South Africa's Secret Nuclear Weapons

F.W. de Klerk's announcement in March 1993 that South Africa had secretly developed a small nuclear arsenal - and then dismantled it - was quite startling. However, President de Klerk's announcement left many questions unanswered regarding the scope and sophistication of the program, as well why it was developed. Many years later, with only a few answered, some questions still linger.

Nuclear blackmail

The bedrock question, of course, is why South Africa developed and built seven fission weapons in the first place. Some claim that the weapons were never intended for military use.

According to sources, the weapons came out of a technological "can-do" mentality that coincided with South Africa's increasing international isolation in the 1970s and 1980s. They believe that using nuclear weapons would have been akin to committing suicide. Instead, they say, the government gradually developed a strategy that involved using South Africa's bombs for "political" purposes.

The emerging strategy was designed to bring Western governments to South Africa's aid in the event of an overwhelming attack by Soviet-inspired military forces then in southern Africa. At a moment of crisis, the government would have declared or "demonstrated" the weapons. An official who described this "strategy of uncertainty" said the government would have revealed its nuclear arsenal only if "the country found itself with its back to the wall."

Because its strategy of uncertainty required secrecy to work, South Africa kept its weapons production infrastructure extremely secret. As a consequence, the program could not depend on outside assistance as much as expected.

In the late 1980s the end of the Cold War reduced tensions in Africa. Many in the government came to believe that the nuclear weapons were unnecessary. Shortly after F. W. de Klerk became president in 1989, he ordered a halt to the nuclear weapons program in anticipation of acceding to the Nuclear Non-Proliferation Treaty (NPT). On July 10, 1991, South Africa became a member of the NPT.

Coming clean

It was not until March 24, 1993, four years after ordering their destruction, that de Klerk publicly acknowledged South Africa's nuclear weapons. According to Waldo Stumpf, chief executive officer of the state-controlled, Atomic Energy Corporation (AEC), the government feared that revealing the fact of its nuclear arsenal earlier could have led to confrontational inspections similar to those occurring in Iraq. Stumpf also believes that South Africa's political strife made it difficult to acknowledge the program.

When it acceded to the NPT in 1991, South Africa was under no obligation to reveal past nuclear weapons activities. The NPT essentially looks forward, although it requires extensive accounting of a nation's nuclear material and facilities when the treaty takes effect.

However, soon after International Atomic Energy Agency (IAEA) inspectors began to visit South Africa's nuclear facilities in 1991, they suspected that there had been a nuclear weapons program. Their suspicions cantered on a large inventory of weapon grade uranium metal stored at the AEC's Pelindaba Nuclear Research Centre, 25 kilometres west of Pretoria. This stockpile had been declared to the IAEA as part of the accounting of the nuclear material.

But the IAEA kept its suspicions to itself - the IAEA charter prevents it from sharing confidential safeguards information with the public. In addition, the South African government insisted that the IAEA maintain a strict level of confidentiality.

Still, leaks about the IAEA's inspection activities began immediately, and led the public and the ANC to learn something about the nuclear program. First, the press reported the existence of the stockpiled weapon-grade uranium. Later press reports estimated its size and described old nuclear weapons production facilities at Pelindaba.

In late 1992, the ANC intensified its efforts to uncover the nuclear weapons program, charging that the government might have hidden some weapon-grade material from the IAEA. De Klerk acknowledged the effect of ANC and other efforts in his March 1993 announcement, saying that charges were "regularly taken up by both the local and international press," and, that they were "beginning to take on the dimensions of a campaign." (See "Uranium Tucked Under the Mattress," below.) Although the ANC welcomed the public disclosure of the bomb program, it greeted de Klerk's announcement with suspicion and it continues to raise questions about the program.

Although doubts still linger, a great deal of information about the nuclear weapons program has been made public. Disclosures by Armscor and the AEC - the South African government's weapons and nuclear agencies - as well as the IAEA have led to a more complete picture of the South African nuclear weapons program.

Pulling the pieces together

The South African nuclear weapons program demonstrated perseverance, patience, and technical competence. The scale of the program was small at its peak it could produce only one or two weapons a year. Its total cost was also small, only a tiny fraction of South Africa's total defence budget.

From the 1960s until the program was cancelled in 1989, South Africa made steady progress toward safe, secure, and deliverable nuclear weapons. When the program was cancelled, it was poised to develop more advanced weapons including warheads for ballistic missiles.

Like other threshold countries with nuclear weapons programs, South Africa procured many important items overseas. Its imports were also aimed at creating indigenous nuclear capabilities. Because of its technological capabilities, however, South Africa depended less on imports than Iraq or Pakistan.

In the 1950s and 1960s, South Africa's civilian nuclear program received extensive assistance from abroad. Staff members were sent to Europe and the United States for training in various nuclear fields. South Africa was able to build a solid nuclear infrastructure. This foundation was undoubtedly important in its efforts to obtain nuclear weapons.

