



# Highly Enriched Uranium Inventories in South Africa

## Status as of end of 2014<sup>1</sup>

By David Albright

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South Africa produced highly enriched uranium (HEU) for nuclear weapons at the Y plant at the Pelindaba nuclear center located near Pretoria. This plant, which operated from 1977 until early 1990, was designed to make weapon-grade uranium. However, it experienced operational problems that led to the production of less than expected amounts of weapon-grade uranium and a considerable amount of HEU enriched less than 90 percent.

In late 1989, then-President F.W. de Klerk ordered an end to the nuclear weapons program, including the shutdown of the Y Plant, and decided to sign the Nuclear Non-Proliferation Treaty (NPT). Following the dismantlement of its nuclear weapons, South Africa brought the NPT into force in 1991, subjecting its entire inventory of HEU to International Atomic Energy Agency (IAEA) safeguards.

As part of the IAEA's effort to verify South Africa's initial nuclear material declaration, it conducted an unprecedented investigation aimed at determining that South Africa had declared its HEU inventory completely. After a two year investigation into both the production and use of HEU, the IAEA concluded in September 1993 that South Africa had satisfactorily declared its HEU.

Subsequently, the IAEA and South Africa continued to cooperate to verify better the original HEU declaration. The work, which took years to finish, focused on measuring small quantities of HEU in thousands of waste drums stored at the Pelindaba site. This subsequent investigation led to revised HEU inventory values, which are not included in this report. However, the changes, which add to the declared HEU stock, are estimated as relatively small

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and do not significantly affect the estimates in this report that rest on information about South African HEU stocks in the early 1990s.

<b>South Africa's Estimated HEU Stock, end 2014</b>		
<b>Total HEU (post-irradiation mass)</b>		700-750 kg
	Fresh 80% and 90% HEU	220-250 kg
	Fresh 45% HEU	0-75 kg

## **South Africa's HEU Inventory at the End of its Nuclear Weapons Program**

The Y Plant produced in total about 990 kilograms of HEU with an average enrichment of 68 percent. Table 1 shows the forms of this HEU and some information about its use. Table 2 lists the amount of HEU South Africa assigned to its major programs by 1991.

The South African nuclear weapons program received about 478 kilograms of HEU (average enrichment about 87.4 percent). Of this amount, about 88 kilograms ended up in scrap and were recycled, and about 6 kilograms were lost. The remainder of the HEU, or 385 kilograms, was in seven cores of nuclear weapons at the end of the program. Because of problems in the Y Plant, the original output of the plant was HEU enriched to 80 percent. As a result, at least one core is believed to have contained HEU enriched to 80 percent; the rest used HEU enriched to about 90 percent, or weapon-grade. At the end of the program, all of this HEU was converted into metal billets and stored.

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

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

When South Africa signed the NPT in 1991, it had an HEU inventory of over 800 kilograms with an average enrichment of about 70 percent (see table 1). The vast bulk of this HEU was not irradiated and was in readily usable forms.

A special subset of this HEU is the material that was originally sent to the nuclear weapons program and not involved in blending operations. This material totaled about 478 kilograms, with an average enrichment of about 87.4 percent. As the enrichments clustered into two categories, namely HEU with an enrichment of 80 or 90 percent, it is possible to derive an estimate of the amount at each of those two enrichments.<sup>2</sup> The result is an estimate that about

<sup>2</sup> With the assumption that all the HEU is either 80 or 90 percent enriched, one can write two equations in two unknowns, namely the amounts of 80 and 90 percent, and solve them uniquely.

124 kilograms were 80 percent enriched uranium and 354 kilograms were 90 percent enriched material. Because the enrichments varied somewhat this breakdown is approximate. Moreover, the six kilograms lost in this category is ignored here.

## Safari-1 Reactor

After signing the NPT, South Africa assigned much of its HEU stock to the Safari-1 reactor. It implemented a strategy to use both its substantial stock of 90 percent and 45 percent HEU in this reactor.

In 1994, the reactor resumed the use of 90 percent enriched uranium fuel, and its power returned to a power of 20 MWth. South Africa launched a major effort to 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. Over the years, South Africa has become one of the world's leading suppliers of molybdenum 99, often called "moly 99."

Like many reactors at that time, it had been designed to use weapon-grade uranium fuel, which was originally supplied by the United States. Because of South Africa's apartheid policies and secret nuclear weapons efforts, the United States cut off the reactor's fuel supply in the mid-1970s. Afterwards, the reactor used domestically supplied HEU.

