SAPA, March 24, 1993. Also in FBIS-AFR-93-056, March 25, 1995, p. 15.

CHAPTER 10
INTERNATIONAL VERIFICATION

When South Africa decided to abandon its nuclear weapons program, the nuclear nonproliferation regime offered South Africa few precedents for joining the Nuclear Nonproliferation Treaty (NPT) while convincing the international community that it did not have nuclear weapons. Professor Mouton's audit could provide important corroborating evidence, but it was insufficient to replace the need for international oversight.

South Africa's approach was to create a managed transparency policy of its past nuclear activities within the context of the International Atomic Energy Agency's (IAEA's) verification effort under the NPT. IAEA verification had become more stringent following the 1991 Persian Gulf War, after the weaknesses of international safeguards were revealed. As a result, the IAEA requested more information and inspected more sites than South Africa may have expected. Although South Africa was never completely transparent about its past programs, it eventually revealed a remarkable level of information about them. The government's extensive cooperation with the IAEA increased confidence in the truthfulness of its declarations.

The inspection process can be divided into two overlapping periods. The first followed South Africa's submission to the IAEA on October 30, 1991 of a report on its initial inventory of nuclear materials as of the end of September. This declaration is required of all nonnuclear weapon states acceding to the NPT. The submission of this report triggered the IAEA's investigation of South Africa's declaration of the amount and location of all its fissile material. The inspection effort was hindered during this phase by South Africa's decision to mislead the inspectors about its past nuclear weapons program.

The second phase of the inspections followed de Klerk's March 1993 announcement about the nuclear weapons program. In a unique verification exercise under the NPT, IAEA inspectors, augmented by nuclear weapons experts, were tasked to assess the status of the former nuclear weapons program, determine that all weapons had been dismantled, and verify that the highly enriched uranium from this program had been fully accounted for. South Africa gave the Agency's inspectors full access to facilities involved in the past nuclear weapons program along with many of the historical production records of those facilities.

"DO-IT-YOURSELF OPTION"

Verification was complicated by the nature of the South African dismantlement process, which Waldo Stumpf, the then head of the Atomic Energy Corporation, described, as a "do-it-yourself" option followed by accession to the NPT.[1] Although this option allowed South Africa to join the treaty as a non-nuclear weapon state, it immediately raised questions about whether all the nuclear weapons had been dismantled, whether sensitive nuclear weapons design information was hidden away, or whether some highly enriched uranium had been hidden and not declared upon joining the NPT.

Such concerns resurfaced well into the 1990s. For example, Wally Grant, a chief inventor of South Africa's uranium enrichment process and an important member of the right-wing Afrikaaner Peoples' Front (Volksfront), claimed to have documented the entire history of the nuclear weapons program, which he was reportedly preserving for future generations.[2] In early 1995, a British TV documentary produced for the Channel 4 Dispatches, quoted various unnamed sources who claimed (with no substantiation provided) that a South African right-wing group had secretly obtained a stock of nuclear weapons that had not been declared to the IAEA by the South African government. South African officials were quick to dismiss that individuals such as Wally Grant or right-wing groups had obtained nuclear weapons or weapons-grade uranium. Armscor officials called the British documentary "a load of nonsense," and ANC Defense Minister Joe Modize said the program had "caused mirth, but no concern."[3] Nevertheless, the possibility that some HEU was missing can never be completely dismissed. Even the IAEA conclusions do not eliminate such a possibility.

However, Stumpf argues that South Africa's dismantlement choice was the only one available to de Klerk. Because the NPT has only two categories of members — the five acknowledged nuclear-weapon states and non-nuclear weapon states—in effect, it does not allow a state like South Africa, which had not detonated a nuclear explosive by the required date, to dismantle its weapons within the NPT and its associated INFCIRC/153 safeguards agreement.[4] The possession of nuclear weapons by a non-nuclear weapon state would be a violation of the treaty immediately upon accession. Reclassifying the weapons as "peaceful nuclear explosives" also would not be acceptable under the NPT.

The de Klerk government viewed options that would have allowed the IAEA to verify the dismantlement process directly as too burdensome and political. According to Stumpf, these options probably would have also raised international legal problems. The principal alternative involved implementing INFCIRC/66 safeguards agreements on all South Africa's nuclear activities, including the nuclear weapons, before its accession to the NPT. According to Stumpf, however, this path would have also required lengthy negotiations on each facility, and in the end, it might have encountered serious legal obstacles. (For example, redefining the weapons as PNEs would likely have conflicted with more recent interpretations of INFCIRC/66). In addition, South Africa was unsure prior to ratifying the NPT if the IAEA's ruling body, the Board of Governors, would allow IAEA inspectors to become involved directly in a safeguards effort that allowed or required access to sensitive nuclear weapons information.

In choosing the "do-it-yourself" options, the South African government realized that it would need to be fully transparent to the IAEA about its past nuclear materials production activities. Stumpf relates an incident with the IAEA's Director General Hans Blix in February 1991 in Vienna, when it was clear that South Africa would soon be joining the NPT.[5] Blix asked Stump how the IAEA would convince the world that South Africa had acceded to the NPT openly, without a nuclear weapons program. Stumpf replied that South Africa would make available additional records of its enrichment plants. Later, upon implementation of the safeguards agreement, South Africa issued a standing invitation to the IAEA to "visit anywhere, anytime, any place — within reason."[6]

This policy of transparency and openness, according to Stumpf, was chosen as a fundamental part of South Africa's entire "rollback" strategy.[7] The South African government decided that a policy of cooperation and transparency would avoid the type of confrontational inspections that were occurring in 1991 in Iraq and about to commence in North Korea. If such confrontations occurred, according to Stumpf, South Africa's effort to gain international credibility would have been jeopardized.

This policy was also seen as necessary because at the time, the NPT and its associated INFCIRC/153 safeguards agreement contained no agreed-upon procedures to promote transparency of activities or data beyond the nuclear materials and facilities declared in the initial report. Although the initial South African declaration was a comprehensive document which included quantitative data on all types of nuclear material on a facility-by-facility basis, it was limited to nuclear materials subject to safeguards at the time the agreement entered into force, or September 30, 1991.[8] According to Stumpf, based on commonly accepted safeguards interpretations, South Africa was under no obligation to reveal: (1) projects or programs that predated the time of entry-into-force; (2) dual-purpose facilities that already had been converted to non-nuclear work; and (3) historical flows of nuclear materials.

THE IAEA'S INSPECTION EFFORT

When the NPT took effect in South Africa in the summer of 1991, the IAEA was undergoing a fundamental reformation as a consequence of the dramatic revelations of Iraq's secret nuclear weapons program and the failure of the IAEA to detect those secret activities. The IAEA was under intense international pressure to be more aggressive in its verification effort in South Africa and to rely on member states for additional information about South Africa's past nuclear activities.

In a dramatic move, the IAEA General Conference voted on September 20, 1991 to request the Director General to verify the completeness of the inventory of South Africa's nuclear installations and materials and to report back to the Conference. Instead of verifying only the correctness of South Africa's declaration, as it had done in past cases, the IAEA was instructed to also determine that South Africa's declaration was complete. Determining completeness is a more difficult step to accomplish, and it is far more important than just determining the correctness of a declaration when deciding if a country has met its NPT obligations. In practical terms, the inspectors were charged to determine if South Africa had declared all its nuclear material or had hidden some of it. The most important nuclear material when the IAEA's first inspections started in November 1991 was the HEU. Because it is not possible logically to prove that South Africa was not hiding any nuclear material, i.e. one cannot prove a negative, the IAEA had to create methods to develop confidence that South Africa had declared all its HEU. To accomplish these goals, the IAEA's Director General appointed a special technical team of senior safeguards officials, several of whom had gained valuable experience in Iraq after the Gulf War.

Although the IAEA realized that South Africa was hiding its former nuclear program, it was rather tentative in pressing South Africa to reveal it. When the IAEA received South Africa's initial declaration, it saw immediately that much of the HEU was reported in the form of metal ingots, a form which immediately raised suspicions that this material had been removed from nuclear weapons. Yet the IAEA formally said nothing about its suspicions to the public nor directly challenged South Africa's deception in its safeguards reports to its members. Such a direct approach was complicated by INFCIRC/153 safeguards agreements at the time, which were widely interpreted as requiring the IAEA to keep secret virtually all the information in the initial declaration and most other information provided by the state. In addition, South Africa conditioned its transparency policy on the IAEA maintaining a high level of confidentiality about the information the government was providing to the inspectors. As a result, the IAEA believed it had neither a mandate to reveal its suspicions about past use of this material, i.e. to "blow the whistle" on South Africa, nor the motivation to undermine South Africa's commitment to transparency, albeit involving obvious untruths about its nuclear programs.

That the IAEA knew that South Africa was likely lying is also revealed by the information supplied to the IAEA by member states. In August 1992, the IAEA received information, possibly from the United States, about South Africa's nuclear weapons program. According to a declassified 1993 document, the IAEA had "received US briefings on most aspects of the weapon program."[9] The information was detailed and accurate, although like much intelligence information, it also contained inaccuracies (for comparison, see earlier chapters). The IAEA received the following information, according to a "Note to File":

- In 1974 South Africa constructed a criticality facility outside the Valindaba perimeter, which was mothballed in 1978. This reference is to building 5000.
- In 1973 the Kalahari test site was surveyed and two large-diameter shafts were prepared. The site was abandoned in 1978.
- In 1978 responsibility of the nuclear weapons program was transferred to Armscor under the Department of Defense. Armscor's subsidiary Kentron was responsible for producing advanced weapons and missiles, including nuclear weapons. The Jericho missile program was established in the same year.
- The Naschem Boscop Plant in Potchefshoom had a flash x ray, high speed camera, and a high explosive bunker.
- Armscor had a flash x ray bunker, evidently a reference to the high explosive bunker at Advena Central Laboratories.

The Note to File also contained information about the organizational structure of the nuclear weapons program, including identifying the location of the Circle facility. Figure 10.1 duplicates this schematic.

ORGANIZATIONAL STRUCTURE OF THE SOUTH AFRICAN NUCLEAR WEAPONS PROGRAM, AS PROVIDED TO THE IAEA BY MEMBER STATES IN AUGUST 1992

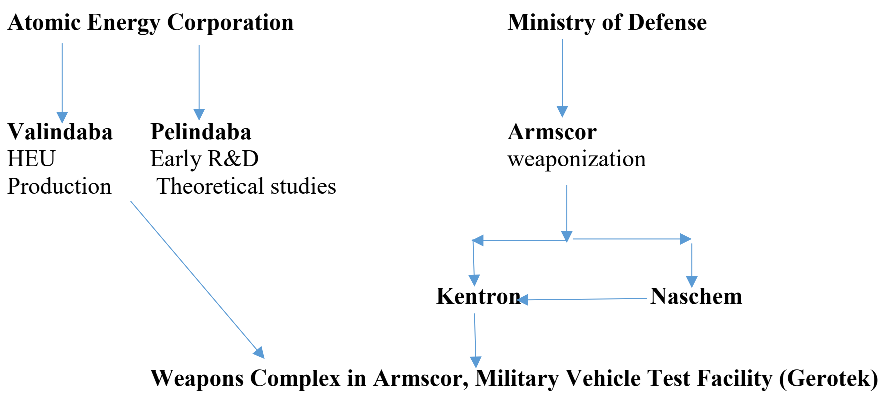


Figure 10.1 From the IAEA "Note to File," recording information provided by a member state to the IAEA.

The information shows that by the late summer of 1992, the IAEA understood important details about key parts of South Africa's nuclear weapons program. Using this information, it asked to visit two sites.

The IAEA started by asking to visit Building 5000 (see figures 10.2 and 10.3).[10] Two inspectors visited the site on August 20, 1992 and took pictures and environmental samples. South African officials told the inspectors that Building 5000 was a former general purpose critical facility for the AEC's Reactor Development Group that had been decommissioned many years earlier. Although the South Africans facilitated access to Building 5000, they deliberately obscured this site's original purpose or specific role in the nuclear weapons program.

IMAGE fig10_2

Figure 10.2 Building 5000 as it looked in early 1994, many years after being emptied of the pulse reactor used in the nuclear weapons program in the 1970s. Visible in the right image are barrels and redundant equipment that appear similar to those described by the IAEA inspectors in their 1992 visit to the building.

Figure 10.3 An aged emergency phone in Building 5000 that likely dates to the 1970s when the building housed the pulse reactor. The phone may have been for communicating with the reactor's control room in Building 5100 (see chapter 2).

The IAEA also requested to visit the Kalahari nuclear test site, which it visited in September 1992. It asked in particular to visit what is called the "shade" (see figure 10.4).[11] To hide renovation activities at the first test shaft from overhead surveillance, Armscor had several years earlier constructed a galvanized corrugated iron hangar on a concrete foundation over one of the test shafts. South Africa referred to this building as the "shade." The South Africans told the inspectors that the Vastrap area was owned by the South African Defense Force and was used as a military target range. They said the shade was used by the air force for storage and as a workshop, providing no indication that the shade covered a nuclear test shaft.[12] The IAEA uncovered no evidence that the building had been used or was then being used for the testing of nuclear explosive devices, although it did not ask to excavate the shade's floor. Its environmental sampling did reveal the presence of natural uranium, but this was not seen as indicative of deceptive behavior.

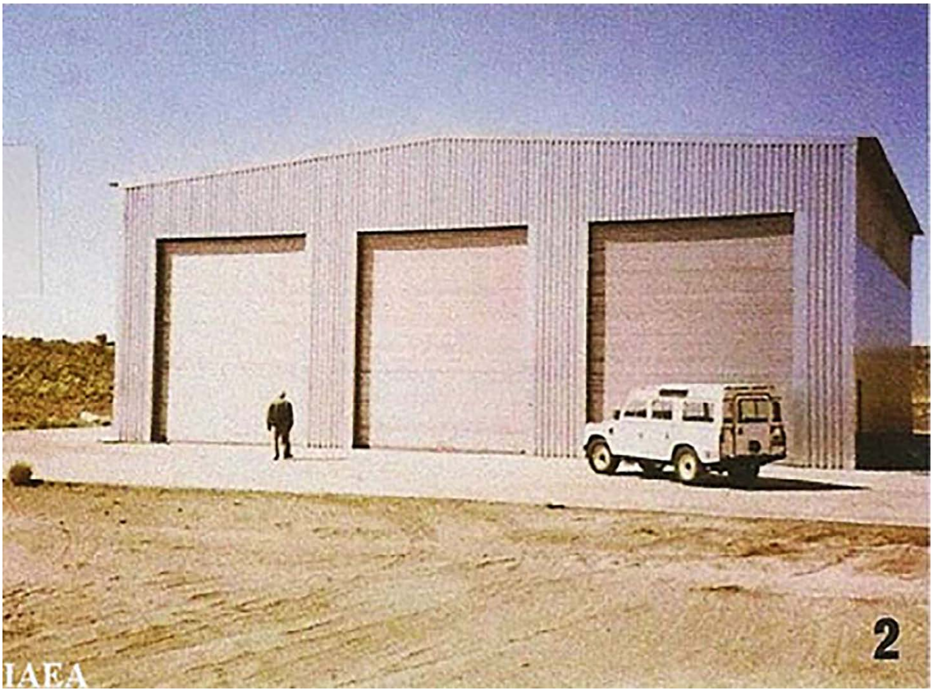


Figure 10.4 The building, or "shade," over the first test shaft at the Kalahari test site. Photo source: IAEA.

The Note to File shows that the IAEA was informed about a nuclear weapons complex at Gerotek, namely the Circle facility. Whether it was given the precise location is unknown. However, the IAEA did not ask to visit this site until after President de Klerk's March 1993 announcement. The reason for not doing so is unknown.

These visits would have added to the IAEA's disbelief in South Africa's willingness to fully disclose its past nuclear activities. In a study of South Africa's deception practices, Frank Pabian, one of the foremost experts on South Africa's nuclear weapons program, identified both building 500 and the test site cases as clear-cut efforts of "dissimulation and obfuscation in keeping with the original NPT accession plan" of South Africa.[13] Nonetheless, the accumulating information necessarily raised questions about whether South Africa was also hiding highly enriched uranium.

HEU VERIFICATION

Because of the difficulty of ensuring that the declaration was complete, in the fall of 1991 the IAEA informed South Africa that success would require closer cooperation. The inspectors intended to create a "balance" in terms of uranium and uranium 235, involving all of South Africa's production, imports, and exports of enriched and depleted uranium. This result would then be verified by comparing it to the accounting and operating records of the Y and Z Plants.

This approach required a greater level of cooperation than Stumpf had earlier volunteered to the IAEA. Nonetheless, consistent with its overall policy to be transparent about nuclear materials, South Africa agreed to supply additional access to records of the Y and Z Plants but without providing the source of imported uranium.