During this period, the United States supplied South Africa with the Safari-1 research reactor, which was commissioned in 1965 at the Pelindaba Nuclear Research Centre and subjected to IAEA safeguards. Over the next ten years, the United States also supplied the reactor with about 100 kilograms of weapon-grade uranium fuel.

However, when the international community began instituting international sanctions against the apartheid government in the 1970s, South Africa's nuclear program was one of its first targets. In 1975, the United States suspended additional shipments of fuel to the Safari reactor.

Faced with sanctions, South Africa began to organize clandestine procurement networks in Europe and the United States, and it began a long, secret collaboration with Israel. These secret dealings for technology, knowledge, material, and equipment were designed to meet South Africa's armaments needs, as effectively and economically as possible.

A common question is whether Israel provided South Africa with weapons design assistance, although available evidence argues against significant cooperation. In any case, Armscor is unlikely to have used Israeli assistance in developing its nuclear devices.

By the end of the 1980s, South Africa had imported machine tools, furnaces, and other equipment for its nuclear weapon program. Most of these items were not proscribed by international nuclear export controls. But they were imported in violation of international sanctions imposed on the apartheid regime.

Fissile material

The hardest part of building a nuclear explosive is acquiring an adequate supply of separated plutonium or highly enriched uranium. The Atomic Energy Board (AEB), the predecessor to the AEC, started researching methods of producing both materials in the 1960s. The program initially focused on uranium enrichment and a locally designed power reactor to produce plutonium.

Plutonium. The power reactor program, aimed at producing plutonium, first attempted to develop a heavy water-moderated, natural uranium-fuelled, sodium-cooled reactor. The indigenously built Pelinduna critical facility, which depended on a U.S.

supply of 606 kilograms of 2 percent enriched uranium and 5.4 metric tons of heavy water, went critical in 1967. Because it was not competitive with light water reactors and was draining resources from the enrichment program, both the critical facility and this reactor type were abandoned in 1969.

Before the enriched uranium was returned to the United States in 1971, the slightly irradiated fuel produced at Pelinduna was sent to Britain for reprocessing.

Enriched uranium. The uranium enrichment program, which ran parallel to the plutonium program, made steady progress throughout the 1960s. It started secretly, in a small warehouse in central Pretoria. As more sophisticated experiments and stricter security measures were needed, the project moved in the mid-1960s to the Pelindaba Nuclear Research Centre.

By the end of 1967, the enrichment program had succeeded in enriching uranium on a laboratory scale. After an external review of the process, the government decided in early 1969 to build a pilot plant.

As more organizations and individuals learned of the project, the government decided that the enrichment program's existence could no longer be kept secret. But the underlying purpose of the program remained highly classified, hidden behind declarations that its purpose was to enrich uranium for commercial applications.

In 1970, the government publicly announced that it intended to build the Y-Plant at Valindaba, next to the Pelindaba Research Centre. It also created a separate state corporation, the Uranium Enrichment Corporation (UCOR) to build the enrichment program. (UCOR and the AEB, were merged into the AEC in 1982.)

The South African enrichment process uses an aerodynamic technique similar to a stationary wall centrifuge. Uranium hexafluoride and hydrogen gas spin inside a small stationary tube. Centrifugal effects created by rapid spinning causes the uranium separation. The mixture enters at high speed through holes in the side of the tube and spirals toward the ends of the tube. When the mixture reaches the holes at the ends of the tube, its radius of curvature is reduced several fold, significantly increasing the separation of uranium isotopes. The heavy fraction, containing more uranium-238, exits to the side. The lighter fraction, which contains more uranium-235, exits straight out the end.

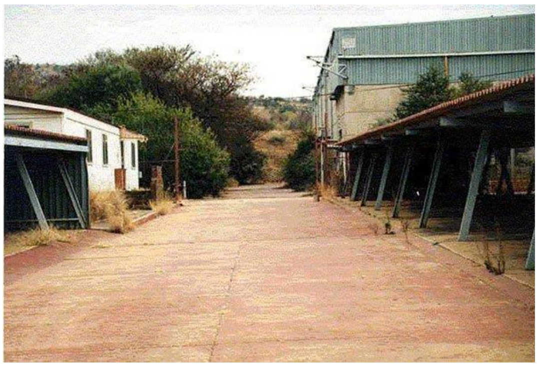
Foreign Assistance. Press reports and members of the ANC often assert that the enrichment program depends almost totally on the Becker nozzle process which was developed in Germany in the 1960s. Not enough is known about the history of the enrichment program to determine if this is true, but the available information strongly suggests that assertions about the importance of the Becker nozzle process are exaggerated.

Undoubtedly, the South Africans learned about the Becker nozzle program from published sources. But the separating elements in the South African process are not the same as Becker nozzle elements. According to participants and Western government experts, the Y-Plant's success depended principally on the skill and initiative of its scientists and technicians. They went through years of trial and error before producing significant amounts of enriched uranium. Behind this talent was the government's willingness to provide adequate funding to solve complicated problems. Because the Y-Plant was a vital part of the nuclear explosives program, it received enough funding to overcome glitches in the enrichment process and in the mass production of high-precision components.

