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South African Uranium Enrichment Program [redacted]

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SOUTH AFRICAN URANIUM ENRICHMENT PROGRAM

[redacted]

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CENTRAL INTELLIGENCE AGENCY
DIRECTORATE OF INTELLIGENCE
OFFICE OF SCIENTIFIC INTELLIGENCE

SECRET

PREFACE

In 1970 South Africa announced that it had developed a new process for enriching uranium in the fissile isotope U-235 and that it was constructing a pilot plant to demonstrate this process. The announced goal of the program was to convert natural uranium, mined from South Africa's extensive deposits, to a more valuable product for export. Since then there has been much interest in determining South Africa's capability to produce weapon-grade enriched uranium and in predicting the role of this new enrichment process in the international uranium enrichment market.

[redacted] Only one scientific report describing the pilot uranium enrichment plant has been released by South Africa. That report was presented to the European Nuclear Conference in Paris in April 1975 by Dr. A. J. A. Roux, head of the South African nuclear program. [redacted]

TECHNICAL FOREWORD

Uranium as found in nature is primarily a mixture of two varieties, or isotopes: uranium-235, the isotope that sustains nuclear reactions, and the fairly inert uranium-238. Nuclear weapons and most nuclear reactors require a greater concentration of U-235 than is found in natural uranium. Consequently, uranium is enriched from the natural state (0.7 percent U-235) to about 3 percent U-235 for power reactor fuel or to about 90 percent U-235 for use in nuclear weapons.

Uranium can be enriched by any of several isotope separation techniques, although only a few methods (e.g., gaseous diffusion, gas centrifuge, and aerodynamic processes such as the Becker nozzle process) are feasible for large-scale application. In each technique uranium is passed through a machine, or *stage*, which separates the feed material into an enriched portion and a depleted portion. The fraction of uranium that is split off to become the enriched portion is called the *cut*.

The degree of enrichment achieved by a stage depends on the *stage separation factor* or *enrichment factor*. In general, decreasing the cut of a stage increases the enrichment factor of the stage, but the flow of enriched material from the stage also decreases. Although a large enrichment factor is desirable, very few isotope separation techniques allow more than a very small degree of enrichment at each stage. To reach a useful U-235 concentration, therefore, uranium must be passed through a succession of stages called a *cascade*. For example, a cascade based on gaseous diffusion, which exhibits an enrichment factor of about 0.004, is made up of more than 1,000 individual stages.

To perform useful enrichment, natural uranium is fed into a stage somewhere in the lower portion of a cascade. The cascade splits that uranium into depleted uranium, which is withdrawn from the low end, or bottom, and enriched uranium, which is withdrawn from the top of the cascade.

The flow of uranium varies from stage to stage in an ideal cascade. The flow is greatest at the stage where natural uranium is fed into the system. On either side of this point the flow gradually decreases and reaches a minimum at the ends of the cascade where product and depleted uranium are withdrawn. In an ideal cascade each stage would be sized according to its place in the cascade, but the associated cost of building each stage a different size would be unacceptably high. Instead, only a few sizes of equipment are manufactured and installed, with a small resultant loss of efficiency.

In dividing uranium into enriched and depleted portions, a certain amount of *separative work* is performed. Enrichment tasks are evaluated by the amount of separative work involved; stages and enrichment plants are classified by their capacities to perform separative work.

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are denied in its/their entirety.

Exemption(s): (b)(1), (b)(3)

SOUTH AFRICAN URANIUM ENRICHMENT PROGRAM

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SUMMARY

The aerodynamic uranium enrichment process developed by South Africa is intended to increase the value of exported uranium and to make the domestic nuclear power program independent of foreign fuel suppliers. As with other aerodynamic enrichment processes, such as the Becker nozzle process, the South African process could be used to enrich uranium to 90 percent U-235, suitable for nuclear weapons production.

Details of the specific isotope separation technique used in the South African enrichment process have been tightly held. Other characteristics of the process have been reported, however, such as the working fluid (a mixture of uranium hexafluoride and hydrogen) and a fairly high enrichment factor (0.03).

