Chapter 12 Highly enriched uranium inventory

Although fears of South Africa reconstituting its nuclear weapons program have faded with time, concerns have remained over the security of the highly enriched uranium leftover at the end of the nuclear weapons program. In 1991 when South Africa signed the Nuclear Non-Proliferation Treaty, it had over 800 kilograms of HEU stored at Pelindaba under heavy security and IAEA safeguards (see tables 1 and 2 in chapter 3). The US government has consistently tried to convince South Africa to eliminate this stock because of the risk that some of it would be diverted or stolen. Concerns remain that extremist groups or criminal elements might seize the HEU for political or material gain. There have been break-ins at Pelindaba, one of which implied a high degree of organization.

The debate over the fate of the HEU started soon after South Africa signed the NPT in 1991. Originally, the question over the future of the HEU centered on the possibility of the Atomic Energy Corporation selling "excess" HEU to a nuclear weapon state. According to then head of the Atomic Energy Corporation Waldo Stumpf, in September or October 1992 South African government officials approached both the British and US governments and asked them whether they would be prepared to buy the excess HEU.[1] Only the US government expressed interest, but US officials told the South Africans that because of the approaching presidential election, they could not act at that time.[2] After the election, the relevant officials either were not yet appointed or were unprepared to act during the transition. In any case, by February 1993, US officials told one of the authors that they expected to take up South Africa's offer within several weeks and were willing to buy all of South Africa's HEU.[3] The US intention was to buy HEU without involving the ANC, which was not yet in government in any case.

Initially in 1992, the ANC was undecided about selling the HEU, emphasizing the need to provide safe transport and assurance that no HEU could end up in the US nuclear weapons program. However, the ANC position on a sale hardened. In 1993 the ANC started to view the sale of this stock of material as another example of the "unilateral restructuring" being undertaken by the de Klerk government, which aimed to transfer many governmental institutions to the private sector and effectively place these institutions beyond the reach of an ANC-led government. The ANC had earlier criticized Armscor's transfer of military industries in 1992 to Denel, and this sale may have contributed to souring the ANC's view of selling HEU. At a July 1993 meeting of senior ANC and AEC officials, Stumpf promised not to dispose of the HEU before the formation of a democratic government.[4]

The AEC told US officials that they could make more money if they used the HEU as fuel in the Safari research reactor at Pelindaba to make radioactive isotopes for sale. Because the government had given the Safari-1 reactor a directive to operate with fewer government

[1] Transcript of talk by Waldo Stumpf, South African Embassy, Washington, D.C., July 23, 1993; and Interview with US State Department official, January 1997.
[2] "A Bungled Nuclear Deal," *Newsweek*, July 25, 1994.
[3] David Albright and Mark Hibbs, "South Africa: The ANC and the Atom Bomb," *Bulletin of the Atomic Scientists*, April 1993.
[4] J. W. de Villiers, Roger Jardine, and Mitchell Reiss, "Why South Africa Gave Up the Bomb," *Foreign Affairs*, November/December 1993, p. 11.

subsidies, the AEC created plans to minimize reactor costs. One option was preserving the existing HEU stock to fuel this reactor. By the summer of 1993, the AEC was considering keeping all HEU enriched above 60 percent to fuel the Safari reactor over its expected lifetime. The AEC was still willing to consider down blending the HEU that was enriched less than 60 per cent to low enriched uranium (LEU) for use as fuel in the Koeberg power reactors.[5]

In the summer of 1993, the US government proposed that the Safari reactor be converted to burn new low enriched uranium fuel rather than HEU fuel. Under this option, the HEU would not be necessary for the successful commercial operation of the Safari reactor, and South Africa could then sell or blend down its stock of HEU to low enriched uranium. By September 1993, the AEC and the US Department of Energy had reached an agreement to jointly study the technical and economic feasibility of converting Safari to LEU fuel.[6] Although the AEC fully endorsed the goal of converting to LEU fuel, it also stated that conversion would be subject to economic constraints, which were expected to increase with time. In the protocol, South Africa also stated that it recognized the importance of minimizing or eliminating international trade in HEU. Toward this end, it agreed that it would not engage in trade in HEU under any circumstances.

During these discussions over the fate of the HEU, the Safari reactor continued to use domestically produced 45 percent enriched uranium fuel and operate at about one-fourth of its design power, or near 5 megawatts-thermal (MWth). In 1994, however, South Africa increased the power of the reactor to 20 MWth and resumed the use of 90 percent enriched uranium fuel.