The priority was the HEU because it had been used in nuclear weapons. South Africa had also produced a large quantity of low enriched uranium (LEU) in the Y and Z Plants, but creating the balance of this material was a lower, albeit no less difficult, priority. Creating an accurate balance of the HEU was complicated because it had been produced for over fifteen years in the Y Plant, which was part of a nuclear weapons program that only slowly met civilian standards of nuclear material accountancy.

The underlying idea of the balance approach was to conduct a consistency check on the isotopic balance of the HEU inventory. It compared the amount of uranium-235 in natural uranium entering the Y Plant to the amount of uranium-235 leaving the plant in enriched uranium product and depleted uranium waste. To illustrate this process, consider 1,000 kilograms of natural uranium entering or being "fed" into the plant. It contains about 7.11 kilograms of uranium-235. If the plant produces uranium enriched to 90 percent uranium-235, and the waste contains uranium with 0.4 percent uranium-235 (tails assay of 0.4 percent), then it would produce about 3.47 kilograms 90 percent material and 996.53 kilograms of waste. In this theoretical example, the product contains 3.12 kilograms of uranium-235 and the waste contains 3.99 kilograms of uranium-235, matching the original amount of the natural uranium feed.

In the case of the Y Plant, however, the situation was highly complex. A balance would prove elusive. The total amount of natural uranium entering the plant—the "feed"—was about 384 tonnes, or 384,000 kilograms. The plant produced HEU of many enrichment levels. In total, South Africa produced almost 1,000 kilograms of HEU with an average enrichment of about 70 percent (see tables 1 and 2 in chapter 3).[14] Of this, about 550 kilograms of HEU were enriched over about 80 percent in the isotope uranium 235. About 480 kilograms of this HEU were assigned to the nuclear weapons program, much of which was later taken from dismantled nuclear weapons at the end of South Africa's nuclear weapons program. Earlier, a fraction of this HEU was returned to the AEC as manufacturing scrap and slated for recovery. Another 90 kilograms of weapon-grade uranium were used to blend up a stock of imported LEU to the appropriate level needed for the Koeberg nuclear power reactors. South Africa also inadvertently produced another 450 kilograms of HEU enriched to less than about 80 percent as a result of problems in the enrichment plant. Almost 250 kilograms of this HEU were deposited in filters and powders or other scraps, most of which were slated for chemical recovery. The Y Plant also produced many tonnes of low enriched uranium for the Koeberg reactors. The depleted uranium waste, or "tails," contained about 371,000 kilograms with a wide variety of tails assays between less than 0.2

percent and up to 0.6 percent, and an average of about 0.45 percent. In addition, the depleted uranium was treated as a waste.

The depleted uranium in the chemical form of uranium hexafluoride had been placed in several hundred large cylinders and sent for storage nearby. It had not been weighed or evaluated carefully enough by the AEC during the program to meet the IAEA's safeguards accountancy standards for measuring the total uranium and its content of uranium 235. Because so much uranium-235 went into waste, the IAEA found it hard to take a balance at the Y Plant. After about a year of investigation, the IAEA concluded that the balance indicated an "apparent discrepancy," which could indicate that some HEU was either unaccounted for or had not been declared.[15] In June 1992, the apparent loss of uranium 235 was estimated as 120 kilograms, enough for more than two gun-type nuclear explosives.[16] Many were skeptical that the balance approach could work.

Nonetheless, during the next year, the IAEA further examined the records, leading to a reduction in this discrepancy. President de Klerk's March 1993 revelations also helped resolve some of the discrepancy in the HEU estimates. Despite all the hard work over two years, and the use of two different approaches, imbalances remained of about 75 and 95 kilograms of uranium 235, still more than enough for a gun-type nuclear explosive.[17] The problems remained mainly because of the uncertainty of the uranium 235 content in the depleted uranium and to a lesser extent chemical and other losses in the enrichment process, which were discussed in chapter 3.

Although the balance approach was refined in the second year of the verification effort, after the first year, in the summer of 1992, the magnitude of the imbalance had stimulated a look for another method. The conclusion was that the balance approach alone could not eliminate suspicions among some member states and the public that South Africa had hidden away some of its HEU. The most straightforward way to reduce the uncertainty would be to measure every cylinder containing the depleted uranium, in addition to all the waste drums containing small amounts of HEU generated during the various recovery operations. Characterizing the depleted uranium would be extraordinarily expensive and time consuming. Later the HEU in the drums would be thoroughly analyzed, but this effort would take years. Measuring the cylinders and drums, while straightforward, was too time consuming to meet the pressing need to verify the completeness of the HEU declaration. Moreover, that approach would have inevitably led to questions about whether South Africa had provided all the cylinders and drums for measurement.

As a result, after the first year of investigation, the IAEA decided on a second approach that would examine the performance of the Y Plant over its entire operating history. The aim was to independently estimate the HEU output of the plant using detailed historical data. This analysis was the first of its kind for the IAEA and potentially an extremely powerful verification technique if the state cooperates sufficiently, which South Africa was willing to do.

This approach depended on knowing how the Y Plant functioned throughout its history. The IAEA therefore asked South Africa for many more documents, hoping they would still exist. AEC personnel had to search for these records, eventually locating them in metal boxes in an unheated, dusty storage shed.[18] Although South Africa had agreed to provide them, it had expected the IAEA to conduct "spot checks" of the records, rather than seek comprehensive sets of operating documents.

Nevertheless, the IAEA experts received a full set of operating records of the Y Plant, representing about 3,000 cascade-days of operating records. The records detailed daily operations at the plant in terms of the availability of each enrichment section of the plant, the rate of uranium feed entering the initial enrichment section, and the rate and assay of the enriched uranium and waste withdrawn from the plant.[19] To ensure that the records were genuine, the IAEA conducted forensic analyses on them.

The IAEA also interviewed people who had produced the records to seek clarification and additional information. The ability of the AEC to find the people involved in the operation of the Y Plant and to arrange for the IAEA to interview them would turn out to be key to the success of this approach.

Yet it was not without complications. Initial IAEA calculations of the maximum production capacity were about double the amount of enriched uranium product that South Africa declared as withdrawn from the Y Plant. The IAEA had not realized all the loss mechanisms in this one-of-a-kind facility.

The IAEA experts had to verify the unique loss mechanism that reduced significantly the expected output of the Y Plant, as discussed in chapter 3. The most important one was the loss of enriched uranium through reactions involving the process gas mixture of uranium hexafluoride and hydrogen and the Teflon filters used throughout the enrichment cascade. Early in the plant's history, this problem led to the plant "crashing" when a catalytic reaction involving larger than expected chloride impurities in the uranium feed resulted in the plating out of large amounts of uranium on the inside of the cascade, halting operation for almost two years.

South African scientists were able to prevent another catastrophe at the Y Plant by carefully monitoring the operation of the cascade and the buildup of uranium solids on filters, changing them before the buildup was too great. Controlling these chemical losses was a key reason that the plant maintained detailed records of the plant's operation. These daily records were invaluable to the IAEA.

Because so much enriched uranium was lost in this process, the IAEA asked South Africa to conduct certain experiments that would confirm this loss mechanism. This exercise was completed satisfactorily in the summer of 1993.

Using all of this information, the IAEA experts put together an independent estimate of the daily HEU production of the Y Plant.[20] The final result was extremely close to South Africa's declared output. For example, the uncertainty in the amount of HEU produced by the Y Plant for the nuclear weapons program was six kilograms, according to South Africa's declaration. This amount is substantially less than one significant quantity, or 25 kilograms of uranium-235. After two years of intense effort, the IAEA wrote: "It is reasonable to conclude that the amounts of HEU which could have been produced by the pilot enrichment plant are consistent with the amounts declared in the initial report."[21] Despite this seemingly vague wording, the sentence allowed the ending of the completeness investigation of the HEU stock. (The lower priority investigation of the completeness of the LEU stock continued).

There will always be some uncertainty attached to quantitative assessments of HEU production. Nevertheless, the second method resulted in an HEU estimate that was so close to the declared value as to provide added confidence that the government's declaration of HEU production was both accurate and complete. In the end, successful verification required the IAEA to obtain large amounts of historical information about the Y Plant, to reconstruct in detail the daily operation of the plant, and to oversee experiments that could help explain apparent discrepancies in the initial report about HEU production.

VERIFYING THE DISMANTLEMENT OF THE NUCLEAR WEAPONS PROGRAM

During his March 1993 announcement, President de Klerk promised the IAEA full access to facilities involved in the past nuclear weapons program, along with their historical records. Two IAEA inspectors, who were already in South Africa, visited several of these facilities the next day, beginning an unprecedented inspection effort that would last five months.[22] This effort focused on ensuring that there were no hidden stocks of HEU or weapons, including major weapon subcomponents.

The key to the success of this inspection effort was the IAEA's inclusion of nuclear weapon experts from the nuclear weapon states. Initial disclosures by South Africans tended to be circumspect, but the ability of the nuclear weapon experts to recognize key activities led to significantly more openness on the part of the past members of South Africa's nuclear weapons program. Using weapons experts also helped to protect sensitive information against unauthorized release to non-weapon states at the IAEA. Moreover, the most sensitive information was communicated orally and not written down. Thus, South Africa revealed the important details of its weapons program only to nuclear weapon experts or to leaders of the IAEA effort, reducing the risk that this information could pass to unauthorized personnel.

In assessing the status of South Africa's former weapons program, the IAEA focused on the program's origin and scope, and on the adequacy of measures taken to dismantle and destroy sensitive components of the devices and to recover the nuclear materials involved. Specifically, the inspectors sought:[23]

- To gain assurance that all nuclear materials used in the nuclear weapons program had been returned to peaceful uses and placed under IAEA safeguards;
- To confirm that all nonnuclear weapons-specific components of the devices had been destroyed, that all laboratory and engineering facilities involved in the program had been fully decommissioned and abandoned or converted to peaceful use (commercial nonnuclear uses or peaceful nuclear uses), and that all weapons-specific equipment had been destroyed and all other equipment converted to peaceful use;
- To obtain information regarding the dismantling program. This involved learning about the destruction of design and manufacturing information, including drawings, and the philosophy followed in the destruction of the nuclear weapons;
- To reduce the likelihood or ease of reconstituting the nuclear weapons program. Specifically, the inspectors consulted on the arrangements for, and ultimately to witness the rendering useless of the Kalahari test shafts;
- To visit facilities previously involved in or associated with the nuclear weapons program and to confirm that they were no longer being used for such purposes; and
- To consult on future strategies for maintaining assurance that the nuclear weapons capability would not be regenerated.

To achieve these objectives, the inspection teams visited many facilities, examined and audited dismantlement, destruction, and recovery records, and had extensive discussions on various phases of the program with former members of the program from both the AEC and Armscor. Where questions still remained, IAEA inspectors requested additional information.

By the start of this phase of the inspections, most of the weapons components and technical documentation had been destroyed. The inspectors, however, were able to correlate the records of the dismantlement of the HEU components of the weapons with corresponding data in AEC nuclear material accountancy records.

A similar procedure with respect to natural and depleted uranium in the devices was unsuccessful. Armscor and the AEC placed little nuclear or financial value on both materials and thus kept few records of the transfer of these materials.

Although Armscor destroyed documents as part of the dismantling process, it kept sections of each device's "build-history" log book and dismantlement record.[24] Items such as drawings and assembly instructions were removed from these records and destroyed, but information such as quantities of material and serial numbers of components were retained.

Inspectors used this information in combination with the hardware destroyed by mechanical cutting to reconstruct a consistent picture of the number and fate of the deliverable weapons, the demonstration device (Melba), and the pre-production experimental models. In particular, they could compare identification numbers on hardware with these records.

In general, Armscor possessed more non-nuclear components than the bare minimum necessary for the nuclear devices and experimental pre-production devices. However, the inspectors were never able to establish the exact number of each component that had been originally ordered. Nevertheless, the inspectors found no indication that South Africa had retained any sensitive non-nuclear components other than those that had been destroyed or converted to commercial non-nuclear applications or peaceful nuclear uses.

Finally, the inspectors audited the records of the transfer of HEU between the AEC and Armscor. The IAEA concluded that the HEU originally supplied to Armscor had been returned to the AEC and placed under safeguards when the safeguards agreement entered into force. The IAEA also concluded that the "findings from the team's examination of records, facilities, and remaining nonnuclear components of the dismantled/destroyed nuclear weapons and from the team's evaluation of the amount of HEU produced by the pilot enrichment plant are consistent with the declared scope of the nuclear weapons program."[25]

To confirm the completeness of the inventory of nuclear installations, the IAEA made visits to a number of facilities not originally listed by South Africa, relying on information that it had received from member states, particularly the United States. Although the NPT did not require such visits, South Africa permitted them in any case and even supplied detailed information about their activities at these sites, helping the IAEA to obtain a more complete history of the past program.

South Africa also took the IAEA to a site of which it had been unaware. It was the Witbank mineshaft where the first nuclear explosive was stored in the late 1970s and early 1980s.

At the end of these intensive inspections, the IAEA said that it did not possess "any information suggesting the existence of any undeclared facilities."[26] The annex to this chapter lists the main facilities visited by the IAEA.

SUMMARY OF INFORMATION AND ACCESS GRANTED; AND INFORMATION NOT PROVIDED

South Africa had initially pledged to provide considerable information to the IAEA. However, faced with the completeness challenge, the IAEA did not consider this information sufficient and requested and received the following additional information from South Africa after the safeguards agreement was implemented in the fall of 1991:[27]

- The accountancy and operating records of the Y Plant, including data on electricity consumption, which was available for the years since 1980[28];
- The accountancy and operating records of the semi-commercial enrichment Z Plant before September 1991;
- The historical flows of nuclear material, including the quantity of all imported material; and
- Historical values of material unaccounted for (MUF), as determined by the AEC for the purpose of financial control.

In the end, South Africa provided the IAEA with extensive information and access, including:[29]

- All historical nuclear material inventories and flows for a period in excess of 15 years;
- All available commissioning and operating records for both enrichment plants, spanning a period of more than 15 years for the Y Plant and a period of more than six years for the Z Plant, where only LEU production had taken place;
- Extensive details of the nuclear weapons program;
- Free access by the IAEA to numerous former facilities, now converted to commercial nonnuclear use, as well as to private industrial companies, military testing sites and conventional armaments factories;
- Free access to identified key individuals associated with the past nuclear weapons program, a number of whom had already transferred to private industry;
- Free access to Wynand Mouton, the independent auditor appointed by President de Klerk to audit the dismantling process; and
- Permission to take environmental samples from any location desired.[30]

In addition, the government updated its completeness report at least three times, incorporating more detail about the enrichment program. After President de Klerk's announcement about the program, South Africa added an overview of the nuclear weapons program to this report.

It is important to note what South Africa decided not to share with the IAEA. The government:

- Decided not to provide certain nuclear material import data. The government provided information on the quantities of imports of enriched, natural, and depleted uranium, but it decided not to provide the name of the suppliers.[31] Separate sources named China as supplying about 60 tonnes of low enriched uranium and France as providing natural uranium hexafluoride. With regards to the latter material, during a 1994 interview with a senior Y Plant official with one of the authors, he freely revealed that France had been the source of natural uranium. Although the official policy was not to name suppliers, informally, those names were provided.

- Decided not to reveal to the IAEA the names of the key suppliers of direct-use and dual-use equipment to its enrichment and nuclear weapons programs. Armscor officials broke with this ban and provided a list of goods it acquired for its nuclear weapons programs, although the list was not comprehensive and the names of the suppliers were sometimes omitted;[32]
- Released little information about the nuclear weapons delivery systems, particularly the Raptor glide bomb and the RSA-3 ballistic missile; and
- Did not reveal the entirety of its nuclear strategy, in particular, the threat to use nuclear weapons on the battlefield.

SOUTH AFRICA'S DEMANDS

In exchange for its cooperation, South Africa also had certain demands on the IAEA. According to Stumpf, the South African government insisted that three key conditions be satisfied. By meeting these demands, the IAEA significantly eased South Africa's task of establishing and maintaining transparency.[33]

First and most important, the IAEA had to assure the confidentiality of the information that it received from South Africa. Although the safeguards agreement contains a strict confidentiality clause, many of the IAEA's activities went far beyond the legal boundaries of the safeguards agreement. As a result, the IAEA and South Africa agreed to maintain confidentiality on activities in these other areas as well. Nevertheless, some information leaked out in news reports as a result of the public's intense interest in this subject. South Africa and the IAEA believed, however, that confidentiality was successfully maintained to the satisfaction of both parties.