South Africa converted the reactor to the use of LEU fuel in 2009.<sup>3</sup> 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 U.S. government to import 975 kilograms of U.S.-origin LEU, containing up to 19.95 percent uranium 235.<sup>4</sup> 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.<sup>5</sup>

The reactor started using LEU targets to make medical isotopes in 2008 or 2009.<sup>6</sup> As in the case of the fuel, the targets have been made by AREVA CERCA, using U.S.-supplied LEU. However, it is unclear from open source information if South Africa has stopped as of late 2014 using HEU targets in addition to the LEU targets.<sup>7</sup> 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 continue using HEU targets to make a fraction of these isotopes.

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<sup>3</sup> NESCA, "Media Release: Nuclear Reactor uses only low enriched uranium (LEU) for the first time," South African Nuclear Energy Corporation, June 29, 2009.

<sup>4</sup> U.S. 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.

<sup>5</sup> For example, according to NRC export license XSNM3643, which approved the export of 975 kilograms of 19.95 percent LEU, the LEU goes to AREVA CERCA in France for fabrication into fuel or targets before being sent to NECSA, the owner of the Safari reactor.

<sup>6</sup> G. Ball and O. Knoesen, "Status Update on Conversion to LEU Based <sup>99</sup>Mo Production in South Africa," RERTR 2011-33<sup>rd</sup> International Meeting, October 23-27, 2011.

<sup>7</sup> See for example, Peter Fabricius, "SA playing both sides of the nuclear coin," *The Star*, March 30, 2012.

South Africa plans on making both its own LEU fuel and targets. Several years ago South Africa signed an agreement with AREVA CERCA to establish a LEU fuel and target manufacturing plant in South Africa.<sup>8</sup> This plant is expected to be completed within a few years. South Africa is expected to continue importing LEU in the future.

## **HEU Use and Stocks, status as of end of 2014**

With South Africa no longer requiring HEU for the Safari reactor, interest has increased in understanding the size and form of its remaining HEU stocks, including the amount that remains unirradiated. A U.S. priority is convincing South Africa to send the bulk of its HEU to the United States for disposition. Understanding South Africa's HEU stock is important to that goal.

South Africa does not participate in the INFCIRC/549 declaration process, under which a number of countries declare their civil HEU holdings. As a result, the following sections estimate the use and fate of South Africa's HEU, as of the end of 2014.

### **Fate of U.S.-Supplied HEU**

In total, the United States sent about 105 kilograms of weapon-grade uranium (WGU) to fuel the Safari reactor. Prior to the imposition of sanctions in the 1970s, South Africa returned to the United States or sent elsewhere about 95 kilograms (initial mass) of this HEU. By the time South Africa signed the NPT, over 10 kilograms (initial mass) of U.S.-supplied HEU remained in South Africa in the form of irradiated fuel. In August 2011, the United States accepted the return of the remaining U.S.-origin HEU, which totaled 49 fuel assemblies.<sup>9</sup>

### **Domestic Civil 45 Percent HEU Use During the Sanctions Period**

From about 1981 until late 1994, the Safari reactor used domestically produced 45 percent enriched uranium fuel and operated at about one-fourth of its design power, or near 5 MWth.

Based on the reactor's operating history, which South Africa publishes periodically, the reactor consumed through fission or transmutation almost 16 kilograms of uranium 235 when it used 45 percent enriched uranium fuel.<sup>10</sup> About 13 kilograms of the uranium 235 fissioned, and the rest was transmuted into uranium 236. Assuming a 45 percent burnup rate, which applies to the total consumption of uranium 235, the fresh fuel had about 34.7 kilograms of uranium 235, or a total of about 77 kilograms of 45 percent enriched uranium, rounded to 75 kilograms in the remainder of this report.<sup>11</sup>

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<sup>8</sup> "Status Update on Conversion to LEU Based <sup>99</sup>Mo Production in South Africa," op. cit.

<sup>9</sup> J.F. du Bruyn, C.J. Herselman, and D.L. Tillwick, "Return of Safari-1 US Origin HEU (Spent) to Savannah River," RERTR 2011, 33<sup>rd</sup> International Meeting, NECSA, October 9-13, 2011. In a 1999 South African Atomic Energy Corporation study on its spent fuel, one of these elements appears to have been identified as UK-origin.

<sup>10</sup> From 1977 to 1994, Safari produced about 300,000 MWhr of energy, see D.L. Tillwick, "Operation and Maintenance at Safari-1 Research Reactor in South Africa," International Conference on Research Reactors: Safe Management and Effective Utilization, Rabat, Morocco, November 14-18, 2011, slide 5. In other units, this energy equals 12,500 MWth-days. At 1.25 grams of consumption of uranium 235 per MWth-days, this energy required the consumption of 15.6 kilograms of uranium 235.