Nevertheless, many components and materials for the enrichment program were acquired abroad. Important instrumentation and valves were imported via circuitous routes. And small quantities of unsafeguarded uranium hexafluoride were imported from France.

However, the program was unable to get everything it wanted. For example, in the South African process, it is particularly difficult to seal the area where a rotating shaft enters a compressor. Unable to get foreign items, personnel were forced to solve this problem on their own, which they eventually did.

The Y-Plant. The Y-Plant began commissioning in 1974 and began producing highly enriched uranium (HEU) in 1978. After overcoming several technical and chemical problems, the plant was able to produce a steady output of HEU for the weapon program. In addition, the plant produced 45 percent enriched uranium for the Safari research reactor, low-enriched uranium (LEU) test assemblies for the Koeberg nuclear power reactors near Cape Town, and LEU blending stock. The blending stock was mixed with imported, unsafeguarded LEU from China. This mix of low-enriched uranium was used for fuel at Koeberg.



The Y-Plant was originally designed to produce about 10-15,000 separate work units (SWUs) a year, but design improvements increased its potential annual output to 20,000. Chemical reactions and inefficient mechanical processes ("mixing") caused losses in the enriched uranium output, and the plant never achieved its design output. Assuming that it averaged about, 10,000 SWUs per year, the plant could have produced about 60 kilograms of 90 percent enriched uranium a year, or roughly enough for one of the devices of South African design. Because the plant was also producing enriched uranium for reactor fuel, it never produced weapon-grade uranium at that rate. During its lifetime, the Y-Plant produced a total of about 400 kilograms of uranium enriched above 80 percent, the minimum enrichment used in South Africa's nuclear weapons. The Y-Plant closed in 1990 - the first official hint that the still-secret weapons program had ended.

"Peaceful Nuclear Explosives"

The effort to build nuclear explosive devices had its origins in the 1960s under the auspices of a "peaceful nuclear explosives" (PNEs) program. According to the AEC's Waldo Stumpf, early investigations were modest and limited to studies of the literature. In 1969, the AEB established an internal committee to investigate the economic and technical aspects of using PNEs in mining.

In 1971, with a source of HEU in sight, the AEB received permission from the minister of mines to begin secret research and development work on nuclear explosive devices for peaceful purposes. These investigations were based on literature studies, theoretical calculations, and preliminary studies of the ballistics of gun-type devices. In addition, limited, theoretical studies of implosion devices were conducted, according to J.W. de Villiers, chairman of the AEC, who is widely believed to have headed the nuclear explosive program in the 1970s. He said that only three engineers were involved in the ballistics research and theoretical implosion work.

Because the AEB lacked adequate facilities at Pelindaba, in 1972 and 1973, a small team of AEB personnel worked under tight security at a propulsion laboratory at the Somchem establishment in the Cape Province. An Armscor official said recently he doubts that the management of Somchem knew what the team was working on. (Until the early 1990s, Somchem was an Armscor facility involved in the development and manufacture of explosives and propellants, and later, rocket launchers. Somchem is now a division of Denel Limited.)

At Somchem, AEB personnel worked on the mechanical and pyrotechnic subsystems for a gun-type device. The team designed a scale model which, with a projectile constructed of non-nuclear material, was tested at Somchem in May 1974.

This test convinced the AEB that a nuclear explosive was feasible. In 1974, Prime Minister John Vorster approved the development of a limited nuclear explosive capability and the construction of an underground test site.

During the next three years, the AEB developed internal ballistic and neutronic computer programs, conducted experiments to determine properties of the materials in the devices, designed and constructed a critical facility in Building 5000 at Pelindaba, and experimented with propellants for a gun-type device. The team working at Somchem tested 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.

The test site and first device

Meanwhile, the AEB selected a test site in the Kalahari Desert, the Vastrap testing range north of Upington. Two test shafts were completed in 1976 and 1977. One was 385 meters deep and the other was 216 meters deep.

In 1977, the AEB established, its own high-security weapons research and development facilities at Pelindaba, and during that year the program was transferred from Somchem to Pelindaba.

In mid-1977, the AEB produced a gun-type device-without an HEU core. The Y-Plant was operating by this time, but it had not yet produced enough weapon-grade uranium for a device. As has happened in programs in other nations, the development of the devices outpaced the production of the fissile material.

AEC officials say that a "cold test" (a test without uranium-235) was planned for August 1977. An Armscor official who was not involved at the time said that the test would have been a fully instrumented underground test with a dummy core. Its major purpose was to test the logistical plans for an actual detonation.

How that test was cancelled has been well publicized. That summer, Soviet intelligence detected test preparations and, in early August, alerted the United States. U.S. intelligence quickly confirmed the existence of the test site, On August 28, the

Washington Post quoted a U.S. official: "I'd say we were 99 percent certain that the construction was preparation for an atomic test."

