CHAPTER 9

VERIFYING THE DISMANTLEMENT OF SOUTH AFRICA'S NUCLEAR WEAPONS PROGRAM

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INTRODUCTION

In its 2011 annual Safeguards Statement, the International Atomic Energy Agency (IAEA) determined that for 58 states where both the Comprehensive Safeguards Agreement (CSA) and Additional Protocol (AP) are in force, it:

> found no indication of the diversion of declared nuclear material from peaceful nuclear activities and no indication of undeclared nuclear material or activities. On this basis, the Secretariat concluded that, for these States, all nuclear material remained in peaceful activities.[1]

This rolling safeguards report that provided a yearly review of the status of IAEA member states' nuclear activities was noteworthy as South Africa was, for the first time, included in the group of states.[2]

In September 1991, South Africa concluded a CSA with the IAEA and submitted its initial declaration on facilities and nuclear material inventories (a summary of South Africa's nuclear program prior to its conclusion of a safeguards agreement is included in Appendix 9-I). The same year, the IAEA General Conference requested that the IAEA Director General "verify the completeness of the inventory of South Africa's nuclear installations and material and to report to the

Board of Governors and to the General Conference."[3] This request was made following the entry into force of South Africa's safeguards and previous long-standing claims made regarding the existence of a possible nuclear weapons program.

While the South African government in Pretoria had already taken the political decision and had dismantled its nuclear weapons program prior to signing a safeguards agreement with the IAEA, it was only in March 1993 that President F. W. de Klerk disclosed South Africa's nuclear weapons program. South Africa's initial nuclear material inventory submitted to the IAEA in 1991 had not contained any reference to its past nuclear weapons program. The IAEA Secretariat's first verification report submitted to the General Conference in September 1992[4] did not mention any indications of a weapons program either, though it concluded that there were "apparent discrepancies" in calculated U-235 isotope balances at the pilot enrichment plant and semi-commercial enrichment plant.

Following Pretoria's disclosure, the IAEA's verification work was extended from 1993 to confirm dismantlement and to put in place mechanisms that would allow for early detection should the weapons program be reconstituted. Parallel to this, inspectors initiated a more extensive examination of nuclear material flows and verification of the historical production of low and highly enriched uranium. By the time of the next verification report in September 1993, the Secretariat was able to conclude, by tallying up prior unreported amounts of highly enriched uranium (HEU) that were used for the weapons program, that the amount of HEU that could have been produced by the pilot enrichment plant was consistent with the amount declared in the initial report.[5] However, at that stage, work for the verification of the completeness of low enriched uranium production continued.

VERIFICATION CHALLENGES

While South Africa's initial declaration to the IAEA was meant to include all information on all nuclear material subject to safeguards, the weapons-related aspects of the South African program were omitted from its initial report. The IAEA was provided with historical accounting and operating records of enrichment plants and other facilities, but records provided to inspectors did not include any reference, *inter alia*, to conversion of highly enriched uranium hexafluoride to uranium metal and further to weapon components. Similarly, its initial report did not mention the existence of such facilities. It is worth mentioning that the IAEA's annual safeguards statements for 1992 only mentioned that the verification of South Africa's initial declaration was proceeding without any reference to possible concerns about the completeness of declarations.

Events took a clear turn with regard to the IAEA's verification activities following South Africa's disclosure. Objectives to inspections took on added dimensions. Assurances were sought that:

1. all nuclear material in South Africa had been placed under IAEA safeguards and is in peaceful use,
2. all nuclear weapons, their components, and related manufacturing equipment had been destroyed,
3. all nuclear weapons-related installations had been fully decommissioned or converted exclusively to peaceful nuclear use, and
4. mechanisms that allowed for early detection of restoration of any nuclear weapons capability were put in place.