<sup>11</sup> The burnup figure is taken from G. Ball, P. Pond, N. Hanan, and J. Matos, "Neutronic Study on Conversion of Safari-1 to LEU Silicide Fuel," 1994 International Meeting on RERTR, September 18-23, Williamsburg, VA.

## Domestic HEU Use, Post NPT

Since resuming the use of 90 percent enriched uranium fuel until its phase out in 2009 and substitution with LEU fuel, the reactor operated at consistently higher power levels. Based on its energy output, the reactor consumed, via fission and transmutation into uranium 236, about 91 kilograms of uranium 235 in HEU fuel.<sup>12</sup> (About 75 kilograms of the uranium 235 fissioned and the rest transmuted into uranium 236.) With a burnup of about 45 percent, the fresh fuel contained about 202 kilograms of uranium 235 or a total of almost 225 kilograms, 90 percent enriched uranium.

## Domestic Spent 90 Percent HEU Fuel

The amount of HEU used in fuel can be related to the total number of fuel assemblies manufactured in South Africa for the Safari reactor. The number and type of spent fuel assemblies are publicly available.

As of 1996, South Africa had manufactured 722 fuel elements containing HEU and 131 control rods containing HEU, for a total of 853 elements and rods.<sup>13</sup> At the time, it was manufacturing about 40 fuel elements and 8-9 control rods annually. It stopped making fuel elements and control rods soon afterwards, as it started converting the Safari reactor to LEU in 2008 and finished in 2009. Assuming that production continued throughout 2007 and perhaps 2008, another 48-98 elements and rods were produced, for a total of about 900-950 elements and rods. It is likely that almost all of the domestically produced HEU elements and rods have been irradiated in the reactor.

As estimated above, the irradiated fuel contained initially about 225 kilograms of 90 percent HEU (initial mass) and about 75 kilograms of 45 percent HEU (initial mass), for an estimated total of 300 kilograms of HEU (initial mass). After irradiation, its actual mass, called post-irradiation mass, would be less by approximately 90 kilograms, reflecting the fissioning of the uranium 235 in the reactor. The value of 90 kilograms is the sum of 75 kilograms of uranium 235 fissioned in the 90 percent HEU and 13 kilograms in the 45 percent HEU, rounded to 90 kilograms (see above). The amount of uranium 236 remains in the irradiated HEU and thus is included in post-irradiation mass.

To better understand the number of HEU fuel assemblies and control elements used in the Safari reactor, the estimated amount of uranium 235 in the domestically produced fresh fuel and control rods derived above, or 237 kilograms of uranium 235, is translated into the number of fresh fuel and rods.<sup>14</sup> Each fuel assembly was loaded with between 200 and 300 grams of uranium 235.<sup>15</sup> Each control rod has somewhat less uranium 235 but is believed to

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<sup>12</sup> From 1994 to 2009, Safari produced about 1,750,000 MWth-hr of energy, see “Operation and Maintenance at Safari-1 Research Reactor in South Africa,” op. cit. In other units, this energy equals 72,917 MWth-days. At 1.25 grams of consumption of uranium 235 per MWth-days, this energy required the consumption of 91 kilograms of uranium 235. The produced uranium 236 is counted as part of the irradiated HEU mass.

<sup>13</sup> R.W. Jamie and A. Kocher, “Fuel Manufacturing in South Africa: The Road to Conversion,” 28<sup>th</sup> International RERT Meeting, October 29-November 2, 2006, Cape Town, South Africa.

<sup>14</sup>  $225 \times 0.9 + 75 \times 0.45 = 236.25$  kilograms.

<sup>15</sup> “Fuel Manufacturing in South Africa: The Road to Conversion,” op. cit.; and R. W. Jamie and A. Kocher, “Establishing a LEU MTR Fuel Manufacturing Facility in South Africa,” Proceedings of the 14<sup>th</sup> International Topical Meeting on Research Reactor Fuel Management, Marrakech, Morocco, March 21-25, 2010.

be within this range.<sup>16</sup> As a result, South Africa would have generated between 790 and 1185 fuel assemblies and control rods.

A more refined calculation considers the total energy produced by the reactor while using domestically produced HEU and the differing loading of uranium 235 in the fuel elements during two time periods—1981-1999 and 1999-2009. From 1981 to 2009, the reactor produced roughly 2,400,000 MWth-hr of energy, where two thirds of the energy was produced in the latter period.<sup>17</sup> During the latter period, the fuel elements were loaded with 300 grams of uranium 235; in the earlier period, the loading was 200 grams of uranium 235 per fuel element.<sup>18</sup> Assuming the same burnup of 45 percent throughout these two periods, then about an estimated 620 fuel elements and control rods were produced in the second period and about 310 in the first period, for a total of about 930 elements and rods. These estimated values are consistent with the above values of 900-950 elements and rods, which were derived from fuel manufacturing data.

