The South African nuclear fuel industry: history and prospects

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EXECUTIVE SUMMARY

South Africa possesses the major stages in the nuclear fuel chain, from extraction of uranium, through conversion, enrichment, and fuel fabrication, to a nuclear power station and a waste repository. Most of these processes are controlled by the Atomic Energy Corporation (AEC), except for uranium mining, which falls under the auspices of the Nuclear Fuels Corporation of the Chamber of Mines, and the Koeberg power station, which is owned and operated by Eskom. In the past, the AEC constituted an essential pillar in the Nationalist government's siege economy: it was considered vital to both energy security and military supremacy. As a result, the nuclear establishment received generous state subsidies that peaked at R705m, or 92% of the Department of Mineral and Energy Affairs budget in 1987/8.

The largest share of government funds to the AEC has been used to finance the operation of the Nuclear Fuel Production (NFP) division, which operates the conversion, enrichment and fuel fabrication plants at Pelindaba and Valindaba, as well as the Vaalputs waste repository. Of all the NFP services, only the operation at Vaalputs is breaking even, with a turnover of about R3-4m/yr. The AEC's own figures reveal that the average production costs at the conversion, enrichment (Z), and fabrication (Beva) plants during the period 1988-92 were between ten and twenty times the spot market price during the same period, and this excludes the capital costs of the various plants. The most inefficient and expensive of these processes is the enrichment plant, which requires operating expenditure in the order of R343m/yr with an income of only R67 million. The AEC itself has acknowledged that the Z-plant can never be operated commercially. Arguments as to why the Z-plant should not be closed forthwith are weak, and appear self serving.

Since 1988, the AEC has been supplying nuclear fuel services to Eskom at prices that are between two and four times higher than the spot market prices. This has meant that Eskom has subsidised the AEC to the tune of at least R220m over the period 1988 to 1992. The reasons for this strange procurement policy are not clear. The Nuclear Fuels Corporation (Nufcor) has similarly been obtaining far higher prices for uranium delivered locally, presumably to Eskom, than it has for its exported product. Again, it is not clear what induced Eskom to contract with Nufcor for uranium it could have obtained at much lower prices elsewhere.

The AEC is hoping to become a one-stop nuclear fuel supplier. This intention runs counter to the historical trend in the nuclear fuel market away from one-stop suppliers to traders and brokers. As it is, the global market is overtraded, with prices at all-time lows, large overcapacity and uncertain future demand. The chances of the AEC establishing itself as a reliable, cheap supplier in this market are small, because at present it cannot offer meaningful volumes nor competitive prices. In the long-term, the AEC is pinning its hopes on a new enrichment technology called MLIS. The AEC believes that the new technique can serve as the platform for the AEC's continued functioning in the nuclear fuel market. It is investing about R40m/yr on MLIS R&D, and claims a number of major breakthroughs. However, it is almost impossible to weigh these claims against results achieved elsewhere, since all institutions researching the MLIS or related AVLIS process guard against information being released, for commercial reasons. It seems implausible, though, that the AEC is succeeding where other nuclear corporations with much larger budgets and far more advanced scientific and technological infrastructures are failing to make significant progress. In the US, for example, the AVLIS program is being severely curtailed, after an investment of more than one billion dollars to date.

It is hard to avoid the conclusion that the NFP division presents a major drain on the country's resources. Because of its astronomical production costs, the AEC will never be able to market products from its present operations at competitive prices on the global fuel market. On a macro-level, the situation at present is that the NFP division is being subsidised by the state to the tune of almost R300m/yr, while generating about R10m income from export contracts, and about R80m/yr from contracts with Eskom.

TABLE OF CONTENTS

TABLES AND FIGURES

Chapter One
THE NUCLEAR FUEL CHAIN IN SOUTH AFRICA

The nuclear fuel chain is based on the utilisation of uranium, which occurs naturally as a mixture of the uranium-235 and uranium-238 isotopes (^{235}U and ^{238}U, written as U235 and U238, respectively, for the remainder of this report). Of these two isotopes, it is U235 which serves as the fuel for a nuclear power station (NPS). Natural uranium is mined, and calcined to uranium oxide (U_3O_8, written as U3O8 for the remainder of this report). The solid U3O8 is then *converted* to gaseous UF6, the feedstock for the subsequent *enrichment* step, during which the amount of U235 is increased from its natural abundance of 0.7% to between 3 and 4.5% for use in a NPS. Thereafter, the enriched uranium is *fabricated* into fuel pellets, which are contained in metal rods bundled together into fuel assemblies. After use in a NPS, the spent fuel is removed and stored on site for up to ten years, in order to reduce the amount of radioactivity and to cool the spent fuel to about 300 degrees centigrade prior to further handling. In principle, the spent fuel may be *reprocessed* to extract plutonium and unused U235. In practice, however, most countries are storing their spent fuel pending a solution to the problem of safe, long-term *disposal*.

In South Africa, uranium is produced as a by-product of gold – the last primary uranium mine having closed in 1984 – and is then marketed through the Nuclear Fuels Corporation (Nufcor), which is part of the Chamber of Mines. Most of this uranium is exported as the oxide, but some is sold locally to Eskom and the Atomic Energy Corporation (AEC), and since 1992 Nufcor has also been exporting small amounts of both natural and enriched UF6. Conversion, enrichment, and fabrication processes take place at the AEC's Pelindaba complex west of Pretoria, while disposal occurs at its Vaalputs site near Springbok in the north-western Cape. Eskom owns and operates the NPS at Koeberg, outside Cape Town, and contracts both Nufcor and the AEC for some of its fuel requirements. To this point, all spent fuel from Koeberg has been stored on site, and Eskom has not yet revealed its disposal plans. However, all other nuclear waste has been disposed of at Vaalputs. The Council for Nuclear Safety is responsible for licensing all nuclear transactions and processes, and for overseeing adherence to regulations governing the industry. However, the nuclear Non-Proliferation Treaty and international safeguards agreements are administered by the AEC.

A short historical overview of nuclear development in SA follows, but a more detailed chronology is included as an appendix. South Africa's nuclear involvement began in the 1940s, when the country was asked by the Allies to investigate uranium deposits with a view to supplying the Manhattan atomic bomb project with uranium. By 1950, SA agreed to supply all its uranium product to the US and UK for weapons purposes, and in 1952 the first full-scale uranium extraction plant was opened. In 1967 Nufcor was established when the state ceded all uranium resources back to the private owners. The SA nuclear industry formally came into being with the establishment of the Atomic Energy Board (AEB) on 1 January 1949, and in 1961 the AEB occupied its present site at Pelindaba. Apart from lobbying for the establishment of a local nuclear power program, the AEB was also involved in operating the country's SAFARI research reactor, and in conducting research into enrichment techniques. In 1969 the Cabinet approved funds for a pilot enrichment plant (the so-called Y-plant). A year later the development of an indigenous new enrichment process was announced, and the Uranium Enrichment Corporation (Ucor) was formed. Construction of the Y-plant began in 1971, although it was apparently commissioned only seven years later. Apart from a halt in production between 1979 and 1981, operation continued until 1989. By 1974 the AEB's brief had been expanded into supplying military technology, when the Prime Minister's ad hoc committee decided to construct nuclear weapons using enriched uranium from the Y-plant, and in 1977 the AEB was issued with instructions to meet Eskom's future fuel requirements.

The AEB commenced construction of both its present conversion plant and the 'semi-commercial' enrichment (Z-) plant in 1979, and a year later also started work on the fuel fabrication (BEVA = Brandstof Element Vervaardigings Aanleg) plant. First production from the conversion plant occured in 1986, while the Z- and BEVA plants began production in 1988; in the case of the Z-plant problems were experienced during the commissioning process which stretched over a number of years. The last link in the chain was put in place when the Vaalputs waste repository became functional in 1986, and in the same year the AEC announced plans for a nuclear research facility near the Gouritz river mouth in the southern Cape. At the time it was widely speculated that this facility was to be a reprocessing plant.

The statal nuclear establishment has been restructured a number of times since its inception as the AEB. In 1982, the AEB and Ucor were converted into two companies – the Nuclear Development Corp. (Nucor) and the the Uranium Enrichment Corp., respectively – with the Atomic Energy Corporation (AEC) as their controlling body. This year also saw the establishment of the Council for Nuclear Safety (CNS) within the AEC. The AEC was then further restructured when, in 1985, Nucor and Ucor were amalgamated into the AEC. In 1988 the CNS become fully independent of the AEC.

In 1968 a subcommittee of the AEB reported to the Minister of Mines and Planning that a 350MW NPS would be viable in the Western Cape by 1978. The decision to build the station was pre-empted by Eskom in 1967, when the utility purchased the farm Duynefontein, site of the future NPS. The contracts to construct Koeberg were signed in 1976, and in 1984 – after repairs of considerable damage sustained during an ANC attack on the NPS – the first reactor at Koeberg became operational, with the second following a year later.

Chapter 2
FINANCIAL HISTORY OF THE AEC

2.1 Global figures

Government funding for the AEB/AEC was apportioned under the vote for the department responsible for mines – the Department of Mines (DOM) prior to 1984, and the Department of Mineral and Energy Affairs (DMEA) subsequently. Table 2.1 lists the annual budgets awarded to the AEC (or its forerunners the AEB and Ucor) and the CNS, as well the total DMEA/DOM vote. The tabulated figures are those obtained from parliamentary records (South Africa, *Estimate of Expenditure to be Defrayed from State Revenue Account.* Government Printer, Pretoria, 2nd and final print, RP2 & 4). In some cases, the amounts budgeted for the AEB/AEC by Parliament were subsequently adjusted within the department administering the funds, so that the parliamentary figure is not always the correct one; for those cases where the actual subsidy in any one year differed by more than 5% from that awarded by Parliament, the actual amount is indicated in parentheses. The latter data were obtained from the AEB Annual Reports, published until 1982, and the data for the years since then were supplied by the AEC (Stumpf 1993a). On average, the AEB/AEC's budget differed by a factor of 1.006 from that awarded by Parliament over the period 1971-93. Because the figures differ so little, Figure 2.1 plots the parliamentary budgets, rather than the AEB/AEC data.

Table 2.1 Annual nuclear and total DOM/DMEA vote. Figures are in Rm.

Year	AEC/AEB	UCOR	CNS	Total	DMEA/DoM	% of DMEA
1971/2	6.390			6.390	39.938	16
1972/3	6.709			6.709	38.605	17
1973/4	8.762			8.762	43.992	20
1974/5	15.978			15.978	82.909	19
1975/6	17.174	51.000		68.174	123.093	55
1976/7	18.603	50.000		68.603	159.647	43
1977/8	19.987	43.000		62.987	168.001	37
1978/9	22.925	67.481		90.406	191.998	47
1979/80	32.400 (33.951)	99.895		132.295 (133.846)	404.828	33 (33)
1980/1	57.060 (59.790)	142.300		199.360 (202.090)	431.085	46 (47)
1981/2	76.835	173.400		250.235	385.634	65
1982/3	114.958	200.600		315.558	477.645	66
1983/4	352.921		0.075	352.996	534.967	66
1984/5	370.000 (351.305)		0.075	370.075 (351.380)	557.637	66 (63)
1985/6	525.878		0.123	526.001	627.553	84
1986/7	775.504 (659.970)		0.179	775.683 (660.149)	871.484	89 (76)

Year	AEC/AEB	UCOR	CNS	Total	DMEA/DoM	% of DMEA
1987/8	671.146 (705.646)		0.183	671.329 (705.829)	768.462	87 (92)
1988/9	619.018		0.180	619.198	745.831	83
1989/90	640.000		5.200	645.200	786.816	82
1990/1	712.700 (673.500)		6.653	719.353 (680.153)	1 133.610	63 (59)
1991/2	685.000		6.966	691.966	896.092	77
1992/3	451.958		5.089	457.047	687.205	67
1993/4	469.096		5.398	474.494	707.606	67

Note: Total government grant includes interest and redemption on state guaranteed loans.

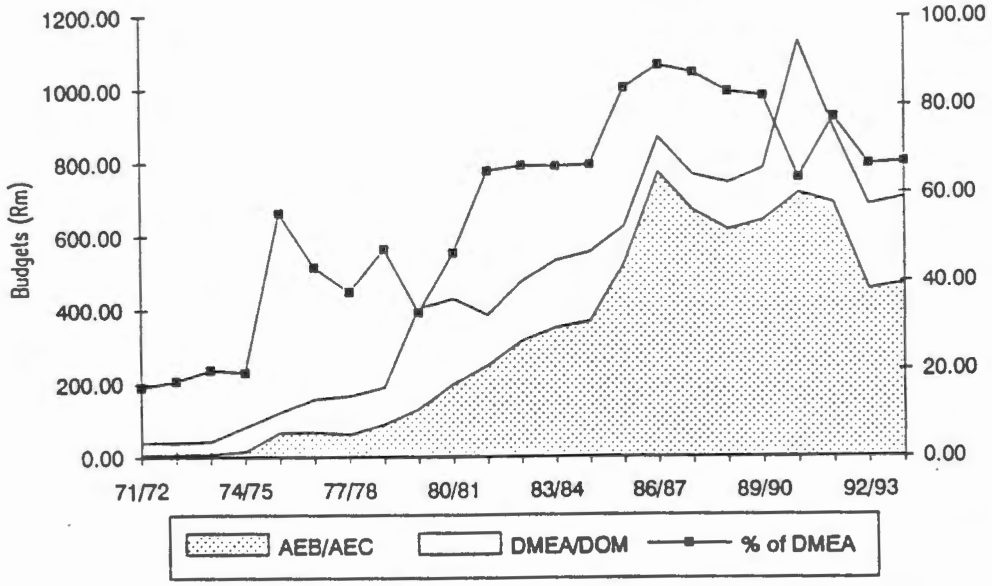

FIGURE 2.1 Annual nuclear budgets and total DOM/DMEA vote.

The data in Table 2.1 and Figure 2.1 reveal five phases in the AEB/AEC's financial fortunes: in the early years, the AEB's portion of the budget was less than 20%, but in the 1975/6 financial year it shot up to 55%, remaining above 33% until 1981/2. The budget then received a second boost and hovered in the region of 66% for four years, before rising again, this time to between 85 and 90% in the years 1985/6 to 1989/90. The proportion then dropped slightly, to around 66%, where it is still located in the current year. Figure 2.2 illustrates the actual budgets, both in current rands, and in 1993 rands adjusted for inflation at rates of 12%/yr for the period 1985-93, and 10%yr for 1970-93.

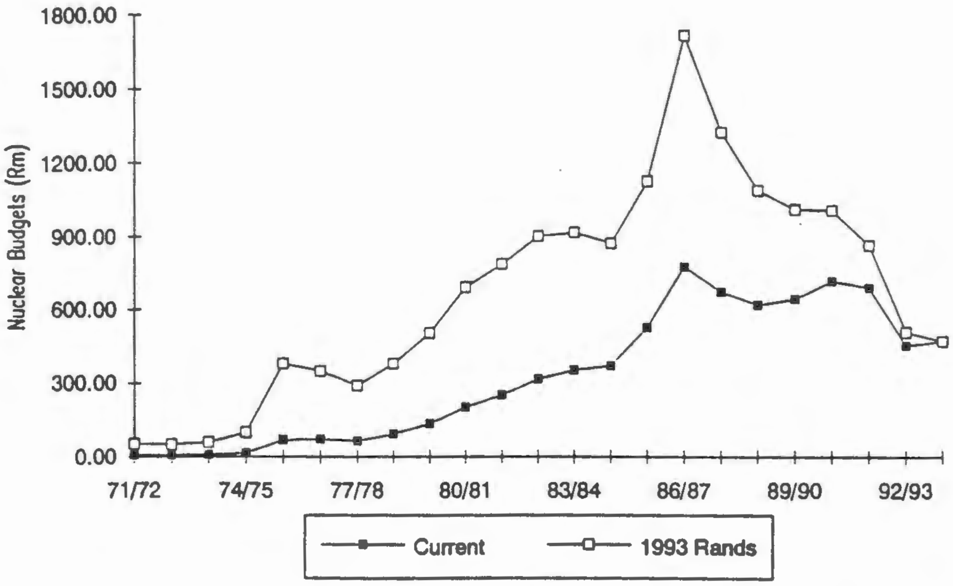

FIGURE 2..2 Annual budgets, in current rands and adjusted for inflation.