Second, the IAEA had to avoid any political bias. Since South Africa often had been criticized at the IAEA's General Conference in the past, the IAEA was probably only able to satisfy this condition because the de Klerk government wanted to abolish apartheid and accomplish other domestic reforms. Prior good experience with the IAEA's safeguards division facilitated the establishment of confidence between the two parties.

Third, South Africa wanted the IAEA to maintain continuity with regard to the inspectors intimately involved in the verification process. Although achieving this goal was difficult for the IAEA, given its other responsibilities and the need to include nuclear weapon specialists, South Africa believed that this goal was met sufficiently.

One has to ask whether South Africa's secrecy requests were excessive. In particular, were these extraordinary secrecy requirements aimed at stifling debate among publics and governments and thereby aiding South Africa's goal of deceiving the IAEA about the past nuclear weapons program?

ANNEX TO CHAPTER 10: FACILITIES VISITED BY THE IAEA INSPECTORS[34]

The facilities visited by members of the team during the assessment of the status of the former nuclear weapons program included:

1. The buildings of the AEC establishment at Pelindaba where the initial research and development phase took place and the first demonstration nuclear device was manufactured (called Building 5000 complex), as well as the buildings where the HEU was produced (Y Plant), the uranium metal was produced (Building 2700), the laboratories involved with the tritium and lithium-6 program, and the development work on neutron generators.
2. The Armscor/Circle establishment where the first device was ultimately stored and the other completed devices were manufactured, assembled and stored. This establishment included the high security vaults where the completed devices were stored, high explosive test cells, nuclear material casting and machining workshops, conventional workshops for the production of mechanical and electrical

components, an environmental testing facility, and a high explosive magazine.

3. The new facilities of the Advena Central Laboratories near the Circle establishment, which were intended for further nuclear weapons development work on advanced gun-assembled and implosion-type devices. The facilities included bunkers for explosives processing and testing, an "integration building" for advanced weapons assembly and integration with delivery systems, high-security storage vaults and an explosion test chamber.
4. An explosives test facility, including a small instrumentation bunker, located on military property near Potchefstroom.
5. A purpose-built high security vault in a military ammunition depot at Roedtan, which had been intended for the storage of nuclear devices.
6. An ammunition depot of the South African Defense Force in an abandoned coal mine, near Witbank, about 90 kilometers east of Pretoria, which stored the first nuclear explosive device from November 15, 1979 until April 1982, when it was sent to the Circle facility for storage.
7. The Vastrap site in the Kalahari Desert, where two shafts prepared for underground testing of the devices were located.
8. Armscor facilities at Naschem, near Boskop, and at the SOMCHEM establishment in the Cape Province. The latter was involved in the 1970s with the research and development work on the mechanical and pyrotechnic sub-systems of gun-type nuclear devices.
9. The site at Gouriqua in the Cape Province, where construction of a reactor facility for the production of plutonium and tritium was planned. Beyond some rudimentary civil engineering preparations, the site was never developed; it was sold by the AEC to a private purchaser.
10. The Alkantpan firing range in the Cape Province, where some development work had been undertaken on heavy metal armor penetrators, involving a small number of test firings using depleted uranium and shaped charges. Although there are common areas between this technology

and implosion technology, the team found no apparent link between the Alkantpan test range and the former nuclear weapons program. The diagnostic facilities at Alkantpan were not considered particularly useful to a nuclear weapons development program.

11. Armscor/Circle facilities at the Kentron Central Factory near Pretoria, where the nuclear weapons program had a secure office. Kentron executives were unaware of the activities of the Circle team in the building and merely provided space. This office contained the headquarters of the nuclear weapons program and conducted special activities, such as job advertising, recruitment, and interviews, and provided a commercial cover to the program. Using this office address, Circle could establish a credit rating with commercial suppliers. In addition, commercial bids and bills passed through this office.

NOTES

1. Waldo Stumpf, "The Accession of a 'Threshold State' to the NPT: The South African Experience," Excerpt from presentation given at the Conference on Nuclear Non-Proliferation: The Challenge of a New Era, organized by the Carnegie Endowment for International Peace, Washington, D.C., November 17-18, 1993.

2. Mitchell Reiss, *Bridled Ambition: Why Countries Constrain Their Nuclear Capabilities* (Washington, D.C.: The Wilson Center, 1995), p. 19.

3. See for example, "Right-Wing Nuke Arms Claim Denied," *The Citizen*, February 16, 1995, p. 3.

4. Information Circular/153 is an agreement detailing the rules and procedures by which IAEA safeguards are carried out in non-nuclear weapon states which have signed the NPT.

5. Stumpf, Transcript of speech at South African Embassy, op. cit.

6. Stumpf, "The Accession of a 'Threshold State' to the NPT," op. cit., p. 8.

7. Stumpf, "The Accession of a 'Threshold State' to the NPT," op. cit.

8. International Atomic Energy Agency, *The Structure and Content of Agreements between the Agency and States Required in Connection with the Treaty on the Non-Proliferation of Nuclear Weapons*, INFCIRC/153 (corrected), June 1972, paragraph 62.

9. Declassified State Department document, "South Africa: Nuclear Case Closed," December 19, 1993. http://nsarchive.gwu.edu/NSAEBB/NSAEBB181/sa34.pdf

10. International Atomic Energy Agency, *Report on the Completeness of the Inventory of South Africa's Nuclear Installations and Material*, GC(XXXVI/1015), attachment, September 4, 1992, http://www.iaea.org/About/Policy/GC/GC36/GC36Documents/English/gc36-1015_en.pdf

11. *Report on the Completeness of the Inventory of South Africa's Nuclear Installations and Material*, op. cit.

12. On the floor on one side of the shade, the inspectors saw a large concrete ramp which appeared to have been cast in situ. This structure may have allowed a test device or other equipment to be wheeled over the test shaft. See "Rendering Useless South Africa's Nuclear Test Shafts in the Kalahari Desert," by David Albright, Paul Brannan, Zachary Laporte, Katherine Tajer, and Christina Walrond (Washington, D.C.: Institute for Science and International Security, November 29, 2011), http://isis-online.org/uploads/isis-reports/documents/Vastrap_30November2011.pdf

13. Frank V. Pabian, "The South African Denuclearization Exemplar," *Nonproliferation Review,* 2015, Vol. 22, No. 1, pp. 27-52. http://dx.doi.org/10.1080/10736700.2015.1071969

14. David Albright, *Highly Enriched Uranium Inventories in South Africa Status as of end of 2014* (Washington, D.C.: Institute for Science and International Security, November 16, 2015). http://isis-online.org/uploads/isis-reports/documents/Highly_Enriched_Uranium_Inventories_in_South_Africa_November_2015.pdf. See for example, Peter Fabricius, "SA playing both sides of the nuclear coin," *The Star*, March 30, 2012.

15. Adolf von Baeckmann, Garry Dillon, and Demetrius Perricos, "Nuclear Verification in South Africa," *IAEA Bulletin*, 1/1995, pp. 42-48. See also IAEA, *South Africa's Nuclear Capabilities* (GC(XXXV)/RES/567), GC(XXXVI/1015), September 4, 1992.

16. This value from an IAEA discussion about the completeness of the South African inventory also had a high degree of uncertainty attached to it.

17. AEC Declaration, March 1994. See also Stumpf, Transcript of talk at South African embassy, op. cit. Stumpf said that the "apparent discrepancy" is "more than five times less than" 526 kilograms, which is the two sigma uncertainty in the uranium-235 content of the tails.

18. Finding these records required the AEC to contact personnel who had already left the AEC's employment.

19. Baeckmann, et al, "Nuclear Verification in South Africa," op. cit.

20. In this analysis, the loss mechanism had to be modeled because the process was so complex. For example, it was sensitive to the radiation background, meaning that effect became more pronounced in higher stages of the cascade where the uranium-235 concentration was greater.

21. IAEA, *The Denuclearization of South Africa*, op. cit.

22. South Africa had informed the Director General of the IAEA in advance of the contents of de Klerk's statement, so the inspectors were prepared to conduct the visits. See IAEA, "IAEA Safeguards in South Africa," PR 93/7, Vienna, March 24, 1993.

23. IAEA, *The Denuclearization of Africa,* op. cit., pp 3-4.

24. The log book listed each part in a device and each change to that device. The dismantling records of the nonnuclear components of the weapons were composed of brief hand-written listings of component systems dismantled from the deliverable devices. The inspectors were told that no records had been kept documenting the dismantling or destruction of the components of the Melba device or any of the pre-production experimental devices (certain series 300 models).

25. IAEA, *The Denuclearization of Africa,* op. cit., p. 11.

26. IAEA, *The Denuclearization of Africa,* op. cit., p. 9.

27. IAEA, *South Africa's Nuclear Capabilities* (GC(XXXV)/RES/567), op. cit., p. 2.

28. Because of particular characteristics of the enrichment stages in the Y Plant, this information was hard to correlate with enriched uranium output.

29. Stumpf, "The Accession of a 'Threshold State,' to the NPT," op. cit., p. 11.

30. Environmental samples taken inside the Y Plant helped determine that LEU had not been used as feedstock, an action that would have significantly increased the HEU output of this facility.

31. IAEA, *South Africa's Nuclear Capabilities* (GC(XXXV)/RES/567), op. cit., p. 1.

32. Armscor officials were more open to providing procurement information but there were limits to what they could have provided because of the destruction of records of what amounted often to cases of illegal overseas procurements. During the 1990s, the United States and South Africa were engaged in settling a criminal case against Armscor's illegal procurements in the United States. As part of that settlement, the United States asked Armscor for the records of its department of foreign procurement, which in essence was a group of smugglers. Armscor is acknowledged by senior former South African officials as having become "quite specialized in 'sensitive procurement.'" [*Armament and Disarmament,* op. cit., p. 82]. However, according to a former senior Armscor official interviewed by one of the authors, "most documents had been destroyed long ago."

33. This section is based on Stumpf, "The Accession of a 'Threshold State,' to the NPT," op. cit., pp. 12-15.

34. IAEA, *Denuclearization of Africa*, Attachment 1, Annex 2; and other sources.

CHAPTER 11
ENSURING AGAINST REVERSAL

After South Africa dismantled its nuclear weapons program, it retained the capability and knowledge to resurrect it. It had many hundreds of kilograms of weapons-grade uranium, and its experts had the knowledge and expertise to turn this material into nuclear weapons despite many of the documents and other records being destroyed. In addition, South Africa had established several sophisticated technologies and capabilities in its civilian industrial sector that could also be used to develop and produce nuclear weapons, if a decision was made to do so.[1]

The leaders of the nuclear programs were well aware of this residual capability and the suspicion that remained in the international community about their or a future government's intentions. To build confidence that South Africa would not build nuclear weapons, the government allowed several transparency steps that would make reconstitution of nuclear weapons more time consuming and subject to detection. However, countries such as the United States wanted South Africa to do more. It did some of these steps, despite their cost. Yet it resisted others, in particular eliminating its HEU stocks, which will be discussed in the next chapter.

ADDITIONAL INTERNATIONAL VERIFICATION MEASURES

One of the first priorities was ensuring that the nuclear weapons program had been thoroughly dismantled. Based on a new mandate to more thoroughly investigate nuclear programs following its failure to detect Iraq's large-scale nuclear weapons effort prior to 1991, the International Atomic Energy Agency (IAEA) undertook a number of initiatives specifically related to nuclear weapons to hinder the recreation of the nuclear weapons program. These steps went beyond the dismantlement steps ordered by the de Klerk government and the practices of traditional safeguards.

One of the IAEA's key steps after President de Klerk's March announcement was to focus on the destruction of remaining nuclear weapons components, blueprints, and documents.[2] By March 1993, when de Klerk revealed the past nuclear arsenal, many nuclear weapons-related items had not been destroyed. Armscor considered these items non-sensitive, but upon examination, the IAEA had a stricter definition of a sensitive item.

The inspectors discovered many of these items in the Circle or Advena storage rooms as they toured these sites under South Africa's expanded transparency policy. The risk of diversion of these items had been minimized because these storage areas had remained classified even after the commercialization of Advena in the early 1990s.

The inspectors inventoried the contents of the storage rooms and other areas in the plants then segregated items into three categories. The first and most sensitive category included items that could reveal significant dimensions or the design of the nuclear material core of the weapons. Examples of such items included tungsten reflector segments, mock-ups, and drawings and photos of key components. The second category included components, such as the gun barrel and computer-controlled electronic boards, that would simplify the engineering design or reveal dimensions of other sensitive components. The reason that the gun barrel was in the second category is probably related to the fact that earlier, during dismantlement, Armscor had cut off what it called the "shoulder" of the gun barrel, rendering it, in its eyes, unusable in a nuclear device.

The third category was everything else, such as motors, brackets, and cables, which the IAEA did not consider sensitive.

After inventorying the leftover goods, the inspectors recommended the complete destruction of any remaining components, photographs, and drawings which could reveal critical design information for nuclear weapons and their components. South Africa destroyed items in the first two categories. If an inspector had a serious concern about an item in the third category, it was also destroyed. The IAEA defined "destruction" to mean that the critical dimensions of a destroyed component would no longer be measurable or reproducible, that the intended function would no longer be recognizable, or that a destroyed item could not be reconstituted faster or more economically than it could be redesigned or rebuilt.

The IAEA also recommended that some equipment specific to the nuclear weapons program should be scrapped. For example, it asked Armscor to destroy the cages for lowering personnel and cameras into the test shafts at the Kalahari site.

DISMANTLING THE KALAHARI NUCLEAR TEST SITE.

One of the more dramatic dismantlement steps followed the IAEA's request that South Africa render useless the two test shafts at the Kalahari nuclear test site. The IAEA specifically requested that South Africa fill in the test shafts in such a way as to make their reconstitution more difficult or expensive than the construction of new facilities.

Filling in the test shafts turned out to be more difficult to do than expected.[3] Work commenced on June 2, 1993 and was finished by August 1993. This process was recorded by Armscor in a video available on the ISIS web site.[4]

The first task involved removing the concrete and steel plugs over the test shafts. Afterwards, the shafts had to be filled with sand and debris in such a manner that re-drilling would be very difficult. The video contains a schematic of the dismantlement plan (see Figure 11.1), which essentially alternated layers of sand with steel and concrete obstructions that would damage drilling equipment (see Figure 11.2). The obstructions were steel drums filled with concrete and scrap metal (see Figure 11.3).

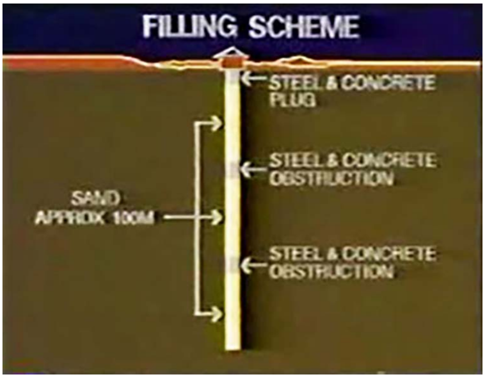


Figure 11.1 The plan for filling in the test shafts at the Kalahari test site. Source: Armscor video on ISIS website, footnote 4.

PROCEDURE
Pump water out of test shafts
Insert first concrete plug
Backfill shaft with sand
Insert second concrete plug
Backfill shaft with sand
Insert third concrete plug
Backfill with sand
Cast concrete cap on first shaft. Remove equipment

Figure 11.2 Procedure for rendering useless test shaft 1, which was located in the shade. Source: Armscor, see video, footnote 4.

However, while attempting to fill the shafts with sand using a large bulldozer, much of the sand was explosively ejected from the shafts, undoubtedly a result of the over-compression of the air in the shafts (see Figures 11.4 and 11.5: Sand shooting out of test shaft, Vastrap, June 2, 1993). Ultimately, while dramatic to watch, this problem merely delayed the completion of this task.

These measures to render useless the test shafts were successfully completed from July 26 to 30, 1993 and were witnessed by

Figure 11.3 Barrels for insertion into the test shafts at Vastrap. Source: Armscor, see video, footnote 4.

Figure 11.4 Sand shooting out of test shaft while destroying it, June 2, 1993. The bulldozer can partially be seen for height reference. Source: Armscor, see video, footnote 4.

Figure 11.5 Casting concrete in test shaft 1 inside the shade (July 1993). Source: IAEA, *Against the Spread of Nuclear Weapons: IAEA Safeguards in the 1990s*, http://www.iaea.org/Publications/Booklets/Safeguards/pia38e14.html

IAEA inspectors. The IAEA team visited the Kalahari site in August 1993 and concluded that Armscor had taken sufficient measures to render useless the two test shafts. Their destruction helped South Africa and the IAEA establish internationally that South Africa had indeed dismantled its nuclear weapons program. It also showed that the IAEA had supplemented its inspection efforts associated with the Nuclear Non-Proliferation Treaty.