According to a U.S. Energy Department official in 2011, South Africa was expected to send 770 spent fuel elements in 2012 and 2013.<sup>19</sup> These 770 spent elements likely are most of South Africa's spent HEU fuel elements. However, contrary to expectations, South Africa has not shipped these spent elements to the United States as of late 2014.

### **Domestic 45 Percent HEU in Targets**

The Safari reactor has used a considerable amount of 45 percent enriched uranium targets to make Mo-99. In fact, one of the arguments advanced by senior South African officials in the early 2000s for converting the reactor to LEU fuel was to conserve the HEU stock for Mo-99 production, which was becoming increasingly lucrative.

Little public information is available about South Africa's total molybdenum 99 sales and thus its total use of 45 percent HEU. However, sales increased rapidly in the 1990s, reaching 12 percent of the world's demand.<sup>20</sup> In the late 2000s, when major reactors that made molybdenum 99 shut down for repairs, South Africa increased its production of molybdenum 99. At one point, the Safari reactor produced up to about 20-25 percent of the world's demand for Mo 99, which has also grown over time. More recently, South Africa's share of the world market may have decreased as a result of the restarting of the other reactors.<sup>21</sup>

A rough estimate is to assume that through about 2000, South Africa needed annually about 5-10 kilograms of 45 percent highly enriched uranium for targets. From 2000 to about 2005, the requirement is estimated to have increased to 10-15 kilograms of 45 percent HEU per year, and afterwards to 15-20 kilograms of 45 percent HEU per year,<sup>22</sup> until 2011, when the use of LEU targets lowered the need for 45 percent HEU by up to one third. In total, from

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<sup>16</sup> G. Ball, P. Pond, N. Hanan, and J. Matos, "Technical Feasibility Study of Converting Safari-1 to LEU Silicide Fuel," Argonne National Laboratory, ANL/RERTR/TM-21.

<sup>17</sup> Operation and Maintenance at Safari-1 Research Reactor in South Africa," op. cit.

<sup>18</sup> "Fuel Manufacturing in South Africa: The Road to Conversion," op. cit.

<sup>19</sup> Dawn Gillas, Used Nuclear Fuel Program Manager, "SRS Used Nuclear Fuel Management" A Presentation to the Citizens Advisory Board, July 2011, slide titled: Used Nuclear Fuel Receipt Forecast.

<sup>20</sup> "Key Considerations," op. cit.

<sup>21</sup> "Global M0-99 Supply Chain-Reactors," Mallnckrodt Pharmaceuticals web site, undated but accessed January 15, 2015. [http://www.mallnckrodt.com/Nuclear\\_Imaging/Global\\_Mo-99\\_Supply\\_Chain\\_Reactors.aspx](http://www.mallnckrodt.com/Nuclear_Imaging/Global_Mo-99_Supply_Chain_Reactors.aspx)

<sup>22</sup> Interviews with senior U.S. RERTR official, September 22, 2000 and July 26, 2002.

1994 through 2014, South Africa is estimated to have irradiated 185-315 kilograms of 45 percent HEU (initial mass) in targets to make Mo-99.<sup>23</sup>

After irradiation, the HEU targets are processed nearby the reactor and the Mo-99 and certain other isotopes separated. The leftover HEU, which is only minimally burned up, is stored, pending final disposition. The form of storage is believed to involve liquids and solids in canisters kept at the nuclear site.

## Total HEU Stock, as of end of 2014

After it signed the NPT in 1991, South Africa had an estimated stock of somewhat more than 800 kilograms (initial mass) of domestically produced HEU (see table 1). The stock at the end of 2014 is composed of both irradiated and unirradiated HEU.

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.

Table 3 summarizes these results. 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 53-54 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.

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<sup>23</sup> Using the assumptions in the text, the estimated amount of HEU used in targets is:

1994-2000 (6 yr):	5-10kg HEU/yr	30-60 kg HEU
2001-2005 (5 yr):	10-15 kg HEU/yr	50-75 kg HEU
2006-2011 (6 yr):	15-25 kg HEU/yr	90-150 kg HEU
2012-2014 (3 yr)	5-10 kg HEU/yr	15-30 kg HEU
Total		185-315 kg HEU (uranium 235: 104-174 kg)

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 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. In any case, these adjustments are believed to be a relatively small fraction of the total 45 percent HEU stock. But with a smaller stock of near 45 percent HEU, more 80 percent HEU could have been blended down to 45 percent HEU.