Table 2.2 gives a breakdown of how the AEC has apportioned its funds. The table shows how operating expenditure rose dramatically following the 1987/88 financial year, while capital expenditure decreased. These changes are related to the completion of capital works on the Z- and BEVA plants, and the beginning of operations. As will be shown later, the Z-plant, in particular, is responsible for considerable operating expense.

Table 2.2 AEC Application of funds. Figures are in Rm. Opex = Operating expenditure, Capex = Capital expenditure, and Interest = payment to loans, bridging finance and interest (Source: Stumpf 1993a).

Year	Opex	Capex	Interest
83/84	250.345	171.293	62.628
84/85	320.313	258.988	83.960
85/86	359.501	194.191	138.467
86/87	421.162	132.647	139.368
87/88	384.897	121.215	175.987
88/89	576.805	22.438	237.775
89/90	592.104	40.695	185.390
90/91	602.505	28.181	389.313
91/92	566.971	10.163	217.836
92/93	556.833	20.690	119.244
93/94	551.155	39.647	169.472

Finally, the AEC projects further state support as follows (figures in Rm) (Stumpf 1993a):

94/95	95/96	96/97	97/98
536.843	460.769	271.233	399.947

2.2 Divisional figures

The AEC has seven Executive General Managers, each responsible for one division. Operating expenditure (Opex) is spread essentially over these divisions: Corporate Business Development, Nuclear Fuel Production (NFP), Pelindaba Technology Products (PTP), Human Resources, Technical Services, Finance and Corporate Services, and Technology Development. In addition, the office of the Chief Executive has its own budget. By far the largest slice of Opex is consumed by the NFP division, which is responsible for operating the conversion, Z- and BEVA plants, as well as the Vaalputs facility. The next largest slice of overall Opex goes to the Technology Development section, formerly the R&D section, whose brief it is to establish new technologies and to create new products and processes. Table 2.3 lists the proportion of overall Opex that has gone to the NFP, PTP and Technology Development (TechDev) sections since their establishments as separate divisions within the AEC.

The NFP division generates the largest income for the AEC, with further income coming from the sale of non-nuclear fuel products such as air filters, flourine chemicals, and radioisotopes through the PTP section, formerly called Peltek. Table 2.4 lists the income generated by the NFP and PTP divisions.

Table 2.3 Breakdown of operating expenditure. Figures are in Rm.

Year	Total Opex	NFP Opex	%	TechDev Opex	%	PTP Opex	%
88/89	576.805	332.699	58	60.942	11		
89/90	592.104	325.867	55	73.403	12		
90/91	602.505	287.207	48	79.537	13		
91/92	566.971	285.378	50	81.527	14		
92/93	556.833	253.421	46	80.191	14	82.833	15
93/94	558.570	253.343	45	84.581	15	72.732	13
94/95	579.622	251.822	43	85.643	15	87.921	15
95/96	594.446	248.676	42	87.657	15	98.521	17
96/97	497.370	161.161	32	64.758	13	106.112	21
97/98	498.964	138.517	28	66.529	13	114.290	23

Table 2.4 Breakdown of own income. Figures are in Rm.

Year	Total sales	NFP sales	%	PTP sales	%
88/89	111.278	60.514	54	50.764	46
89/90	177.643	106.234	60	71.409	40
90/91	146.564	90.391	62	56.173	38
91/92	172.156	93.967	55	78.189	45
92/93	192.821	101.969	53	90.852	47
93/94	217.592	108.004	50	109.588	50
94/95	276.980	129.842	47	147.138	53
95/96	320.631	132.654	41	187.977	59
96/97	320.329	47.096	15	273.233	85
97/98	364.269	51.917	14	312.352	86

A comparison of Tables 2.3 and 2.4 demonstrates that the NFP division is not expected to break even during the period for which projections were supplied. At the same time, however, the AEC's projections indicate that the sale of non-nuclear fuel products will be profitable, generating more income than the operating expenditure which the PTP division will consume. The latter part of this report will deal exclusively with the NFP division and its plans for the future, as well as those aspects of the Technology Development division that relate to the nuclear fuel industry.

Chapter 3
PROSPECTS FOR THE NUCLEAR FUEL INDUSTRY

3.1 Introduction: The MLIS peg

As the cursory examination of the Opex:Income situation for the NFP division in Tables 2.3 and 2.4 has demonstrated, this section of the AEC is currently operating at a loss, and is likely to continue doing so for the foreseeable future. As will be shown later in this report, the only NFP service that is returning a profit is the Vaalputs facility; all other services – conversion, enrichment, and fabrication – are very uneconomic, and it is debatable whether they could ever be operated on a commercial basis. Nonetheless, the division is pegging its hopes for a future in the nuclear fuels industry on the successful development of yet another enrichment process, called the Molecular Laser Isotope Separation (MLIS) technique. The Technology Development division is responsible for implementing the R&D program into MLIS enrichment, and is devoting about R30-40m/yr to the project, out of its budget of R80m/yr. Because of the centrality of this MLIS program to the AEC's plans to remain in the nuclear fuels business, this aspect will be discussed first.

3.2 An overview of enrichment technologies

Enrichment technologies can be divided into two broad types depending on the atomic processes they employ: those that utilise the 1.3% difference in mass between U235 and U238 atoms (mass action processes), and those that utilize the differences in the electronic energies of the two types of atom (quantum processes). Currently only technologies based on mass action processes are in use, but many enrichment corporations believe that it is merely a matter of time before most of these are replaced by newer and more efficient technologies that employ quantum processes instead. Mass action-based technologies include diffusion and centrifuge methods, as well as the avowedly indigenous jet nozzle (Helikon) method. About 90% of global enriched uranium is produced in government-owned diffusion plants in the US, France, and Russia, while the remaining 10% originate from privately-owned gas centrifuge plants in Holland, the UK, and Germany. Of these two processes, the centrifuge method is by far the more efficient, and while diffusion plants look set to make way for new technologies over the next decade, the operators of the centrifuge plants do not intend changing to quantum process-based technologies.

Quantum process technologies under investigation are the AVLIS (Atomic Vapor Laser Isotope Separation), MLIS (Molecular Laser Isotope Separation), and CRISLA (Chemical Reaction by Isotope Selective Activition) methods. Early commercial deployment does not seem feasible for either of these. Before giving a brief overview of these proposed new enrichment technologies, some basic terminology and concepts need to be introduced.

The rate at which an enrichment facility performs a separation of U235 and U238 is measured in Separative Work Units (SWU); this is essentially a measure of the amount of work that needs to be done in order to enrich natural uranium – containing 0.71% U235 – to a certain higher percentage of U235. About 5 SWU and 6kg of natural U3O8 are required to produce 1kg of 3.4% enriched uranium, but both of these quantities depend quite strongly on the amount of U235 that is left in the tailings from the enrichment process (the 'tails assay').

A very important parameter in determining the efficiency (and profitability) of an enrichment process is the amount of energy consumed to produce one SWU.

The following table gives the approximate energy consumption for the various technologies (Eerkens 1989):

Becker nozzle:	3000 kWhr/SWU
Diffusion:	2500 "
Centrifuge:	50 "
AVLIS:	40 "
MLIS:	30 "
CRISLA:	10 "

As can be seen, diffusion technology and the local method – which is equated with the German Becker technique in the article from which these data were obtained – are orders of magnitude less efficient than the centrifuge process, which, by comparison, is about as energy-intensive as the quantum processes. The data presented above are only averaged data that are intended to give an indication of the difference in efficiency between the methods, and the actual quantities might differ from plant to plant. In addition, since this is a very important operating and price parameter, the energy-intensivity is generally not made public by plant operators. However, in the case of South Africa's semi-commercial enrichment plant, figures published by the AEC in its 1990 Review suggest a consumption of 9200 kWhr/SWU on a design efficiency of 5800 kWhr/SWU, way above the published average figures.

3.2.1 Quantum-based technologies

Laser-based enrichment methods

These techniques use the variations in the spectra of U235 and U238 feedstock material to separate the isotopes. There are essentially two competing methods: the atomic vapor laser isotope separation technique (AVLIS), and the molecular laser isotope separation method (MLIS). The two techniques are significantly different, and demand solutions to quite different sets of technological hurdles. In the AVLIS method uranium metal is vaporized and atomized, and the U235 atoms selectively excited and ionized by lasers operating at specific excitation frequencies of the U235 atom, as opposed to those of the U238. After ionization, U235 atoms can be separated from U238 by electromagnetic means. Problems associated with the technique are that it is based on uranium metal, which implies a change from the usual enrichment feedstock (UF6) of the nuclear fuel chain, and the need for materials that are capable of resisting corrosion with gaseous uranium at around 2200 degrees Celsius.

In MLIS the feed material is UF6 vapor, with ^{235}UF6 molecules being selectively ionized and subsequently dissociated into UF5, which is formed as a solid and can easily be separated from the gaseous feed. The major hurdle here is the complexity of the molecular spectrum of UF6 which considerably complicates the choice of excitation frequency; in AVLIS, on the other hand, there is a well-defined isotope shift in the spectra of U235 and U238. Research suggests that both techniques are able to enrich to nuclear power plant levels in one step, but the separation factor (ie, the efficiency) for AVLIS is much higher than for MLIS. In addition, the high-power copper lasers used in AVLIS are commercially available, whereas the carbon dioxide laser needed for MLIS is at an earlier development stage. These factors, coupled to the more complex nature of the selective excitation process for MLIS, have presumably militated against the choice of MLIS technology in the US, UK, France and Japan, where AVLIS was chosen instead; in Holland both AVLIS and MLIS are being studied, while in Germany the focus is on MLIS (Clark & Addington-Lee 1989: 42-4). (Perhaps the close cooperation between the German and South African nuclear industries that has existed in the past, has played a role in persuading the AEC to opt for MLIS.) Basic research on MLIS began in SA in 1983.

The US and France were hoping to have pilot laser-enrichment plants in operation by the mid 1990s, and commercial plants by about the turn of the century. However, after eight years of advanced R&D efforts in AVLIS technology, and an investment of more than one billion dollars by the US Department of Energy (DOE), even the most optimistic forecasts do not see this technology being ready for commercial exploitation before 2005 (Meade & Schwartz 1992: 56-8). One independent assessment (by Energy Resources International) of the commercial viability of an AVLIS plant in the US determined that in order to merely recover all R&D and construction costs, a 9 million SWU/yr plant would require prices of $130/SWU, while a smaller 3 million SWU/yr plant would need a price of $282/SWU (Meade & Addington-Lee 1992). In another study, the Edison Electric Institute found that production costs could well be much higher than $74/SWU (NEI 6/91: 2). These estimates should be compared to the DOE's projected production costs of between $25 and $37/SWU (NEI 3/90: 4; NEI 6/91: 2), and to the current spot market price of about $68/SWU.

In the face of such cost escalations, the DOE is now expecting either private investors or a restructured government enrichment corporation to deploy a commercial AVLIS plant. NEI sardonically comments that 'the financial risks would appear to make such an undertaking by either sector unlikely', in light of the present situation in the international nuclear fuel market (Meade & Schwartz 1992). In response to such gloomy prospects, the DOE has severely curtailed the AVLIS budget, and has redistributed the R&D costs accrued (one billion dollars) into the operation of its gaseous diffusion plants. (This may be one of the factors for the high enrichment prices that the DOE is charging; see Section 3.4.1.)

Chemical methods

In laser enrichment methods the energy for the separation of U235 from U238 is derived from industrial-scale lasers, while in the centrifuge and diffusion techniques it is supplied by electrical power which drives the pumps, compressors, and rotating machinery that bring about the separation. In the Chemical Reaction by Isotope Selective Activation (CRISLA) method, the energy for this separation is mainly chemical. Here a laser, tuned to specifically excite $^{235}UF_6$, catalyses a reaction between this molecule and a co-reactant, to produce a chemical species that can then be separated from $^{238}UF_6$ by normal chemical means. The energy needed to activate the reaction is much less than that needed to ionize uranium atoms (AVLIS) or UF6 molecules (MLIS), giving CRISLA a competitive edge on the other methods (Eerkens 1989).

Until April 1993, the CRISLA method was being developed in a cooperative R&D effort by US and Canadian private corporations, who had planned to have a modular plant with a capacity of 250 000 SWU in operation by the mid 1990s. Since then, however, the Canadian partner – Cameco Corp. – decided to terminate its joint project. One reason given was that the surplus of enriched uranium from the CIS had 'significantly' changed the enrichment market, so that the opportunity Cameco saw when it entered the joint venture 'has diminished in the near term' (*NF* 12/4/93: 4).

3.2.2 The future

Although diffusion technology is extremely inefficient, diffusion plants produce about 90% of global enriched uranium, with the more efficient centrifuge enrichment method supplying the balance. Apart from the US's $1 billion AVLIS R&D program which has recently been cut back, research into new enrichment technologies has been fairly modest in budgetary terms, and it is therefore impossible to say at this stage how they might compete against present technology, in particular against centrifuge methodology. Indeed, Urenco – the Dutch, German, and British conglomerate which operates centrifuge plants in Europe – is so confident of the commercial viability of its technology, that it is participating in a venture to construct a 1.5 million SWU/yr plant in Louisiana and is expanding its Almelo plant in Holland.

Even if new enrichment technologies such as AVLIS or MLIS are developed to the point where they are commercially viable, it would be some time before they could supplant significant amounts of production from existing diffusion and centrifuge plants, owing to long lead-times in construction. In the interim, diffusion plants would not be shut down, even if their continued operation is economically unfeasible, because enrichment has always constituted a strategic service – and will continue to be regarded as such, notwithstanding the end of the Cold War. Undertakings to introduce new technologies would therefore face considerable political and financial obstacles, and it may well be that these factors – as much as technological difficulties – have militated against greater R&D efforts into these new technologies.

3.3 The South African MLIS program

In 1983 the AEC embarked on a research program into laser separation technologies. The MLIS method was chosen above AVLIS largely because of the experience with UF6-handling technologies and aerodynamics, gained from the local aerodynamic enrichment process. For a long time this program was run in parallel with research into centrifuge methods, but in 1986 a decision was taken to concentrate on the development of a pilot MLIS plant, and 1991 the centrifuge research was closed down. The AEC is unwilling to release details of its investment in MLIS research thus far, but it is widely believed that the annual budget is about R40m (in 1993 rands), and the total investment not more than R250-300m. In fact, the AEC prides itself on having spent relatively little on the program, while having achieved considerable successes.

The AEC claims four major breakthroughs in its MLIS research. The first concerns the design of a very efficient nozzle (a variant of the Laval nozzle) that allows extremely rapid cooling over fairly long distances of the incoming UF6 stream. (When irradiating the UF6 molecules, it is essential that they are at very low energy levels, which means temperatures have to be extremely low, of the order of -173 degrees centigrade. Ordinary refrigeration methods are insufficient and far too inefficient for this process, and so instantaneous expansion of the gas into a vacuum is used to cool the feed.) In addition, the AEC claims to have developed the first industrial-scale carbon dioxide laser; this is another crucial aspect of the MLIS method, since commercial MLIS enrichment plants would require massive lasers for the supply of sufficient energy to large-scale UF6 streams. Thirdly, it claims to have developed the first industrial-scale Raman cell, which retunes the laser's frequency to the exact frequency for irradiation of the ^{235}UF6 molecules. Lastly, the AEC claimed recently to have achieved a single-step enrichment process up to about 4% U235 on a macro scale (Stumpf 1993b) This would bring it approximately in line with the reputed efficiency of the AVLIS process.