FUTURE TRANSPARENCY VISITS

In addition to further dismantlement requests, the IAEA also requested South Africa to continue to provide transparency. To that end, it stated that it intended to request access on a case-by-case basis to former nuclear weapons sites and other locations or facilities that it believed warranted inspection.[5] The rationale was based on a recognition that the IAEA's inspection efforts to establish confidence in the absence of undeclared activities necessarily entailed uncertainties. Moreover, a state can resume nuclear weapons activities in secret. The IAEA's conclusions therefore leave open the possibility, however remote, that some undeclared activity has been missed. To reduce these uncertainties the IAEA wanted to conduct additional visits or inspections in the years after the initial revelations and inspections. In the ensuing years, the IAEA has in fact visited facilities associated with the former nuclear weapons program.

STEPS AGAINST REVERSAL

South Africa took a number of steps independently to maintain public and international confidence that the nuclear weapons program would not start again or spread. In Waldo Stumpf's view, these efforts, like the dismantling of its nuclear arsenal and joining the NPT, "should be seen in the light of a fundamental reappraisal of South Africa's constructive role in promoting international nonproliferation."[6] In response, the South African government was increasingly seen as an international leader of nonproliferation and nuclear disarmament initiatives.

Recognizing that it needed to do more than ratify the NPT, the government launched a series of measures to better ensure that nuclear and missile technologies would not be exported to countries that were seeking weapons of mass destruction. In 1992, even before de Klerk's announcement, Armscor established an interdepartmental committee chaired by Gideon Smith, a senior Armscor official and former leader of the nuclear weapons program, to draft nonproliferation legislation specifically aimed at creating a national non-proliferation authority.[7] Smith recommended creating an independent statutory body, but the government decided to place the authority, called the Council for the Non-Proliferation of Weapons of Mass Destruction, under the Minister for Trade and Industry.

The draft bill was finished at the end of 1992 and circulated widely for review, including to the US government. According to a South African Foreign Ministry official, almost all the changes suggested by the United States were included in the final bill. In July 1993 South Africa brought this act into force as the Non-Proliferation of Weapons of Mass Destruction Act (Act no. 87 of 1993).

The act created the national legal framework for the Council for Non-Proliferation and for the government to prevent the development of weapons of mass destruction (WMD), including controlling trade in goods potentially related to WMDs. The act made it a criminal offense for any South African citizen to develop or assist in the development of chemical, biological, and nuclear weapons as well as missile delivery systems for such weapons, including ballistic missiles.[8] This act established national control over the use, import, or export of dual-use equipment, relevant materials, or purpose-built equipment. The list of controlled nuclear dual-use items reflected the dual-use list of the Nuclear Suppliers Group (NSG).

The Nuclear Energy Act (Act no. 131 of 1993) was revised in 1993 to embody the obligations undertaken by South Africa when it acceded to the NPT and signed a safeguards agreement with the IAEA. This act and associated regulations prohibited the export of nuclear materials, equipment, or facilities to non-nuclear weapons states unless they have full-scope IAEA safeguards in operation, a condition that is equivalent to the obligations assumed by members of the Nuclear Suppliers Group. Under this legislation, the AEC was given responsibility to control nuclear exports.

The standing up of the Council for Non-Proliferation involved establishing a range of regulations based on the 1993 Non-Proliferation Act. Many of the arrangements went beyond the efforts of many countries at the time, including some in the NSG. Companies had to register if they possessed, manufactured, or used controlled goods. Exports from South Africa would be subject to extensive end use checks. The Non-Proliferation Council's process of evaluating export requests involved an impressive checklist of factors.

A few problems were identified while the implementation regulations were being debated.[9] The 1993 legislation did not require the establishment of corporate internal compliance systems or a clear mechanism for holding company leaders at fault for illegal exports. Such systems were being developed in Europe at that time as a result of the failures in their implementation of export controls.[10] There were concerns that the South African government would not allocate sufficient resources to implement its export controls and adequately enforce them. One related concern was whether South Africa would seek cooperation with other international organizations and foreign governments, especially regarding problem countries that may use front organizations or trading companies to acquire items from South African companies.

Diplomatically, South Africa took the initiative to become a leader of international and regional non-proliferation efforts. At the April 1995 NPT Review and Extension Conference, South Africa played a decisive role in achieving the indefinite extension of the NPT. Led by nuclear policy experts of the ANC and officials from the de Klerk government, South Africa declared its early support for indefinite extension of the NPT. This strongly affected other members of the Non-Aligned Movement (NAM) and helped to block efforts for a united NAM position advocating limited NPT extension. South Africa's proposal of Principles and Objectives on Nonproliferation and Disarmament, which created a yardstick to measure states' progress on nonproliferation and disarmament goals, was the basis of the formula that overcame the differences between the Western and NAM nations over indefinite extension. According to U.S government, "Without South Africa's contribution, the achievement of the indefinite extension of the NPT without conditions would have been far more difficult."[11] Its action demonstrated the new government's commitment to nuclear non-proliferation and its ability to bridge the gap between the developing and Non-Aligned Movement.

Within the region, South Africa fully supported the creation of an Africa-wide nuclear weapons free zone treaty. The Organization for African Unity (OAU) had sought the denuclearization of Africa for three decades, but progress could not occur until South Africa dismantled its nuclear arsenal. In April 1996, over 40 nations signed the treaty, which is known as the Treaty of Pelindaba in honor of South Africa's role.

INTERNATIONAL INCENTIVES

Although incentives are not typically viewed as a defense against reversal, they created an important motivation for South Africa to stay its course of action. They also served to better integrate South Africa into the international community, which has also been an important defense against reversal.

South Africa received several specific incentives for its decision to terminate its past nuclear program and join the NPT, some of which include:

- In the early 1990s, the United States and other Western countries lifted their nuclear sanctions, allowing South Africa to proceed with expanding its sales of uranium and other nuclear materials;
- South Africa and the United States negotiated a new bilateral nuclear cooperation agreement;
- The IAEA re-admitted South Africa to its many bodies, including the General Conference and the Board of Governors. It appointed a South African to the Advisory Groups on Safeguards Implementation (SAGSI) in 1992; and
- South Africa held bilateral discussions with other African states regarding agreements on the use of medical isotopes and training programs. South Africa became a member of the African Regional Cooperative Agreement (AFRA), an IAEA organization that coordinated peaceful nuclear projects in the region.

South Africa also joined a number of international efforts to control exports and prevent the spread of nuclear weapons and other weapons of mass destruction, including the:

- Zangger Committee of the NPT;
- Convention on the Physical Protection of Nuclear Materials;
- Chemical Weapons Convention and the Biological Weapons Convention;
- Conference on Disarmament;
- Nuclear Suppliers Group (NSG); and
- Missile Technology Control Regime (MTCR).

Membership in the NSG and MTCR brought international prestige and access to technology and international markets in nuclear and high tech goods. However, obtaining that membership also required South Africa to take additional steps, some of which would turn out to be painful for Armscor and the defense industries.

DEMISE OF THE SPACE LAUNCH PROGRAM AND TOUGH CONTROLS ON ARMSCOR

Gaining membership to the Missile Technology Control Regime included tough conditions. The United States demanded that South Africa end its space launcher program, the rocket program that US officials viewed as essentially a dangerous ballistic missile program. It also demanded that South Africa further limit its foreign sales of missile goods. The US government also imposed a range of conditions on Armscor (and Denel, a state-owned commercial company that took over the Armscor manufacturing subsidiaries in 1992) because of past illicit trade practices. South Africa agreed, but the damage to Armscor and in particular Denel was immense. Hundreds if not thousands of high-tech defense jobs were lost.[12]

When the South African government ended the nuclear weapons program, it approved Armscor commercializing what had been a military space program that aimed to launch spy satellites and eventually develop a nuclear-tipped ballistic missile. The space launch/missile programs involved thousands of personnel and conducted three launches of solid-propellant rockets from June 1989 to November 1991, including a two-stage missile that travelled down range from the Oberberg Test Range almost 1,500 kilometers. With the demise of the military program, Armscor was charged with finding commercial, civilian projects. Armscor subsidiaries such as the Oberberg Test Range and Somchem, which made the rocket launcher, became part of the government owned commercial company Denel in 1992 and sought new customers (see Figure 11.6). According to a senior South African foreign ministry official, France was asked to participate, but the cooperation did not materialize.

The United States opposed this commercialization. It insisted that South Africa end its indigenous program to build and launch rockets. It did not object to South Africa pursuing its commercial satellite and final-stage booster program, but it wanted any exports tightly controlled and consistent with US and international standards. The level of mistrust between the U.S. government and Armscor was so high that US officials insisted on witnessing the destruction of the remaining South African launchers, materials,

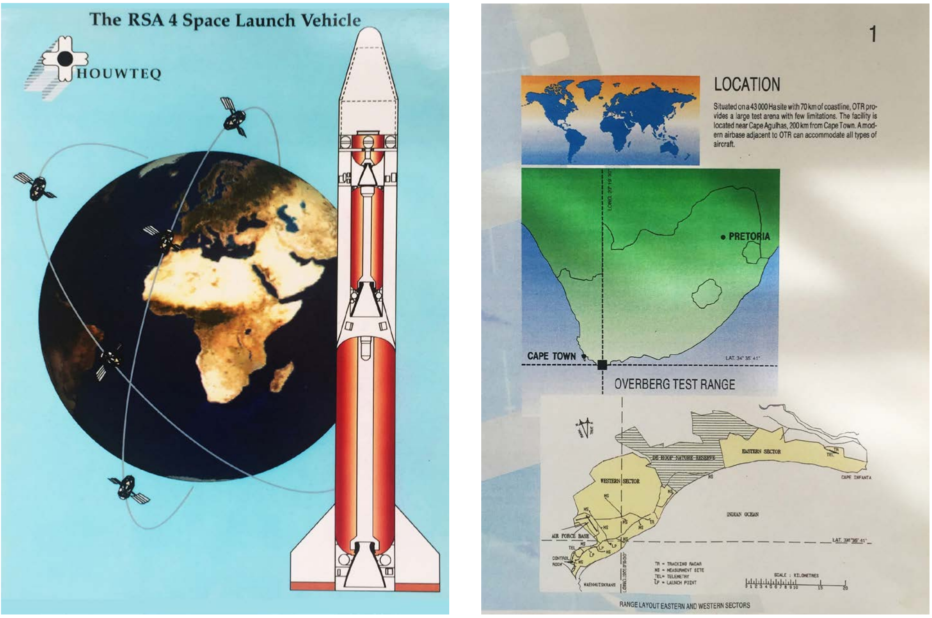


Figure 11.6 Examples from Denel's commercial literature advertising its space launch capabilities at Houwteq and the Oberberg Test Range (OTR).

and manufacturing equipment. Denel's rocket division Houwteq destroyed its larger rockets. Somchem destroyed its inventory of rocket fuel, rocket casting pits, and static motor rocket stands. Faced with a lack of funds, South Africa insisted that the United States pay a substantial portion of the destruction costs.

Denel's subsequent commercialization effort was not successful. By mid-to-late 1994, the satellite program was without customers, and these programs were ended as well. The new ANC-led government was no longer willing to subsidize defense industries since funds were needed for national reconstruction, despite the loss of many more high technology jobs.

Further hurting Denel's (and Armscor's) prospects, the US government remained very suspicious of Armscor's past and potential illicit procurement activities, even after South Africa ended its nuclear weapons program and halted its cooperation with Israel on rockets.[13] In 1991 the United States had indicted Armscor, its subsidiary Kentron, and seven South African citizens allegedly acting under instructions of Armscor for illegal exports from the United States that violated the arms embargo.[14] It also banned Armscor from obtaining exports from the United States that were on the MTCR lists.[15] After the ANC took over the government in 1994, it asked the United States to drop the charges. The Clinton administration was unwilling to do so, insisting that these past crimes must be prosecuted.[16] The US Justice Department sought guilty pleas and a fine of $50 million, according to a senior Armscor official.[17] The South African government was unwilling to pay such a high fine or allow Armscor, a government entity, to plead guilty, principally citing the financial demands of national reconstruction. In 1994 Armscor, along with Denel and its subsidiaries, were formally debarred under US law and banned from doing business in the United States. In 1997 a deal was finally reached, whereby Armscor and Kentron pled no contest to violating US export controls and agreed to pay relatively small fines. As part of settling this case, Armscor had to provide information about past illegal procurements and agreed to accept stringent export controls on its trade activities. It also had to create tough internal compliance mechanisms, including a compliance manual approved by the US State Department, in order to ensure that its international trade met the highest international standards. After Armscor met all of the conditions set out in the plea deal, the United States dropped sanctions on Armscor temporarily in March 1998, then permanently in 2004.[18]

EX-EMPLOYEES OF ADVENA

As its problems with the United States intensified, Armscor faced threats from former employees that they would reveal nuclear secrets. These threats occurred against the background that South Africa had committed to preventing ex-employees of the nuclear weapons or ballistic missile program from aiding other nuclear weapons or missile efforts. To that end, Advena Central Laboratories had been commercialized in an effort to find other sources of funding for members of South African nuclear weapons programs. However, the commercialization program was not profitable, and Advena was closed permanently in early 1993.

That closure involved the transfer of the remaining staff to Armscor and other Denel subsidiaries, but also required laying off 60 people.[19] The next year, sixteen of these laid-off individuals threatened to reveal to the highest bidder secret information about nuclear weapons, South Africa's secret cooperation with Israel on missiles, and specialized equipment suppliers in Britain, France, and Germany. In return for their silence, they asked for more than a million dollars in unemployment benefits.

In response, Armscor obtained an injunction barring the 16 from revealing any sensitive information about Armscor's and Denel's armament supply, export, import, manufacture, or research. Armscor officials also visited each of the 16 to ensure that they understood their prior oath of secrecy, the conditions of the injunction, and the danger of their actions. Condemning the threats as tantamount to blackmail, ANC officials supported Armscor's action. Roger Jardine, the ANC's National Coordinator of Science and Technology, told the newspaper *The Citizen*, "The threats can be construed as holding South Africa hostage to a nuclear threat."[20]

As far as is known, the 16 individuals complied with the injunction and admitted that their threat was a bluff, essentially a tactic to negotiate a better retirement package. It is hard to judge the damage they could have done if they had carried out their threat. According to a senior Armscor official knowledgeable about the case, the individuals, of whom only about 2-3 were scientists, had limited knowledge about nuclear weapons. They knew some details about the pyrotechnical side of the nuclear device, but none had knowledge of the entire device.[21] However, they were knowledgeable about the cooperation between Israel and South Africa.

During 1994, as the defense sector continued to shrink, Armscor reached out to the United States for financial help for those who had worked on its nuclear and space launch vehicle programs or possessed skills and know-how that could "contribute to proliferation and who are either unemployed or threatened by lay-offs."[22] In addition to preserving South Africa's industrial capabilities, these efforts aimed at domestically utilizing highly trained scientists, engineers, and technicians in order to keep them from unknowingly or deliberately posing proliferation risks by leaving the country or selling to foreign buyers in South Africa. The Institute for Science and International Security aided in this effort by reaching out to the US government to recommend non-proliferation aid for these

South Africans.[23] At the time, the United States was providing assistance to former members of the Soviet nuclear weapons complex at the newly created International Science and Technology Center headquartered in Moscow. Broadening the assistance to South Africa made sense and was certainly needed. However, this effort was unsuccessful, largely due to lack of awareness of the issue and lingering mistrust of Armscor residing among US officials.

Several years later, André Buys studied the fate of the roughly 400 personnel who had been in the nuclear weapons programs at Pelindaba and Circle/Advena right after they left the program.[24] This group is only a small subset of the total number of individuals who produced enriched uranium for weapons or acquired or supplied components, equipment, materials, and services for sensitive nuclear programs. Nonetheless, the group Buys investigated is composed of those who in essence worked on making and maintaining the nuclear weapons themselves. As such, it is a relatively small group but one possessing highly sensitive knowledge and expertise. He found that most were proud of the work they had performed for their country and found it hard to do "ordinary" work again. Only a small minority believed that the program should not have been terminated.

Buys estimated that about 16 percent of this group worked abroad after leaving the program; several individuals reported receiving a nuclear or armaments related job offer overseas. However, he did not report evidence that any of these individuals aided a foreign country's nuclear effort, although he did not have the resources to investigate these cases.

