

Nuclear verification in South Africa

Verifying South Africa's declared nuclear inventory, and the termination of its weapons programme, was a complex task

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South Africa's accession to the Treaty on the Non-Proliferation of Nuclear Weapons (NPT) on 10 July 1991 was promptly followed by the signing of a comprehensive safeguards agreement with the IAEA on 16 September 1991. Four days later, the IAEA General Conference adopted a resolution aimed at ensuring early implementation of the safeguards agreement and verification of the completeness of the inventory of South Africa's nuclear installations and material.

In November 1991, a team of senior IAEA safeguards officials specially appointed by the Agency's Director General carried out the first inspections under the comprehensive safeguards agreement. The activities to verify the correctness of South Africa's declared inventory of nuclear material extended over several months and involved long-established measures. These included the examination of contemporary operating and accounting records, and analysis of the nature and quantity of nuclear material. South Africa's extensive nuclear fuel cycle made the task complex, requiring considerable inspection resources and extensive co-operation from South African authorities regarding the provision of access to defunct facilities and historical operating records.

The task was further complicated when, on 24 March 1993, State President de Klerk announced that South Africa had developed and subsequently dismantled a "limited nuclear deterrent capability" involving the design and manufacture of seven gun-assembled devices. The news prompted the IAEA to augment its safeguards team in South Africa with, among other specialists, nuclear weapons experts. The team's assignment was extended to include assessing the status of the former nuclear weapons programme and ascertaining that all nuclear ma-

terial involved in the programme had been recovered and placed under safeguards.

Over the months that followed, the team thoroughly examined detailed records and verified the inventories of nuclear materials in South Africa. As a result, it was able to conclude that there were no indications to suggest that the initial inventory is incomplete or that the South African nuclear weapons programme had not been completely terminated and dismantled.

This article highlights the IAEA's verification activities in South Africa and the main activities associated with its assessment of the termination of South Africa's former nuclear weapons programme.

Verifying the correctness of South Africa's declared nuclear inventory

As required under the comprehensive safeguards agreement, South Africa submitted to the IAEA an initial report of its nuclear programme. The initial report is a comprehensive document and includes quantitative data on all types of nuclear material, on a facility-by-facility basis. It is expanded by attachments which provide detail on the location and the number of items of nuclear material contained in each respective facility.

For the IAEA, it was therefore possible — on the basis of the data contained in the initial report and subsequent inventory changes — to establish an itemized list of each facility's nuclear material inventory. Verification of such itemized lists was carried out during the first few months of the implementation of the comprehensive safeguards agreement. This was done in accordance with the requirements for physical inventory verification (PIV) specified in the IAEA 1991-95 Safeguards Criteria, using established accountancy verification measures.

Unlike other States which had entered into comprehensive safeguards agreements, South Africa had been operating a number of nuclear facilities, of unique indigenous origin, that pre-

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viously had not been subject to safeguards. Details of their design and operation were thus relatively unknown to the IAEA at the time the comprehensive safeguards agreement was concluded. (See box.)

This situation made it necessary to devote considerable effort to understanding the facility processes. This would enable establishment of workable safeguards approaches for interim implementation during the period in which the facility attachment would be negotiated. This process was facilitated through a joint seminar. The meeting provided the opportunity for the IAEA to explain the accountability procedures appertaining to a comprehensive safeguards agreement (INFCIRC/153-type) and for the South African State System of Accounting and Control (SSAC) and facility operators to provide insight into the facilities and their operating procedures.

Since the time of the "initial inspections" in late 1991, verification activities carried out in South Africa have continued to be based on the IAEA 1991-95 Safeguards Criteria. In October 1992, a near-simultaneous PIV, involving all South African facilities, was successfully carried out. All quantity goals were attained during that first material balance period. Similar exercises were carried out in August 1993 and October 1994.