The pilot plant facilities developed thus far, and the AEC's claims about its successes may well appear impressive to outsiders. But it is not possible to make an independent assessment of the true state of the technology in this program, since the AEC jealously guards what it views as proprietary information. This reluctance to divulge details about the MLIS program is, of course, not unique to the AEC; it is shared by all other bodies involved in research into new or improved enrichment technologies. This also means that even if it were possible to examine the AEC claims, there would be no yardstick to measure them by.

Emboldened by its success, the AEC embarked in 1991 on the construction of the pilot MLIS plant due for completion in 1995. Although it will have a nominal capacity of 20 000SWU/yr, the plant will be operated continuously for short periods only. It is intended that the pilot plant will supply the data that are necessary for evaluating the feasibility of a commercial MLIS undertaking in 1995. However, the AEC's phrasing of the purpose of the pilot plant ('to *confirm* the operating parameters on plant scale'), suggests that a decision about the feasibility may already have been made on the basis of operating experience gained in the MLIS R&D program thus far (du Toit, Ronander & Birkill 1993). In the event of positive results from the pilot plant, the intention was to begin construction of a commercial plant in 1996, subject to an outside investor being found. This plan has in the meantime been postponed by a few years because of uncertainty in a number of variables, particularly the potential source of funds (Stumpf 1993b). It seems that the earlier insistence on private sector financing has been relaxed somewhat, since the AEC now does not believe 'that the Government should *necessarily* fund such a commercial plant' (Stumpf 1993b).

Given a 10 year lifespan for the commercial MLIS plant and real capital costs of between 6 and 12%, the AEC conservatively estimates that a plant with a capacity of 400-500tSWU/yr and a specific energy consumption of about 150kWhr/SWU should produce SWU at a price of US$60 per unit (du Toit, Ronander & Birkill 1993) – even though the projected energy intensity does not compare favourably with the averaged figures presented earlier. If the AEC's predictions were fulfilled despite the apparently high energy requirements of the plant, it would certainly make the plant highly competitive, considering the current spot market price of about $68/SWU. However, in the case of the DOE's cost projections for its AVLIS process (see above), the economic models on which the predictions were based were found to be seriously flawed by independent evaluators, and it is possible that the local models may also exhibit flaws on closer analysis. (The AEC has indicated a willingness to open its models to independent scrutiny.)

As mentioned before, an objective evaluation of the prospects for the AEC's MLIS technology would be extremely difficult to perform, owing to the (perhaps necessary) commercial secrecy surrounding it. It may be possible to evaluate certain aspects – such as the laser and Raman cell performance – against industry benchmarks, if the AEC were to make benchmark data available. But even if individual components are truely competitive, this by no means implies that the process in its entirety would be so. Moreover, as was argued above, there is no guarantee that new enrichment technologies would be able to break into the market, even though they may be far more efficient than diffusion or even centrifuge plants, since for strategic reasons governments are unlikely to let their enrichment plants be mothballed by simple economic rationale. On face value alone, it seems implausible that with an outlay not exceeding US$100m the AEC could have produced a technology that rivals or outdoes its AVLIS and MLIS competitors in other countries with scientific and technological infrastructures far more advanced than those in this country, and R&D budgets many orders of magnitude greater. In this regard, it should perhaps not be forgotten that in the early 1970s the AEB made similar claims to having developed a new, economically viable enrichment technique entirely on its own – a process that we now know to be wholly unviable.

3.4 The international nuclear fuel market

3.4.1 Historic overview and present situation

Scale of market

In order to give some perspective to the discussion of the global uranium and nuclear fuels market, it is useful to gain an appreciation of the average annual consumption of these products by a typical late-generation nuclear power station: an average 900MW pressurized water reactor, of the type situated at Koeberg, operated at 65% capacity and fueled by 3.25% enriched uranium requires about 150t/yr of U3O8, equivalent to 127t uranium, about 16tU/yr low enriched uranium, and approximately 80 000SWU/yr of separative work (du Toit 1993). In 1991 total uranium demand in the West was 47 000tU, of which 42 000t were procured on the market. Those countries previously classified as the World Outside the Centrally Planned Areas (WOCA) produced 27 000t. (Western and 'Eastern' nuclear industries were largely separate until 1990, and so most historical data refer only to the Western uranium market.) Table 3.1 gives a breakdown of the global uranium market in 1989, listing total output, total existing production capacity, mothballed capacity, and capacity that is planned or under construction. In terms of active or passive capacity little has changed since then, and it is true to say that for all stages of the fuel chain, supply and/or capacity outstrip present demand.

Table 3.1 World nuclear fuel market. Summary of data from the *Fuel Review 1991, Nuclear Engineering International* (NEI), and the *1991 Report* and *1992 Update* from the Uranium Institute (UI). Figures given in parentheses refer to global totals, those without parentheses to WOCA countries only.

	1989 output	production capacity	mothballed	on drawing board
U3O8 (ktU)	34.215 (UI) (50.575)	57.200 (NEI)	23.820 (NEI)	6.530 (NEI)
Conversion (ktU)	54.000 (UI) (65000)	97.242 (NEI) (67.390) (UI)		0.300 (NEI)
Enrichment (ktSWU)	24.00[a]	33.30 (NEI&UI) (43.3)	8.35 (NEI)	1.61 (NEI)
Fabrication (ktU)	9.000 (UI)	14.119 (NEI) 10.280 (UI) (14.819) (NEI)	0.616 (NEI)	4.637 (NEI)

[a] Rough estimate from *Nuclear Energy* 1990, v29(4).

Overview

The international uranium and nuclear fuels market has undergone a metamorphosis since the early days of commercial nuclear power in the 1970s. In those days utilities invariably took out long-term supply contracts at specified prices, often with the suppliers of their NPSs, who in turn usually dealt directly with primary producers. Hardly any spot markets for nuclear fuel products and very few intermediate traders existed. Today, a major portion of transactions takes place on the spot market, contracts are for shorter terms often linked to spot and without floor prices, and the traditional suppliers of nuclear fuel products now compete with traders, some of whom can offer a much larger menu of products and terms than primary suppliers. For example, in the period 1987 to 1990 the level of spot market activities increased from about 4 000tU/yr to about 16 000t/yr in 1990 (Neff 1991: 11-15). Of the latter about 10 000t were sold by traders, 5 000t by producers, and the balance by utilities, with an additional amount of about 9 000t delivered at spot market price under long-term spot-linked contracts. These volumes should be compared to the amount of 38 000tU procured during 1990, and a total requirement of 43 000t; that is, about 66% of total trade, and 58%

of total requirements were obtained from the spot market, or under prices linked to spot, and 12% (5 000tU) were met from inventory.

These changes in market structure have been accompanied by a steady decline in the price of uranium since it reached its highest point in 1977 at about $208/kg U3O8 (in 1992 dollars), with prices currently as low as $19/kg. As a consequence of this decline, trading in uranium assets at spot market-related prices has almost always resulted in negative returns, with the exception of the late 1970s, when positive returns were recorded if assets were bought early in the decade and sold within a few years. An analysis of price performance by market analyst Thomas L. Neff (Massachusetts Institute of Technology) has shown that it has not been possible to earn a positive real return since 1976 if assets were held for three years or more, and spot-based transactions were engaged in: the average three-year return in the period 1980-1990 was -13.5% with a standard variation of 7.3. However, for shorter holding times there have been brief periods when it was possible to earn a positive return, with the average one-year return being -12.3% and a large standard deviation of 18.5 (Neff 1991).

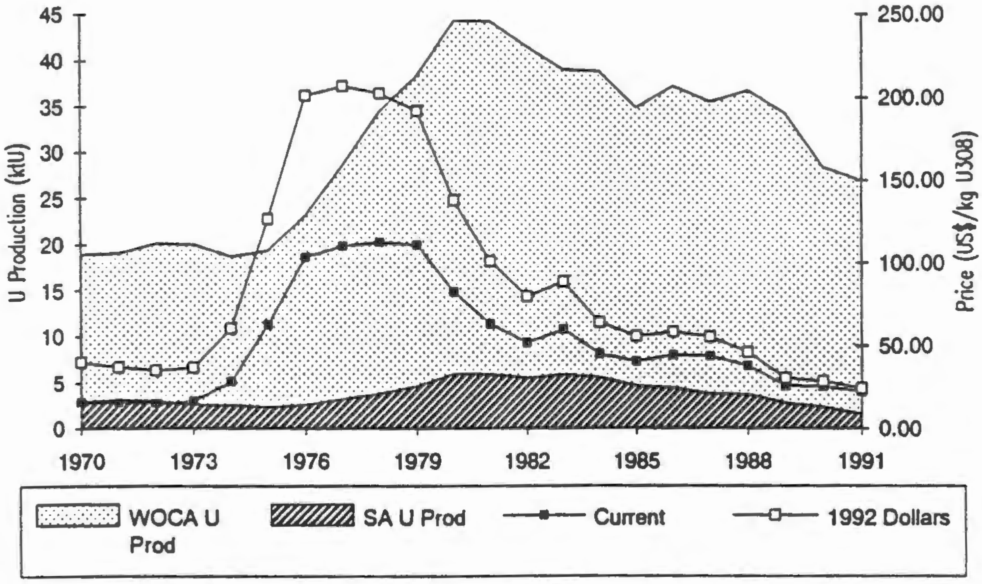

FIGURE 3.1 South African and WOCA uranium production. Data for the period 1970 to 1991, as a function of current price, and price adjusted for inflation (in US$/kg U3O8). (Source: Uranium Institute 1993.)

In fact, apart from a short boom period between late 1974 and 1981, the price of U3O8 has remained below $75/kg (in 1992 dollars) for most of the past quarter century, and one could argue that the boom was an aberration of the market brought about by a specific and unusual confluence of events. Several factors played a role, including the Arab oil embargo of 1973, a depletion of uranium inventories held by the major producers, and an increase in the tails assay allowed by the US government – which means that more ore has to be used in order to manufacture a given quantity of uranium oxide. In addition, there have been allegations that a cartel of the major uranium producers – represented by companies in Canada, France, South Africa, Australia and the UK – conspired to drive up the market price, with the connivance of their governments. These allegations arose out of a number of anti-trust suits tabled in US courts which were never publicly resolved, since they were all settled out-of-court (Moss 1981 ch 8). Interestingly, until 1993 South Africa's Nuclear Energy Act prohibited dissemination by *anyone* of *any* information relating to *any* uranium transactions, 'whether in or outside the Republic', during the period 1 January 1972 to 31 December 1975.

The development of a spot market and the decline in uranium prices, has also been linked to an oversupply of uranium and other nuclear fuel products on the market. Prices started dropping when global inventories of uranium built up during a period of high prices in the 1970s, began to be sold, partially as a response to a slower than expected growth in nuclear power programs. Inventories were originally built up in anticipation of a major NPS construction phase. This was not realised, however, as a result of a downturn in political and popular support for nuclear power, a slower rate of increase in electricity demand than had been expected, and increasingly unclear economic benefits. As pressure to reduce the costs of nuclear power began to mount in the 1980s, so utilities began to sell off inventories. At the same time they began taking advantage of the greater flexibility of the emerging spot market, by unbundling nuclear fuel into its component parts, in order to have greater control of their fuel procurement schedules and practices. This diversification of supply further stimulated the emergence of the spot market.

Although supply of uranium outstrips demand, production currently lags behind. Since 1987 demand has been bigger than production, and has been partially fed from inventory. However, these inventories are large, since total WOCA uranium production up to 1991 was 1016ktU, while total requirements during that time were only 591ktU (*UI* 1992). In other words, total Western overproduction corresponds to requirements over nine or ten years at current levels, though it is not clear what proportion of this surplus is avaliable to the market. It must be mentioned here too, that these estimates of inventory refer only to uranium produced for civilian use (Uranium Institute maintains only records of uranium mined for civilian purposes), and do not reflect amounts that might become available through dismantling of nuclear weapons. These amounts may be vast, since most uranium mined prior to 1970 was channeled into weapons programs. The case of ex-Soviet highly enriched uranium from weapons sources, for example, will be discussed in more detail later.

The changed market structure has brought about substantial changes in price formation. Instead of being determined by production costs, the level and direction of price are today set in a trading-dominated spot market environment, in which the role of the traditional supplier has been supplanted by the increasing predominance of traders as purchasers and intermediates, and which is fueled by inventory liquidation and ex-Soviet and other non-traditional supply sources. Utilities act as traders, converters as brokers, brokers as traders, producers as buyers, and so on; de-enrichment, de-conversion, loans, swaps, interchanges, and other new kinds of transactions have proliferated and bedevilled the process of price formation. (For instance, the decline in U3O8 spot price from about $50/kg in 1987 to less than $26/kg in 1990, was inversely correlated with the increase in spot activity (Neff 1991).) These changes suggest that nuclear fuel is taking on the attributes of a commodity market. And even in cases where utilities do still take out long-term contracts, these are more often than not linked to spot prices – without floor price provisions – creating the same market impact as if a series of spot purchases were being made. With the entry into the market of large amounts of ex-Soviet uranium and nuclear fuel products, the influence of production costs on price formation is likely to be reduced even further, since in the case of the CIS states, those costs are only quantifiable with great difficulty, if at all, owing to a combination of inadequate accounting methodologies and restrictive disclosure practices. In addition, most of these supplies will be marketed through traders, thereby further distancing production from the market.

The general malaise that has developed in the global U3O8 market has also infected the enrichment market, whose size is of the order of US$ 3 to 4 billion per annum (*Nuclear Energy* 1990, 29(4): 229). At present there is overcapacity with about 33m SWU/yr capacity compared to 24m SWU/yr demand; this situation is compounded when mothballed US and UK capacity (about 8m SWU/yr) and active Russian capacity (conservatively estimated at 10m SWU/yr) are included (Nuclear Energy 1990, 29(4)). In addition, an expansion of capacity by at least 1.6m SWU/yr is planned for the next five years, which would mean that global capacity would outstrip present demand by a factor of at least two in the late 1990s (Quinn 1990: 29-32) – though some of the plants at that stage may require large subsidies in order to compete on the market. In addition, the spot price per SWU has dropped from about $105 in 1986 to $65 in 1993 (both in 1993 dollars). This decline in the market has occurred even though investment in enrichment capacity has almost always, because of its importance in the manufacture of nuclear weapons, been politically motivated – and has therefore not been subject to economic rationale.

Until the early nineties, the SWU market was dominated by the US Department of Energy (DOE) and the French enrichment corporation Eurodif, whose marketing is controlled by Cogema, the French nuclear fuel organisation. Together they accounted for about 90% of WOCA production, with Urenco – a German, Dutch, and British consortium – producing the balance. Since then, the Russian export agency for nuclear products, Techsnabexport (TENEX), has entered the market and is fast becoming the lowest-cost producer and supplier, thereby increasing the downward pressure on prices to an even greater extent. This intervention has reduced the US DOE's market share, and in response there have been moves to privatise the facility in the hope of enabling it to respond to market trends and demands more quickly. On July 1, 1993, the US DOE enrichment services were transformed into a government corporation as an intermediate step towards full commercialisation, and in its first month the new US Enrichment Corporation (USEC) offered SWU at slightly over $100/SWU, while spot price was around $70. Whether or not USEC will be able to compete with spot prices is not clear, though the DOE is certainly buffeting the corporation against real costs: in terms of the legislation setting it up, USEC will lease two plants from the DOE (at a cost of $5.19m), while a wide range of environmental, safety, and personnel liabilities – that would otherwise raise USEC's costs – are to remain with the DOE.