The Soviet and Western governments were convinced that South Africa was preparing for a full-scale nuclear test. During the next two weeks in August, the Western nations pressed South Africa not to test. 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 contract to provide South Africa with the Koeberg nuclear power reactors.

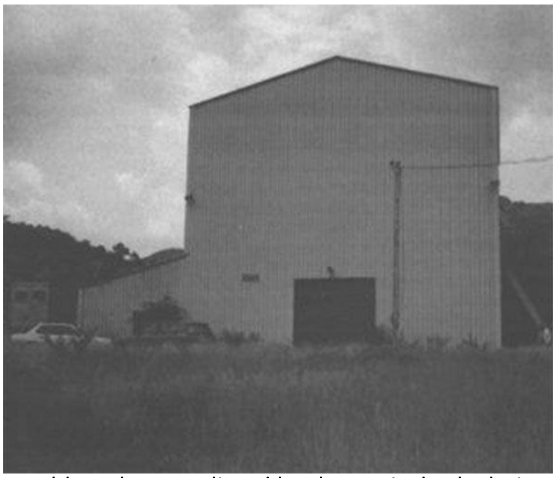
Looking back, the South African explanation of a planned cold test at the Kalahari site is plausible. Perhaps the AEB believed the site would not be discovered. In any case, in the summer of 1993, de Villiers told me that when the test site was exposed, he ordered its immediate shutdown. The site was abandoned and the holes sealed.

(Commodore Dieter Gerhardt, the commander of the Simonstown Naval Base near Cape Town who was arrested as a Soviet spy in 1982, says that the Soviets expressed their concern to the United States a year earlier. He said in an interview that a Russian 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 U.S. cooperation in stopping it. Gerhardt said that one of several options mentioned by the Russians was a pre-emptive military strike on the Y-Plant. He said the United States rejected that option.)

Although the test was cancelled, the nuclear explosive program continued unabated. In 1978, the AEB built a second, smaller device. This device was designed to be rapidly deployed for a fully instrumented underground nuclear test at the Kalahari site.

This second device was still not loaded with fissile material. The Y-Plant had produced its first HEU, but it was not until the second half of 1979 that the plant would produce enough for a device, about 55 kilograms of material. This first batch of HEU was only about 80 percent enriched. The device was designed to use weapon-grade uranium (greater than 90 percent enriched), but the principal effect of the lower enrichment would have been a lower yield. According to the IAEA, this device was kept for demonstration purposes throughout the program and was never converted into a deliverable weapon. Its code name was reported to be "Melba."

Building 5000



When the Y-Plant had produced enough HEU, the material was converted into metal and sent to the recently completed critical assembly facility in Building 5000. This tall grey building sits in a valley on the south-western portion of the Pelindaba site, away from the main complex. Building 5000 was operated by the Reactor Development Group.

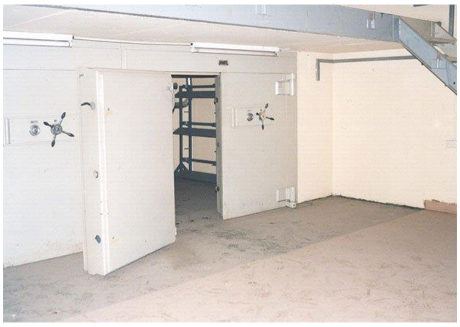
I recently drove to Building 5000, which is in a small compound inside a security fence about five minutes by car from the main research site. The compound is at the end of a narrow paved road on an isolated portion of the Pelindaba site. The building is empty except for some old equipment and waste barrels from other parts of the Pelindaba site.

In the late 1970s, this building tested the gun-type device. For a brief moment, the HEU metal went critical, providing confidence that the device would work as predicted by theoretical calculations. When the Manhattan Project scientists conducted this dangerous experiment, they called it "tickling the dragon's tail."

Several other buildings with addresses such as 5100 or 5200 are also located in this valley and were dedicated to developing a nuclear explosive. The AEB had the capability to develop propellants for gun-type devices and high explosives for implosion weapons. Today, these facilities are either abandoned or dedicated to non-nuclear uses.

According to an AEC official, after the first test the critical facility was never loaded with HEU again, even for civilian experiments.

Within a few years, Pelindaba's weapons manufacturing capabilities were replaced by new Armscor facilities several kilometres away. The critical facility, however, was not replaced. Since the basic "physics package" of South Africa's device remained unchanged, a single experiment was apparently considered adequate.



When the IAEA began its inspections in 1991, South Africa was not obligated to reveal the existence of the critical facility or the other buildings in the valley. The NPT requires only that nuclear facilities existing at the time of signing the treaty be declared. The IAEA however, had learned of Building 5000 from Western intelligence, and asked for and was granted permission to inspect it.