It also decided to keep the 45 percent HEU. South Africa launched a major effort to commercialize the Safari reactor and make molybdenum 99 (Mo-99) for medical uses through the irradiation of targets fashioned from 45 percent HEU. Neutrons produced in the reactor fuel irradiate the HEU targets, causing the uranium 235 to fission; one fission product is Mo-99, which is the parent isotope of the short-lived technetium 99m, the most widely used isotope in nuclear medical diagnostic procedures. South Africa decided to become a leading supplier of molybdenum 99, which signified it was no longer interested in blending down its HEU enriched to less than 60 percent. It essentially decided to keep all its HEU.

The joint reactor conversion study was completed in 1995 and concluded that conversion to LEU fuels was feasible.[7] However, the economic feasibility study, which was done by the AEC alone, concluded that conversion could significantly add to the cost of running the reactor and threaten its commercial viability.[8] Based on an economic analysis of a limited number of options, the AEC argued that conversion would be "economically penalizing" during the time the AEC was concentrating on developing commercial customers for the reactor products. AEC officials, however, said that the AEC would be willing to convert to low enriched uranium fuel if the funds

---

[5] See for example, Stumpf, Transcript of talk at South African embassy, op. cit.
[6] "Protocol Discussions between the AEC of South Africa and the RERTR Program at Argonne National Laboratory and the US Department of Energy," September 8-10, 1993, Pelindaba, South Africa.
[7] G. Ball of AEC and R. Pond, N. Hanan, and J. Matos of Argonne National Laboratory, "Technical Feasibility Study of Converting Safari-1 to LEU Silicide Fuel," Argonne National Laboratory, ANL/RERTR/TM-21, May 1995.
[8] G. Ball and F. J. Malherbe, "Techno-Economic Study on Conversion of Safari-1 to LEU Silicide Fuel," Atomic Energy Corporation, Paper presented at 18th International Meeting on Reduced Enrichment for Research and Test Reactors, Paris, September 1995.

were provided. Given that the South African government would not provide the funds to convert, the question became what would the United States do?

The US government's first reaction was to question the economic study. According to a senior member of the US Reduced Enrichment for Research and Test Reactor (RERTR) program, the AEC's economic study appeared to ignore important options for domestic fuel fabrication that would significantly lower the total costs of the conversion effort. A complete appraisal of all the major options, in this view, would be vital to determine the true costs that would accompany conversion to LEU fuel. If costs were fairly derived, he added, the US government may be willing to contribute to the conversion costs.

However, during 1996 and early 1997, the US government did not act because of internal disagreements between the State Department and the Energy Department over the full cost of converting the Safari reactor.

Meanwhile, the AEC proceeded to institutionalize the use of HEU fuel and targets in the Safari reactor. The impasse over conversion to LEU was to last over a decade.

Only in 2009 did South Africa finally convert the reactor to the use of LEU fuel.[9] Since then, it has obtained LEU fuel from abroad, and thus it no longer requires the use of its domestically produced HEU in fuel. In 2012 South Africa received approval from the US government to import 975 kilograms of US-origin LEU, containing up to 19.95 percent uranium 235.[10] Currently, the near 20 percent LEU is sent to the French fuel manufacturer AREVA CERCA, which makes the fuel for the South African reactor operator NECSA. South Africa's integration into the international fuel cycle system showed that HEU fuels are unnecessary.

The reactor started using LEU targets to make medical isotopes in 2008 or 2009.[11] As in the case of the fuel, the targets have been made by AREVA CERCA, using US-supplied LEU. However, it is unclear from open source information if South Africa has stopped using HEU targets in addition to the LEU targets.[12] It appears that the process of complete conversion to LEU targets has slowed as some of South Africa's overseas customers have encountered delays in obtaining approval from their governments' licensing authorities to use medical isotopes produced via LEU targets instead of HEU targets. In the meantime, South Africa is believed to have continued using HEU targets to make a fraction of these isotopes.

---

[9] NESCA, Media Release: Nuclear Reactor uses only low enriched uranium (LEU) for the first time," South African Nuclear Energy Corporation, June 29, 2009.
[10] US Nuclear Regulatory Commission (NRC) export license XSNM3643, which was approved in 2012, and permits the export of 975 kilograms of 19.95 percent LEU for use in Safari fuel and targets.
[11] G. Ball and O. Knoesen, "Status Update on Conversion to LEU Based 99Mo Production in South Africa," RERTR 2011-33rd International Meeting, October 23-27, 2011.
[12] See for example, Peter Fabricius, "SA playing both sides of the nuclear coin," *The Star*, March 30, 2012.