The pattern of depressed prices, overcapacity, large inventory, and vigorous competition described above for the U3O8 and enrichment markets, also holds for the conversion and fuel fabrication markets. In the US, for example, expected demand for fuel fabrication services for the next ten years lies at 2000tU/yr, while capacity is estimated to be in excess of 4000tU/yr (Schwartz 1990: 19-20.) In summary, it can be said that the present state of the nuclear fuel market is a utility manager's dream and a nuclear fuel producer's nightmare.

3.4.2 The role of Eastern Europe and the CIS

Without a doubt, the two most destabilising factors in the global uranium and nuclear fuel market are the unknown size of the Russian uranium inventory, and uncertainty regarding the costs of its enrichment capacity – which means that Russian SWU prices cannot be anticipated by other market competitors. Little is known about the Eastern European (EE) nuclear industry, because it has historically been fairly separate from that in the West. None of the EE countries developed their own nuclear fuel chain; instead they had to deliver all uranium mined to the Soviet Union (specifically Russia), which then supplied all nuclear technology and plant. Spent reactor fuel also had to be returned to the Soviet Union. Trade between market economies and centrally planned ones was fairly limited until the late 1980s, even though TENEX first appeared on the primary enrichment market in the early 1970s. It entered the spot market in 1986, and in 1990 the USSR for the first time allowed the sale of concentrates and enriched uranium product (EUP). (EUP is low enriched uranium, ready for fabrication into reactor fuel; its cost includes the cost of U3O8, conversion, and enrichment services.) Even though Russia and the CIS states have been in the spot market for just three years, they have already made a considerable impact, and are set to gain larger market shares in the future.

The likely CIS – and specifically Russian – impact on the market is linked to the size of its accumulated uranium reserves, which are not known with any degree of accuracy. However, the authoritative German nuclear trading company NUKEM estimates that about 600ktU was produced in EE between 1945-90, of which 100kt went into power production, about 200kt to the weapons program, leaving a stockpile of around 200ktU (Schreiber 1991: 7-11). The trade journal, *NF* conservatively estimates that at least 385ktU were produced up to 1990, of which about 200kt have been stockpiled (Knapic & Dizard 1993a: 1-3), while the Uranium Institute estimates the stockpile to be 140-160ktU (*UI* 1991). In other words, the range of estimates of CIS stock is 140-200ktU. It is not known in what form the inventory is held, but TENEX is aggressively marketing its products abroad, and it can supply large amounts quickly. For example, during its first year (1990) in the EUP market the agency shipped EUP containing about 800tSWU and 1700tU equivalent, and in the last few years, Russian and CIS uranium has begun to swamp the US: in the four years from 1988 to 1991 imports climbed from 73tU (0.5% of the US requirement) (*NEI* 1/92: 3) to 5600tU (33.6%) (*NF* 21/10/92: 1-6). In those years US production stood at 5072 and 3036tU, respectively, which means that Russian imports rose from practically nothing to almost double US production in the period 1988-90. Not only is Russia/CIS able to supply large quantities to the market, it also offers bargain-basement prices. For example, in mid-1993 the CIS offered UF6 to a US utility at below the spot market price of US$ 24.30/kgU, at a time when the most recent deals had been concluded at around US$30.30/kgU (*NF* 7/6/93).

The apparently huge Russian uranium stockpile and its ability to produce services at below marginal Western cost, has considerably unnerved the nuclear fuel market, and there have been attempts in the US and in Europe to control and/or embargo imports from CIS states. In the US, a complaint about unfair trade practices, based on perceived dumping of uranium and enrichment services, was filed by US uranium companies, in conjunction with the Atomic Workers Union and the DOE against the CIS states. The outcome was that the US agreed to import at least ten tonnes/yr of highly enriched uranium (HEU) from Russian nuclear weapons for deconcentration, in return for which the CIS states agreed to abide by a quota for uranium imports. Some CIS states have not acceded to this accord and their imports are subject to surcharges in the region of 120%, but this surcharge may not be justifiable under GATT regulations. While this agreement may not seem ideal to US uranium and SWU producers, it does at least mean that Russian uranium and enriched uranium will not swamp the market, but will be imported in known quantities, linked to price limits – the higher the spot price, the bigger the quota. The exact amount of HEU imported annually is not stipulated in the agreement, and it is independent of the imported U3O8. While the Euratom Supply Agency (ESA) has not yet imposed quotas on CIS uranium, it has attempted to set floor-prices of about US$ 33.80/kgU3O8 below which the CIS uranium may not be sold – much to the irritation of the European utilities. In return, the CIS is proposing a price of US$ 18.20/kgU3O8 – close to the spot price of about $18.50/kgU3O8 in mid 1993 – but a price between $46 and $62 is needed for profitable production in the West. The issue has not yet been resolved (MacLachlan 1993: 1-4). According to its deputy director, the ESA's brief is to maintain a European fuel industry, as well as to help EC consumers and their governments to support uranium producers 'that are indispensable to the economy of certain countries' such as Niger or Namibia. (Of course, one should not forget that in many such cases the uranium mines are owned by European and North American multinationals, and in any event, uranium production is also vital for the economies of some of the countries whose uranium is being embargoed.)

Despite concerted attempts by Western uranium and SWU suppliers to control the release of Russian production onto the market, TENEX is bullish about its prospects. The vice-minister of Russia's Ministry for Atomic Energy (MINATOM) has claimed, for instance, that Russia's world market share could rise to between 20 and 25 per cent and that based on production capacity its exports should be at least 5ktU/yr (twice their present level) and 8-10ktSWU/yr (MacLachlan 1993). Domestic demand, and demand in those countries traditionally supplied by Russia, will determine how much of the CIS stockpile is available to the market. The current trend for nuclear electricity in the CIS is downwards: plans for NPS construction have been reduced, and slowed for those under construction, and in addition, there have been many shutdowns in the last few years, as safety standards in the EE nuclear industry are slowly forced to comply with those in the West. Uranium requirements in the former non-WOCA countries is expected to increase marginally from about 7000tU/yr in 1991 to 8000tU/yr by the turn of the century, and then remain at that level until 2010 (*UI* 1992).

3.4.3 Future scenarios

The future of the nuclear fuels market is dependent on the future of nuclear power, and the latter is extremely difficult to predict owing to a combination of political uncertainty and changing patterns in global energy demands. In the space of just one year, for instance, the Uranium Institute had to alter its 1991 forecasts for world nuclear generating capacity downwards by 6% as a result of a 42% reduction in the forecast for generating capacity in Eastern Europe and the CIS. Nonetheless, the Uranium Institute forecasts a 23% rise in global nuclear generating capacity between 1991 and 2010, with a rise of 14% by the turn of the century (*UI* 1992). Most of the increase is forecast to come from Japan, France, South Korea, and Taiwan whose respective capacities are predicted to grow by 82, 31, 189, and 41%, from 1991 values of 31.9, 55.7, 7.2, and 4.9GWe – in the latter two cases, therefore, the increase comes from a low base. It is not clear from the UI data to what extent the envisaged increase in Japanese and French generating capacity derives from hypothetical fast breeder reactor construction, and to what extent it can be attributed to proposed new (traditional) light-water reactors. (Fast breeder reactors would have a quite different impact on uranium and, particularly, on enrichment requirements.) Interestingly, in those countries in which political opposition to nuclear power is more vociferously expressed – the US, UK, and Germany – capacity is expected to remain constant, or even to decrease slightly.

Table 3.2 World nuclear generating capacity forecast. Data are taken from the Uranium Institute's 1992 Update, and figures are given in net GWe. Values for 1991 are actual figures.

	1991	1995	2000	2005	2010
West	279.8	298.9	319.3	335.6	345.6
East	40.9	45.2	46.8	47.7	47.4
Global	320.8	344.1	366.1	363.3	393.0

Western uranium requirements are projected to rise from the 1991 values by about 17% by 2005, thereafter flattening out, while non-WOCA requirements are expected to rise slightly above present levels. Conversion, enrichment and fuel fabrication capacities are forecast to remain about constant, or to increase slightly, but in all cases capacity is expected to run well ahead of demand. Predictions for price behaviour partially follow those for uranium turnover, according to forecasts by the energy policy research organisation Energy Resources International (ERI) in its *1993 N F Cycle Supply and Price Report* (Knapic & Dizard 1993b: 1, 14-15).

ERI predicts a rise in U3O8 price from $26/kg in 1993 to $31-42/kg in 1995 and 36-57 (1993 dollars) by 2000. (Actual spot price in mid 1993 was $18-21/kg.) The predicted increases for conversion, enrichment, and fabrication services are not quite as large, probably as a consequence of the projected overcapacity for the foreseeable future. Thus UF6 prices are expected to rise from about $4.74/kgU (mid 1993 spot) to between $5.50 and $6 in 2000, thereafter levelling off, while SWU price is forecast to change from a spotprice of about $68/SWU (mid 1993) through $82-93 (1995) and $95-117 (2000) to $95-135 in 2005 and beyond (Knapic & Dizard 1993b). Prices of fabricated fuel are expected to remain 'flat' at $200/kgU for PWR and $300/kgU for BWR fuel.

Table 3.3 Forecasts for the nuclear industry. Uranium Institute forecasts for uranium requirements in the former WOCA and non-WOCA countries, as well as estimates for conversion, enrichment, and fuel fabrication capacities and demand up to 2010. Figures for 1991 are actual figures; data from the Uranium Institute 1992 Update.

	1991	1995	2000	2005	2010
U requirements West (ktU)	46.92	50.31	54.11	54.70	54.75
U requirements East (ktU)	6.57	8.59	8.44	7.73	7.57
Conversion capacity (ktU)	67.39	67.89	67.89	67.89	67.89
Enrichment capacity (ktSWU)	42.9	44.6	47.7	47.7	47.7
Enrichment demand (ktSWU)	23.0	25.8	27.6	29.1	30.0
Fabrication capacity (ktU)	10.28	10.48	10.68	10.68	10.68

Predictions about trends in the nuclear industry can clearly be wrong, and when they are made by nuclear industry participants or members they are sometimes inclined toward bullish sentiments. For instance, the UI 1979 forecasts for uranium production for the years 1979-85 and 1990 were, on average, 49% optimistic, its (conservative) 1979 estimates of theoretical uranium demand for the years 1979-90 were, on average, 62% above actual demand, and 1986 estimates of uranium requirements for the years 1986-91, while correctly predicting a downturn, tended to overestimate demand by 23%.

Hanging above all these uncertainties inherent to the nuclear industry, are the additional questions regarding the size of the Russian inventory, the ability of CIS states to deliver natural uranium, the effect of the dismantling of Russian nuclear weapons, and the likely production costs of Russian SWU. The size of the uranium inventory has already been discussed, and we will turn here to an examination of enrichment capacity. By current estimates, Russia can produce about 10kt SWU/yr, with at least one plant using modern – and therefore possibly competitive – centrifuge technology. Domestic and Eastern European demand is about 5kt SWU, demand for other contracts is about 2kt SWU, leaving about 3kt SWU for fresh production. In addition, it is likely that inventory can be drawn on, so that there should be enough excess capacity to provide well over 5kt/yr SWU by the end of the decade. Accordingly, NUKEM predicts that by 2000 TENEX will have absorbed 40% of WOCA unfilled demand, giving it a total market share of at least 15%. If this happens, the West's uncommitted enrichment capacity will be considerably more than twice unfilled demand at the end of the 1990s, which means that new enrichment suppliers will experience great difficulty in establishing themselves in that market (Schreiber 1991).

Contracts have already apparently been drawn up between TENEX and Western traders. According to reports in trade journals, for example, it seems likely that Global Nuclear Services & Supply Ltd. (GNS&S) – a joint venture by TENEX and the nuclear fuel trading company NUEXCO – will seek to market 2-2.5ktSWU/yr at prices between $70 and $80/SWU. This would make GNS&S the global price leader for long-term contracts. (NEI 8/91: 14) Even in South Africa, the private nuclear fuel company Nutron Energy Services International claims to have contracted TENEX to supply a minimum of 40t and a maximum of 200tSWU/yr for ten years at prices of about $80/SWU. At these prices, purchasers willing to take on the possible risks associated with supplies from Russia may be able to build up stockpiles at very low prices, to see them through possible periods of disrupted supply. The extremely low prices that TENEX is able to offer for SWU have led some US Senators and nuclear industry representatives to raise the spectre of trade barriers on the grounds that the low-priced SWU would threaten 'national security concerns' (NEI 8/91), although, in contrast to the situation with natural uranium imports, no barriers have yet been erected. (Recent reports suggest that the price of SWU supplied by TENEX to Korea is 'well below' the USDOE $90/SWU (*NF* 7/6/93).)

In addition to highly competitive Russian SWU production, there is the question of the market impact of Russian highly enriched uranium (HEU). The quid pro quo deal between the US and Russia (see Section 3.4.2) will see USEC paying about $780/kg for 500tHEU blended down with 1.5% U-235 feed to a level of 4.4% U-235. USEC apparently breaks down the price of the resulting low enriched uranium (LEU) into $82.10/SWU plus $28.50/kgU as UF6. These prices compare unfavourably with the marginal cost of SWU production (less than $60/SWU at present), and the spot price for UF6 (about $25/kgU). It is therefore not clear whom USEC will be able to persuade to contract for the de-concentrated HEU. Nonetheless, it is unlikely that the HEU will have no market impact, since the volumes of LEU derived from it are huge. According to Julian Steyn of Energy Resources International, 10tHEU, the minimum the US has to import annually when blended down as per contract will result in about 310t of 4.4% LEU, which equates to about 1.8ktSWU and about 21ktU3O8 (Knapic & Dizard 1993c: 1,19). In other words, the minimum HEU import into the US, at a cost of $232 million, is equivalent to the annual LEU, and therefore SWU, requirements of about 20 reactors, while the U3O8 content approximates half the present global demand. It is not clear what USEC will do with all the excess uranium, though the possibility has been raised of selling it to Japan as a strategic uranium reserve to prevent use of plutonium by that country.

The worst scenario for nuclear fuel price recovery would be the maintainance of the status quo in the CIS: 'a situation where uranium is one of the few hard currency earners for the exSoviets and the Soviet economy continues to stumble, but for Western political reasons trade continues to be encouraged with the Soviet Union' (Combs 1991: 2-6). In this regard it is interesting to note that in 1992 Russia offered to pay Korea interest on loans with enriched uranium. In the near to medium-term future, it is unlikely that there will be an easing of the economic pressures on the newly emerging suppliers to keep their prices low in order to maximize turnover, and so even if demand begins to pick up, and inventories drop, uranium and nuclear fuel prices are unlikely to improve soon.

Finally, although there appears to be little public discussion of the fate of US-origin HEU from dismantled nuclear weapons, there can be no doubt that the amounts involved will be similar to those being generated in the CIS. One recent report indicates that up to 40tHEU may be supplied to the USEC in an attempt to balance the importation of Russian HEU (Knapic & Dizard 1993c). This issue, however, is very new to the market, and is surrounded by a spectrum of political considerations that make it difficult to anticipate the market impact of US HEU. Although the economic pressures in the US are not likely to result in pressure to liquidize military surplus uranium, there may well be individual interest groups in that country who will press for the release of such materials. And if US HEU enters the market, the apple cart will be even more upset.

3.4.4 Summary

Ever since the early nineteen eighties, the international uranium and nuclear fuel market has been in decline. Production of natural uranium as well as prices for U3O8, and for conversion and enrichment services have reached historical lows. With the decline has come a major restructuring of the market. There has been a very strong shift away from the one-stop nuclear fuel supplier toward traders in natural uranium, conversion or enrichment services, who obtain their products on a spot market. For example, more than half global U3O8 requirements are now apparently being obtained on the international spot market. In line with this shift, price formation has become less dependent on production costs. This trend is likely to increase as non-traditional suppliers – specifically Russia and the CIS states – gain bigger market shares, since for many of these production costs are not easily quantified and they have large historical inventories: their pricing policies will therefore be largely determined by spot market prices.