The first benchmark for the IAEA in terms of nuclear material accountancy undertaken was to tally up enriched uranium stocks and ensure that no significant quantity of highly enriched uranium was missing from the declared inventories (the absence of nuclear material for one or more nuclear weapons could have been concealed, e.g., by overstating nuclear material inventories or MUFs).

In equation form:

$$MUF = BI + X - Y + HU + BE$$

Where,

BI= Beginning physical inventory
X= Inventory increases, then
Y= Inventory decreases
HU = Holdup
BE = Ending inventory unaccounted for

By the time the IAEA was called upon to verify South Africa's dismantled nuclear weapons program, the agency was already in the midst of strengthening its safeguards verification process. New winds started to blow in the early-1990s after the discovery and dismantlement of an undeclared nuclear program in Iraq, where it soon became obvious that an enhancement of the effectiveness of the IAEA safeguards system was needed. As a result, a number of safeguards measures were strengthened, including those that were being applied to safeguards undertaken in both North Korea and South Africa. The enhanced evaluation process brought together not only declared data and verification results through a statistical analysis based on the propagation of the operators and inspectors measurement errors in order to detect diversion of declared material into material imbalance, but ways were also sought to more closely corroborate data and trends, such as cumulative MUFs, performance of the operators' nuclear material accountancy system, and operator/inspector measurement differences.

Another new development being implemented in the South African case was the re-examination of verification processes involving nuclear materials. Non-nuclear production parameters were also evaluated alongside the overall consistency of nuclear material accountancy records. To cite an example, uranium metal quantities must be consistent with parameters to produce uranium metal. In such a process, uranium tetra fluoride (UF4) is reduced to uranium metal using customarily calcium on magnesium metals. The process produces ashes and slag, which contain calcium or magnesium. The amounts of these elements found in wastes should be in conformity with the uranium metal produced. Furthermore, the amounts of ashes and slag need to match with the stated amounts of uranium metal produced. Similarly, one can estimate losses in casting and machining of uranium metal components to their final forms. Again, those need to match up with the amount of uranium metal produced. Evaluation of the choke points, for example for a production chain, yellowcake—UO2—UF4—UF6—enrichment—UF4—uranium metal, provides additional assurances about the completeness of a state's declarations.

While the enhancement of safeguards measures was still evolving and in its early days, South Africa's declaration that it had given up its nuclear weapons and would open its nuclear program to safeguards provided inspectors the learning process and experience that helped shaped a more analytical safeguards process.

The South African case had essentially two dimensions under which verfication activities fell: dismantlement and assurances. These processes, while not the same, were also not exclusive and overlapped. In fact, one could not be achieved fully without the other. Assurances that all (present and future) nuclear activities would remain in peaceful use meant reconstructing and understanding the historical aspects of the weapons program. In South Africa's case, even with the case of admission of a weapons program and subjecting its program to IAEA dismantlement, there were gaps of ambiguity that the agency faced. While it is unlikely to ever achieve a 100 percent score, the IAEA's role was to provide the necessary assurances required to both dismantle and prevent reconstitution of the weapons program.

Prior to disclosure, South Africa had destroyed documents related to the design and manufacturing of nuclear weapons. However, at the same time, thousands of operating records, including historical accounting and operating records of its two enrichment plants and uranium conversion and fabrication plants, were available to the IAEA. Such papers were, however, far from sufficient in themselves to detail a full picture. For instance, some of the wastes, scrap, and tails were poorly characterized in terms of their nuclear material quantities. The enrichment plant used to produce highly enriched uranium mainly for the weapons program had already been dismantled, while the other was still kept operational until 1995. From a technical perspective, the challenge was to estimate uranium holdup in equipment. Precise verification of nuclear material held in equipment was only possible from equipment decontamination liquors or sludges, which was time consuming and stretched over many years. Until then, the starting point of the holdups had to be based on estimates.