A small enrichment plant, the Valindaba pilot plant near Pretoria, has been built to demonstrate the South African enrichment process [redacted]

[redacted]

South Africa hopes to capture 10 percent of the world-wide uranium enrichment business in the mid-1980s with a commercial enrichment capacity of 5,000 tonnes of separative work per year. [redacted]

DISCUSSION

THE ENRICHMENT PROCESS

Suspicions that South Africa's enrichment process was a modification of a West German process, the Becker nozzle process, were only partially confirmed in 1975 when Dr. A. J. A. Roux described an aerodynamic process which used a "stationary-walled centrifuge" as the separating element. The operating pressure given for the process gas, a mixture of uranium hexafluoride (UF_6) and hydrogen, was too high to suggest a simple modification of the Becker process. Whereas the Becker process has always operated below atmospheric pressure, Roux stated that all process pressures in the South African plant were above atmospheric and indicated a maximum pressure of up to 6 atmospheres.[1] The two processes, therefore, cannot be equated.

The separation factor for the South African separation element was stated to be "1.025 - 1.030 depending on economic considerations." This factor was explained by Roux in 1973 to be the degree of enrichment achieved by a South African separation element.[2] The fact that Roux described the South African separation factor as depending on economic considerations rather than engineering constraints implies that this separation can be achieved not only in the laboratory but also in an enrichment plant.[1]

In the gaseous diffusion process the separation element is a porous membrane; in the Becker process it consists of a curved wall and a knife edge. Except for the vague description given by Dr. Roux, the separation element in the South African process remains unknown. [redacted]

According to Roux's presentation, the South African process involves a small cut;* that is, the amount of enriched uranium leaving each stage in an enrichment plant is a small portion of the uranium fed into the stage. Figure 1 shows, for example, flow diagrams of two stages that have a cut of 1/4. The enriched stream of Stage 1 has 1/4 the flow of the feed stream; the depleted stream has the remaining 3/4. This is the usual kind of stage; with a cut of 1/4, the effect of isotope separation is three times greater for the enriched stream than for the depleted stream. The use

*The value of the cut is discussed in Appendix A.