To derive a post-irradiation HEU estimate, the amount of uranium 235 that fissioned must be subtracted from the initial mass. As discussed earlier, about 90 kilograms of uranium 235 is estimated to have fissioned, leaving 725-745 kilograms. There are other uncertainties in this HEU estimate which 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.

## **Final Word**

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 should 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).

South Africa should also be encouraged to blend down to near 20 percent LEU its remaining fresh 80 or 90 percent HEU, which amounts to about 220-250 kilograms. However, a wiser economic strategy would 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 partners, namely the United States or France.



**Table 1: HEU Production in the Y Plant, in kilograms**

<b>HEU Produced in Y Plant</b>	<b>HEU U 235</b>		<b>% U235 (average)</b>
Shipped as uranium hexafluoride for further processing	515	437	85%
Shipped in the form of uranium bearing process filters for recovery	144	60	42%
Shipped in the form of uranium bearing powder for recovery	93	39	42%
Used for upgrading (blending) imported low enriched uranium (LEU)	92	83	90%
Used for upgrading (blending) domestic LEU	77	28	36%
Other(a)	72	30	42%
<b>Total</b>	<b>993</b>	<b>677</b>	<b>68%</b>

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

**Table 2: Assignment of HEU to Major Programs by September 1991, in kilograms(a)**

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

(a) The difference between the amount of HEU produced by the Y Plant and the quantity assigned to major programs is 128 kilograms. Most of this material was never assigned to a program and was stored. Small amounts of HEU in this category were used in other programs and about 10 kilograms were classified as lost during processing. South Africa stated in 1991 that the Y plant produced and used about 921 kilograms of HEU, which implies that about 55 kilograms of usable or recoverable HEU were not assigned to major programs. The other 70 kilograms of HEU were recovered, identified, or measured after the Y plant closed.

(b) The HEU assigned to the nuclear weapons program was either about 90 percent or about 80 percent enriched, with most being 90 percent enriched.

**Table 3: Estimated HEU Inventory and its Fate, Reflecting Use of Domestically Produced HEU in the Safari-1 Reactor, as of the end of 2014, in kilograms, initial mass(a)**

<b>Category</b>	<b>HEU Inventory (early 1990s)</b>	<b>HEU Fate (initial mass) as of end 2014</b>
1) About 90% enriched(b)	354	225, irradiated; 129, fresh
2) About 80% enriched(b)	124	90-124, fresh(d)
3) About 45% enriched		
a) Assigned to Safari, pre-1991	213	75, irradiated in fuel 185-315, irradiated in targets(d)
b) Other(c)	123	
<b>Subtotal</b>	<b>336</b>	<b>260-390, irradiated 0-76, fresh</b>
<b>Total (initial mass)</b>	<b>814</b>	<b>814-836(d)</b>

(a) This table estimates the amount of HEU in certain key categories as defined by its use in the Safari-1 reactor as either fuel or targets. HEU is labeled having a specific enrichment, although the actual average enrichments vary somewhat.

(b) These values have not been reduced by a total of 10 kilograms of 80 and 90 percent HEU declared as losses during processing prior to 1991. Some of these losses could have been recovered from the waste drums after they were investigated subsequent to 1995.

(c) This category includes HEU of various enrichments and forms. It was estimated by taking 993 kilograms (see table 1) and subtracting the prior three categories in table 3 which amount to 691 kilograms, the 169 kilograms of HEU used in blending operations, and ten kilograms lost during processing. The result is 123 kilograms of HEU with an average enrichment estimated at roughly 45 percent. Some of this material should be treated as waste.

(d) It is unknown if South Africa blended down some of its 80 or 90 percent HEU to make 45 percent HEU. The higher values in the range, 260-390 kg, exceed the estimated initial stock of 45 percent HEU of 336 kg. Thus, if larger amounts were used to make targets, more 45 percent HEU would have been required, and blending down some of the 80 or 90 percent HEU would have had to occur. South Africa is more likely to have used the 80 percent HEU, since it was not using this stock as reactor fuel. If up to 54 kg of 45 percent HEU were needed, then this would have required the blending down of up to about 30 kg of 80 percent HEU, depending on dilution stock, e.g. LEU, natural uranium, or depleted uranium. If less than 336 kg of 45 percent HEU were used to make targets, there would remain fresh 45 percent HEU. See text for additional discussion. The totals are  $814 = 225 + 131 + 122 + 75 + 185 + 76$ , and  $836 = 225 + 131 + 90 + 75 + 315$ .