As a result, the first material balances tallied by the IAEA after 1991 resulted in an apparent discrepancy in the U-235 balances of the two enrichment plants.[6] With respect to HEU produced by the pilot enrichment plant and LEU produced by the semi-commercial enrichment plant, it showed a substantial amount of unaccounted for uranium-235. After the first evaluations in 1992, the IAEA continued with the re-examination of records, additional decontamination activities, and further sampling to obtain more precise estimates of nuclear material in wastes, tails, and holdups.

Another difficulty in confirming the statements made by South Africa was the fact that some of the installations that were used for its nuclear weapons produced nuclear material for both its civilian and military parts of the nuclear program. As a result, for example, wastes were mixed, hence complicating verification assessment. This technical matter alone, which has an impact on the wider picture of determining South Africa's nuclear program, resulted in additional and further verification steps. The dismantling, decontamination, and re-characterization of the wastes extended well over a decade.

The nuclear waste storage facility held tens of thousands of drums containing substantial amounts of high and low enriched uranium waste from the former enrichment plants and other decommissioned facilities (see Figure 9-1).

Figure 9-1. Temporary Storage of Waste Drums in a Decommissioned Enrichment Plant.[7]

During the re-characterization process, the contents of each drum were recorded after opening it, and nuclear material quantity was verified using special drum scanners (see Figures 9-2 and 9-3).

Figure 9-2. All Waste Drums Opened, Contents Characterized, and Nuclear Material Verified.[8]

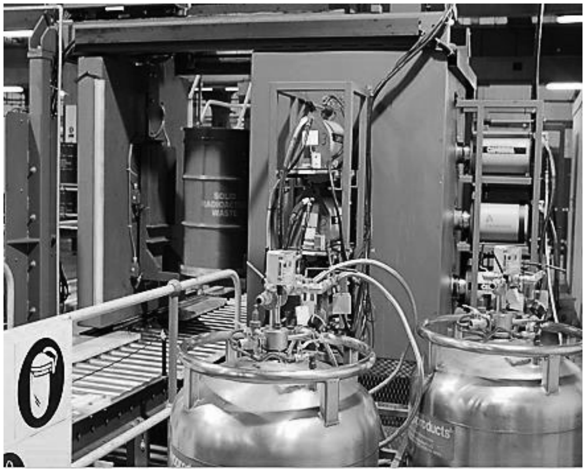

Figure 9-3. IQ 3 Scanner Used for Verification of Uranium in Waste Drums.[9]

LONG-TERM MONITORING

After deciding to terminate its nuclear weapons program in 1989, South Africa proceeded with dismantling its weapons and related infrastructure, including the destruction of weapons-related documentation without the presence of the IAEA.

To confirm the statements made by the South African authorities and to set up a baseline to monitor that the program or its parts were not reconstituted, the IAEA had extensive discussions and briefings by former staff personnel to understand the country's nuclear program from a "cradle to grave" approach. Such information received was reconciled with other information received by IAEA from other member states; compared against dismantlement records kept by the South African authorities; and cross-checked against independent IAEA nuclear material verification results, facility designs, and environmental samples taken. These steps were undertaken to create an independent understanding of the chronology and contours of South Africa's nuclear program. Apart from the IAEA using its tools available to draw its own conclusions, the verification process was also a dynamic process of dialogue with South African authorities that defined what assurances were further required along the way. For example, the IAEA made additional suggestions to Pretoria to destroy additional equipment and to render the test shafts in Kalahari useless.

Due to the embargos imposed under apartheid rule and the secrecy that necessitated the development of its nuclear weapons program, South Africa established an extensive indigenous industrial infrastructure to support its civilian and weapons programs. This infrastructure produced, *inter alia*, equipment and components needed for its enrichment program. This created a different problem: While the IAEA was monitoring nuclear installations and materials under the safeguards agreement and verifying dismantlement, some of the South African companies involved in nuclear weapons-related matters became engaged with the illicit nuclear trade. For instance, one of the companies had built Libya's uranium hexafluoride feeding system and was only busted in 2003 when the A. Q. Khan clandestine nuclear network was unraveled. While it is known that part of the process of dismantlement also included rehabilitation of personnel involved in nuclear weapons work, the clandestine and indigenous nature by which states like South Africa operated have meant that some of the companies managed to slip the attention of the IAEA and also, apparently, that of the South African authorities.