South Africa still possesses a sizeable inventory of HEU. The sidebar shows that as of the end of 2014, South Africa had hundreds of kilograms of HEU, including a few hundred kilograms of unirradiated 80 and 90 percent enriched uranium, the most dangerous types.[13]

Much of the HEU in South Africa is in forms that can be transported to the United States for disposition. The plans to send the HEU in spent fuel to the United States are well underway, although they do appear delayed. The HEU in the leftover target material could also be shipped to the United States. The total amount of HEU in irradiated forms is estimated to be 485-615 kilograms (initial mass) or equivalently 395-525 kilograms (post-irradiation mass). The United States may also encourage South Africa to blend down to near 20 percent LEU its remaining fresh 80 or 90 percent HEU, which amounts to about 220-250 kilograms. An alternative strategy may be for South Africa to avoid the costs of blending down this fresh HEU and instead sell or barter it for LEU to its closest nuclear partners, namely the United States or France.

Sidebar: South Africa's HEU Inventory, End 2014[14]

From 1994 to the end of the use of HEU fuel, the Safari reactor irradiated about 225 kilograms (initial mass) of domestically produced 90 percent enriched uranium. This material is stored in spent fuel. The Safari-1 reactor is estimated to have also irradiated about 75 kilograms (initial mass) of 45 percent enriched uranium in fuel. So, in total, about 300 kilograms (initial mass) of HEU is in spent fuel. Another 185-315 kilograms (initial mass) of domestically produced 45 percent HEU are estimated as used to make Mo-99. This lightly irradiated material is stored. In total, about 485-615 kilograms (initial mass) of HEU are in irradiated form.

Because of the irradiation of the HEU fuel, as discussed above, the mass of the HEU stock would have decreased by about 90 kilograms uranium 235. The HEU used in targets is lightly irradiated and only a small fraction of the uranium 235 would have been consumed. Therefore, the decrease in mass due to the fissioning of uranium 235 in the targets is not included here. Accounting for fission, the total mass of irradiated HEU is estimated as 395-525 kilograms (post-irradiation mass).

About 220-250 kilograms of HEU remain in the form of fresh 80 and 90 percent HEU. The range is determined in this estimate by the possible need to blend down up to 30 kilograms of 80 or 90 percent HEU to produce additional 45 percent HEU for targets. Likely, the 80 percent HEU would have been preferred for blending, since it was not being used as fuel. Blending down would have increased the total stock of 45 percent HEU by up to almost 55 kilograms. The net increase in the total HEU stock would be about 23-24 kilograms of HEU. Depending on the amount of 45 percent HEU used in targets, there may also be stocks of fresh 45 percent HEU. In this estimate, this stock would not exceed about 75 kilograms.

---

[13] David Albright, *Highly Enriched Uranium Inventories in South Africa Status as of end of 2014* (Washington, D.C.: Institute for Science and International Security, November 16, 2015). http://isis-online.org/uploads/isis-reports/documents/Highly_Enriched_Uranium_Inventories_in_South_Africa_November_2015.pdf
See for example, Peter Fabricius, "SA playing both sides of the nuclear coin," op. cit.
[14] *Highly Enriched Uranium Inventories in South Africa Status as of end of 2014*, op. cit.

In terms of the initial mass of the HEU, South Africa had a stock at the end of 2014 of about 815-835 kilograms of HEU. The increase in the initial mass of the stock in this estimate relative to the total initial mass in the early 1990s results from the blending down of some 80 percent HEU to 45 percent HEU.

This estimate assumes that all of the HEU produced in the Y Plant is available for use. In fact, some small amount of the HEU enriched near 45 percent may be economically unrecoverable or better treated as waste. However, such a reduction would be offset somewhat by the additions to the HEU inventory that occurred after 1994 or 1995, as HEU was found in waste drums.

To derive a post-irradiation HEU estimate, the amount of uranium 235 that fissioned must be subtracted from the initial mass. About 90 kilograms of uranium 235 are estimated to have fissioned, leaving 725-745 kilograms. There are other uncertainties in this HEU estimate that are hard to quantify with the available information. As a result, the final estimate of the total HEU stock at the end of 2014 is broadened to 700-750 kilograms of HEU.