New production of U3O8 fell below annual demand in 1986, but the market has since been fueled from inventories built up in the 1970s and early 1980s. These inventories are large: in the West they are about 153ktU (*UI* 1992 Update), while conservative estimates put those in the East anywhere between 140 and 200ktU. In total, civilian inventory may be as high six to eight times global annual demand. The unknown Russian stockpile has unsettled the market, while TENEX's ability to produce SWU at very low prices has undermined it. In addition, with the global political changes of the last few years, uranium and HEU from military inventory and/or dismantled nuclear weapons is becoming available to the market. A contract between the US and Russia will see at least 10tHEU deconcentrated per year out of 500t covered by the contract. This amount of HEU contains the equivalent of about half the annual global uranium requirement, and in terms of SWU and LEU it corresponds to at least twenty annual reactor loads – in a world with about 400 reactors.

While industry analysts predict small rises in the market, their predictions have in the past been over optimistic about the likely expansion of the global nuclear industry. The expected increases in nuclear generating capacity are all predicted for countries in which there is little or no effective opposition to nuclear power; countries with effective opposition are forecast to show no growth, or small negative growth in the industry. In any event, all analyses agree that conversion, enrichment, and fuel fabrication capacity for the next fifteen to twenty years will outstrip demand by as much as 70 or 80%.

3.5 The AEC's Nuclear Fuel Production division

3.5.1 Production costs and prices

The Nuclear Fuel Production (NFP) division of the AEC is responsible for operating and maintaining the conversion, enrichment (Z-) and fuel fabrication (BEVA) plants, as well as the Vaalputs installation, and earth and environmental technologies. In addition, it seems NFP is also responsible for the AEC's uranium stockpile. The environmental aspects of this division were not investigated as part of this report. Capital expenditures on the NFP plants as reflected in the AEC's books are given in Table 3.4. In estimating the 1992 amounts, it was assumed that the book value supplied by the AEC was current in the last year of construction of each plant.

Table 3.4 Capital expenditure on NFP plants. Values are given in Rm.

	CAPEX	Year[a]	1992 Rands[b]
Conversion	55.200	1985	122.030
Z-Plant	785.000	1987	1 383.438
BEVA	267.500	1985	591.357
Y-Plant	210.000	1977	877.222

[a] Year refers to the last year of construction, and is assumed to be the year in which the indicated CAPEX figures appeared on the books of the AEC.
[b] Inflation rate assumed to be 10% for 1977-92, and 12% for 1985-92 period.

Before discussing the present NFP activities, a brief mention of the historical cost of the pilot enrichment (Y-) plant must be made. As shown in the table above, the original capital investment was R210m, and annual operating costs have been reported as R40m (Venter 1993a). Construction of the plant began in 1971, but first production occurred only in 1979. Eight years is a long time for construction and commissioning of a small pilot plant, and it seems fair to assume that, for at least part of this time, operating expenses were already being incurred as commissioning proceeded. Accordingly, if one assumes that the annual operating expenditure commenced in 1975, and continued until decommissioning in 1989, then production costs for this period must have amounted to at least R560m, which, added to the original CAPEX, yields a total cost of R770m (in current rands). (Not included in this total is the R18m cost of decommissioning the Y-plant.) These figures should be contrasted to the AEC's claims to have contributed R682m to the development of the nuclear 'devices', 83% of which (R566m) allegedly constituted the cost of the Y-plant (Ryan 1993).

In the following discussion of production and operating costs for NFP activities, the above capital expenditures have been ignored, except where an attempt has been made to indicate the extent by which the estimated production costs would have to be scaled upwards, in order to recoup the amounts invested in the plant through sales of nuclear fuel. All the NFP data used here were supplied to this investigation by the AEC on the understanding that they represent grossly averaged figures. It seems fair to assume that if there is any bias in the data, it would probably reflect positively on the AEC, rather than negatively. In this sense, the estimates derived below may be assumed to reflect *minimum* costs (or *maximum* income), with the proviso that the estimates are very approximate ones. Table 3.5 outlines the proportion of the annual NFP budgets spent on its various services since the formation of the NFP as a separate accounting division within the AEC.

Table 3.5 Breakdown of annual NFP operating expenditure for the different NFP services. All figures are in millions of current rands. SUM represents the sum of the individual services, while NFP OE indicates the total NFP operating expenditure (excluding depreciation) as given in the global AEC flow of funds table (see Table 2.3). (Source: P. Venter & A. Vermaak, AEC)

	88	89	90	91	92	93	94	95-98
Conversion	19.592	21.301	24.624	21.034	20.542	24.800	27.275	104.346
Enrichment	81.893	170.209	171.089	183.200	233.969	213.504	141.204	268.462
BEVA	62.440	75.136	50.448	46.531	47.209	46.957	49.738	183.436
Decommission				10.754[a]	7.273[a]			40.000b
Vaalputs	1.600	3.382	3.398	3.197	3.160	3.424	3.425[c]	13.698[d]
SUM	165.525	270.028	249.559	264.716	312.153	288.685	221.897	610.964
NFP OE		332.699	325.867	287.207	285.378	253.421	253.343	798.176

[a] Cost of decommissioning pilot enrichment (Y-) plant.

[b] The minimum cost of decommissioning the semi-commercial (Z-) enrichment plant is estimated at R80m.

[c] This figure is the average annual cost based on the total projected cost (R13.698m) for the period 1994-97.

[d] This figure is the projected total cost for 1994-97.

In the following analysis of production costs in the NFP division, only those operating expenditures explicitly listed by the AEC for conversion, enrichment, fabrication, Vaalputs, and decommissioning were used; as can be seen from Table 3.5, however, the actual NFP budget is in some cases considerably higher than the sum of the individual operating expenditures. This difference is partly ascribable to additional services that NFP renders, which the division does not consider part of either conversion, enrichment, fabrication, Vaalputs or decommissioning. It is possible that opinions may differ on whether some of these additional services should not, in fact, be included, with the result that the operating expenditures listed in Table 3.5 would be higher.

Table 3.6 lists annual volumes produced by the NFP division, as well as percentage utilization of capacity. In calculating the utilisation, the following capacities were assumed (Venter 1993a): conversion plant (1200tU/yr), Z-plant (275tSWU/yr), BEVA plant (100tU/yr). Table 3.7 gives the income generated from sales in these sectors

Table 3.6 Annual production from NFP division. (Source: P. Venter, AEC)

	88	89	90	91	92	93	94	95-98
Conversion (tU)	91	383	428	160	678	525	625	2224
% Utilization	8	32	36	13	57	44	52	46
Enrichment (tSWU)		23	165	77	189	243	250	500
% Utilization		8	60	28	69	88	91	130[a]
BEVA (tU)[b]	1.81	17.62	25.31	29.37	25.31	20.79	18.98	90.38
% Utilization	2	18	25	29	25	21	19	23

[a] Calculated assuming that the Z-plant will cease production on 31 March 1996, as per the AEC's recommendations to the Minister of Mineral and Energy Affairs.

[b] These amounts were calculated from the number of fuel assemblies listed for the respective years, assuming an amount of 451.9kgU/assembly.

Table 3.7 NFP income for various services. Figures are given in millions of rands. (Source: P. Venter & A. Vermaak, AEC)

	88	89	90	91	92	93	94	95-98
Conversion	1.761	2.917	3.752	6.886	9.786	8.442	11.367	46.316
Enrichment	1.265	52.628	74.790	60.052	67.921	67.814	66.550	152.475
BEVA	0.085	9.293	32.099	32.367	19.973	21.613	18.446	130.944
Vaalputs	1.600	3.523	3.540	3.330	3.362	3.689	3.680[a]	14.720[b]
Uranium Sales						8.805	15.403	43.973
Turnover	4.711	68.361	114.18	102.635	101.042	110.363	115.446	388.428

[a] This figure is the average annual income based on the total projected income (R14.720m) for the period 1994-97.
[b] This figure is the projected total income for 1994-97.

Even a cursory examination of the data presented in the above tables reveals that with the exception of the Vaalputs facility, all the NFP services listed have been operated unprofitably, with expenditure outstripping income. Table 3.8 gives the average unit production cost for the years 1988-92 and 1988-93, the average price obtained per unit for the period 1988–93, (excluding obvious outliers) as well as the average spot market price for conversion, enrichment and fuel fabrication services during those periods. Unit production costs were calculated by averaging the annual production costs, which were established by dividing annual operating expenditure for each sector by the volume produced. It is possible that the volumes produced refer to the calendar year (1/1 – 31/12), whereas the operating expenditures listed refer to the financial year (1/4 – 31/3), so that production costs may not be accurate. However, by averaging out the annual production costs, the error inherent in this approach is likely to be minimized. Finally, because the operating expenditures listed in Table 3.5 arguably may not include all costs incurred in operating the plants, the estimates in Table 3.8 are likely to represent bare-bones estimates, and the true costs may actually be higher.

Average AEC prices were calculated by averaging the annual prices, which in turn were established by dividing annual income for each sector by volume produced. Inherent in this approach to estimating prices is the assumption that inventory levels remained constant, that is, each unit produced was also sold. If sales were lower than the volumes produced, then the average prices obtained would clearly be higher than those indicated in Table 3.8; these prices, therefore, represent the absolute minimum that the AEC is likely to have obtained for conversion, enrichment and fuel fabrication services during the years 1988-93. Also listed in Table 3.8 is a rough estimate of the additional unit production cost if the capital investment in each plant were to be recouped during the (assumed) ten year life-span of the plant. This estimate for depreciation of the plant is included here in order to remind the reader that in a truly commercial operation these costs would also need to be considered.

Table 3.8 NFP unit production cost and price.

	Conversion (R/kgU)	Enrichment (R/SWU)	Fuel Fabrication (R/kgU)
NFP Production Cost (88-92)	98	3014	8848
NFP Production Cost (88-93)	90	2587	7750
AEC Price obtained (88-93)	18	466	1050
Spot Price (88-92)[a]	9.32	156.90	1100[b]
Spot price (June 93)[c]	15.51	224	1100
AEC Price 1993[d]	24	619	1394
AEC Production Cost 1993[e]	47	879	2259
Depreciation[f]	23	559	2365
Total AEC Cost[g]	70	1438	4624

[a] Averaged spot price for 1988-mid1993, converted into SA Rand at 2.5 ZAR/US$.

[b] No spot market for fabrication exists; this value is the approximate going rate according to the Nuclear Fuel Procurement Manager at Eskom.

[c] Spot price for June 1993, converted at rate 3.30ZAR/US$.

[d] Calculated assuming that the average price obtained for 1988-1993 will be maintained, and adjusting this for inflation (12%) over an average 2.5 years.

[e] Cost of production in 1993, established by dividing operating expenditure for 1993 by volume produced. These figures are probably lower than the real costs, owing to the problem of non-overlapping production (1/1/93 – 31/12/93) and financial years (1/4/93 – 31/3/94).

[f] Calculated assuming a ten year plant life, CAPEX as indicated in Table 3.4 in 1992 rands, and average utilizations of 45% (conversion plant), 90% (Z-plant), and 25% (BEVA), with maximum annual capacities as indicated in the text.

[g] AEC production cost 1993 + depreciation.

The average cost of production in each sector varies widely from year to year, as shown in Figure 3.4. For all three sectors, costs in the first year of production were astronomical: R215/kgU for conversion (1988); R7 400/SWU for enrichment (1989); and R34 535/kgU for fuel fabrication (1988). On average, production costs for the period 1988-92 were between 8 and almost 20 times higher than the international spot market price. Costs have since dropped, but even now are still between two and four times higher than the spot price, and this despite the weakening of the rand against the dollar (which inflates the spot prices). AEC and Eskom officials have claimed that part of the reason production costs are so high, is that the plants are underutilised (see Table 3.6). This may be true for the conversion and BEVA plants which had average utilizations of 45 and 23%, respectively, if one excludes abnormally unproductive years. However, considering the size of the differential between the historic operating costs of both plants and the level of the spot price this assumption must surely be questioned. Even when the simplistic estimates of 1993 production costs – which are likely to be too low (see note e in Table 3.8) – are compared with spot prices in mid 1993, a gloomy picture emerges: for conversion, costs are still three times higher than spot, for fabrication they are about double the price offered at Westinghouse or Siemens. And if the original capital investment were to be recouped through fuel sales, the true production cost would be even higher.

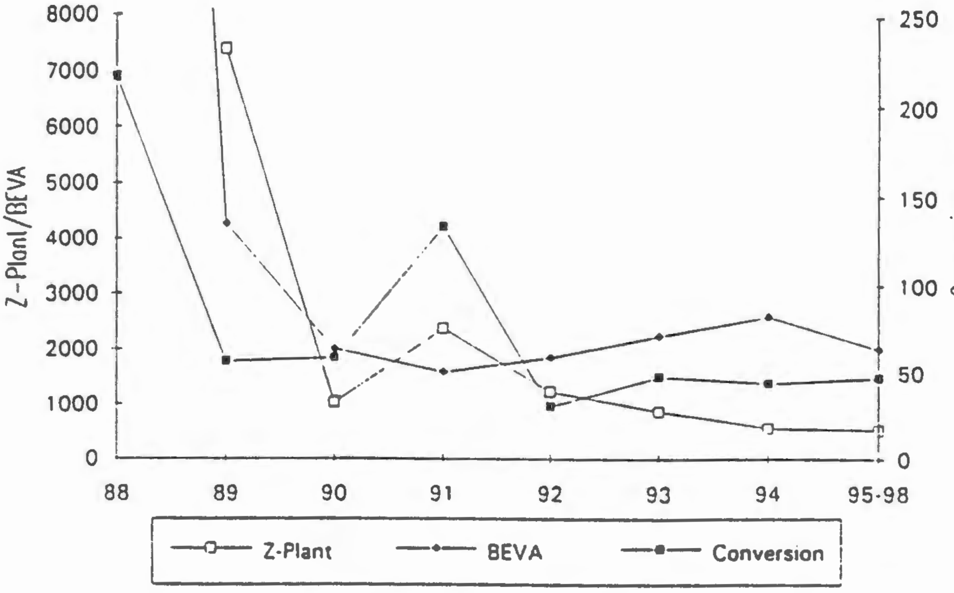

FIGURE 3.2 Annual production costs.

3.5.2 The Z-plant

In the case of the Z-plant, the AEC acknowledges that the plant can never be operated profitably, even though its average utilisation has been a reasonable 68%, and in recent years even appears to have been above 85%. Part of the reason for this is its extreme inefficiency. In its 1990 Review, the AEC reported an operating efficiency of 105 MWyr/100tSWU, which converts to 9 200 kWhr/SWU, whereas the design intensity of the plant was reported as 66 MWyr/100tSWU (5 800 kWhr/SWU). Neither of these values compares favourably even with the average 2 500 kWhr/SWU intensity quoted (Eerkens 1989: 48) for diffusion plants, which are acknowledged to be totally uncompetitive by comparison with centrifuge plants. Assuming an improvement in efficiency to 85 MWyr/100tSWU (7 450 kWhr/SWU) from the value quoted in 1990, it is possible to estimate the electricity bill that this plant alone would incur if it were billed by Eskom at the (cheapest) rate (tariff E) for large-scale, off-peak consumers, ie, R0.0538/kWhr plus a demand charge of R26.89/kVA:

assuming full production of 275tSWU/yr, the energy bill would be

7450kWhr/SWU x 275 000SWU x R0.0538/kWhr = R110 millon;

assuming an average demand of 180MW or 180MVA, the demand charge would be

180×10^3kVA x R26.89/kVA = R55 million.