CONCLUSION

There are a few lessons to be drawn from the IAEA's role in verifying South Africa's dismantled nuclear weapons program. Long-term monitoring and verification of nonproliferation efforts are necessary and require a significant period of time, even with self-disclosure of nuclear weapons, as seen in South Africa's case. The fact that secret nuclear programs, like South Africa's, often develop their own indigenous processes throws light on the need for monitoring all such nuclear-related facilities. Attention should also be given to understanding the extent of indigenous production capabilities and their potential links to nuclear proliferation.

Verification work is painstaking as well as time and resource consuming. Inspectors are faced with ambiguities, inconsistencies, and gaps. A historical and composite understanding of the nature and dimensions of a nuclear program, including the military/weapons dimensions, is needed to ultimately provide the assurances of a peaceful nuclear program. Because the IAEA needs to draw its own conclusions and corroborate information it is provided by the inspected state, details and (re)examining issues from various perspectives are required. This is not a case of nitpicking but a step within the larger verifications process in order to derive the correctness and completeness of a program that had developed in a clandestine nature.

The IAEA has the necessary tools and practices to verify nuclear inventories, map the chronologies of a nuclear program, and suggest additional steps needed to be taken by the inspected state to help the IAEA fulfill its requirements. Each case of nuclear concern and complexity is different, and prescriptions may differ but have the same aim of ultimately providing the international community the needed assurance of a peaceful nuclear program. In the case of South Africa, much of the weapons-related information had been destroyed, and weapons and their manufacturing installations had been dismantled without the presence of the IAEA inspectors. While there can be a number of conjectures as to why South Africa chose to do so, it is clear that the process of verification after the fact of dismantlement having taken place meant time added to the clock for the IAEA in terms of providing assurances on the completeness and correctness of South Africa's nuclear program.

Since only limited verification was possible during the operation of the nuclear facilities, and parts of the program were dismantled without the presence of the IAEA, any final assessment would have to be reconciled with the fact that an absolute account of every single event is unlikely. However, through the refinement of the material balance evaluations process, coupled with verified information that became available from decontamination activities carried out and the recharacterization of wastes, the IAEA was able to state, after a period of time, that there is no reason to indicate that the nuclear material inventory of South Africa is incomplete.

Aside from the IAEA's verification requirements, full cooperation and transparency from the authorities and operators of the inspected state are equally essential in resolving outstanding issues. South Africa's policy—access any time, any place with a reason—was important for the IAEA work. Its authorities also cooperated with and provided access to people who were working in its weapons program during the various phases. Ongoing inspections and verification work conducted, along with the accommodation and cordial cooperation provided by the South African government to the IAEA, were ingredients that eventually put the country back on the path to attaining its full bill-of-health assessment in 2010.

ENDNOTES - CHAPTER 9

1. "Safeguards Statement for 2011" and "Background to the Safeguards Statement," IAEA, available from *www.iaea.org/safeguards/documents/es2011.pdf.*

2. South Africa concluded a Comprehensive Safeguards Agreement in 1991 and adopted the Additional Protocol in September 2002.

3. General Conference Resolution GC(XXXV)/RES/567, IAEA, September 1991, available from *www.iaea.org/About/Policy/GC/GC35/GC35Resolutions/English/gc35res-567_en.pdf.*

4. The Denuclearization of Africa, GC(XXXVI)/1015, IAEA, September 4, 1992, available from *www.iaea.org/About/Policy/GC/GC37/GC37Documents/English/gc37-1075_en.pdf.*

5. The Denuclearization of Africa, GC(XXXVII)/1075, IAEA, September 9, 1993, available from *www.iaea.org/About/Policy/GC/GC37/GC37Documents/English/gc37-1075_en.pdf.*

6. According to the provisions of the safeguards agreement, the IAEA Secretariat can disclose information about nuclear material inventories only with the consent of its Board of Governors or the concerned Member State. In the case of South Africa, the agency has not made public any nuclear material accountancy information, also due to security reasons.