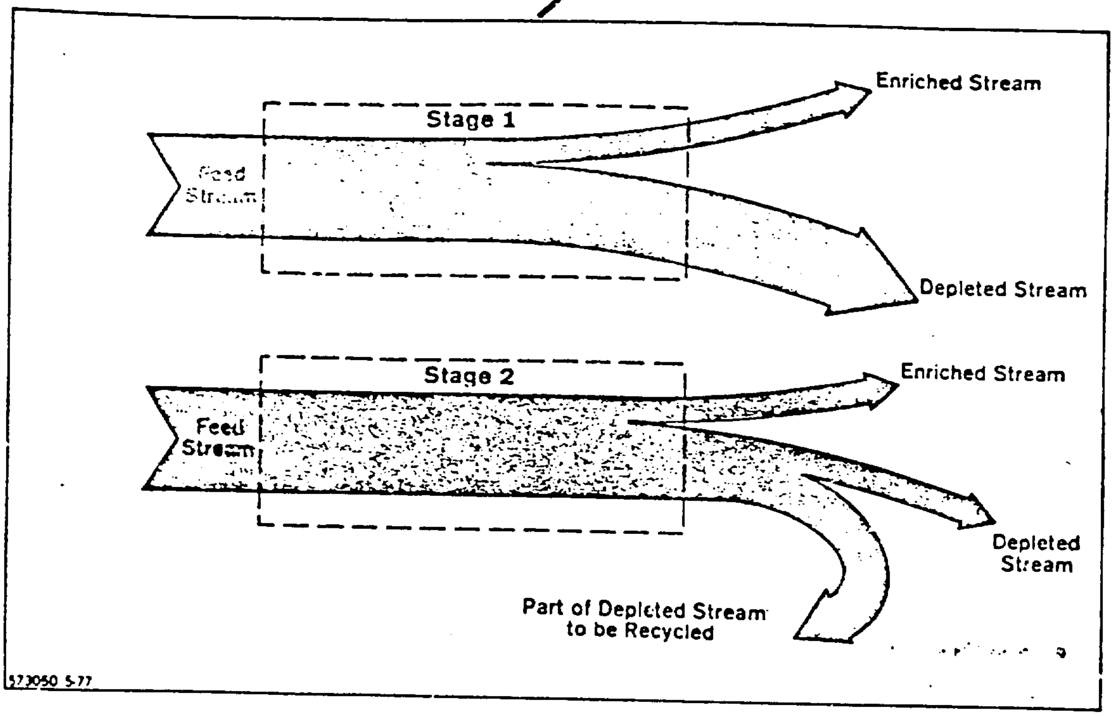


Figure 1. Uranium Flow Through Two Types of Stages

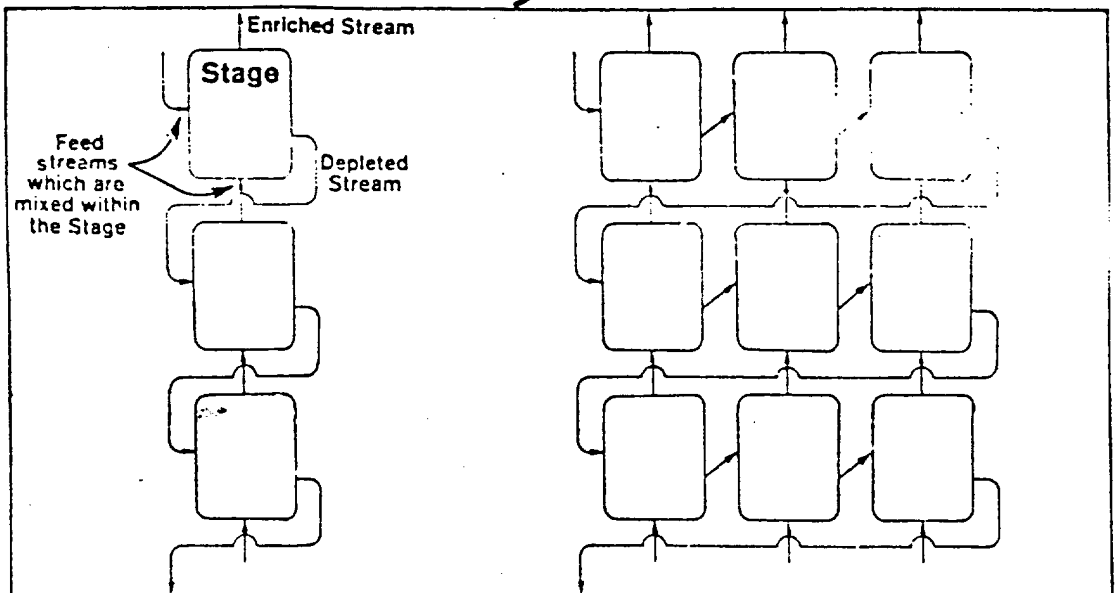
of a small cut creates a higher enrichment factor than would be achieved by the same equipment operating with a cut of 1/2, but it complicates the interconnection of stages in a plant. Figure 2 shows how stages like this may be arranged in a cascade to produce useful levels of enrichment (and to deplete the remaining waste to low U-235 concentration). The appropriate arrangement for stages like Stage 1 of figure 1 is seen to be a complicated cascade with three enriched streams. If the cut were smaller there would be an even greater number of enriched streams.

[redacted]

[redacted]

Roux claimed, in his presentation at the European Nuclear Conference, that the small cut associated with the South African process led to the development of a novel cascade arrangement "based on the principle that an axial flow compressor can simultaneously transmit several streams of differing U-235 concentrations without there being significant mixing between them." He called his cascade technique the "helikon technique." It was developed later than the pilot plant technology and hence is not used at Valindaba. [redacted] Gas entering each section tends to follow a fairly discrete path along the compressor and reemerges with little mixing, compressed and ready to be fed into the next stage. The actual mixing that will occur in the compressor is not known. [redacted]

A module consists of "one set of compressors' (interpreted to mean one compressor carrying several



Cascade 1 – made up of stages like Stage 2. Stage 1 cannot be used in this arrangement if the cut is less than [illegible].