Although the educational level of this group was relatively high, their employment immediately after being terminated was not as lucrative as would have been expected for those who had performed such a vital national security task. The largest fraction of those Buys studied, or 44 percent, indicated that their monthly income decreased after they left the nuclear weapons program. For about 34 percent of this group, their income was unchanged. Only 22 percent reported that their income increased. Overall, Buys concluded that most of these former members of the program did not pose a proliferation risk. However, he assessed that a minority of them did in fact pose a risk. It was namely those that had been laid off, about 40 percent of the total, who then went on to face unemployment and financial hardships. Although he did not quantify this minority, to reduce the risk, he concluded that this subgroup should have received more generous compensation packages and additional assistance finding new employment.

Although Buys documented no cases of individuals in this sub group proliferating, he did not investigate those cases where former members had worked overseas. He also did not investigate the larger group of people associated with supplying South Africa's nuclear programs. A few members of that group turned out to be proliferating on a major scale.

LEAKAGE

Although the post-apartheid South African export control system contained several innovative measures, it was unable to detect or stop major violations by a small group that had already been secretly supplying Pakistan's and likely others' nuclear programs for many years. Key members of this group spent years helping bust sanctions for the apartheid regime. When business with the regime lessened in the mid-1980s, they turned to helping other countries' nuclear programs. Their illicit proliferation activities continued well past the end of South Africa's nuclear weapons program.

Unlike the group of ex-nuclear weapons people, who were periodically checked on by Armscor authorities in the 1990s, the other, far larger group of individuals who produced enriched uranium for weapons or acquired or supplied components, equipment, materials, and services for the sensitive nuclear programs were largely not scrutinized by trade control officials. Armscor officials from the former nuclear weapons program, who could have helped detect suspicious activities and keep track of former members of the illicit supply chains of the old regime, were largely sidelined starting in about 1995 by the Non-Proliferation Council, when it ended a key contract with Armscor aimed at implementing export controls regulations and practices. Key officials in the AEC from the earlier nuclear program, such as Waldo Stumpf, were likewise losing their positions and influence in the new government, further eroding the ability of government to detect illicit trade.

Later, during the late 1990s and early 2000s South African trade control authorities missed or ignored hints of this group as it expanded its illicit procurements to include a major nuclear weapons program in Libya. It learned of this group only after it was exposed by the United States and Britain. The exposure followed the interdiction by the United States and Britain of the BBC China in October 2003 in the Mediterranean carrying a load of centrifuge parts to Libya. The evidence gathered by the United States and Britain revealed a vast, transnational network of smugglers headed by the Pakistani A.Q. Khan, with a long-established node in South Africa run by this group.[25]

The key members of the South African node were Gotthard Lerch, Gerhard Wisser, Daniel Geiges, and Johan Meyer. From the mid-1980s until 2004, these four individuals and others at their companies became secret suppliers of centrifuge equipment to not only Pakistan, but also Libya, India, and possibly Iran and North Korea. They also tried unsuccessfully to sell centrifuge designs to South Africa's centrifuge program. Until they were exposed following the seizure of the BBC China, they operated their illegal operation in South Africa undetected and mostly unhindered.

Lerch was a German, who arranged to buy nuclear and dual-use equipment for Pakistan's gas centrifuge program starting in the 1970s. Frustrated in his attempts to buy these sensitive goods and equipment for Pakistan in Europe with its more stringent trade controls, in about 1985 Lerch recruited Gerhard Wisser, another German who had moved to South Africa years earlier. Wisser had established a lucrative business with the South African nuclear and armaments industry as the agent for the German companies Leybold-Heraeus (later Leybold) and AEG Telefunken.

Wisser was interested in Lerch's new business with Pakistan. In 1984 and 1985, his company Krisch Engineering had lost a substantial amount of its business with the South African nuclear establishment, as it reduced its procurements. Earlier, Krisch Engineering was a "major supplier of systems, components, and technology" to South Africa's nuclear programs, "including its uranium enrichment activities."[26] One senior AEC official said that Wisser was the "AEC's vacuum equipment supplier," among two to three other suppliers.[27] Geiges, a Swiss citizen, joined Krisch Engineering in 1978 and rose to become the company's chief engineer. Meyer met Wisser and Geiges in the 1970s while he was working at the Valindaba enrichment plants run by UCOR. By 1980, Meyer had formed one of his companies, Roxound Engineering Works and started making equipment for UCOR's enrichment plants.

Lerch's choice of South Africa was inspired. In the 1980s, the South African government depended on smuggling for its nuclear programs, and Krisch Engineering was involved in this smuggling. South Africa was unlikely to detect Krisch selling to Pakistan's centrifuge program. What better place to hide a clandestine, illegal procurement operation for Pakistan than within an illegal one for South Africa.

Although South Africa had pledged in 1984 to abide by the guidelines of the Nuclear Supplier Group and not export nuclear goods or sensitive technology to any unsafeguarded nuclear program, it never established a credible enforcement mechanism until 1993 with the passage of the Non-Proliferation and Nuclear Energy Acts.[28] The main intent of the 1984 announcement was to assuage US concerns that the South African government itself would sell sensitive nuclear materials, equipment, and other goods to unsafeguarded programs, not to pledge that it would work to stop South African companies from making such sales without government authorization. In addition, this pledge did not cover dual-use goods, which were a critical part of what Krisch would supply to Pakistan and others.

The individuals in this group left visible traces of their illicit activities. Moreover, members of the group were known to senior nuclear officials because of their earlier procurement activities for South Africa. Meyer did not hide all his sales to sensitive overseas customers; he openly discussed them. One of his company's archived web sites from the early 2000s notes a 1988 export of process piping for an enrichment plant to a sensitive country or customer.[29] The site adds that if the reader is interested in more information about such a sale, he or she should contact the managing director. However, the AEC, renamed the Nuclear Energy Corporation of South Africa (NECSA) in 1999, and the Non-Proliferation Council did not appear to have the resources or capabilities to detect this web site or other slip-ups by the Khan network.

In the end, the South African node was fully exposed after South Africa received the evidence from the United States and Britain in 2004. Meyer subsequently agreed to cooperate with South African authorities, which guaranteed the success of the prosecutions against Wisser and Geiges. Lerch was tried in Germany and pled guilty. However, the sentences were relatively minor for such a heinous crime.

The Khan case should serve as a reminder to all of the difficulty of controlling nuclear assets and those who supply sensitive nuclear programs. In the case of South Africa, this case should also serve as a lesson that maintaining control over a diminishing nuclear program and its remnants is fraught with uncertainties.

NOTES

1. Tielman de Waal, "South Africa's Past Nuclear Program" (paper presented at a press briefing in South Africa, April 6, 1995), p. 6.

2. Report by the Director General, International Atomic Energy Agency, *The Denuclearization of Africa (GC(XXXVI/RES/557)*, GC(XXXVII/1075), September 9, 1993, pp. 8-9.

3. For a detailed discussion of the Kalahari Test site dismantlement, see David Albright, Paul Brannan, Zachary Laporte, Katherine Tajer, and Christina Walrond, "Rendering Useless South Africa's Nuclear Test Shafts in the Kalahari Desert" (Washington, D.C.: Institute for Science and International Security, November 30, 2011). http://isis-online.org/uploads/isis-reports/documents/Vastrap_30November2011.pdf.

4. The video can be found at: http://isis-online.org/conferences/detail/destruction-of-south-african-test-shafts-by-iaea-inspectors/13

5. IAEA, *The Denuclearization of Africa*, op. cit., p. 11.

6. Stumpf, "South Africa's Nuclear Weapons Program," op. cit., p. 25.

7. De Waal, "South Africa's Past Nuclear Program," op. cit., p. 7.

8. The new South African laws did not provide for the extradition of any person from the former weapon programs working on weapons of mass destruction in another country. If they returned to South Africa, however, they could potentially be prosecuted for violating secrecy agreements.

9. Memorandum by David Albright and Kevin O'Neill, "South Africa Council on Non-Proliferation," November 16, 1994, provided to South African officials.

10. For more information about the development of internal compliance systems in German companies, see Albright, *Peddling Peril* (New York: Free Press, 2010), Chapter 11.

11. U.S. Arms Control and Disarmament Agency (ACDA) (now defunct), "Nuclear Proliferation Assessment Statement" pursuant to Section 123(a) of the Atomic Energy Act, as amended, with respect to the Proposed Agreement for Cooperation between the United States of America and the Republic of South Africa Concerning the Peaceful Uses of Nuclear Energy, undated, p. 7.

12. Hannes Steyn, Richardt van der Walt, and Jan van Loggerenberg, *Armament and Disarmament: South Africa's Nuclear Weapons Experience* (Pretoria: Network Publishers, 2003), pp 101-103.

13. In 1991, the US government waived mandatory US sanctions against Israel as part of an agreement where Israel pledged to stop exporting missile technology to South Africa by the end of 1991.

14. On October 31, 1991, a federal grand jury in the Eastern District of Pennsylvania returned an indictment charging Armscor and others, but not Denel which did not exist until about 1992, with conspiracy to violate and with violation of the Arms Export Control Act (AECA). The Department of State therefore had reasonable cause to believe that during the period 1978 through 1989, Armscor and the other cited entities engaged in an ongoing conspiracy to export, and did export, defense articles and defense services to the Republic of South Africa and to Iraq without the requisite Department of State licenses or approvals. Effective June 8, 1994, it became the policy of the Department of State to deny all export license applications and other requests for approval involving, directly or indirectly: the Armaments Corporation of South Africa, Ltd. (a.k.a. Armscor), an agency of the South African Government; the Denel Group (Pty.) Ltd. (a.k.a. Denel), a wholly-owned company of the South African Government; Kentron (Pty.) Ltd. (Kentron); Fuchs Electronics (Pty.) Ltd. (Fuchs); William Randy Metelerkamp; Vern Davis; Brian Scott (a.k.a. "Graham Craighness"); Bert Quinn; Johan Lombard; Jaco Budricks; Gerrit Pretorius (a.k.a. "Bull"); and any divisions, subsidiaries, associated companies, affiliated persons, or successor entities [Vol. 59, *Federal Register*, p. 33811, June 30, 1994].

15. *Federal Register,* p. 51734, October 15, 1991.

16. Defendants may have been involved in other cases involving exports from the United States to South Africa that were sanctioned by the US government, in particular US intelligence agencies. These sanctioned cases were not prosecuted by the United States; only the non-sanctioned ones.

17. Interview with senior Armscor official, August 4, 1994.

18. See *Federal Register* notice at https://www.federalregister.gov/articles/2004/07/21/04-16588/bureau-of-political-military-affairs-rescission-of-statutory-debarment-and-reinstatement-of#h-4

19. SAPA, "Armscor Threatens 'Disgruntled Scientists with Prosecution," *Johannesburg Business Day*, March 30, 1994.

20. *The Citizen*, March 28, 1994.

21. Interview with senior Armscor official, March 30, 1994.

22. Facsimile from Gideon J. Smith, Armscor, to David Albright, "Non-Proliferation Initiatives," August 11, 1994.

23. Letter to Dan Reicher, Deputy Chief of Staff, Office of the Secretary, Department of Energy, from David Albright, President, ISIS, on providing non-proliferation assistance, May 11, 1994. See also the *New York Times* editorial "South Africa's Other Deadly Legacy," May 12, 1994, which recommended joint US/South African projects to put the skills of bomb builders to peaceful uses.

24. André Buys, *Proliferation Risk Assessment of Former Nuclear Explosives/ Weapons Program Personnel: The South African Case Study*, University of Pretoria, Graduate School of Technology Management, July 21, 2007.

25. The complicated tale of the Khan network is only briefly summarized here. The interested reader is referred to *Peddling Peril*, op. cit. A variety of Khan network reports and related documents can be found on the ISIS web site at http://isis-online.org/peddlingperil.

26. The State vs. Daniel Geiges, Gerhard Wisser, and Krisch Engineering Co limited, "Summary of Substantial Facts," High Court of South Africa, undated. http://isis-online.org/uploads/conferences/documents/SouthAf_Court_summary.pdf

27. Interview with former senior AEC official, June 3, 2009.

28. AEC Press Release by J.W.L. de Villiers, January 31, 1984.

29. *Peddling Peril*, op. cit., pp. 103-104.

CHAPTER 12
HIGHLY ENRICHED URANIUM INVENTORY

Although fears of South Africa reconstituting its nuclear weapons program have faded with time, concerns have remained over the security of the highly enriched uranium leftover at the end of the nuclear weapons program. In 1991 when South Africa signed the Nuclear Non-Proliferation Treaty, it had over 800 kilograms of HEU stored at Pelindaba under heavy security and IAEA safeguards (see tables 1 and 2 in chapter 3). The US government has consistently tried to convince South Africa to eliminate this stock because of the risk that some of it would be diverted or stolen. Concerns remain that extremist groups or criminal elements might seize the HEU for political or material gain. There have been break-ins at Pelindaba, one of which implied a high degree of organization.

The debate over the fate of the HEU started soon after South Africa signed the NPT in 1991. Originally, the question over the future of the HEU centered on the possibility of the Atomic Energy Corporation selling "excess" HEU to a nuclear weapon state. According to then head of the Atomic Energy Corporation Waldo Stumpf, in September or October 1992 South African government officials approached both the British and US governments and asked them whether they would be prepared to buy the excess HEU.[1] Only the US government expressed interest, but US officials told the South Africans that because of the approaching presidential election, they could not act at that time.[2] After the election, the relevant officials either were not yet appointed or were unprepared to act during the transition. In any case, by February 1993, US officials told one of the authors that they expected to take up South Africa's offer within several weeks and were willing to buy all of South Africa's HEU.[3] The US intention was to buy HEU without involving the ANC, which was not yet in government in any case.

Initially in 1992, the ANC was undecided about selling the HEU, emphasizing the need to provide safe transport and assurance that no HEU could end up in the US nuclear weapons program. However, the ANC position on a sale hardened. In 1993 the ANC started to view the sale of this stock of material as another example of the "unilateral restructuring" being undertaken by the de Klerk government, which aimed to transfer many governmental institutions to the private sector and effectively place these institutions beyond the reach of an ANC-led government. The ANC had earlier criticized Armscor's transfer of military industries in 1992 to Denel, and this sale may have contributed to souring the ANC's view of selling HEU. At a July 1993 meeting of senior ANC and AEC officials, Stumpf promised not to dispose of the HEU before the formation of a democratic government.[4]

The AEC told US officials that they could make more money if they used the HEU as fuel in the Safari research reactor at Pelindaba to make radioactive isotopes for sale. Because the government had given the Safari-1 reactor a directive to operate with fewer government subsidies, the AEC created plans to minimize reactor costs. One option was preserving the existing HEU stock to fuel this reactor. By the summer of 1993, the AEC was considering keeping all HEU enriched above 60 percent to fuel the Safari reactor over its expected lifetime. The AEC was still willing to consider down blending the HEU that was enriched less than 60 per cent to low enriched uranium (LEU) for use as fuel in the Koeberg power reactors.[5]

In the summer of 1993, the US government proposed that the Safari reactor be converted to burn new low enriched uranium fuel rather than HEU fuel. Under this option, the HEU would not be necessary for the successful commercial operation of the Safari reactor, and South Africa could then sell or blend down its stock of

HEU to low enriched uranium. By September 1993, the AEC and the US Department of Energy had reached an agreement to jointly study the technical and economic feasibility of converting Safari to LEU fuel.[6] Although the AEC fully endorsed the goal of converting to LEU fuel, it also stated that conversion would be subject to economic constraints, which were expected to increase with time. In the protocol, South Africa also stated that it recognized the importance of minimizing or eliminating international trade in HEU. Toward this end, it agreed that it would not engage in trade in HEU under any circumstances.

During these discussions over the fate of the HEU, the Safari reactor continued to use domestically produced 45 percent enriched uranium fuel and operate at about one-fourth of its design power, or near 5 megawatts-thermal (MWth). In 1994, however, South Africa increased the power of the reactor to 20 MWth and resumed the use of 90 percent enriched uranium fuel.

It also decided to keep the 45 percent HEU. South Africa launched a major effort to commercialize the Safari reactor and make molybdenum 99 (Mo-99) for medical uses through the irradiation of targets fashioned from 45 percent HEU. Neutrons produced in the reactor fuel irradiate the HEU targets, causing the uranium 235 to fission; one fission product is Mo-99, which is the parent isotope of the short-lived technetium 99m, the most widely used isotope in nuclear medical diagnostic procedures. South Africa decided to become a leading supplier of molybdenum 99, which signified it was no longer interested in blending down its HEU enriched to less than 60 percent. It essentially decided to keep all its HEU.

The joint reactor conversion study was completed in 1995 and concluded that conversion to LEU fuels was feasible.[7] However, the economic feasibility study, which was done by the AEC alone, concluded that conversion could significantly add to the cost of running the reactor and threaten its commercial viability.[8] Based on an economic analysis of a limited number of options, the AEC argued that conversion would be "economically penalizing" during the time the AEC was concentrating on developing commercial customers for the reactor products. AEC officials, however, said that the AEC would be willing to convert to low enriched uranium fuel if the funds were provided. Given that the South African government would not provide the funds to convert, the question became what would the United States do?