As might be expected, it proved necessary to make a number of corrections to the data included in the initial report. This resulted from the continuing efforts of the SSAC to ensure the accuracy of the data, errors identified during the inspection process, and corrections to estimations resulting from measurements made by facility operators after issuance of the initial report. This latter aspect was particularly relevant in the case of material recovered as a result of decontamination of plant components.

At present, facility attachments are in force for six facilities and it is intended to complete negotiations for the remaining facilities during 1995.

Assessing the completeness of South Africa's declared nuclear inventory

An important aspect of the IAEA's safeguards implementation in South Africa was the assessment of the *completeness* of the declared nuclear inventory, which is extensive. The complex task was carried out as a separate exercise by a team of senior members of the IAEA Department of Safeguards specifically appointed for the purpose by the Director General. It required considerable inspection resources and co-operation from the State authorities regarding the provision of access to defunct facilities and historical operating records.

South Africa's nuclear installations

Installations under IAEA safeguards which were formerly inspected in accordance with an INFCIRC/66-type safeguards agreement

- SAFARI-1 research reactor, Atomic Energy Corporation, Pelindaba
- Hot cell complex, Atomic Energy Corporation, Pelindaba
- Koeberg nuclear power reactor units 1 and 2, Electricity Supply Commission

Additional installations under IAEA safeguards since September 1991 in accordance with a comprehensive safeguards agreement (INFCIRC/153-type)

- Uranium conversion, uranium hexafluoride (UF₆) production plant
- Pilot highly enriched uranium (HEU) enrichment plant (Y-plant), now defunct
- HEU storage facility
- HEU-UF₆ and metal/alloy production plant
- HEU fuel fabrication plant
- Semi-commercial low-enriched uranium (LEU) enrichment plant (Z-plant)
- MLIS laser enrichment R&D facility
- LEU fuel fabrication plant
- Natural uranium/depleted uranium metal plants
- Decontamination plants
- Waste storage compound
- Locations outside facilities

A practical basis was established through which the mutual consistency of the inventory of nuclear installations and material — and hence their completeness — could be determined. The declared inventory was first evaluated with respect to production, imports, and usage. Then the isotopic balance of the inventory was calculated and compared with its natural uranium origin.

Through this process, the declared inventory was found to be consistent with the declared production and usage data, but the calculated isotopic balance indicated "apparent discrepancies" with respect to the highly enriched uranium (HEU) produced by the defunct pilot enrichment plant (called the Y-plant) and with respect to the low-enriched uranium (LEU) produced by the semi-commercial enrichment plant (called the Z-plant). The direction of these "apparent discrepancies" could be interpreted to indicate that an amount of uranium-235 was unaccounted for.

Having regard to the period of time involved (for the Y-plant in particular) and the absence of accurate accountancy of the depleted uranium waste stream, such "apparent discrepancies"



As part of its assessment of the status of South Africa's former nuclear weapons programme, a team of IAEA inspectors were able to visit all facilities once connected with the programme. Shown here are the secured vaults at the ARMSCOR/Circle facility, where the weapons were produced and stored (*top and below*); the general purpose critical facility that was dismantled near the AEC Pelindaba site (*lower left*); and IAEA inspectors outside the building (*left*) over the Kalahari test shaft, which was rendered harmless (*facing page*). (Credits: V. Mouchkin, IAEA; AEC)



were not unexpected. It was, however, considered necessary to continue efforts to further clarify them, with priority being given to the Y-plant data. Further examination of records, particularly those covering the recovery of HEU material following the shutdown of the plant, resulted in a significant reduction of the magnitude of the "apparent discrepancy".

To supplement these activities, an exhaustive examination of the performance of the Y-plant over its entire operating history was undertaken. This examination involved the analysis of data from several thousand operating records, which detailed the plant status, on a daily basis, in terms of availability of separating modules, the feed rate and the assay of feed, product, and tail streams. Technical documents describing phenomena which had affected the plant performance were also studied.