From explosives to bombs

All South African officials agree that the shift in emphasis from peaceful nuclear explosives to strategic deterrence was in response to South Africa's deteriorating security situation. The apartheid regime feared Soviet expansionist policies in southern Africa. It was alarmed by the build-up of Cuban forces in Angola starting in 1975. Increasingly isolated, the South African government was convinced that outside assistance was unlikely in the event of an attack.

There is some disagreement, however, about when officials adopted a military justification for South Africa's nuclear explosives program. President de Klerk said in his March 1993 announcement that the decision to develop a limited nuclear deterrent capability was taken as early as 1974, and de Villiers agrees.

In contrast Stumpf says that the program was, not military in nature until 1977. The shift may have been stimulated by the episode in the Kalahari. Stumpf says that the prime minister's formal approval of a deterrent strategy came only in April 1978.

Armscor, which agrees with Stumpf, says that the formal shift occurred in 1978. One Armscor official characterized the entire AEB nuclear explosive program as civilian. The AEB, he said, did not "fly" anything. He was apparently referring to the inability of the nuclear establishment to produce a deliverable weapon, which, in Armscor's view, was necessary for a credible deterrent.

The deterrent strategy that began to emerge in this period was ultimately based on three phases, the final aim of which was to obtain Western assistance in the case of an overwhelming military threat. The first phase was a "strategic uncertainty" during which South Africa's nuclear capability would be neither acknowledged nor denied.

If the country were threatened militarily, it would move to phase two. The government would covertly acknowledge the existence of its nuclear weapons to leading Western governments, particularly to the United States. If phase two failed to persuade the international community to come to South Africa's assistance, the government would move to phase three: It would publicly acknowledge its capability or demonstrate it with an underground test.

This policy required a credible nuclear weapon. And, according to Armscor officials, credibility required deliverability. They said that if the government had decided to show its nuclear devices to a Western power as part of phase two, the devices would have had to have been deliverable. If the nuclear devices were only test devices, the Western powers might not take South Africa's threat seriously enough to intervene on its behalf.

According to the de Klerk government, the weapons were never intended for actual use, and they were never deployed militarily or integrated into the country's military doctrine. In essence, the weapons were the last card in a political bluff intended to blackmail the United States or other Western powers. Whether it would have worked is impossible to determine.

Armscor takes over

With the shift to strategic deterrence in 1979 the government gave Armscor the job of manufacturing additional nuclear devices. The AEC was charged with providing nuclear materials, health physics support, and theoretical studies and development work in more advanced nuclear weapons technology.

ARMSCOR
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The Armscor-run nuclear weapons program had three main components:

- Development and production of a number of deliverable gun-type devices;
- Studies of implosion and thermonuclear technology, including "boosted" devices. (Boosting increases the explosive yield of a fission device. In such a device, the thermonuclear reaction of tritium and deuterium produces a spike of neutrons that fission significantly more plutonium or highly enriched uranium); and

- Research and development of production and recovery of plutonium and tritium, and production of lithium.

The Circle building. Armscor used AEB designs to build the Kentron Circle facility about 15 kilometres east of Pelindaba. (This site was later renamed Advena.) Armscor's chief responsibility was the manufacture of deliverable gun-type devices. The Circle building essentially duplicated, under one roof, most of the development and manufacturing capabilities at Pelindaba.

Circle was built in 1980 and commissioned in May 1981. The facility essentially comprised the Circle building and a nearby environmental test facility that was involved in the development and integration of cannon type devices.

Circle was built deep within another Armscor site, Gerotek. This site tests vehicles at high speeds and on various types of road surfaces and grades. The turn-off to Circle, marked only with a sign that says "Workshop," is several minutes' drive inside Gerotek's main gate. The entire site is hilly. On the hillsides are many graded tracks for testing vehicles.

> The exterior of the Circle building is nondescript. Inside are two floors with a total of 8,000 square meters of floor space. The lower floor was dedicated to making nuclear devices. The top floor contained mostly offices and conference rooms. The only external clue to the potential importance of the building was a large embankment built next to the building to block prying eyes from seeing the building from a nearby road deep within the Gerotek compound. Advena's managers blocked proposals to place sophisticated communications on the roof to avoid a "signature" that might attract the attention of intelligence agencies.

The first floor of the Circle building had conventional workshops for making mechanical and electrical equipment; storage rooms; uranium casting and machining workshops; a large vault; integration rooms where portions of the devices were assembled; and eight "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 also used to conduct plane-wave experiments with shaped charges and to develop high-speed instrumentation for preliminary work on implosion designs. Another cell contained the "pig sty," a wood enclosure where projectile tests were done for the gun-type device.

The designers put a "plenum" or large room above these cells. 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.

Manufacturing HEU shapes for the devices generated scrap and nuclear waste, which were sent back to the AEC for recovery or disposal. The shipments were sent at night to minimize detection.

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

The Armscor approach

Armscor approached the problem of building nuclear weapons very differently than the AEB. 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, and placed in a special vault. It had been temporarily stored in an abandoned coal mine at Witbank, a former military ammunitions depot.