The total annual bill would therefore be about R165m. It seems self-evident that Eskom is supplying electricity at substantially lower rates than this, since the total operating expenses for the plant are only slightly above this value, but Eskom officials have not released data on the pricing compact reached with the AEC, which possibly includes a swap of SWU for electricity. Considering the enormous subsidies that are necessary to keep the Z-plant operating, the question needs to be asked why the AEC has recommended to the Minister of Mineral and Energy Affairs that the plant be kept operational until 31 March 1996, instead of it being closed down forthwith. The AEC argues that (i) there would be a 'domino-effect' on other operations at the AEC if the plant were closed; (ii) some core competencies, such as UF6-handling technology, are dependent on the Z-plant; (iii) closure might affect MLIS prospects; and (iv) there are contractual obligations to Eskom that need to be filled.

That there would be a domino-effect following the closing of the Z-plant is undoubtedly true; this is always the case when an industrial plant closes down, but by postponing the closure the effect does not disappear – instead it is only pushed into the future, in this case at enormous cost. Secondly, the argument that some competencies, especially the technology for UF6 gas, may be dependent on the plant seems implausible, since the plant has now been operating for close on six years on the basis of technologies that to a large extent had already been mastered *prior* to its commissioning. For example, the experience gained with the handling of UF6 gas contributed greatly to the decision *taken in 1983* to develop the MLIS method. Moreover, it also seems improbable that the AEC would operate the Z-plant as an experimental station on the basis of as-yet poorly understood technologies; it is most likely that the technologies employed in this plant are fully matured and understood, and their transfer to other areas should not be dependent on continued experience with the Z-plant. The possible negative effect of closure on the MLIS programme does not seem a very persuasive argument either, since the MLIS process employs radically new kinds of technologies – this is the whole point of the MLIS programme – and intersects with the operation of the Z-plant only at the level of the common UF6 feed.

Finally, the argument concerning contractual obligations to Eskom is disingenuous, since these contracts have obliged the utility to purchase nuclear fuel services from the AEC at super-premium prices, when they could have been procured on the spot market for a fraction of the price. During the years 1989-93 AEC sales to Eskom totalled at least R430m (Venter 1993a), or 89% of the NFP income. By taking the average AEC:spot price ratio as 1.95 (for both conversion and enrichment) for the period 1988-92, we can estimate that Eskom in effect subsidised the NFP division of the AEC by at least R220m over the period 1989-93, or about R44m/yr. This estimate of the annual premium paid by Eskom for fuel from the AEC is remarkebly close to the R40m/yr additional cost claimed by the Parliamentarian R. Hulley, as reported in the *Sunday Times* (3/10/93). Moreover, the approximate prices established in this report for NFP products (see Table 3.8), specifically for SWU (1993: R619/SWU), compare well with those claimed by undisclosed (but apparently knowledgeable) sources in an article in the *Sunday Times* on 21/2/93, where it was reported that Eskom paid US$200/SWU to the AEC. These costs, of course, have been passed on to the consumer of (Koeberg) electricity.

Since these services could have been obtained elsewhere at a fraction of the cost to Eskom, it is likely that the strategic imperatives that dictated energy policy in the past still have influence. Indeed, the Eskom Nuclear Fuel Procurement Manager has spoken of 'awkward' inherited contracts. However, it is surprising that Eskom continues to contract with the AEC now that these imperatives no longer apply and considering that the contracts come up for re-negotiation every year. Yet it does, albeit for smaller amounts than before: the AEC projects that Eskom will purchase services of the order of R48.379m during 1994, and R222.420m during 1995-98 (Venter 1993a), while Eskom admits that it will continue to contract the AEC for conversion, enrichment and fabrication services for a value of R74m/yr, or R296m during 1995-98 (Woodcock 1993) It is not clear how to account for the difference between the AEC and the Eskom figures, but considering these revelations about the relationship between the two, Eskom's refusal to supply even averaged data regarding its purchases from the AEC can be more easily understood. In this regard it is perhaps also useful to point out that the chairman of Eskom, Dr. I. McRae, has also been a long-standing member of the AEC board. Needless to say, the additional costs incurred by Eskom as a result of its fuel procurement policies will be passed on to the consumer.

In light of the above analysis of NFP performance, the claim published in the AEC 1992 Annual Report that 'the AEC has succeeded in fulfilling its contractual obligations economically' has to be questioned.

3.5.3 Reliability of data

Lastly, it is necessary to comment on the reliability of the data supplied by the AEC. There is no way of knowing whether these data give an accurate reflection of the state of affairs in NFP, but some internal inconsistencies were noted, that suggest either opaque accounting methods within the AEC, or inaccurate data:

1 Two graphs in the AEC 1992 Annual Report seem to suggest that by the end of 1991 cumulative production for the last three quarters of that year stood at about 215tU (320tUF6) from the conversion plant, and about 138tSWU from the Z-plant, whereas the data supplied to this report suggest that only 160tU were processed and 77tSWU produced during the entire year.

2 The AEC 1988 Review mentions that 287tU (425tUF6) were converted during that year, while the data supplied to this report indicate production of only 91tU. (This discrepancy may be related to the difference between the financial and the production year, although the 1990 Review reflects exactly the same amount of converted uranium – 428tU – as do the data supplied here.) And in a paper presented in Washington in June 1993, P. Venter, Executive General Manager of NFP, claims that 734tSWU were produced from 1988 to 'date' (mid 1993) (Venter 1993b). According to the information supplied to this report, the total amount of SWU produced by end of 1992 was 454t, and by end of 1993 would be 697t.

3.5.4 NFP future plans

In the long term, depending on the success of its MLIS programme, the NFP division would like to set itself up as a one-stop nuclear fuel supplier, while in the short term 'the AEC has set firm goals for obtaining some near-term contracts in specific niches within the conversion and enrichment markets' (Venter 1993b). The AEC harbours these plans despite the acknowledged 'somewhat less than attractive trade conditions' in the international nuclear fuel market. However, given the dismal situation that exists with respect to production costs of the conversion, Z-, and BEVA plants, the AEC does not seem well-positioned to break into this market without substantial and consistent subsidisation by the state.

For instance, the AEC claims to have exported about 37tSWU (5% of production) and 340tU as UF6 (20%), (Venter 1993b) and claims an income of R13.754m from these exports. At the average prices listed in Table 3.8 these amounts should have generated about R17.242m and R6.120m, respectively, giving a total income of R23.362m. Since the actual reported income from exports is lower, the conclusion must be either that the income from the exported products has not been fully tabled, or that the products were sold at prices that were considerably cheaper than those charged to Eskom. The latter is the more likely conclusion, since there does not appear to be any reason why non-South African consumers would be willing to pay the premium prices that the AEC has been obtaining from Eskom; the AEC must therefore have been charging more realistic prices abroad. Indeed, at presumed spot prices of R215/SWU and R15/kgU, the amounts allegedly exported would generate R13.055m (= R7.995m + R5.100m), a sum very close to the claimed income from exports. This means that production must have been even more heavily subsidised than was the case with Eskom! It also means that the estimated R222.420m premium which Eskom has paid to the AEC is probably an underestimate. In summary, it does not seem plausible to assume that the AEC will be able to offer prices for any of the NFP products that are simultaneously internationally competitive, while at least covering production costs. (The question, therefore, is whether the AEC should continue to be subsidised in order to produce products that are exorbitantly expensive in rand terms, in order to earn some foreign exchange.)

Another export order, for 40 573SWU, mentioned in the 1993 Annual Report, was in fact placed with the AEC by Nufcor, and does not represent an international marketing success by the AEC itself. Nufcor earned R5.458m from this order, which implies that Nufcor charged its overseas client a bargain-basement price of R134.52/SWU, less than a third of the average price Eskom paid during the years 1988-92. It is likely that the AEC will have sold the SWU at less than R134/SWU. Other such super-discount arrangements between Nufcor and the AEC have also been reported. One 1992 contract to supply 320tU as UF6 earned Nufcor R31.124m, while two in 1993 for 32 and 37tU as UF6 respectively generated R2.106m and R4.924m. These amounts translate into R97.41, R65.80, and R132.64/kgU as UF6. Although these values fall into the range of the spot market prices in 1992/93, they are much lower than the average price of R157.90/kgU that Nufcor obtained for unconverted U3O8 during 1992. This implies that the charges for conversion must have been negligible, in order for Nufcor to be able to sell the converted UF6 at such discount prices. One could argue that these examples constitute aberrations, meant as sweeteners to Nufcor's international clients, but that does not do away with the point that AEC exports will always, by necessity, have to be subsidised by central government, and therefore by the taxpayer.

Turning briefly to the NFP projections for the period 1994-98, it is interesting to note that the AEC expects to sell more SWU in the period 1995-98 than it would be capable of producing if plans to decommission the Z-plant by April 1996 are fulfilled. This would only be possible, if SWU are being stockpiled from undeclared excess production at present (- not likely, since the plant is already running at almost full capacity), or if SWU bought on the international market are to be resold at a small premium. In this case, the AEC would then be acting as a trader on the international nuclear fuel market – a role that it has not traditionally played – and one that a state-subsidized organization is perhaps not best placed to fulfill.

The AEC's long-term plans for becoming a one-stop nuclear fuel supplier are also highly problematic, not the least because they fly in the face of the historic trend away from one-stop suppliers toward brokers and traders. (In fact, one could argue that were it not for its long years of protection as the only fuel supplier in South Africa, the AEC would not entertain such plans.) Even if the MLIS programme turns out to be a success, there will be a lag of at least six years between the closure of the Z-plant and the possible future opening of a commercial MLIS plant. During this time the AEC will not be able to supply SWU – whatever customers they attract by 1995 will almost certainly be lost to them during that time. This means that re-entry into the market in about 2003/5 will be extremely difficult, since the AEC will have little or no market history or reputation to judge it by: consumers would not know how reliable a supplier the AEC is likely to be, nor would they be able to estimate the quality of its products. In addition, by the turn of the century the US Enrichment Corporation will be well on its way to privatisation, possibly making a new entry onto the market that much more difficult. Finally, the likely overcapacity in the enrichment market for the foreseeable future will not make a penetration by the AEC any easier.

3.5.5 Summary

The NFP division of the AEC has been burdened with conversion, enrichment, and fuel fabrication plants that have demanded totally uneconomic production costs. Even ignoring the capital investments originally made in the plants, production costs have been up to twenty times higher than international market prices. In the case of the conversion and fabrication plants, the AEC maintains that the major reason for their uneconomic performance is the low utilisation rate. But the historic production costs have been so high, that this argument does not immediately seem plausible. As far as the Z-plant is concerned, the AEC admits that the plant can never perform economically, but maintains that its continued operation (until at least April 1996) is important for a number of other activities at Pelindaba. When examined more closely, these arguments do not appear very persuasive, however. Only in the case of the Vaalputs facility is the NFP turning in a profit.

The AEC has not been able to recover the full costs of production from the products sold to Eskom, but it has nevertheless been able to hold Eskom to contracts in terms of which the utility has been paying up to three times what it would have to, if it had been free to procure its requirements on the international market. Despite having to pay high premiums for fuel from the AEC, Eskom continues to contract to the AEC for reasons that can only be surmised. It seems reasonable to assume that these premiums are passed on as additional costs borne by the consumer of electricity.

While Eskom has been paying premiums for AEC services, Nufcor has been obtaining discounts for converted or enriched UF6 that it has exported. Some of these export orders obtained by Nufcor have appeared in AEC Annual Reports as export orders placed with the AEC, thereby creating the impression that the AEC is active on the international fuel market. While the AEC is known to have independently completed a deal on this market, this is a recent development.

In the long-term, the AEC hopes to set itself up as a one-stop nuclear fuel supplier, but in the near-term its plans for the 1994-98 period seem to suggest that it intends to act as a trader on this market. Considering the long years of (allegedly) little or no contact with the outside nuclear world, the AEC's experience on this market is likely to be limited, and its chances of success as a trader accordingly seem slim. Even if the MLIS programme is successful, the lag between the decommissioning of the Z-plant and the commissioning of a commercial MLIS plant will make it very unlikely that the AEC will be able to penetrate an already very competitive market, especially since it will have little or no market history.

3.6 The Nuclear Fuels Corporation (Nufcor)

Nufcor is the Chamber of Mines uranium marketing organisation. Its ownership alters from year to year, since the uranium-producing mining houses own shares in it in proportion to the amount of uranium they produce. Uranium-producing mines supply ammonium diuranate slurries to Nufcor's plant near Johannesburg, where they are blended and calcined into exportable concentrates containing U3O8. The plant employs about forty people, while the head office in Johannesburg has a staff of eight which market uranium mainly to utilities in Europe, North America, and the Far East. Nufcor has been marketing South African uranium abroad since its formation in 1967, and according to data supplied undertook its first local delivery in 1980 (Scorer 1993). By the end of 1992 Nufcor had exported 89.956ktU out of a total production of 94.184ktU, generating an income of R6 498m. In addition, 4.774ktU had been delivered locally for a rand value of R607.317m. Of the total volume produced, 855tU are unaccounted for in the data supplied by Nufcor; possibly this amount constitutes inventory held by Nufcor.

South African uranium production has followed international trends fairly closely, peaking in 1980 at 6 028tU, constituting 13.6% of uranium produced by WOCA countries during that year. Since the mid-eighties, however, SA production has declined faster than WOCA production, so that in 1991 SA production (1 601tU) constituted just less than 6%. Figure 3.3 depicts SA uranium production as a function of WOCA production for the period 1970-91, while Figure 3.4 illustrates the performance of Nufcor prices for exported and locally delivered uranium in relation to the international spot market price. The data for the latter graph were calculated using averaged, annual historical ZAR:US$ exchange rates supplied by the Standard Bank of SA, but the rates used for the years prior to 1978 were kept constant.