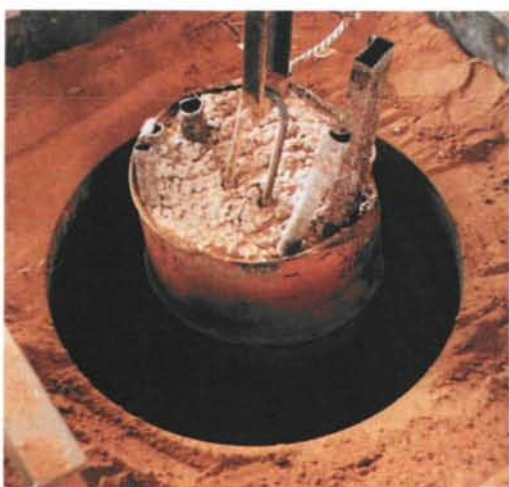
The results of this examination showed that the amount of HEU declared to have been produced by the Y-plant was consistent with the plant's production capacity.

On the basis of these studies the IAEA determined that it was reasonable to conclude that the uranium-235 balance of the HEU, LEU, and depleted uranium produced by the Y-plant was consistent with the natural uranium feed; and that the amounts of HEU that could have been produced by the plant were consistent with the amounts declared in the initial report.

The operating records of the Z-plant were subject to detailed scrutiny which enabled the plant operation to be modelled, on a daily basis, from its very beginning to the day of the initial inventory. A comparison of records showed, for a certain period of plant operation, that the amount of U-235 transferred to depleted uranium waste storage as indicated in the operating records was substantially more than that recorded in the accounting records. Further examination of records and measurement of samples of

South Africa's former nuclear weapons programme: Chronology of the main events

- 1970 — Uranium enrichment project announced
- 1971 — Approval for R&D based on gun-assembled device relating to nuclear explosions for peaceful purposes
- 1973 — Investigation into separation of lithium isotopes
- 1974
 - Prime Minister approves limited programme for development of nuclear weapons as deterrent
 - First stage of pilot enrichment plant commissioned
 - Approval for test site development in the Kalahari desert
- 1975 — Work on the Kalahari test shafts commenced
- 1976 — Export from the USA of fuel for the SAFARI-1 research reactor stopped.
- 1977
 - Kalahari test site abandoned
 - Full cascaded operation of the pilot enrichment plant
- 1978 — First HEU product withdrawn from the pilot enrichment plant
- 1979
 - First nuclear device completed by the AEC
 - Decision that ARMSCOR should take over programme from the AEC and produce all further devices.
- 1980 — Construction of tritium handling laboratory completed
- 1981
 - ARMSCOR/Circle facilities completed
 - Approval of the Gouriqa programme for commercial PWR technology development, as well as possible future tritium and plutonium production
- 1982 — Second device completed
- 1985
 - Government decision to limit number and type of devices to seven gun-assembled devices, to further develop implosion technology and to study more advanced concepts
 - Lithium-6 Avlis programme redirected towards lithium-7 production for water chemistry control in commercial power reactors
- 1987 — Commercial programme for tritium radioluminescent light sources started
- 1987-1989 — Completion of four additional devices
- 1989-1991 — Construction of facilities at ARMSCOR/Advena central laboratories
- 1989 — Decision to terminate nuclear weapons programme (November). Gouriqa programme stopped.
- 1990
 - Pilot enrichment plant ceased operation (February)
 - Order by State President for destruction of the six completed nuclear devices and the incomplete seventh device (26 February)
- 1991:
 - Accession to the NPT (10 July)
 - All HEU returned from ARMSCOR/Circle to the AEC (14 March to 6 September)
 - Signature and entry into force of the safeguards agreement (16 September); Initial report submitted (30 October)
 - Start of IAEA ad hoc inspections (November)
- 1993
 - Destruction of documentation relating to nuclear weapons programme ordered by State President on 17 March; destruction completed on 23 March
 - State President's announcement to Parliament of the existence and subsequent abandonment of the former nuclear weapons programme (24 March)
 - Preliminary visit by IAEA team members to the ARMSCOR/Circle facilities (25 March)
 - Visits of the IAEA team to assess the status of the former nuclear weapons programme (22 April to 4 May, 3-11 June, and 9-13 August).



stored depleted uranium confirmed that the data recorded in the accounting records were based on inaccurate nominal values and that the data contained in the operating records more correctly reflected the actual material transfers.