7. T. C. Hlongwane, "NECSA [Nuclear Energy Corporation of South Africa] Solid Radioactive Waste Management Plan," Regional Practical Workshop on the Decommissioning of Radioactive Contaminated Facilities, August 24, 2011.

8. *Ibid*.

9. *Ibid*.

APPENDIX 9-I

In the 1970s and 1980s, South Africa's nuclear program focused first on the manufacture of a gun-type device, and subsequently pursued research and development (R&D) for an implosion-type nuclear device. In the 1970s, Pretoria's Atomic Energy Commission's nuclear weapons-related work was concentrated at Pelindaba (Building 5000), where criticality experiments were conducted to develop a gun-type nuclear device.[1] The area had also housed R&D laboratories, as well as premises for the machining of uranium metal components for a first nuclear device, which was completed by 1979.[2]

When the decision to develop deliverable nuclear weapons was made later in the 1970s,[3] the Kentron Circle Facility (Advena Circle Facility or Advena Central Laboratories) was built for the production of South Africa's second nuclear device, followed by the construction of four other gun-type weapons. Physically, the Kentron Circle Facility was located in an entirely separate geographical area a few kilometers away from Pelindaba. Services of Somchem, an ARMSCOR weapons-dedicated facility, were also used for the development of explosives for nuclear purposes. This phase of the nuclear weapons R&D program included studies on possible use of tritium boosted devices, research on implosion, and thermonuclear technology, and the production and recovery of plutonium and tritium.[4]

South Africa also built testing areas for its nuclear weapons program. The Vastrap test range was located in the Kalahari Desert and had two nuclear test shafts.[5] The test shafts had a depth of 385 and 216 meters, respectively.[6] The shafts were sealed off in 1993 under IAEA supervision.

Highly enriched uranium was a natural choice for Pretoria's weapons program given its rich uranium ore resources. In 2011, South Africa retained 5 percent of the world's known recoverable uranium resources.[7] By 1952, South Africa had started producing uranium. At the peak of its mining program, until 1965, South Africa operated 26 mines, but since then, mining has decreased. In 2012, South Africa produced 465 tons of uranium, which is less than 1 percent of world production.

Today, South Africa maintains one operating uranium recovery plant, the Vaal River South uranium plant,[8] compared to the early-1980s when it operated three uranium production plants.

FACILITIES UNDER SAFEGUARDS BEFORE SEPTEMBER 1991

Before 1991, and the conclusion of a comprehensive safeguards agreement with the IAEA, there were three installations under IAEA Information Circular 66 safeguards agreement in South Africa.

Research Reactor.

In 1965, South Africa Fundamental Atomic Reactor Installation (SAFARI-1), a 20-megawatt (MW) light water reactor, started operation in Pelindaba. The reactor had an original supply of 90 percent highly enriched uranium (HEU) fuel from the United States until 1976.

Hot Cell Complex, Pelindaba.

The Hot Cell Complex facility at Pelindaba has been used for isotope production purposes. South Africa is today one of the main molybdenum-99 producers. In 1984, South Africa made a policy decision—due to risks that the IAEA may find clandestine operations—that the installation would not be used for the R&D on plutonium reprocessing. For the same reason, the SAFARI-1 reactor was not used for any plutonium production experiments.

Koeberg Nuclear Power Plant.

The Koeberg Plant, commissioned in 1984-85, was designed and built by Framatome, France. It has twin 900-megawatt electrical class pressurized water reactors.