The US government's first reaction was to question the economic study. According to a senior member of the US Reduced Enrichment for Research and Test Reactor (RERTR) program, the AEC's economic study appeared to ignore important options for domestic fuel fabrication that would significantly lower the total costs of the conversion effort. A complete appraisal of all the major options, in this view, would be vital to determine the true costs that would accompany conversion to LEU fuel. If costs were fairly derived, he added, the US government may be willing to contribute to the conversion costs.

However, during 1996 and early 1997, the US government did not act because of internal disagreements between the State Department and the Energy Department over the full cost of converting the Safari reactor.

Meanwhile, the AEC proceeded to institutionalize the use of HEU fuel and targets in the Safari reactor. The impasse over conversion to LEU was to last over a decade.

Only in 2009 did South Africa finally convert the reactor to the use of LEU fuel.[9] Since then, it has obtained LEU fuel from abroad, and thus it no longer requires the use of its domestically produced HEU in fuel. In 2012 South Africa received approval from the US government to import 975 kilograms of US-origin LEU, containing up to 19.95 percent uranium 235.[10] Currently, the near 20 percent LEU is sent to the French fuel manufacturer AREVA CERCA, which makes the fuel for the South African reactor operator NECSA. South Africa's integration into the international fuel cycle system showed that HEU fuels are unnecessary.

The reactor started using LEU targets to make medical isotopes in 2008 or 2009.[11] As in the case of the fuel, the targets have been made by AREVA CERCA, using US-supplied LEU. However, it is unclear from open source information if South Africa has stopped using HEU targets in addition to the LEU targets.[12] It appears that the process of complete conversion to LEU targets has slowed as some of South Africa's overseas customers have encountered delays in obtaining approval from their governments' licensing authorities to use medical isotopes produced via LEU targets instead of HEU targets. In the meantime, South Africa is believed to have continued using HEU targets to make a fraction of these isotopes.

South Africa still possesses a sizeable inventory of HEU. The sidebar shows that as of the end of 2014, South Africa had hundreds of kilograms of HEU, including a few hundred kilograms of unirradiated 80 and 90 percent enriched uranium, the most dangerous types.[13]

Much of the HEU in South Africa is in forms that can be transported to the United States for disposition. The plans to send the HEU in spent fuel to the United States are well underway, although they do appear delayed. The HEU in the leftover target material could also be shipped to the United States. The total amount of HEU in irradiated forms is estimated to be 485-615 kilograms (initial mass) or equivalently 395-525 kilograms (post-irradiation mass). The United States may also encourage South Africa to blend down to near 20 percent LEU its remaining fresh 80 or 90 percent HEU, which amounts to about 220-250 kilograms. An alternative strategy may be for South Africa to avoid the costs of blending down this fresh HEU and instead sell or barter it for LEU to its closest nuclear partners, namely the United States or France.

ANNEX: SOUTH AFRICA'S HEU INVENTORY, END 2014[14]

From 1994 to the end of the use of HEU fuel, the Safari reactor irradiated about 225 kilograms (initial mass) of domestically produced 90 percent enriched uranium. This material is stored in spent fuel. The Safari-1 reactor is estimated to have also irradiated about 75 kilograms (initial mass) of 45 percent enriched uranium in fuel. So, in total, about 300 kilograms (initial mass) of HEU is in spent fuel. Another 185-315 kilograms (initial mass) of domestically produced 45 percent HEU are estimated as used to make Mo-99. This lightly irradiated material is stored.

In total, about 485-615 kilograms (initial mass) of HEU are in irradiated form.

Because of the irradiation of the HEU fuel, as discussed above, the mass of the HEU stock would have decreased by about 90 kilograms uranium 235. The HEU used in targets is lightly irradiated and only a small fraction of the uranium 235 would have been consumed. Therefore, the decrease in mass due to the fissioning of uranium 235 in the targets is not included here. Accounting for fission, the total mass of irradiated HEU is estimated as 395-525 kilograms (post-irradiation mass).

About 220-250 kilograms of HEU remain in the form of fresh 80 and 90 percent HEU. The range is determined in this estimate by the possible need to blend down up to 30 kilograms of 80 or 90 percent HEU to produce additional 45 percent HEU for targets. Likely, the 80 percent HEU would have been preferred for blending, since it was not being used as fuel. Blending down would have increased the total stock of 45 percent HEU by up to almost 55 kilograms. The net increase in the total HEU stock would be about 23-24 kilograms of HEU. Depending on the amount of 45 percent HEU used in targets, there may also be stocks of fresh 45 percent HEU. In this estimate, this stock would not exceed about 75 kilograms.

In terms of the initial mass of the HEU, South Africa had a stock at the end of 2014 of about 815-835 kilograms of HEU. The increase in the initial mass of the stock in this estimate relative to the total initial mass in the early 1990s results from the blending down of some 80 percent HEU to 45 percent HEU.

This estimate assumes that all of the HEU produced in the Y Plant is available for use. In fact, some small amount of the HEU enriched near 45 percent may be economically unrecoverable or better treated as waste. However, such a reduction would be offset somewhat by the additions to the HEU inventory that occurred after 1994 or 1995, as HEU was found in waste drums.

To derive a post-irradiation HEU estimate, the amount of uranium 235 that fissioned must be subtracted from the initial mass. About 90 kilograms of uranium 235 are estimated to have fissioned, leaving 725-745 kilograms. There are other uncertainties in this HEU estimate that are hard to quantify with the available information. As a result, the final estimate of the total HEU stock at the end of 2014 is broadened to 700-750 kilograms of HEU.

NOTES

1. Transcript of talk by Waldo Stumpf, South African Embassy, Washington, D.C., July 23, 1993; and Interview with US State Department official, January 1997.

2. "A Bungled Nuclear Deal," *Newsweek*, July 25, 1994.

3. David Albright and Mark Hibbs, "South Africa: The ANC and the Atom Bomb," *Bulletin of the Atomic Scientists*, April 1993.

4. J. W. de Villiers, Roger Jardine, and Mitchell Reiss, "Why South Africa Gave Up the Bomb," *Foreign Affairs*, November/December 1993, p. 11.

5. See for example, Stumpf, Transcript of talk at South African embassy, op. cit.

6. "Protocol Discussions between the AEC of South Africa and the RERTR Program at Argonne National Laboratory and the US Department of Energy," Pelindaba, South Africa, September 8-10, 1993.

7. G. Ball of AEC and R. Pond, N. Hanan, and J. Matos of Argonne National Laboratory, "Technical Feasibility Study of Converting Safari-1 to LEU Silicide Fuel," Argonne National Laboratory, ANL/RERTR/TM-21, May 1995.

8. G. Ball and F. J. Malherbe, "Techno-Economic Study on Conversion of Safari-1 to LEU Silicide Fuel," Atomic Energy Corporation (paper presented at 18th International Meeting on Reduced Enrichment for Research and Test Reactors, Paris, September 1995).

9. NESCA, Media Release: Nuclear reactor uses only low enriched uranium (LEU) for the first time," South African Nuclear Energy Corporation, June 29, 2009.

10. US Nuclear Regulatory Commission (NRC) export license XSNM3643, which was approved in 2012, and permits the export of 975 kilograms of 19.95 percent LEU for use in Safari fuel and targets.

11. G. Ball and O. Knoesen, "Status Update on Conversion to LEU Based 99Mo Production in South Africa," RERTR 2011-33rd International Meeting, October 23-27, 2011.

12. See for example, Peter Fabricius, "SA playing both sides of the nuclear coin," *The Star*, March 30, 2012.

13. David Albright, *Highly Enriched Uranium Inventories in South Africa Status as of end of 2014* (Washington, D.C.: Institute for Science and International Security, November 16, 2015). http://isis-online.org/uploads/isis-reports/documents/Highly_Enriched_Uranium_Inventories_in_South_Africa_November_2015.pdf. See for example, Peter Fabricius, "SA playing both sides of the nuclear coin," op. cit.

14. *Highly Enriched Uranium Inventories in South Africa Status as of end of 2014*, op. cit.

CHAPTER 13
LESSONS FOR TODAY

The case of South Africa shows that nuclear disarmament is possible even after a country has built nuclear weapons. Its extensive cooperation allowed a rigorous verification of denuclearization by the International Atomic Energy Agency (IAEA), which was aided and supplemented by nations with a special stake in ensuring that all of South Africa's weapons were dismantled and the highly enriched uranium fully accounted for.

Sadly, no other country with nuclear weapons has followed South Africa's example. Twenty-five years after dismantling its arsenal, South Africa remains the only country to have produced nuclear weapons and given them up. The situation is no better today and is perhaps even worse. Although Ukraine, Belarus, and Kazakhstan gave up inherited Soviet-era nuclear weapons, North Korea has joined the ranks of countries with nuclear weapons, bringing the total to nine. The other eight countries with nuclear weapons—Britain, China, France, Russia, the United States, Israel, India, and Pakistan—have made little progress on achieving nuclear disarmament, despite reducing the size of their arsenals in some cases. India and Pakistan have even substantially increased their numbers of nuclear weapons. In short, the set of circumstances that led South Africa to give up its nuclear weapons has not been duplicated in other states that possess them. This lack of progress highlights the remarkable confluence of factors that led to South African disarmament.

Despite nuclear-armed states not following the example of South Africa, its experience remains a rich example for stopping the proliferation of nuclear weapons and understanding the conditions necessary to achieve nuclear disarmament. There is detailed information of why, how, and when it pursued nuclear weapons, although a sufficiently detailed picture of its nuclear efforts has taken a few decades to emerge.

There are a few remaining dim spots. The full story of the 1979 flash in the South Atlantic is a good example. Exactly what happened in what many regard as a secret, low-yield Israeli nuclear atmospheric test remains unsettled, including if there was any South African involvement or knowledge of the alleged test. There also remain questions about the South African Air Force's and Armscor's plans for the production of additional and more capable nuclear weapons in the 1990s.

On balance, the current picture is sufficient to discuss a number of lessons on non-proliferation, export controls, sanctions, verification, nuclear strategy, and IAEA safeguards. Those presented here are admittedly motivated by the more technical focus of this book. However, the subject is rich enough to support many perspectives, and political and social scientists may choose to focus on other aspects of the South African case

MORE HOLISTIC VIEW OF A NUCLEAR WEAPON

For South Africa, a nuclear weapon was both a nuclear device and a delivery system. Rarely did the members of the nuclear weapons program run by Armscor ever call the device or warhead itself a nuclear weapon. South Africa's most threatening delivery system was Armscor's ballistic missiles, which were under development at the end of the program. A ballistic missile capable of carrying a nuclear weapon is in key ways the same as a space launch vehicle capable of putting a satellite into orbit. Therefore it is significant that, in addition to dismantling its nuclear devices and associated infrastructure, South Africa also dismantled its civilian space launch vehicle program. South Africa's agreement to dismantle its most threatening nuclear-capable delivery system is often overlooked in discussing its denuclearization. Yet it remains a significant action, despite its cost in terms of lost jobs and technological development.

The dismantlement of both South Africa's nuclear device and space launch programs highlights their close connection, which is a view in contrast to traditional ones in the nuclear non-proliferation community. In many cases, the delivery system is not treated as the other part of a nuclear weapon. A recent example is the Iran nuclear deal, or Joint Comprehensive Plan of Action (JCPOA), whose designers pride themselves on having sculpted a deal that limits itself to nuclear issues without directly involving other areas, such as ballistic missiles. The JCPOA does not contain a word on Iran's ballistic missiles, some of which appear to be designed to carry nuclear weapons. Even United Nations Security Council resolution 2231, which institutionalizes the JCPOA in international law, accepts a weaker ban on Iranian ballistic missiles than the previous Security Council resolutions on Iran. Further, as Iran violates the new Security Council ban on testing ballistic missiles, the United States has carefully stated that Iran has not violated the JCPOA and its ban on nuclear weapons. This is in spite of the concern that these Iranian missiles could eventually carry a nuclear warhead.

It is certainly important to focus on the nuclear device itself, since it may be that a state first wants to develop the capability to detonate one in order to demonstrate nuclear weapons status. South Africa sought to do this with its first device codenamed Melba, even though it decided against detonating it. However, a narrow view of a nuclear weapon as only constituting the device can leave significant portions of the nuclear weapons program outside the specified limits or verification arrangements of an agreement. It specifically risks fostering agreements that do not limit ballistic missile programs, even though these programs may still be part of a secret nuclear weapons plan or ambition.

In the case of Iran and the JCPOA, unless more is done, Iran will essentially be able to work on one key facet of nuclear weapons – perfecting its nuclear-capable missile delivery systems – while only temporarily limiting its nuclear programs. This schism will likely create further regional and international insecurity regarding Iran's intentions when the nuclear restrictions start to lift in year 10 of the

JCPOA. Thus, treating the warhead or device separately from the missile is counterproductive.

The United States should re-orient its policy on Iran and make stopping its ballistic missile program a higher priority. Otherwise, when most of the nuclear limitations in the JCPOA end after year 15, it may face an Iran not only racing to a nuclear warhead, but also one well positioned for rapidly deploying those warheads on long-range ballistic missiles. Iran's nuclear arsenal could be highly threatening in short order.

Likewise, any future nuclear deal with North Korea should involve limits on its space launch and missile programs, as the 2011 Leap Day deal tried to do. Although the Institute for Science and International Security has been sympathetic in the past to allowing a space launch exemption in any nuclear deal with North Korea, its domestic space launch capability hides a ballistic missile program. It should at least be frozen in any nuclear deal.

More generally, a lesson of the South African case is not to isolate the effort to build a nuclear device from the development or acquisition of advanced delivery systems, in particular ballistic missiles. They go together. The goal of nuclear non-proliferation and disarmament should be achieving limits on both.

NUCLEAR MATERIALS PRODUCTION

In addition to confirming the importance of ballistic missile programs, the South African case reaffirms the common view that producing enough fissile material for nuclear weapons is challenging. Moreover, it also proves that efforts to acquire such material may hide secret or latent nuclear weapons intentions and should be seen as dangerous, justifying steps to prevent or limit these activities.

South Africa was able to build its first nuclear explosive device two years before it had enough highly enriched uranium to do so. Because of problems in its enrichment plant, it could not produce enough for its second device for another two to three years.

Further, South Africa started its uranium enrichment program before it knew for sure it would build nuclear weapons. It was ambivalent about its ultimate intentions during almost the entire first decade of its enrichment program.

As a result, efforts to enrich uranium and separate plutonium, the two primary ways to acquire nuclear explosive materials, should be discouraged in regions of tension, particularly the Middle East, South Asia, and Northeast Asia. As a matter of policy, these activities should be viewed with concern and as an indication of possible nuclear weapons intentions, regardless of national statements that they are for peaceful use or will be under IAEA safeguards. Perhaps they are peaceful. However, the South African case would suggest that a more suspicious attitude about efforts to separate plutonium or enrich uranium is prudent when that activity occurs in regions of tension.

As discussed, Iran's centrifuge program will likely remain a risk that will grow after the nuclear restrictions in the JCPOA lift starting in year ten. The United States and its allies need to view Iran's centrifuge program as an on-going risk to international security and step up their efforts to constrain or negotiate an end to Iran's centrifuge program.

More broadly, the United States needs to ensure that other states in the Middle East do not seek plutonium separation or uranium enrichment capabilities. Several countries may be motivated to follow Iran's lead in seeking sensitive nuclear facilities and capabilities.

The reprocessing programs in the non-nuclear weapon states of North Asia deserve another look, as North Korea's expanding nuclear weapons program leads to increased discussions among U.S. allies about acquiring their own nuclear weapons. Although the governments in these countries remain against them, the security situation is fluid and could shift over the next several years. In certain cases, the pressure to acquire nuclear weapons could increase and the easy availability of separated plutonium may assist the motivations in deciding to build nuclear weapons. As a result, new reprocessing or enrichment programs in North Asia should be discouraged. In the case of existing ones, if reprocessing or enrichment is not economical or otherwise clearly justified, these programs should be reduced and eventually eliminated.

EVASION

Deception was critical to South Africa's nuclear weapons program. It was fundamental in keeping its adversaries and allies guessing about its nuclear efforts and intentions. Its nuclear strategy depended on maintaining a highly sophisticated concealment effort. Moreover, illicit procurement required a great deal of deception about the end use of the goods Armscor and the nuclear establishment bought overseas. Failures to hide the program, such as unfortunate statements by uninformed or misguided South African government officials, were denied officially; however they were also used to create uncertainty about the existence of South Africa's nuclear weapons as part of phase 1 of its nuclear strategy.