The consequential corrections to the records to take account of this finding essentially resolved the "apparent discrepancy" in the previously calculated isotopic balance for the Z-plant. In addition, some other less prominent errors and omissions were identified in the initial report and their correction contributed to the conclusion that isotopic balance of the Z-plant was satisfactory.

Ascertaining the status of South Africa's former nuclear weapons programme

The inventory of HEU declared by South Africa in its initial report was substantial. The IAEA recognized that this material could have been taken to indicate that a significant component of the HEU inventory had been recovered from an abandoned nuclear weapons programme or, less likely, had been accumulated to supply a planned nuclear weapons programme which had been abandoned prior to its implementation.

South Africa had no obligation to declare what had been the past purpose of this material. Equally, the primary task of the IAEA was to ascertain that all nuclear material had been declared and placed under safeguards; priority was given to this task during 1992.

In addition to the established accountancy verification measures, the IAEA, acting on information received from Member States, carried out a number of inspections. They included the taking of environmental samples, at a location that was later declared to be an unused nuclear weapons test facility in the Kalahari desert and at a number of abandoned buildings (including a general purpose critical facility) located just outside the Pelindaba security fence. The South African officials were very co-operative in facilitating access to these locations but claimed lack of detailed knowledge of their past use.

It is now a matter of record that, on 24 March 1993, President de Klerk, in a speech broadcast to the South African Parliament, made a declaration that "at one stage, South Africa did, indeed, develop a limited nuclear deterrent capability".

President de Klerk's statement included a description of the scope and objective of the "capability" and the rationale for its abandonment and South Africa's accession to the NPT.

It is significant to note that on the day of the declaration, two members of the IAEA team were present at the Atomic Energy Corporation

(AEC), Pelindaba. They were carrying out follow-up actions directed towards the clarification of the "apparent discrepancy" in the isotopic balance of the HEU material produced by the Y-plant. On the day after the declaration, these two team members made a preliminary visit to a number of key facilities concerned with the abandoned nuclear weapons programme.

Over the following 5-month period, the team, augmented by nuclear weapons experts, carried out inspections at a number of facilities and locations that had been declared to have been involved in the former nuclear weapons programme. The objectives of these inspections were to:

- gain assurance that all nuclear material used in the nuclear weapons programme had been returned to peaceful usage and had been placed under IAEA safeguards;
- assess that all non-nuclear weapons specific components of the devices had been destroyed; that all laboratory and engineering facilities involved in the programme had been fully decommissioned and abandoned or converted to commercial non-nuclear usage or peaceful nuclear usage; that all weapons-specific equipment had been destroyed and that all other equipment had been converted to commercial non-nuclear usage or peaceful nuclear usage;
- obtain information regarding the dismantling programme, the destruction of design and manufacturing information, including drawings, and the philosophy followed in the destruction of the nuclear weapons;
- assess the completeness and correctness of the information provided by South Africa with respect to the timing and scope of the nuclear weapons programme, and the development, manufacture, and subsequent dismantling of the nuclear weapons;
- consult on the arrangements for, and ultimately to witness, actions at the Kalahari test shafts to render them useless;
- visit facilities previously involved in or associated with the nuclear weapons programme and to confirm that they are no longer being used for such purposes;
- consult on future strategies for maintaining assurance that the nuclear weapons capability would not be regenerated.