Cascade 2 – made up of stages like Stage 1 operating with a cut of [illegible]. The number of stages in a row would be greater with a smaller cut.

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Figure 2. Two Cascade Techniques

streams) "and one set of separation elements" (which implies that the South African separation unit will also be capable of handling several streams of different U-235 concentration without mixing). Furthermore, according to Roux, a module is not limited to one separation factor of enrichment; a module "can produce various degrees of enrichment up to a maximum of several times the separation factor over the element."[1]

Consideration of this information has resulted in a concept of a South African module, shown in figure 4. The axial compressor and separation unit are built into an integrated unit, perhaps including the heat exchanger that is needed to remove the heat generated by compression of the process gas. The entire module is divided into segments, with physical barriers between the segments wherever possible to limit mixing. For the purpose of illustration, six segments are shown.* Each compressor segment has a high-pressure inlet and a low-pressure inlet, because according to Roux,[1] feed streams are separated into enriched streams that are at 2/3 the original pressure and depleted streams that are at 9/10 the original pressure.

There are certain advantages in such a module. The module could be installed as one group of six stages operating with a cut of 1/7. This system would ameliorate the complicated cascade arrangement required by individual stages operating with cut of 1/7, consistent with Roux's remark that the helikon technique was developed because of the small cut associated with the South African process. Also, a module could be further segmented and operated as several smaller groups of six stages. One size of equipment could then be used throughout the cascade, using multiple groups of small segments where the flow requirements are small and using one group of large segments where the flow requirements are greatest. This would reduce the capital costs involved in building a plant.

THE VALINDABA ENRICHMENT PLANT

[redacted]

*Reports received while this paper was being processed indicated that the modules consist of 19 segments, or stages, and that each operates with a cut of 1/20. This does not significantly alter the assessments made in this paper.

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[redacted]

Enrichment Capability

[redacted]

The equation which predicts the maximum enrichment that normally will be achieved by a fixed number of stages arranged in a simple series is the following:

$$y/(1-y) = (x/(1-x))\, e^{(\psi N/2)}$$

The variables y and x are the U-235 concentrations of the product and waste material, respectively. The quantities ψ and N are the enrichment factor* and number of stages, respectively. The maximum enrichment level, therefore, is related to the U-235 concentration in the waste material and is a function of the enrichment factor and number of stages. Table 1 shows the maximum enrichment levels associated

*The enrichment factor and separation factor differ by 1

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[redacted] with a variety of U-235 waste concentrations and enrichment factor values, for normal operations. [redacted] There is little use, however, for uranium enriched to levels between 4 and 90 percent U-235. [redacted]

[redacted]

Plant Capacity

Several studies of the Valindaba pilot plant conducted in recent years form the basis for calculating the plant capacity, as discussed below.

[redacted]

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[redacted] each requiring 24 tonnes of 3.25-percent-enriched uranium annually.

Operational Status

There is little evidence and much debate concerning the operational status of the Valindaba enrichment plant. In the absence of physical evidence, one must choose among conflicting reports to assess plant operations.

In his April 1975 presentation, Dr. Roux confirmed that "part of the pilot plant together with its associated hydrogen separators and all other ancillary equipment has been successfully brought into operation."[1] [redacted]

The Koeberg nuclear power station near Cape Town will consist of two 925-MWe pressurized-water reactors,

*Based on West German experience with the Becker aerodynamic isotope separation process.

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APPENDIX A

Estimate of Cut and UF_6 Concentration at Valindaba

[redacted]

The cut is defined as the ratio of the enriched flow to the feed flow or, in this estimate, (1 percent of the enriched stream flow rate) /(sum of the enriched and depleted stream flow rates multiplied by the feed concentration of UF_6).

[redacted]

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