Armscor manufactured its first device in April 1982, which it considered a "pre-qualification" model. According to an Armscor official, it could be kicked out the back of a plane.

Armscor engineers emphasized reliability, safety, and security. 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: repeatability of projectile velocity; repeatability of symmetry requirements when the projectile is injected; the density of the neutron reflectors; the plating of uranium components with nickel; and the reliability of arming and safing devices.

Ultimately, though, Armscor's design was highly reliable - it had redundancy built into the system whenever possible and it was thoroughly qualified in terms of its internal ballistics and mechanical arming and safing operations.

Security. Armscor emphasized the physical security of both the devices and the HEU. A special high-security vault with many smaller vaults inside was installed inside the Circle building. Access to the vault was tightly controlled.

Each nuclear device was divided into two sections, a front and back. With the HEU distributed between the two halves, the design minimized the possibility of accidental detonation or unauthorized use.

According to an Armscor official, a front and back end were never worked on simultaneously. Both ends could leave the vault at the same time only after three top ministers and the head of government inserted their separate sections of the code into the vault. No one person had the complete code.

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.

Safety. Circle engineers carefully studied failure modes and effects and conducted 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."

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 cause a criticality accident, risking workers and contaminating the adjacent area.

To prevent such accidents, each device had mechanical safing mechanisms that blocked the projectile from reaching the other end and dissipated the pressure caused by the propellant firing. The first attempt at the safing mechanism did not work adequately, but later versions performed well.

Although implosion designs were never a high priority, safety considerations were already being factored into them. An implosion device poses a risk that an accidental detonation of high explosives will trigger a nuclear explosion. To reduce this risk, Circle engineers begin 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.

Producing more devices. With such stringent specifications, weapon production was slow. The first "qualified" gun-type device was not completed until August 1987. This model could be delivered by a modified Buccaneer bomber. By the time the program was cancelled, three more deliverable devices had been completed. The HEU core and some non-nuclear components for a seventh device had also been manufactured. This last device was intended as a second test device, more advanced than the first.

According to Armscor, "All the devices were incidental in principle, but detail changes were made to enhance reliability." Parts of some earlier models were recycled during the years of production.

The total mass of a completed device was about one metric ton. It had a diameter of nearly 65 centimetres and was about 1.8 meters long. Each device contained an estimated 55 kilograms of HEU. The cores of the second through seventh contained weapon-grade uranium. The reflector was made of tungsten. The calculated yield of each device was about 10 to 18 kilotons when the core had weapon-grade uranium. Using 80 percent enriched material halved the expected yield.

By the end of the program, according to an Armscor official, they could have routinely manufactured these devices. At that point, the annual operating expenditures were about 20 to 25 million rand, or about $5.9 to $7.4 million at today's exchange rate. In the early 1980s, the annual budget was about 10 million rand, or about $2.9 million.

Boosted devices

Although Armscor took over most of the weapons portfolio, the AEC remained in charge of several important aspects. Its scientists, however, became increasingly discouraged by their role and began to leave the program.

The AEC was charged with developing more advanced weapons. One result was that the AEC evaluated the use of tritium to boost gun-assembled devices. Apparently, the purpose would have been to boost the explosive yield from less than 18 to roughly 100 kilotons. According to the IAEA, AEC officials said that this work did not involve the use of tritium, although the AEC had obtained a small stock of tritium in the mid-1970s from Israel and other sources. The work was theoretical and did not involve any hardware, according to an Armscor official.

Armscor had little interest in the AEC's work on boosted gun-type devices. Its weapons program was simply not ready for such an advanced concept. Circle did not have any facilities to handle tritium, which is very radioactive and difficult to handle. In addition, Armscor officials said recently, if the purpose of the bomb program was to demonstrate capability, why would yield matter? The goal was a workable device.

- **Plutonium and tritium production.** The AEC was also responsible for evaluating methods to produce and recover plutonium and tritium. The AEC concentrated on the design of a reactor to be built at Gouriqua, near Mosselbay in the Cape Province. They planned to build a 150-megawatt pressurized-water research and development reactor that could also produce plutonium and tritium, but the site was never developed beyond some rudimentary civil engineering preparations. In 1985, the weapons program stopped funding the reactor program, and 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.
- **Neutron initiators.** A unique feature of South Africa's gun-type design is that it did not use 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 microseconds after the HEU projectile hit the fixed HEU component. As long as the device was intended for an underground test or an airburst with an imprecise height, the lack of an initiator did not matter. Implosion devices, however, typically require a neutron initiator. As a result, the AEC began developing a miniaturized neutron generator based on accelerating deuterium into a tritium target. Only minute quantities of tritium and deuterium are required for a generator, and small quantities can be easily bought or produced.

Cutbacks

In September 1985, the government decided to limit the scope of the weapons program. According to an AEC official, de Klerk's predecessor, P.W. Botha, recognized that the cost of the weapons program could escalate significantly.