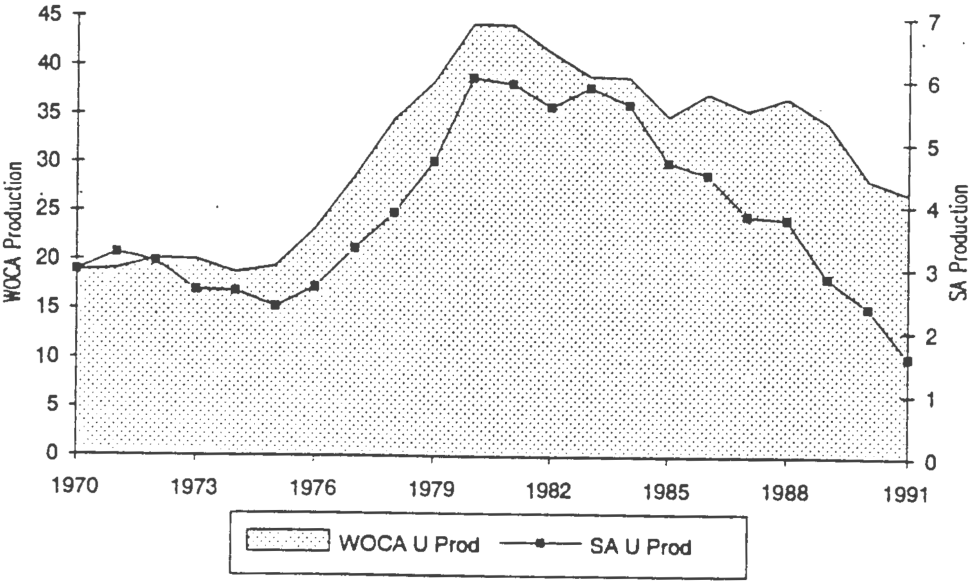

FIGURE 3.3 SA and WOCA uranium production.
(Source: Nufcor & Uranium Institute)

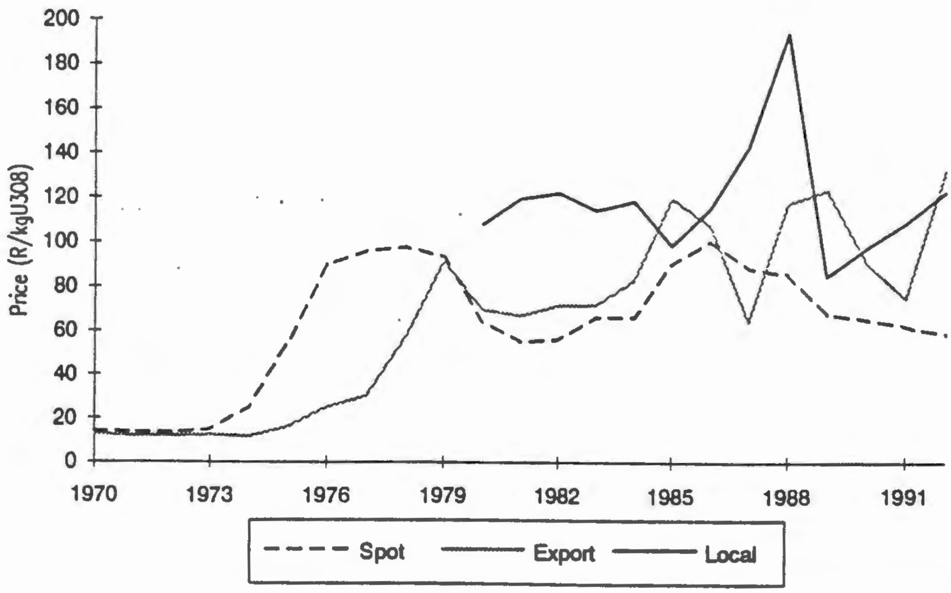

FIGURE 3.4 Nufcor prices. Local delivery of uranium only commenced in 1980, according to Nufcor data. Prices are in current rands. (Source: Nufcor & Uranium Institute)

Figure 3.4 suggests that Nufcor largely failed to capitalise on the uranium boom of 1973-79, its prices only reaching parity with spot in 1979. Since then, Nufcor export prices have remained marginally above spot, except for the years 86/87, when its prices dipped below spot, perhaps as a result of an initial panic reaction to the imposition of comprehensive anti-Apartheid sanctions in the US. While its performance in the export market has been fairly erratic, Nufcor has performed consistently and remarkably well on its locally delivered product, managing to persuade local consumers to pay premium prices for home-grown product. Thus, during the years 1980-92 the price of locally delivered U3O8 was on average 71% higher than spot, and 38% higher than the export price. Since there would not appear to be any local consumers of large U3O8 quantities other than Eskom and possibly the AEC, it is fair to conclude that Eskom must have been paying Nufcor at the premium rate estimated above. Bearing in mind the discounted prices offered to Nufcor by the AEC – as discussed in Section 3.5.4 – it is furthermore fair to assume that Nufcor will have reciprocated by supplying the AEC with uranium at prices that do not approach those paid by Eskom. This means that the average 38% increment on the cost to overseas clients, or the 71% increment over the spot price, represent minimum premiums paid by Eskom, with the real prices perhaps being significantly higher than this.

Since Eskom has been extremely reticent about communicating its nuclear fuel requirements or purchases, it is impossible to estimate with any degree of accuracy the quantities that Eskom will have purchased from Nufcor over the past decade. Considering the differential between Nufcor's export prices and those obtained for local delivery, it would certainly appear, however, that Eskom overpaid not only for NFP services from the AEC, but also for uranium supplied by Nufcor. Again, it is unlikely that the real reasons for this unusual procurement policy will become public knowledge. What is certain, however, is that the privately-owned mining houses profited from this arrangement between one of their businesses and a statal or parastatal corporation. The costs of this arrangement were most likely borne by electricity consumers.

Chapter 4
SUMMARY AND CONCLUSION

The NFP division of the AEC generates income of about R90m/yr, R80m of which accrues from contracts with Eskom. These agreements oblige the utility to purchase fuel from the AEC at prices that are inflated by about R40m/yr over what Eskom would have to pay for the same products on the international spot market. An additional income of R13m was generated in 1992/3 and 1993/4 from a contract to supply Nufcor with products for export. In order to produce this income, the NFP division requires annual operating expenditure of about R280m/yr.

The major reason for the NFP division's apparent economic unviability is the huge operating costs that its conversion, Z- and BEVA plants demand. The AEC's own figures reveal that the average production costs at the conversion, enrichment, and fabrication plants during the period 1988-92 were between 10 and 20 times the spot market price during the same period, and this excludes the capital costs of the various plants. In the case of the conversion and BEVA plants, it is claimed that the main reason for these high operating costs is their underutilisation. While this may be the case for these plants, it certainly is not so for the Z-plant, which the AEC admits will never be viable. However, the corporation argues that for a number of reasons the plant should not be closed down yet. On closer scrutiny, these arguments appear weak and opportunistic.

In part, the AEC's short-term hopes for survival in the nuclear fuel market appear to involve plans to trade in SWU on the international market, and to supply conversion and fabrication services to this market. This market is totally overtraded at present and will continue to be so for at least the next decade, resulting in fierce competition. The AEC, having little or no experience in the market, is therefore unlikely to be successful in this endeavour. It can only enter the global nuclear fuel market as a trader by offering exceptionally low prices. Who, then, would be subsidising these prices?

In the long-term, the AEC hopes to survive in the market on the back of its MLIS program. If the pilot MLIS plant confirms the AEC's apparent belief that the process could be economically viable, the AEC hopes to find private investors for construction of a commercial MLIS plant. The AEC may also be entertaining some hope of persuading a future government to support the venture. The AEC's claimed successes in its MLIS R&D program cannot be verified independently owing to commercial secrecy surrounding all such programs. However, it seems implausible that with an outlay not exceeding US$100m, the AEC could have produced a technology that rivals or outdoes its AVLIS and MLIS competitors in other countries with scientific and technological infrastructures far more advanced than those in South Africa, and R&D budgets many orders of magnitude greater.

This report has only been able to deal with the nuclear fuels aspects of the AEC's future plans. A similar investigation of the PTP side of operations, which would assess the markets that the non-nuclear fuels products hope to penetrate, and estimate the AEC's ability to succeed in this, is required.

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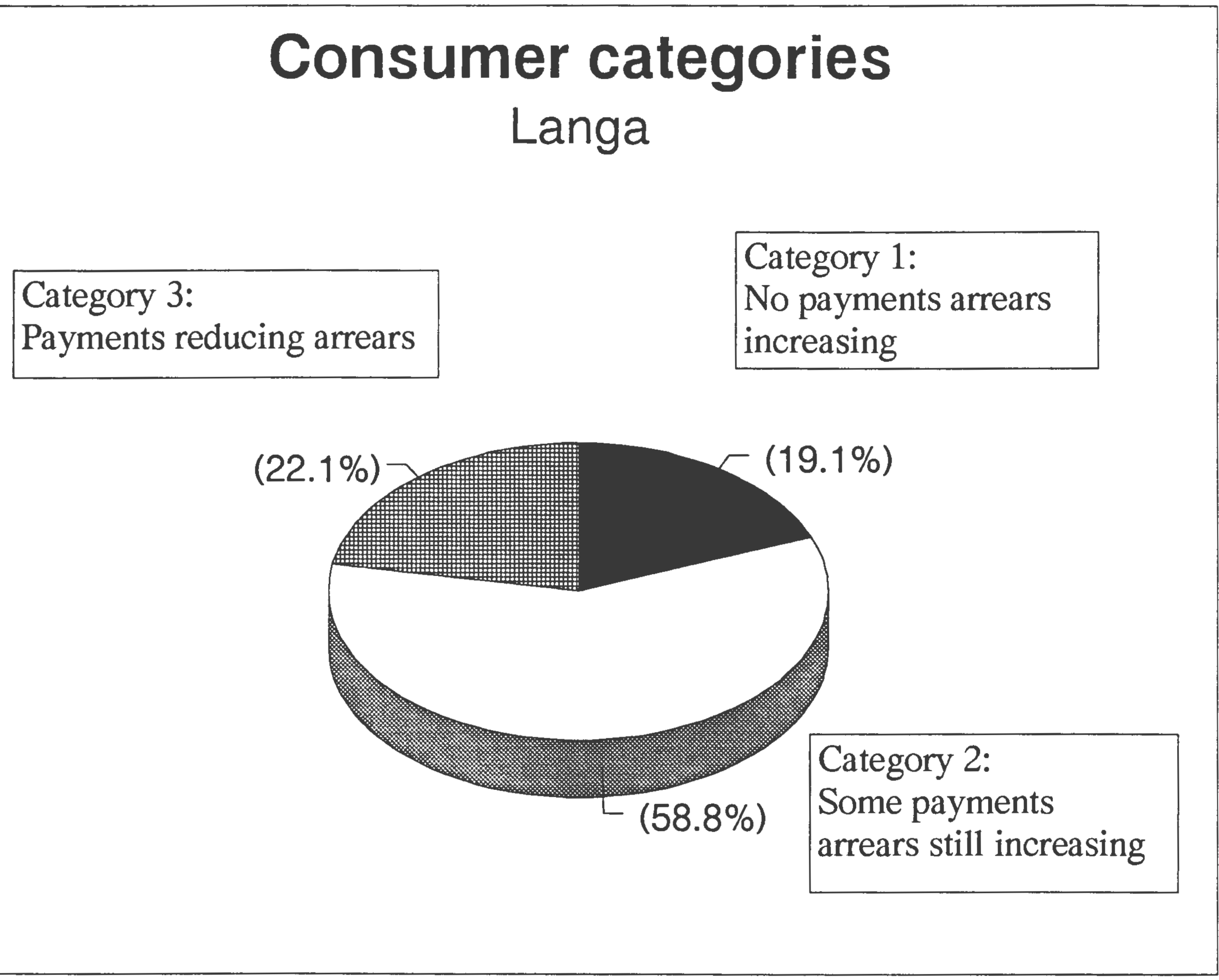
CHRONOLOGY OF NUCLEAR DEVELOPMENT IN SOUTH AFRICA

1945	SA requested to investigate deposits of radium and pitchblende by UK government, in connection with the Manhattan project.
1946	Formation of a Uranium Research Committee.
1948	Promulgation of Atomic Energy Act setting up the AEB.
1949	AEB created 1 January.
1950	SA signs Heads of Agreement with UK-USA to supply all uranium for weapons. (Lasts, with amendments, until 1964.)
1952	First full-scale uranium extraction plant at West Rand Consolidated mine.
1956	Governor-General of the Union of SA appoints a Commission of Enquiry into the application of nuclear power in SA. (Commission only reports back in 1961.)
1957	IAEA established with participation of SA
1959	National nuclear research program of the AEB approved by Cabinet.
1961	Pelindaba established. Decision to investigate the vortex tube aerodynamic separation method, also known as the stationary wall centrifuge method.
1964	Enrichment research begins.
1965	SAFARI-1 commissioned. (Safeguard agreement with IAEA in 1967.) Minister of Mines and Planning asks AEB to investigate and report on the possible introduction of nuclear power in SA. (Report in 1968 recommends a 350MW CANDU reactor would be viable in the Western Cape by 1978.) Separation of U235 from U238 first demonstrated.
1967	Work on indigenous natural uranium, heavy-water moderated research reactor (Pelinduna or SAFARI-2) at Pelindaba halted. (Development commenced in 1962.) Uranium enrichment demonstrated locally at laboratory level. Nufcor established. Eskom purchases Duynefontein farm, future site for Koeberg.
1969	Cabinet votes funds for pilot (Y) enrichment plant. W. Stumpf and others receive training at Gesellschaft fuer Kernforschung, Karlsruhe, Germany.
1970	Prime Minister Vorster announces development of 'unique' vortex tube method. UCOR established in terms of the Uranium Enrichment Act (Act 33).
1971	Minister of Mines approves short study of the potential for 'peaceful nuclear explosives'. Construction on pilot enrichment (Y) plant begins.
1973	UCOR and STEAG (Germany) together undertake 'feasibility study' of enrichment processes. Some claim this was a smokescreen for collaboration around the transfer of enrichment technology, although the AEC has always denied this. Construction of pilot conversion plant begins.
1974	Prime Minister's ad hoc committee decides to construct a nuclear weapon. Decision to use pilot enrichment plant for production of HEU.

1975	First separate vote of funds (called 'shares') for UCOR. Prior to this UCOR funds were channelled through the AEB. Commissioning of pilot UF_6 conversion plant.
1976	Commercial UF_6 production at Pelindaba commences.Production begins at Rossing mine, Namibia. Koeberg contract signed. (Safeguards agreement with IAEA in 1977.) US exports of nuclear fuel for SAFARI 1 denied. Prepayment for this fuel was returned by the Reagan administration in 1981.
1977	AEB instructed to prepare plans for meeting ESKOM's future fuel requirements.Detection (by Soviet satelite) and subsequent dismantling of Kalahari test site.
1978	Y-plant commissioned, first production.
1979	Construction of 'semi-commercial' centrifuge enrichment plant (Z-plant) commences. Technology based on the Helikon technique, cascade design. (Completed in 1986.) First production from pilot conversion plant. Detection of (unexplained) double flash over South Atlantic by US spy satelite.
1980	BEVA fuel fabrication plant construction begins at Pelindaba. Uranium production peaks at 6143tU. First fissile 'device' completed. Construction of BEVA (Brandstof element vervaardigings aanleg) plant begins.
1981	First fuel elements produced by project ELPROD for SAFARI-1.
1982	Nuclear Energy Act (Act 92) promulgated, in terms of which the AEB and UCOR are converted to companies - NUCOR (Pty.) Ltd. and UCOR (Pty.) Ltd., respectively - and the Atomic Energy Corporation (Pty.) Ltd. is established as their controlling body. Council for Nuclear Safety (CNS) established within AEC. ANC sabotages Koeberg NPS. Afrikander (primary uranium producer) lease closed.
1983	Start of laser enrichment studies. Molecular laser isotope separation (MLIS) technique chosen above atomic vapor laser isotope separation (AVLIS) mainly because of experience gained with UF_6.
1984	Koeberg 1 reaches criticality. Beisa section of St. Helena gold mines (only remaining primary uranium producer in SA) is closed due to depressed uranium market.
1985	Koeberg 2 critical. Restructuring of AEC; NUCOR and UCOR are integrated under the AEC in terms of the Nuclear Energy Amendment Act. Exploration of Karoo Sequence for uranium is terminated due to slump in the uranium market. Start of BEVA plant commissioning. Start of Z-plant commissioning.
1986	First production at conversion plant. Vaalputs National Radioactive Waste Repository becomes operational. US sanctions against nuclear cooperation with SA are imposed. AEC announces plans for a nuclear research facility at Gouriqua, Southern Cape. (Speculation that this is to be a reprocessing facility.) AEC state subsidy peaks at 89% of the total vote for the Department of Mineral and Energy Affairs (R775m out of R871m).