ADDITIONAL NUCLEAR INSTALLATIONS DECLARED IN SEPTEMBER 1991

The initial declaration included a number of nuclear facilities, laboratories, and small locations using nuclear material. South Africa also had uranium enrichment studies using gas centrifuges and working with laser enrichment. The major installations related to uranium enrichment, uranium processing, and nuclear material storage and recovery are as follows.

Uranium Conversion.

In the 1960s, South Africa started small-scale uranium conversion experiments. A uranium conversion facility was built in the early-1980s to produce feed material for uranium enrichment. At some point, South Africa also constructed, and operated, a second UF6 production plant. It was shut down by 1998.

Pilot Uranium Enrichment Plant, Y-Plant.

Production of HEU (this facility also produced low enriched uranium [LEU]) began in January 1978 and ended in November 1989 at Valindaba, adjacent to the Pelindaba site. The United States stopped exporting HEU fuel for the SAFARI-1 reactor in protest against the construction of Y-Plant and South Africa's nuclear weapons program. The Y-Plant then started producing 45 percent enriched uranium in 1979 for SAFARI-1. The plant was already under decommissioning when Pretoria provided its initial declaration to the IAEA.

Semi-Commercial Enrichment Plant, Z-Plant.

Production of low enriched material began in August 1988 at Valindaba. The plant was still in operation when Pretoria submitted its initial state declaration in 1991. Enrichment activities at the plant were terminated in October 1995. Prior to shutdown, the Z-plant had a capacity of 300,000 separative work unit (SWU)/yr. It supplied 3.25 percent enriched uranium for the Koeberg Plant. Originally, fuel for Koeberg was imported. During the height of sanctions, South Africa's AEC was tasked to set up and operate uranium conversion, enrichment, and fuel manufacturing services to keep the Koeberg reactors in operation. (See Figure 9-AI-1.)

Figure 9-AI-1. View of the Enrichment Plant before Dismantlement.[9]

Highly Enriched Uranium Fuel Fabrication.

The pilot scale plant was built to produce fuel elements for the SAFARI-1 research reactor after the United States stopped the fuel deliveries in 1976.

LEU Fuel Fabrication Plant.

The fuel fabrication plant produced LEU fuel elements for the Koeberg power reactors.

There was also a zircaloy tubing facility in Pelindaba to produce cladding for fuel assemblies used in Koeberg reactors. In 1993, it was closed and sold to a Chinese enterprise.

Decontamination Plants and Waste Storages.

These plants are at Pelindaba and are used for decontamination of equipment, storing of wastes, and packing wastes for the final disposal.

Spent Fuel and Waste Disposal.

South Africa has two radioactive waste disposal sites: the Thabana Hill site and the Vaalputs National Waste Repository.

ENDNOTES - CHAPTER 9, APPENDIX I

1. David Albright, "South Africa and the Affordable Bomb," *Bulletin of the Atomic Scientist*, Vol. 50, No. 4, July-August, 2004.

2. David Albright and Corey Hinderstein, "South Africa's Nuclear Weaponization Efforts: Success on a Small Scale," Washington, DC: Institute for Science and International Security (ISIS), September 13, 2001.

3. *Ibid*.

4. Albright.

5. Mark Hibbs, "South Africa's Secret Nuclear Program: From a PNE to a Deterrent," *Nuclear Fuel*, May 10, 1993.

6. Albright.

7. World Nuclear Association, available from *www.world-nuclear.org/info/Nuclear-Fuel-Cycle/Mining-of-Uranium/World-Uranium-Mining-Production/*.

8. *Uranium 2011: Resources, Production and Demand*, A Joint Report by the Organization for Economic Co-operation and De-

velopment Nuclear Energy Agency and the International Atomic Energy Agency, 2012.

9. Elna Fourie, Decommissiong Projects at the Nuclear Energy Corporation of South Africa (NECSA), 2011.