Frank Pabian has pointed out that despite the "shining success story" of South Africa's nuclear disarmament, there "are the concealment efforts that continued despite outward signs of cooperation and transparency."[1] These continued until March 1993. Even after, there were further efforts to hide parts of the nuclear weapons program and downplay certain aspects, such as the delivery systems of the nuclear weapons, the full nuclear strategy, the sophistication of the nuclear weapons, and foreign procurements. Likewise, distortions were readily disseminated in expert and governmental communities.[2]

Both Iran and North Korea also use deception as a tactic. Despite the overwhelming evidence, including IAEA judgements, Iran still denies it ever had a nuclear weapons program. It is also still hiding parts of nuclear efforts of which the IAEA had evidence. North Korea both hides activities, such as it did for years with the centrifuge program, and exaggerates its accomplishments. For example, North Korea recently claimed that it could strike the United States with a nuclear-tipped ballistic missile.

One obvious implication of the South African case is to treat official Iranian and North Korean statements with a high degree of skepticism, along with the echoes of their supporters. The simple fact is that Iran and North Korea, like South Africa and others, lied about nuclear weapons. They did so out of a recognition that their success depended on maintaining secrecy and out of knowing that lying can minimize the international consequences of the truth.

Countering the nuclear deceptions of countries such as Iran and North Korea requires robust international inspections and intelligence operations. It also requires an independent non-governmental community willing to uncover and challenge their deceptions. North Korea's exaggerations need to be guarded against lest they increase instability and overreactions among the United States and its allies.

SAFEGUARDS, TRANSPARENCY, AND REVERSAL

The IAEA was profoundly affected by its experience in South Africa 25 years ago. It deployed new approaches, such as verifying the completeness of a declaration, gaining access to military industries associated with the former nuclear weapons program, deploying nuclear weapon experts to investigate, and conducting in-depth interviews with those involved in making nuclear weapons. All of these practices have become important tools for IAEA safeguards.

For its part, South Africa's eventual transparency and cooperation stand out as one of the most significant aspects of its dismantling its nuclear weapons program and coming into compliance with the Nuclear Non-Proliferation Treaty (NPT). Full access, openness, and transparency were vital to ensuring the credibility of the dismantlement effort and reaping the sought after international engagement.

South Africa's initial positon on transparency was not adequate. However, in reaction to calls for more transparency, fortunately, the government agreed. The evolution of President de Klerk's thinking from 1991 to 1993 was especially important. When the IAEA launched its verification of South Africa's initial inventory of nuclear materials, South Africa first sought to manage the amount of transparency it would provide. It even misled inspectors about its past activities in Building 5000 and at the Kalahari test site. Nonetheless, after the ANC, the United States, Russia, and the natural course of the IAEA's investigation pressured de Klerk to allow greater transparency, he had the wisdom to modify the South African government's position and come clean. By coming clean and committing to greater transparency, South Africa also avoided serious conflicts with the IAEA that would have also undermined its international goals. The experience showed that in order to counter remaining international suspicions and revive international engagement, South Africa had to eschew an attitude of "the past doesn't matter" regarding its nuclear weapons program. For South Africa, this path also helped achieve the important security goal of a nuclear weapons free zone in Africa.

The evolution of South Africa's transparency also shows the critical role of international oversight in the dismantlement process. It is needed so that the international community, and in particular regional neighbors, can gain confidence in full dismantlement and future intentions.

Although South Africa rejected IAEA involvement while it was dismantling its nuclear weapons, it is still worth considering whether a different course would have been more effective. Had the IAEA been able to supervise the dismantlement from the start and oversee how the components of the program were destroyed, repurposed, or dispersed, it may have also been able to reach a quicker determination about the correctness and completeness of South Africa's nuclear declaration along with the absence of an ongoing military nuclear program.

Relatedly, if a state initially decides to secretly dismantle large portions of a nuclear weapons program like South Africa did, needed documentation and information can be lost. This delays the process of IAEA verification – particularly nuclear material accountancy. The South Africa dismantlement process, even though it was overseen by the auditor Wynand L. Mouton, left IAEA inspectors lacking uniform and rigorous records about nuclear weapons dismantlement, which affected the investigation. Nevertheless, with careful and recalibrated verification processes, the IAEA was able to overcome most of these challenges.

In its initial investigations, the IAEA was relatively tolerant of South Africa's deceptions about its nuclear weapons program. Confronted with the existence of highly enriched uranium in metal form soon after South Africa signed the NPT, the IAEA was immediately suspicious about South Africa's initial declaration. Its suspicions were clearly increased by the information about the past program received from member states about a year later. However, in its initial investigations, the IAEA said little to South Africa, IAEA member states, or the public about its doubts about the truthfulness of South Africa's declarations. At the time, the IAEA and many states viewed traditional safeguards agreements as requiring the IAEA to keep secret virtually all the information in the initial declaration along with most other information provided by the state. Complicating the IAEA blowing the whistle on this deception, South Africa had conditioned its transparency policy on the IAEA maintaining a high level of confidentiality. As a result, the IAEA had neither a mandate to reveal its suspicions about the past use of this material nor the motivation to undermine South Africa's commitment to transparency, albeit involving untruths about its nuclear programs. This hesitancy to reveal critical information is a problem that even today the IAEA has not fully settled.

Another key lesson for future dismantlement cases is that taking specific, publicly reassuring steps is important in ensuring against the restart of a dismantled nuclear weapons program. A key step South Africa took was permitting the IAEA to determine the scope of the program by allowing inspectors "anywhere, anytime" access to sites, along with access to nuclear weapons program officials. South Africa also revealed and allowed visits to sites that the IAEA had not previously known about. Further, South Africa agreed to allow ongoing investigations and case-by-case visits to former nuclear weapons related sites and experts upon IAEA request. This was done in order to ensure the program was not reconstituted.

South Africa also recognized that it needed to do more. It passed necessary domestic nonproliferation legislation and instituted export controls on sensitive goods. In addition to joining the NPT and engaging in efforts to expand NPT membership and compliance, it also joined other international nuclear nonproliferation regimes and groups and became a strong advocate for nuclear disarmament. Later in 2002 it began adhering to the IAEA Additional Protocol, and even today encourages broader signature of these expanded IAEA inspection authorities. All of these steps have helped reassure the international community and regional neighbors that South Africa is committed to its reformation as an NPT-compliant non-nuclear weapon state.

Ambiguous nuclear weapon states seeking greater international engagement may be less able to extract concrete benefits for denuclearization. Such states must grapple with whether revealing a nuclear weapons program while asking for concessions would harm efforts to be seen as a newly responsible member of the international community. By initially dismantling its program in secret, South Africa removed the option of trading dismantlement and accession to the NPT for concrete benefits from the international community. This decision was premised on an attempt to save face and not incur any additional sanctions or negative repercussions. It remains unclear if this decision making model has set any precedents for future dismantlement cases. The only similar case for comparison would be officially nuclear-ambiguous Israel, as it would be difficult to imagine Israel demanding concessions for a future decision to undertake nuclear weapons dismantlement.

Despite its eventual high level of cooperation and transparency, South Africa does not represent the "gold standard" for IAEA verification. Olli Heinonen, a former Deputy Director General of safeguards at the IAEA who was involved in the South Africa inspections in the early 1990s, believes South Africa represents a "silver standard" for verification. To him, Libya represents a "gold standard." South Africa of course abandoned deliverable nuclear weapons, while Libya fell short of even making them. Yet once former dictator Muammar Gaddafi decided in 2003 to abandon the turn-key nuclear weapons program purchased from the Pakistani A.Q. Khan network, he immediately allowed unhindered access to IAEA inspectors, in addition to the full scale removal of the program from the country, which included nuclear weapons designs, components, and documentation. The IAEA was able to reach a conclusion in its Libya investigation with only a few remaining caveats on its knowledge of a weaponization effort. Not only did South Africa delay providing full access, it also initially tried to mislead the inspectors about its nuclear weapons program. It decided not to reveal to the IAEA details about its nuclear delivery systems, and it withheld foreign procurement information from the inspectors. Much of this information has emerged since the mid-1990s as a result of new, less restrictive declassification policies of the ANC-led government, decisions by former members of the nuclear weapons program to reveal more about the program, and research by independent experts and the media.

In comparison to South Africa and Libya, Iran has met neither the gold nor silver standard. Heinonen judges Iran as approaching a "bronze standard," with potential for placing higher if the JCPOA succeeds or if Iran comes clean about its past nuclear weapons activities. Iran has pursued a much more limited transparency strategy than South Africa, and IAEA verification of Iran's military nuclear weapons program has been highly limited. Iran continues to deny it ever had one, despite the overwhelming evidence and the IAEA judgment that it did have one. To reach even a superficial determination about Iran's past military nuclear activities, the IAEA was forced to rely on evidence it had gathered or obtained from member states. Iran denied access to most sites, experts, and documentation of concern. Under the JCPOA, Iran has accepted the Additional Protocol, which requires the IAEA to re-look at its past nuclear activities. However, it is unclear if Iran will allow the IAEA sufficient access to sites and individuals in order to provide assurance that Iran's nuclear program is peaceful. International concerns about its intentions are likely to remain for some time. Moreover, Iran has not made a credible effort to show that its military program has indeed ended. Remnants of the military nuclear effort likely remain in-country, largely unknown to the IAEA, and are available for use if needed. Iran will thus represent a case that provides less international and regional confidence over the longer term about its potential for building nuclear weapons. Further, while it remains at the bronze level of IAEA compliance, Iran may also face far greater obstacles to international economic engagement than it initially counted on. Whether it will ever reach the silver or gold standard is unknown.

Like in the South Africa case, US on-going involvement remains critical in the case of Iran and the nuclear deal. As a result of uncertainty about Iran's nuclear weapons program, the United States should ensure independently that Iran's nuclear program is indeed peaceful. It should insist upon thorough IAEA verification and Iranian implementation of the conditions in the deal, but it should in parallel make its own determination annually about whether Iran has taken any action that indicates Iran's nuclear program is not peaceful.

Could South Africa, after all of its efforts, reverse course and decide to reconstitute its nuclear weapons program? Once a country has acquired the knowledge needed to produce nuclear weapons, it is unlikely that it can be lost forever. Moreover, it retains hundreds of kilograms of HEU. Despite the burning of ostensibly all weapons-related records, could nuclear weapon designs or other sensitive documents remain somewhere in South Africa? Several government documents that were thought to be destroyed have reemerged over the years, although none that relate to sensitive nuclear weapons information have appeared. Nonetheless, the possibility remains that weapons documents still exist; at the very least South Africa would have a head start at reconstitution.

On a practical level, this concern is minimal, at least today, given the absence of the conditions that led to its nuclear armament in the 1970s and 1980s. A democratic government currently remains in power, South Africa's engagement with the international community is strong, and it lacks major security concerns. Nevertheless, the situation requires on-going monitoring.

Overall, the South Africa experience demonstrates that increasing the effectiveness of IAEA inspections has tangible security benefits. In addition, this case confirms that IAEA verification is critical in ensuring international peace and security.

ILLICIT TRADE

As has been the case for many developing countries, South Africa's military and civilian nuclear programs depended on the overseas procurement of a wide variety of goods and sensitive technologies. South Africa pursued a tactic of exploiting international cooperation and procurements to obtain additional sensitive information for its nuclear programs. The South African case confirms that the detection of these procurements is a reliable indicator of secret nuclear activities, including nuclear weapons efforts.

South Africa was hardly alone in efforts to illicitly acquire many nuclear-related goods from abroad. India, Pakistan, Israel, Iran, Iraq, and North Korea, were also active during this historical period in buying for their covert nuclear programs.

South Africa made most of its key procurements when export controls were in their infancy. Only after the end of the South African nuclear weapons program and after the IAEA inspectors exposed Iraq's vast, covert nuclear programs and its extensive amount of foreign procurements, were dual-use goods controlled internationally.

Nonetheless, the controls existing during the 1980s did complicate South Africa's procurements. Despite that dual-use goods were not specifically controlled internationally until the early 1990s, the growing number and effectiveness of embargoes on South Africa's military and nuclear programs posed a challenge. Armscor, after all, was a military entity subject to sanctions. To counter them, South Africa employed many deceptive and inventive tactics to acquire needed, controlled goods from abroad. South Africa exploited weak export controls internationally to obtain key equipment. It sent engineers and technical professionals abroad to gather expertise from friendly countries willing to violate the embargoes. For example, its missile engineers worked with Israeli counterparts, which in at least one case informed related nuclear weapons applications. As the program matured, South Africa also developed advanced, indigenous nuclear and military capabilities. However, it still required procurements from abroad for its rocket programs and Advena Central Laboratories.

The international focus on restricting the supply of goods slowed South Africa's nuclear efforts. In that sense, the South African case confirms that trade controls can create key chokepoints and bottlenecks that can slow programs and raise their cost. Thus, they can provide time for diplomacy or other remedies to have success in convincing countries' leadership to change course. The South African case also shows that without rigorous enforcement of sanctions and export controls, proliferant states can more readily and more quickly acquire the goods they seek and expand their nuclear programs.

South Africa sought many goods for its military programs that were not on control lists; however, they were critical to a particular nuclear or missile program, including uranium enrichment and nuclear weaponization. Although more goods are controlled now, this type of strategy continues today among those seeking goods illegally such as Iran, North Korea, and Pakistan. This phenomenon underlines the need for governments and companies to expand export control lists and more effectively implement "catch-all" provisions in export controls and UN Security Council resolutions. Toward that goal, a helpful strategy is to develop and use "watch lists" to detect and prevent illicit nuclear and missile procurements. A watch list is a list of both controlled and non-controlled components, equipment, and materials that make up the technical aspects of nuclear programs, such as centrifuge enrichment programs. Governments and suppliers can work together to determine what goods may be targeted by proliferant states and add them to watch lists in order to better detect when a new proliferant state emerges or uncover strategic and tactical intelligence about a particular program.[3] A proliferant state seeking several goods on a watch list may sound an alarm to authorities and suppliers, enabling them to better stop such efforts.

During the dismantlement phase, extensive, prior illicit commodity trafficking by South Africa for its nuclear and missile programs posed an unexpected problem. In particular, Armscor's smuggling history was difficult to reconcile with South Africa's denuclearization and caused conflict within the new government and with the United States. It also undermined South Africa's new stature as a nonproliferation and disarmament leader. Armscor's transparency and cooperation was critical in overcoming these problems.

Iran's public commitment to on-going illicit procurements for its missile and arms programs and possible illegal acquisitions of nuclear-related goods likewise undermines confidence in doing business with Iran. Companies and banks need to exercise extreme caution not to become entangled inadvertently in Iran's on-going, illegal procurement activities.

Nuclear dismantlement is made easier and more verifiable by revealing past illicit nuclear and delivery system procurements. Moreover, methods are needed to assure the international community that the state has revealed enough and will not illicitly procure again. The Iran deal lacks these and is weaker as a result. In the case of North Korea, a nuclear agreement should include conditions banning illicit nuclear and missile trade. It should also have a mechanism to determine what has been acquired in the past.

The South African case highlights another type of leakage of nuclear assets, other than the leakage of dangerous nuclear materials highlighted in the post-Soviet context and the Nuclear Security Summits. This other type of leakage is associated with nuclear commodity trafficking and involves insiders and former members of a program illegally selling dangerous goods and technologies to other covert nuclear programs. The continuation of the South African node of the A.Q. Khan network was a particular egregious oversight. Such leakage was not fully anticipated by the government or the nuclear or armaments industries.

Following a country's decision to dismantle or limit its nuclear programs, a priority is developing methods to prevent leakage of nuclear assets. These activities should certainly target nuclear materials, such as HEU, but they should also do more. They should focus on blocking the leakage of expertise to foreign nations and shutting down illicit procurement networks. In essence, the South African case shows that the problem of leakage after dismantlement needs to be understood more broadly than just focusing on nuclear materials.

SANCTIONS

The trade controls imposed by other nations on South Africa were made more effective by sanctions flowing from international opposition to the combination of apartheid and nuclear weapons. In fact, the concern about nuclear weapons served to expand international opposition to the apartheid state because the nuclear weapons program was viewed as more of a threat to world security. However, like trade controls, the sanctions were not capable of stopping the nuclear weapons program, although they slowed it and made it more costly. Moreover, political isolation increased the incentives to build nuclear weapons. It led South Africa's defense establishment to become more self-sufficient and more determined to defend itself.