These objectives were based on the IAEA's rights and obligations under the safeguards agreement and on the stated policy of the South African Government for full transparency with respect to the country's former nuclear weapons programme. The IAEA team had extensive discussions with the South African authorities and technical staff at the AEC and at the State-owned armaments corporation (ARMSCOR) which had

been responsible for the production phase of the nuclear weapons programme. Detailed briefings were provided on the various phases of the programme and on the associated development and production facilities. Information on the future development of the programme, which had been envisaged before the order to dismantle the nuclear weapons programme intervened, was also provided.

Information from IAEA Member States was used to confirm that all relevant facilities/locations had been inspected.

On the basis of official documents, programme records, and information obtained through interviews with principal personnel at the various facilities and locations involved in the programme, the IAEA team was able to document the timing and scope of the nuclear weapons programme. (*See box on page 45 for a chronology of the main events.*)

In the 10-year period up to 1979, all research and development work on nuclear explosive devices was done by the South African Atomic Energy Board, the forerunner of the AEC. This work resulted in the production of a "non-deliverable demonstration device", which was designed in such a way that, if the need arose, it could be rapidly deployed for an underground test to demonstrate South Africa's nuclear weapons capability. Its purpose remained that of a demonstration device throughout the programme; it was never converted to a deliverable device.

It was in 1979 that the responsibility for the nuclear weapons programme was transferred to ARMSCOR, while the AEC was made responsible for the production and supply of HEU and for theoretical studies and some development work in nuclear weapons technology. ARMSCOR's principal nuclear weapons activities were carried out in the so-called Circle facilities, located some 15 kilometers away from the AEC's establishment at Pelindaba. The Circle facilities were constructed during 1980 on the basis of designs provided by the AEC and were commissioned in May 1981. The nuclear weapons programme thus established involved:

- the development and production of a number of deliverable gun-assembled devices;
- lithium-6 separation for the production of tritium for possible future use in boosted devices;
- studies of implosion and thermonuclear technology;
- research and development for the production and recovery of plutonium and tritium.

In September 1985, the South African Government decided to limit the scope of the programme to the production of seven gun-assembled devices, to stop all work related to possible

plutonium devices and to limit the production of lithium-6; however, it allowed further development work on implosion technology and theoretical work on more advanced devices.

The first prototype deliverable device had been completed in December 1982, but it was not until August 1987 that the first qualified production model was completed. The delay was largely due to the implementation of a rigorous engineering qualification programme directed towards safety and security under a range of postulated storage, delivery, and accident scenarios. When, in November 1989, the decision was taken by the Government to stop the production of nuclear weapons, four further qualified deliverable gun-assembled devices had been completed and the HEU core and some non-nuclear components for a seventh device had been fabricated. On 26 February 1990, the State President issued a written instruction that, *inter alia*, all existing nuclear devices were to be dismantled and the nuclear materials were to be melted down and returned to the AEC in preparation for South Africa's accession to the NPT.

By the time of the IAEA team's visit in April 1993, the dismantling and destruction of weapons components and the destruction of the technical documentation had been nearly completed. Dismantling records concerning the HEU components of the weapons were available. They provided sufficient detail to enable the ARMSCOR data to be correlated with the corresponding data in the nuclear material accountability records maintained by the AEC.

The dismantling of the non-nuclear components of the weapons had been carried out in accordance with procedures approved by the South African authorities. A number of destroyed or partially destroyed components had been retained and were shown to some members of the team in April 1993. Remaining records, in the form of "build history" logbooks for the completed weapons and the experimental devices, were examined and compared with the dismantling listings. Identification numbers of remaining components were compared and found to be consistent with those shown in the records.

The team carried out an audit of the records of the transfer of enriched uranium between the AEC and ARMSCOR/Circle. As a result of this audit, the team concluded that the enriched uranium originally supplied to ARMSCOR/Circle had been returned to the AEC and was subject to IAEA safeguards at the time the safeguards agreement entered into force.