The government limited the program to the seven gun-type weapons, stopped all work related to plutonium devices, halted efforts to produce plutonium and tritium for weapons, and limited the production of lithium-6. But implosion development and theoretical work on more advanced devices continued.

Despite the cutbacks, the weapons program was not ending most of the weapons were manufactured after 1987. One Circle employee said that this period was one of considerable stress for employees it Advena.

In the mid-1980s, tensions in the region were high. About 50,000 Cuban troops were in Angola. According to one official, if the Soviet Union had made a greater effort in Angola, South Africa could not have stopped them. He said that the crisis was reaching a "semi-conventional state."

South Africa's nuclear "strategy of uncertainty" was reaffirmed in the mid-1980s, and the government wanted to know how long it would take to conduct an underground test. Before answering, Armscor wanted to assure itself that the underground test shafts could be used in a timely manner. According to Armscor it needed to check the condition of at least one of the shafts in the Kalahari. To minimize the risk of exposure, Armscor built a shed over a shaft. The military conducted target shooting at the same time to provide a plausible cover for the operation.

In the desert, the water pumped out of the shaft could not be dumped on the ground without possibly tipping off intelligence agencies to what was happening. As a result, the water was put into containers and hauled off the site. After removing the water, technicians lowered a specially designed inspection probe that determined that the shaft was still intact.

Some South African officials have said that they believe that Western or Soviet intelligence discovered the shed and that this exercise convinced the Western powers that South Africa was serious about nuclear weapons. This in turn led them to start putting pressure on the Soviet Union and Cuba to withdraw from Angola. Whatever the case, during the mid-1980s the South African nuclear weapons program was under the twin pressures of budget cuts and heightened requirements. As a result, the government decided to fund a new facility.

1990s: The Advena Central Laboratories

The government approved plans to build a new complex, the Advena Central Laboratories, which were about five minutes away from the Circle building.

The Advena buildings were just being completed when the program was canceled in 1989. The total cost of the new complex and upgrading the Circle building was 36 million rand, or about $10 million at today's exchange rate.

Although Advena would have had many capabilities for advanced nuclear weapons work, its rate of weapons production would have been modest. Each year, it could have produced two to three weapons.

According to Armscor, the "occupation of the new Advena facilities started during 1988 and the process of commissioning was still under way when the program was terminated." Armscor has said that the Circle building "would have been used for the maintenance of the seven cannon-type devices" after the expansion to Advena.

After the program was cancelled, both facilities were converted to commercial enterprises operated by Denel. The commercial program continues to use the Advena and Circle facilities, although on a smaller scale than originally hoped.

In the late 1980s, Armscor had been preparing to upgrade the seven gun-type devices. 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." The replacement devices would have been deliverable by aircraft and most likely also by ballistic missile, although a final decision about missiles had not been made.

The decision to build new facilities was motivated by several factors. Armscor needed more modern and sophisticated facilities for its long-term goals. It was going to replace the gun-type devices and conduct nuclear-weapons development work on advanced gun-type and implosion-type devices. At the same time, Armscor was diversifying into conventional military pyrotechnics and missile control components, such as "jet vanes".

The program had outgrown the Circle building. The labour force had increased from 100 to 300, and more space was needed. Workers were tired of 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.

In addition, the Circle building had been designed so that only project participants could enter the building. The new site made it possible to host visitors without divulging the true purpose of the program.

Advena had an extensive array of nuclear weapons manufacturing capabilities aimed at advanced designs. It had sophisticated capabilities in high explosives, theoretical calculations, metallurgy, high-speed electronics, environmental and reliability testing, and ultra-high-speed diagnostics.

Implosion. Although, research on implosion-type devices had been conducted since the beginning of the nuclear explosive program, implosion research was never a priority. One possible reason is that the designers did not believe that an implosion weapon was really needed unless South Africa decided to build a thermonuclear weapon. The weapon scientists, however, never appeared serious about building thermonuclear devices.

According to Armscor, its implosion program started in the mid-1980s. At the beginning, the goal was not strictly the development of an implosion design. The purpose was to help maintain a technology base for the maintenance of gun-type devices. According to an Armscor official, work on more advanced systems, such as implosion, helped to keep the weapon scientists and technicians interested in their work on gun-type systems. The primary focus of the implosion effort, according to Armscor, "was on the development of measurement systems which could be used during the 1990s."

Armscor said that "no implosion tests were done up to the time that the nuclear program was terminated by the Head of the Government and no prototypes were constructed." Only a couple of concepts were on the table.

Advena was equipped, however, with the capability to develop and manufacture implosion-type devices. It is unclear whether Armscor would have built such weapons as replacements for the gun-type devices. Armscor engineers might not have been able to produce an implosion weapon manufactured to the same level of demanding safety, security, and reliability specifications as the gun-type device without conducting a full-scale nuclear test.