Nuclear-related sanctions did slow down the nuclear programs by forcing them to economize. In the long term, economic and nuclear sanctions contributed to the draining of South Africa's economy, including its nuclear programs. As the 1985 budget cutbacks discussed in chapter 5, sanctions and an impacted economy played a role in slowing South Africa's nuclear program and forcing it to prioritize. The nuclear program was required to make difficult decisions, such as halting the construction of a plutonium and tritium production reactor and discontinuing lithium production efforts intended for making thermonuclear-type weapons. Sanctions, combined with trade controls to restrict the supply of sensitive foreign goods to a nuclear program, do have an effect on restricting spending, forcing a nuclear program to make difficult priority choices, and constraining nuclear expansion.

Achieving the desired effect of sanctions can take time. Affecting South Africa's leadership to limit its nuclear weapons program was a slow process. Sanctions in the mid-1970s served to reinforce the mentality and deepen the resolve of South African leaders to weaponize their nuclear device. Thus, any country imposing sanctions on a proliferant state should anticipate keeping them in place over a long duration in order to see desired change. They may be faced with the reality of needing to eschew competing policy requirements. Convincing a proliferant state to undertake nuclear dismantlement or significant nuclear limitations should take precedence over other policy goals if sanctions are to have success.

Sanctions influenced political events in South Africa in part because they had equal effects on the minority whites. This democracy of effects, albeit narrow, allowed for the creation of dissent against the pro-nuclear policies of the defense and nuclear establishments. The election of President de Klerk amounted to "regime change" on this issue, but it happened in a white-controlled democratic process.

There is now a case to be made for strong nonproliferation sanctions of the kind that were levied against Iran starting in 2012. These impacted its oil sales, foreign investment, banking, shipping, and other commercial ties. Many analysts judge that these sanctions had a direct result in changing Iran's cost-benefit analysis regarding its nuclear program, in part as a result of rising domestic discontent. Iranian president Hassan Rouhani, who was elected in 2013, was less internationally combative. He was soon understood to have a mandate to seek sanctions relief in return for limits on the nuclear program. So, on balance, strong sanctions may influence political events and bring into power leaders who support reducing sanctions. Iran's elections are of course highly constrained as far as the extent of democracy, and such a mandate would likely have been approved or even initiated by Iran's Supreme Leader, but the grievances of citizens appear to have had an impact on the political leadership.

By contrast, however, sanctions on North Korea have not had the same effect. North Korea's highly isolationist dictator and military regime have been able to remain largely untouched by nuclear and other sanctions. Their needs are met with what they are able to reap from the poor economy, and citizens are unable to rise up in protest. It remains to be seen whether newly strengthened sanctions against North Korea in the form of UN resolution 2270 (2016) will have an effect on convincing its leaders to undertake new nuclear talks and consider limitations in return for sanctions relief and other incentives.

In the case of South Africa, the sanctions became another reason to eliminate the nuclear weapons program, especially when it no longer served a security purpose. South Africa expected rewards for its actions, in particular a quick end to its international isolation. As the leading economic and military power in Africa, South Africa viewed itself as contributing importantly to the peace, stability, and development of Southern Africa. It also stood to benefit from new trade and investment in the region. South Africa expected significant rewards from the international community, particularly for joining the NPT. It is doubtful whether the actual rewards matched the original expectations, but South Africa's international political prestige benefited enormously from its actions.

On the negative side, as discussed above, sanctions and isolation led to the rise of Armscor as a highly militarized, independent defense organization. The defense industry, cut off from foreign purchases by the UN arms embargo, developed an autonomous attitude and contempt for international and national trade controls. It secretly procured many defense goods abroad. It procured many goods from abroad in violation of embargos by using a wide range of deceptive means with suppliers. Arguably this phenomenon is present with regard to the Iranian Revolutionary Guards and Iran's defense industries, as well as similar entities in North Korea. All have also benefited in that way from sanctions. In South Africa, as well as Iran and North Korea, foreign expertise and goods were sought as needed and often obtained. As in the case of Armscor, efforts to limit nuclear programs in Iran and North Korea should also seek to limit their indigenous defense establishments, particularly those involving the most threatening military systems associated with nuclear weapons.

Overall, the South African case would argue that economic sanctions need to be carefully balanced with ongoing efforts to engage the political leaders of a proliferant state and other attempts to reduce security concerns. Otherwise, the effect may merely be to turn the country further inward and increase its focus on nuclear weapons armament. On balance sanctions did play a positive role in limiting and contributing to ending the apartheid regime and South Africa's nuclear weapons program. Their application elsewhere remains a valuable policy tool.

NUCLEAR STRATEGY IMPLICATIONS

South Africa's initial reasoning for its nuclear weapon strategy followed the revelation of its nuclear test site in 1977 and its decision to gain the ability to test rapidly. From that point onward, the strategy evolved as South Africa built its nuclear arsenal. Although the nuclear strategy drove specific decisions on building nuclear weapons, it also paralleled and in some ways helped justify the country's efforts to acquire more sophisticated delivery systems.

South Africa's nuclear strategy was unique. It is the only nuclear strategy in the short history of nuclear weapons that was based on the theory that they would never be used. South Africa's political leaders saw deterrent value in nuclear weapons, but argued that the use of such weapons would amount to political suicide and undoubtedly result in a devastating nuclear counterattack from the Soviet Union, its primary strategic threat. According to those in the program, South Africa would have rather capitulated than use nuclear weapons and suffer Soviet retaliation or more accurately utter destruction.

The exclusion of the operational application of nuclear weapons appealed to the scientists and engineers who built the bombs. Some of their leaders contended that the top political leadership had promised them that the weapons would never have been used offensively.

But it is necessary to ask whether the strategy would have worked. And would the leadership in the end have reneged on their non-military use commitment and made a last stand against the Soviet Union rather than capitulate?

Determining whether the strategy would have worked in deterring a Soviet attack is difficult. In many cases, one would expect that the United States would have sought a resolution between the two that would be short of South Africa losing a war. However, this nuclear strategy was risky. The implied threatened use of nuclear weapons could escalate a crisis dramatically as South Africa instituted its strategy and did not receive the expected response from the United States or the Soviet Union. Moreover, the United States may not have been able to constrain the Soviet Union in some situations, potentially escalating the regional conflict to a global superpower one. The strategy's final step of threatening to use nuclear weapons on the battlefield could have prompted a pre-emptive nuclear strike by the Soviet Union.

There was also the risk that as the crisis worsened, and the reactions were not as expected, the South African leadership could do something desperate and highly dangerous. For example, in thinking thorough various options in case a crisis was not going well, according to a former leader of the nuclear weapons program, the South African planners thought about the possibility of putting a nuclear warhead on a torpedo and shooting it at a U.S. aircraft carrier. It is unclear if the warhead would be set to detonate but even in the case of a dud, the United States would be highly threatened, perhaps seeing it as an act of war. Certainly, it would have viewed an actual detonation as such an act. This option, according to this same official, was never seriously pursued. Nonetheless, it serves as an example of what could happen in desperation.

The strategy could have backfired. The United States and the Soviet Union could have banded together to end the South African regime rather than intervening to negotiate an outcome favorable to South Africa.

In terms of actual use, the issue was not with the strategic planners. It centered on P.W. Botha and the South African military. ANC officials did not believe that the government would have refrained from dropping nuclear bombs on black Africans to defend the Afrikaaner way of life. ANC officials wondered, in particular, what would have happened if a confrontation in the 1980s had spiraled out of control, and South African troops had faced a major military defeat against Cuban forces? If Cuban troops with full Soviet backing had invaded South African territory, for example, would South Africa have detonated its nuclear weapons?

A concern is that State President P.W. Botha in a moment of desperation may have overridden the strategy plans and used them, leading to a devastating Soviet counterattack. However, it is by no means clear that he would have done so, given that the other side had nuclear weapons and appeared ready to retaliate in kind.

This strategy was embedded in a regional security threat environment that proved to be temporary. With the demise of the Soviet Union and the rise of regional peace, a nuclear weapons program became a liability as South Africa transformed to a democracy. But if the apartheid regime had somehow continued, the strategy may have been further developed under the control of the Air Force. It is unclear if the no-operational military use condition would have survived. It is also unclear if an apartheid South African government would have refrained from testing nuclear weapons in the 1990s or 2000s as a way to certify advanced weapons or project itself as possessing nuclear weapons, as India, Pakistan, and North Korea have done since South Africa dismantled its nuclear weapons.

In the 1980s, Cuban forces reportedly were deterred from invading by South Africa's perceived nuclear arsenal. The senior Cuban official Jorge Risquet, who led the Cuban delegation in the talks ending the southern African conflict in 1988, told former South African officials Pik Botha and Waldo Stumpf many years later that Cuba feared South Africa's nuclear weapons and was deterred from invading Namibia.[4] Risquet said that Cuban planners believed that South Africa had deliverable weapons from 1985 onward.

There were mistaken perceptions on the part of South Africa. André Buys said in an interview in 2011 that based on Cuban writings, the Soviet Union did not support Fidel Castro's decision to send Cuban troops to Angola.[5] Buys said that South Africa had thought the opposite and had been deterred from sinking Cuban ship transports or taking over Angola, fearing a harsh Soviet intervention. But the implication of these writings is that the Soviet Union would not have intervened if either had happened. Lack of Soviet support would have likely also deterred Cuba from invading Namibia, regardless of South Africa's perceived nuclear weapons capabilities. Thus, one of the major motivations for a nuclear deterrent, namely Soviet intervention, may have been overstated.

Taken as a whole, it is difficult to see how South Africa's nuclear weapons contributed to regional stability or deterred its enemies from pursuing their goals in Angola and other parts of southern Africa as well as within South Africa. It is unclear whether nuclear weapons provided anything other than temporary assurance to an overly cautious and embattled government. South African officials were wholeheartedly convinced, on the other hand, that the Soviet Union would attack and saw its backing of communist leaning parties in South Africa as a sign of possible interventionist plans.

As the security situation for South Africa improved, and perhaps unfairly in hindsight given what is known today about Soviet calculations, one must ask whether nuclear armament was ultimately a necessary expenditure or simply wasted effort and resources with an untenable nuclear strategy undergirding it. That question will likely remain controversial.

In any case, the two sides' militaries did not engage in security dialogues. Perhaps, such dialogues would not have been possible. Nonetheless, if South Africa and the Soviet Union and its allies had found a way to open a dialogue on their security issues in the 1980s, South Africa in particular may have benefited. It may even have avoided some of the effort and expense of nuclear weapons development.

In general, security dialogues among adversaries' militaries are valuable. They can reduce misperceptions and threats. As a result, the United States should make special efforts to establish and maintain strategic dialogues among adversaries.

HIGHLY ENRICHED URANIUM STOCKS

One piece of unfinished business is South Africa's sizeable stock of highly enriched uranium that was produced for use in nuclear weapons. As Thomas Cochran, former director, Nuclear Program, Natural Resources Defense Council, has pointed out, South Africa's breakout time is zero. The breakout metric measures how close a country is to having enough HEU or separated plutonium for a nuclear weapon and was critical in the Iran nuclear debate. Being at zero means that if South Africa were to decide to build nuclear weapons, it could do so relatively quickly. For comparison, Iran having reached a breakout time of 2-3 months was seen as alarming.

The chance that South Africa would build nuclear weapons today seems small. World events in recent times, however, show how security calculations can sometimes quickly change.

Moreover, concerns remain over the HEU's security against theft or diversion by criminal or extremist groups. Although the government has taken steps to increase security, these concerns remain.

For 25 years, the United States has worked to convince South Africa to blend down this HEU into low enriched uranium or send it out of the country. However, most of this HEU remains in South Africa. One of the most challenging aspects of South Africa's nuclear dismantlement has been its desire to hold onto its HEU stock. The United States did finally succeed in convincing South Africa to convert its Safari reactor to the use of low enriched uranium fuel and targets. However, this conversion took years and is not completely finished, as South Africa may still use some small amount of its HEU in targets for medical isotope production. This residual, temporary requirement for HEU does not change the underlying fact that South Africa has no reason to hold onto its large HEU stock, either as fuel or targets for the Safari reactor.

It should be noted that in the early 1990s, some senior nuclear officials in South Africa considered sending all or a significant amount of the HEU abroad. A stumbling block was that no nation, including the United States, was prepared to act quickly and take the HEU before South Africa revoked the offer. The United States and other countries, including Russia, are better prepared today to seize such opportunities. The South African experience should serve as a reminder of how important these programs are.

A remaining step that South Africa should take to ensure against leakage of nuclear material is to blend down or ship out its remaining highly enriched uranium or trade it for low enriched uranium. This step would also signify a commitment to nuclear security norms which seek to reduce the amount and presence of HEU worldwide. The United States and other countries should remain steadfast in pressing and helping South Africa achieve the goal of having little or no HEU.

PROLIFERATION AND DISMANTLEMENT PROSPECTS TODAY

The experience of South Africa and the factors which led to its decision to acquire nuclear weapons and then abandon them can inform today's discussion of the risk of proliferation or the chance for nuclear disarmament. The factors discussed in earlier chapters that affected South Africa's proliferation and dismantlement decisions are present in other countries faced with difficult national security decisions. In the case of South Africa, perceived security threats, lack of security guarantees, political leadership conducive to international isolation and domestic power centralization, and a growing technological capability, were determining factors for nuclear armament. For dismantlement, key factors were the diminishing of the security threat, and political evolution wherein leaders seek international engagement and domestic power sharing. The length of time a country possesses a nuclear weapons appears to also be a factor in dismantlement likelihood; for example, the longer a country possesses them, the risk grows that they become embedded in the national security structure. South Africa's dismantlement notably came relatively early after the manufacture of its first deliverable nuclear weapons.

One of the most striking implications of South Africa's actions is that for most countries the prospects of nuclear proliferation or disarmament must be evaluated within the context of regional tensions and insecurities. If the security situations in the Middle East, South Asia, North Asia, can be resolved, proliferation may be prevented and wide-scale nuclear disarmament may become more likely. However, no one should underestimate the challenges of solving these regional problems, and solving the regional tensions may not be enough to prevent proliferation or achieve disarmament. Nonetheless, ignoring or downplaying the need for a regional focus is unlikely to stop proliferation or raise the chances of denuclearization.

Overall, nuclear dismantlement has to be assessed to be rare. The factors that led South Africa to dismantle are currently missing among countries with nuclear weapons. In looking at Israel, India, Pakistan, and North Korea, only one – North Korea – is assessed as possibly abandoning its nuclear weapons in the short to medium term, and only if political and security conditions are adequate. India, Pakistan, and Israel may undertake limited reductions at some future point.

The likelihood of dismantlement for the NPT nuclear weapon states is assessed to be very low, except for Great Britain, which occasionally reevaluates the existence of its nuclear weapons. These countries have integrated nuclear weapons as part of their great power and national security status. These arsenals are also perceived to preserve a balance between China, Russia, and the United States and the US nuclear umbrella is perceived as preventing aggression in Europe and North Asia. The NPT nuclear weapon states will thus likely be the last to disarm. Despite this difficulty, arms control restrictions and reductions should be diligently pursued among these states. However, they should be seen as having limits, absent the prevention of further proliferation and the resolution of regional security threats from which proliferation stems.

One of the most important lessons from South Africa is that proliferation can be prevented and nuclear disarmament achieved. However, that effort has to start locally, or by focusing on the regions facing the most dire security threats.

NOTES

1. Frank V. Pabian, "The South African Denuclearization Exemplar," *Nonproliferation Review, 2015,* Vol. 22, No. 1, pp. 27-52. http://dx.doi.org/10.1080/10736700.2015.1071969

2. See for example, Waldo Stumpf, "South Africa's Nuclear Weapons Program: From Deterrence to Dismantlement," *Arms Control Today,* December 1995/ January 1996. Here, he downplays the sophistication and deliverability of the weapons and the nuclear strategy. That he likely knew differently is confirmed by a statement of Nic von Wielligh in his book *The Bomb* [Nic von Wielligh and Lydia von Wielligh-Steyn, *The Bomb* (Pretoria: Litera Publications, 2014), p. 513.] The authors write that von Wielligh had obtained the set of official documents at the back of his book, which discuss missile delivery of nuclear devices, the more detailed nuclear strategy, and plans to expand the arsenal, from the AEC and Armscor "at the time of the IAEA's investigation of South Africa's nuclear weapons programme." Given that von Wielligh reported directly to Stumpf and both interacted heavily with Armscor and the IAEA, these omissions in such journals as *Arms Control Today* must have been deliberate.

3. For more reading on preventing illicit nuclear procurement, see David Albright, Houston Wood, and Andrea Stricker, *Future World of Illicit Nuclear Trade: Mitigating the Threat* (Washington, D.C.: Institute for Science and International Security, July 29, 2013). http://isis-online.org/uploads/isis-reports/documents/Full_Report_DTRA-PASCC_29July2013-FINAL.pdf

4. *The Bomb*, op. cit. p. 281.

5. Interview with Buys, April 4, 2011.