The team visited all facilities identified as having connection with the former nuclear weapons programme. It is appropriate to record the active co-operation of the South African authori-

ties in arranging for access to all facilities that the team requested to visit — both those facilities which had been provisionally listed by the South African authorities as having direct connection with the former nuclear weapons programme, or with peripheral activities, and additional facilities identified by the team. The IAEA is not in possession of any information suggesting the existence of any undeclared facilities connected with the programme.

Actions were taken by ARMSCOR to render useless the test shafts at the Vastrap (Kalahari) site, in accordance with a plan incorporating specific suggestions made by the IAEA team. Although the implementation of this plan met with some initial practical difficulties, the measures to render the test shafts useless were successfully completed in July 1993 and were witnessed by IAEA safeguards inspectors.

The equipment used for uranium metallurgy at ARMSCOR/Circle had been returned to the AEC at the end of the programme. The whole uranium metallurgy process area at ARMSCOR/Circle had been dismantled and decontaminated. The machine tools used for manufacturing the HEU and high explosives components had been decontaminated and are now available for commercial non-nuclear applications. The South African authorities stated that specialized equipment supporting the weapons systems in the form of computerized testing equipment has been rendered useless through the destruction of the specific software.

General conclusions

Based on the IAEA's extensive verification activities in South Africa, a number of general conclusions have been made.

It was determined that the magnitude of the "apparent discrepancy" in the uranium-235 balance associated with the Y-plant was such that — having regard to the normal uncertainties expected to be involved in the plant historical operating and accounting records — it was reasonable to conclude that the uranium-235 balance of the HEU, LEU, and depleted uranium produced by the pilot enrichment plant was consistent with the uranium feed. Assessment of the production capacity of the pilot enrichment plant, on the basis of operating records and supporting technical data provided to the IAEA team by the AEC, indicated that it was reasonable to conclude that the amounts of HEU which could have been produced by the plant were consistent with the amounts declared in the initial report.

The IAEA team's audit of the associated records indicated that all of the HEU provided by

the AEC to the nuclear weapons programme had been returned to the AEC and was subject to IAEA safeguards at the time the safeguards agreement entered into force.

The findings from the team's examination of records, facilities, and remaining non-nuclear components of the dismantled/destroyed nuclear weapons, and from the team's evaluation of the amount of HEU produced by the pilot enrichment plant, showed consistency with the declared scope of the nuclear weapons programme.

The team found no indication to suggest that there remained any sensitive components of the nuclear weapons programme which had not been either rendered useless or converted to commercial non-nuclear applications or peaceful nuclear usage.

Also, for the Z-plant, it was possible on the basis of the team's examination of the operational records, sampling, and analyzing of UF₆ from certain tail containers and the correction of minor other errors in the initial inventory to conclude that the amounts of LEU reported as produced by the plant was consistent with the documented operation of the plant.

These general conclusions had strong technical bases and were significantly supported by the transparency and openness of the South African authorities with respect to access to information and locations, in particular the stated and demonstrated willingness of the authorities to facilitate access to any location that the IAEA may identify.

The IAEA's assessment of the completeness of South Africa's inventory of nuclear facilities and materials and its assessment of the status of the former nuclear weapons programme — as in all cases where a large nuclear programme comes under safeguards — is not free from uncertainty.

In the case of South Africa, the results of extensive inspection and assessment, and the transparency and openness shown, have led to the conclusion that there were no indications to suggest that the initial inventory is incomplete or that the nuclear weapon programme was not completely terminated and dismantled. However, in the future, and without prejudice to the IAEA's rights under the safeguards agreement, the IAEA plans to take up the standing invitation of the South African Government — under its reiterated policy of transparency — to provide the IAEA with full access to any location or facility associated with the former nuclear weapons programme and to grant access, on a case-by-case basis, to other locations or facilities that the IAEA may specifically wish to visit. □