According to an Armscor official, a decision on building implosion weapons was still ten years away when the weapons program was cancelled. He said that, in any case, an implosion-weapon program would have required a full-scale cold test of the implosion system with a natural uranium core. Such a test, he said "would have caused contamination which was not acceptable to Armscor and would have posed risks with regard to detection." 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, or about $3.5 million at today's exchange rate. This sum, he said, was considerable -and perhaps prohibitive- for the Advena program.

Although P.W. Botha limited the number of weapons to seven in 1985, preliminary estimates suggested that the seven gun-type devices had enough HEU for 14 implosion weapons.

Missile Warhead. The design of Advena's integration building implies that South Africa was thinking of an enhanced weapon in the long term. The building had enough space to load a warhead onto a ballistic missile and the new storage vaults contained space suitable for one small re-entry body.

An unusual feature of the South African program is that if the government had deployed nuclear-tipped ballistic missiles, the warheads might have used gun-type devices, not implosion warheads as is often thought necessary.

Armscor might have preferred a gun-type warhead because it was within reach of the existing design, although it would have required further development. The existing design was not symmetrical enough for a missile warhead. Developing an acceptable design, however, was seen as well within Armscor's capabilities.

It might have been difficult to build an implosion weapon that simultaneously met rigorous specifications while remaining small enough to fit on the end of a missile. The relatively small missile diameter would have placed a tremendous constraint on Armscor's implosion system.

Dismantling the program.

Before the weapons program could occupy Advena, the security situation in southern Africa eased. In December 1988, South Africa, Angola, and Cuba signed a tripartite agreement for a phased withdrawal of Cuban troops in Angola. In April 1989, Namibia was granted independence. At the end of 1989, the Berlin Wall fell, signalling the end of the Cold War and superpower rivalry in Africa.

In September 1989, F.W. de Klerk was elected president. He immediately took steps to bring about fundamental political reforms aimed at ending apartheid and creating a democratic South Africa.

Within a short time, the nuclear weapons program had become a liability. It stood in the way of South Africa re-joining the international community. In November 1989, the government decided to stop the production of nuclear weapons. On 26 February 1990 de Klerk issued written instructions to terminate the nuclear weapons program and dismantle all existing weapons. The nuclear materials were to be melted down and returned to the AEC in preparation for South Africa's accession to the NPT.

The government also decided that it would not admit to the existence of the nuclear weapons program before accession to the NPT. As a result, the dismantling project -like the weapons project- was classified top secret. Dismantling started in July 1990. By 6 September 1991 all of the HEU had been removed from the weapons, melted down, and sent back to the AEC for storage. During the dismantlement process at Circle, criticality-safe shelves were installed in one vault to store recast HEU ingots.

To insure secrecy, the HEU was sent from Circle to Pelindaba at night. Initially, Armscor had military guards patrolling the road, but stopped when the guards attracted the attention of people living in the area. One person demanded to know what was happening. Subsequent shipments aroused less curiosity.

Soon after sending the last material to the AEC, the Circle building was completely decontaminated and the equipment that had been used for the re-melting and casting of HEU sent to the AEC. The main uranium processing section of Circle was carefully decontaminated. Walls were removed, and the concrete floor was jacked out.

Radioactive contamination was reduced to background levels. An Armscor official said that they wanted the room clean enough so that they could plausibly deny the existence of the program. Several did not believe that the weapons program would ever be revealed.

Although all the HEU had not gone to the AEC when South Africa acceded to the NPT on July 10, 1991, all of it had been sent before the safeguards agreement entered into force on September 16, 1991. The first IAEA inspection team arrived in South Africa in November 1991.

The major non-nuclear components of the weapons, detailed design drawings, and photos of components remained. Destruction of many of these items began in 1992. By March 24, 1993, when de Klerk announced the program's existence, most of the classified documents had been shredded and the sensitive weapon components destroyed or damaged beyond repair. Destruction of less important components continued into 1994.

Conclusion

South Africa’s renunciation of nuclear weapons is a major success for international efforts to stop the proliferation of nuclear weapons. Its program, however, shows how difficult it is to thwart a country that has a certain level of technological sophistication and is determined to build nuclear weapons.

South Africa's nuclear weapons production complex remained a secret for many years. Circle and Advena were essentially invisible to prying intelligence. Although the purpose of the Y-plant was widely suspected when the government announced its construction in 1970, no one knew when it started to produce HEU or how much it produced. The Y-Plant's visibility reinforces the view that the refusal to apply safeguards to a nuclear facility should be construed as evidence of weapons intentions.

However, South Africa also reminds us that political isolation can increase the incentives to build nuclear weapons. It can lead a country to greater technological self-sufficiency and make it prone to take extreme acts in self-defence. International sanctions cannot always be relied on to stop a technologically capable country. But sanctions can slow down a country’s program. Linked to incentives, sanctions can reduce the political will of a country to remain isolated.

This case demonstrates the need for aggressive international and national efforts aimed at early detection of nuclear weapons programs. The monitoring must include machine tools and other important equipment not covered by export control lists. If the international community had obtained clear evidence of South Africa’s weapons program, South Africa might have found its nuclear weapons far less political useful and been