1987	AEC opens office in Gansbaai, Southern Cape, possible site for next NPS development. Development program for new enrichment plant initiated. This later leads to the decision to stop work on the centrifuge method, and concentrate on the development of a pilot MLIS plant. Agreement between ESKOM and the AEC on fuel supply.
1988	First full production at Z-plant. Fuel fabrication (BEVA) plant goes on-line. The first four fuel assemplies are delivered to Koeberg. (Up to September 1991 three full reloads will have been supplied.) CNS becomes independent, reporting to the Minister of Mineral and Energy Affairs. Pelindaba, Valindaba, and Vaalputs facilities are brought into the formal licensing process. US Senate fails to pass House of Representatives legislation designed to close loophole allowing SA uranium into the US.
1989	First full reload for Koeberg of nuclear fuel elements locally produced. Six fissile 'devices' produced to date. Decision by ad hoc Cabinet to dismantle the devices. Pilot conversion plant decommissioned.
1990	AEC adopts commercial strategy (AEC 2000-PLUS); plans to be independent of state subsidy in 15 years. Closure and start of decommissioning procedure of Y-plant.
1991	Closure of Zirconium production plant. Construction of pilot MLIS plant begun. Capacity 20 000 SWU/yr, but will only be operated continuously for short periods. Discontinuation of research into centrifuge enrichment. Hot cell complex at Pelindaba commissioned. (Safeguard agreement signed in 1987.) SA becomes signatory to the Nuclear Non-Proliferation Treaty, and reaches a safeguard agreement with the IAEA on all nuclear facilities. US embargo on SA uranium lifted. Start of phase-out of fusion research.
1992	Planned completion of CO_2 laser test facility. First exports of enrichment services (37 000 SWU) and UF_6 (340 000 kg).
1994	Proposed start of phase-out of Z-plant. (Minister of MEA or Cabinet will make the decision about closing the Z-plant.)
1995	Planned completion of pilot MLIS enrichment plant.
1996	Assessment of viability of commercial 120 000 SWU/yr MLIS plant.
	Planned start of construction on commercial MLIS plant. (The civil works for the pilot plant were designed to accomodate the complete commercial plant in the same building.)
1998	Temporary storage ponds for irradiated fuel at Koeberg are expected to be full. Transfer of unreprocessed spent fuel to Vaalputs?
2003	Approximate planned phase-in of commercial MLIS plant.



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Category 2:
Some payments arrears still increasing
Category 3:
Payments reducing arrears
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(58.8%)
(22.1%)

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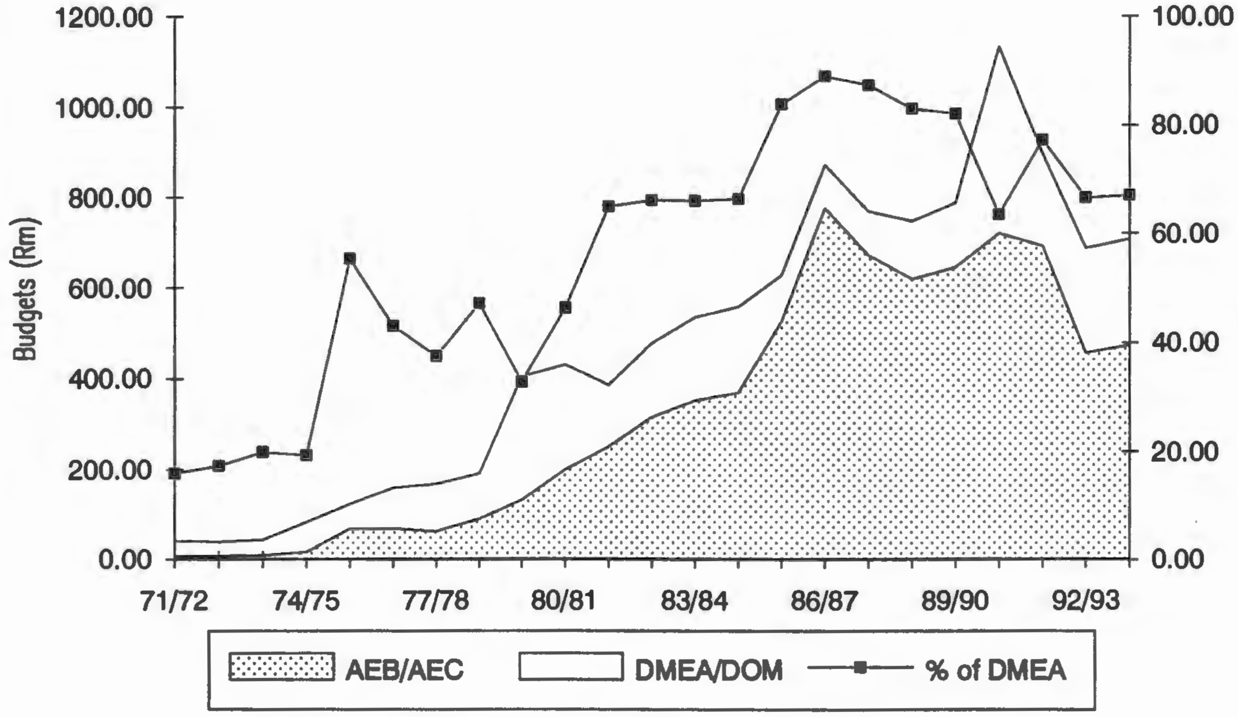
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400.00
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0.00
100.00
80.00
60.00
40.00
20.00
0.00
71/72
74/75
77/78
80/81
83/84
86/87
89/90
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AEB/AEC
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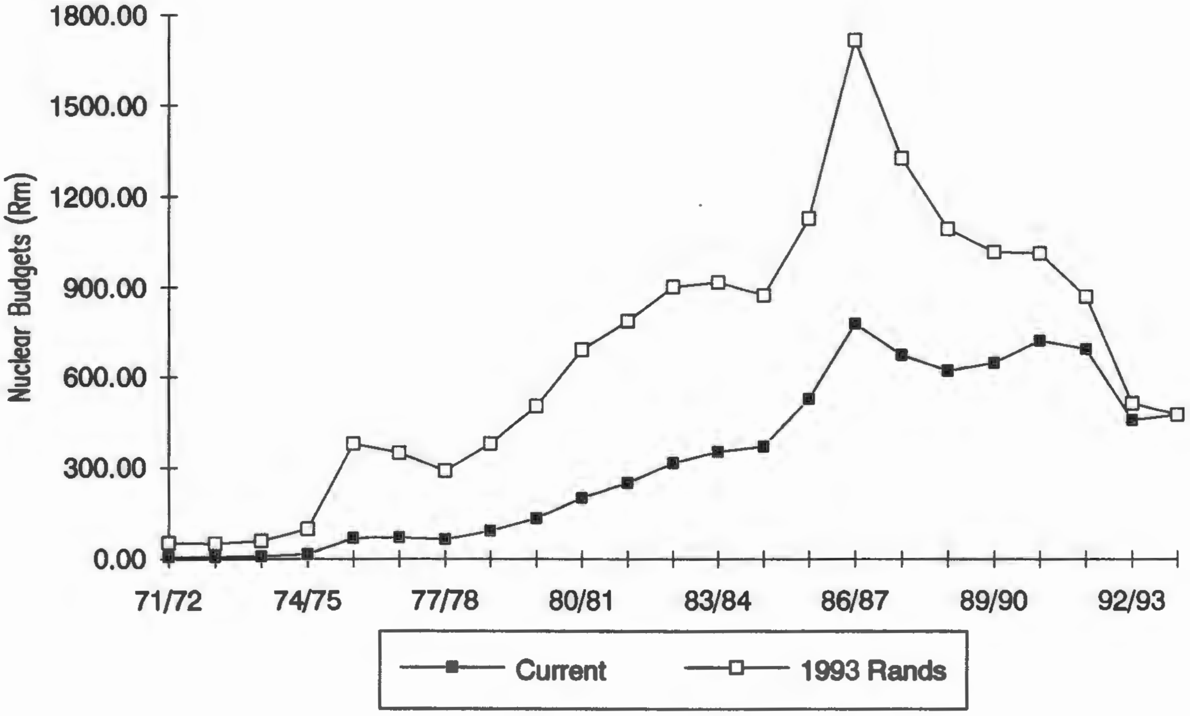
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92/93
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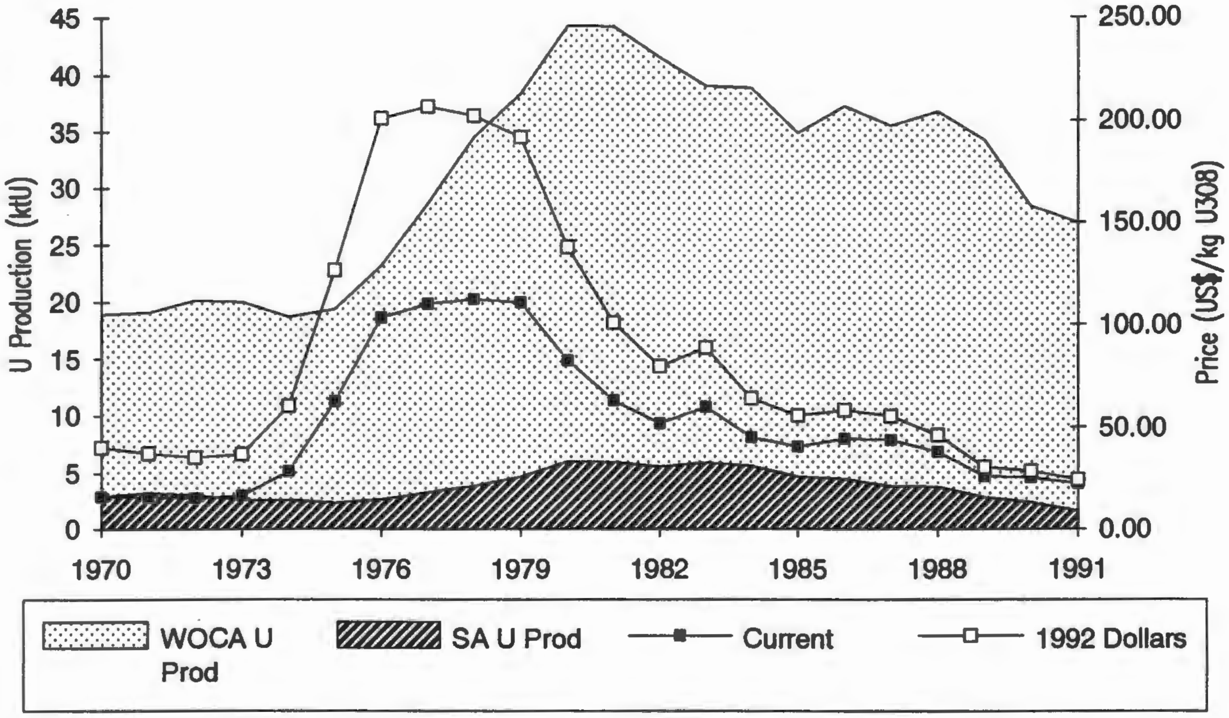
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25
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15
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5
0
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150.00
100.00
50.00
0.00
Price (US$/kg U308)
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1976
1979
1982
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1988
1991
WOCA U Prod
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Current
1992 Dollars

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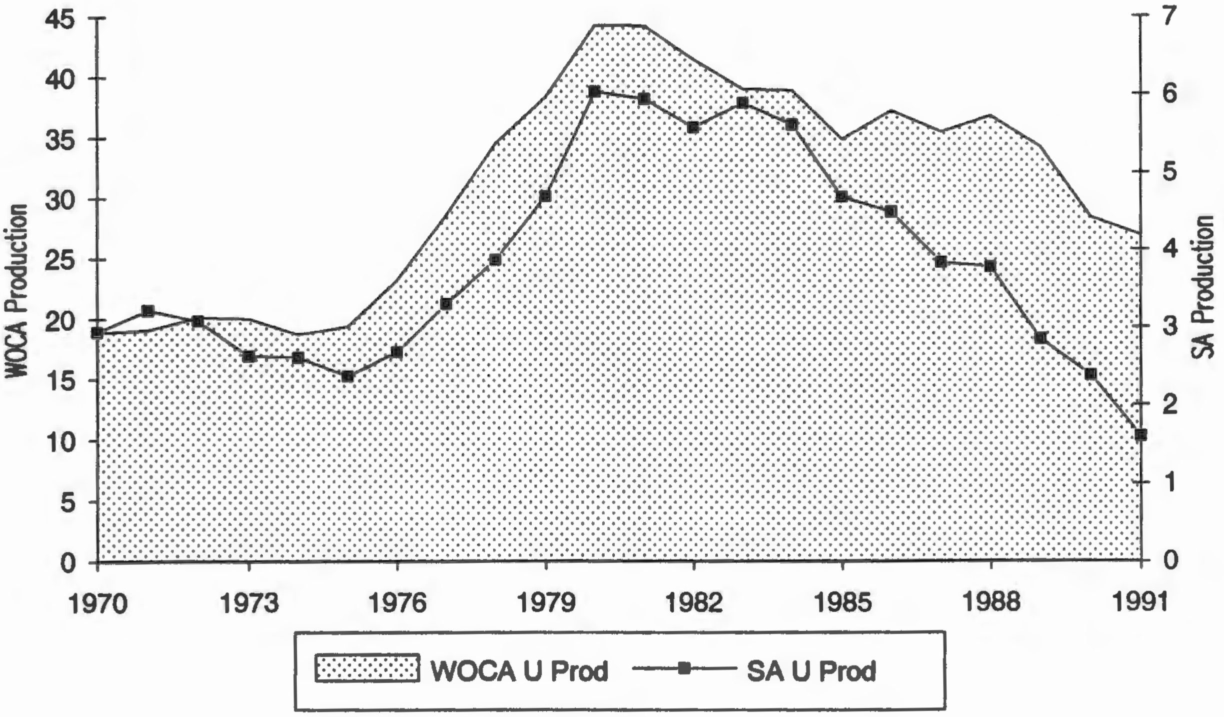
WOCA Production
SA Production
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WOCA U Prod
SA U Prod

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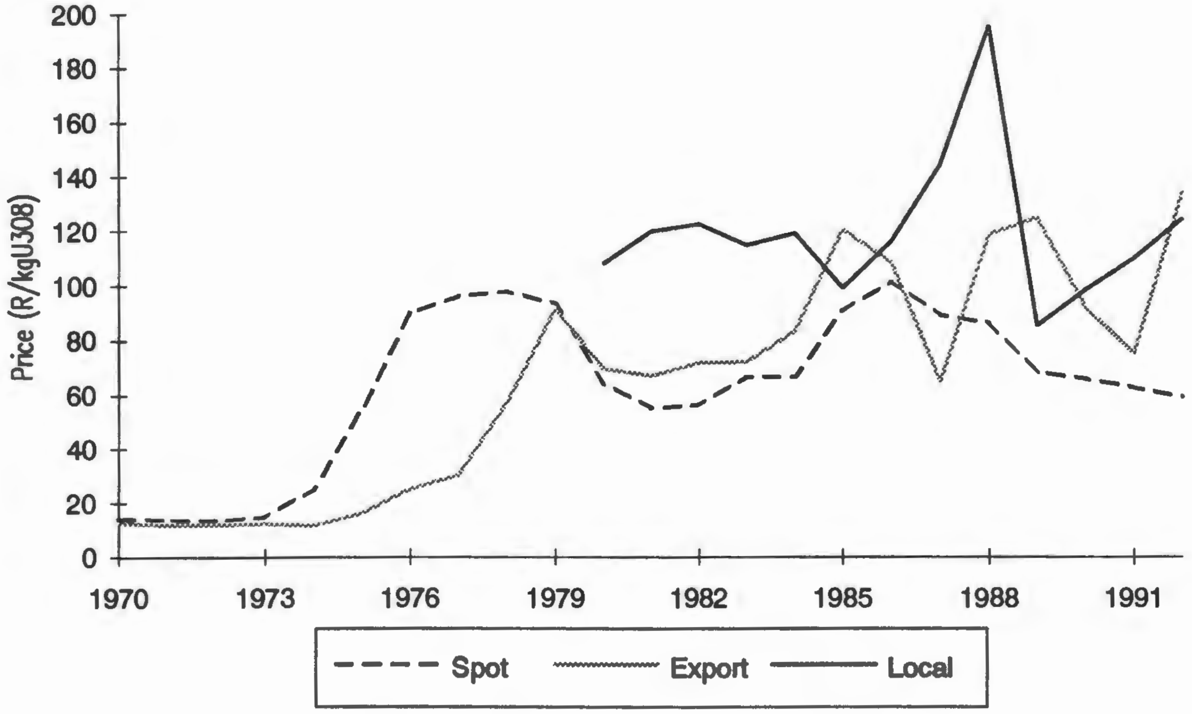
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100
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1970
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Spot
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Local

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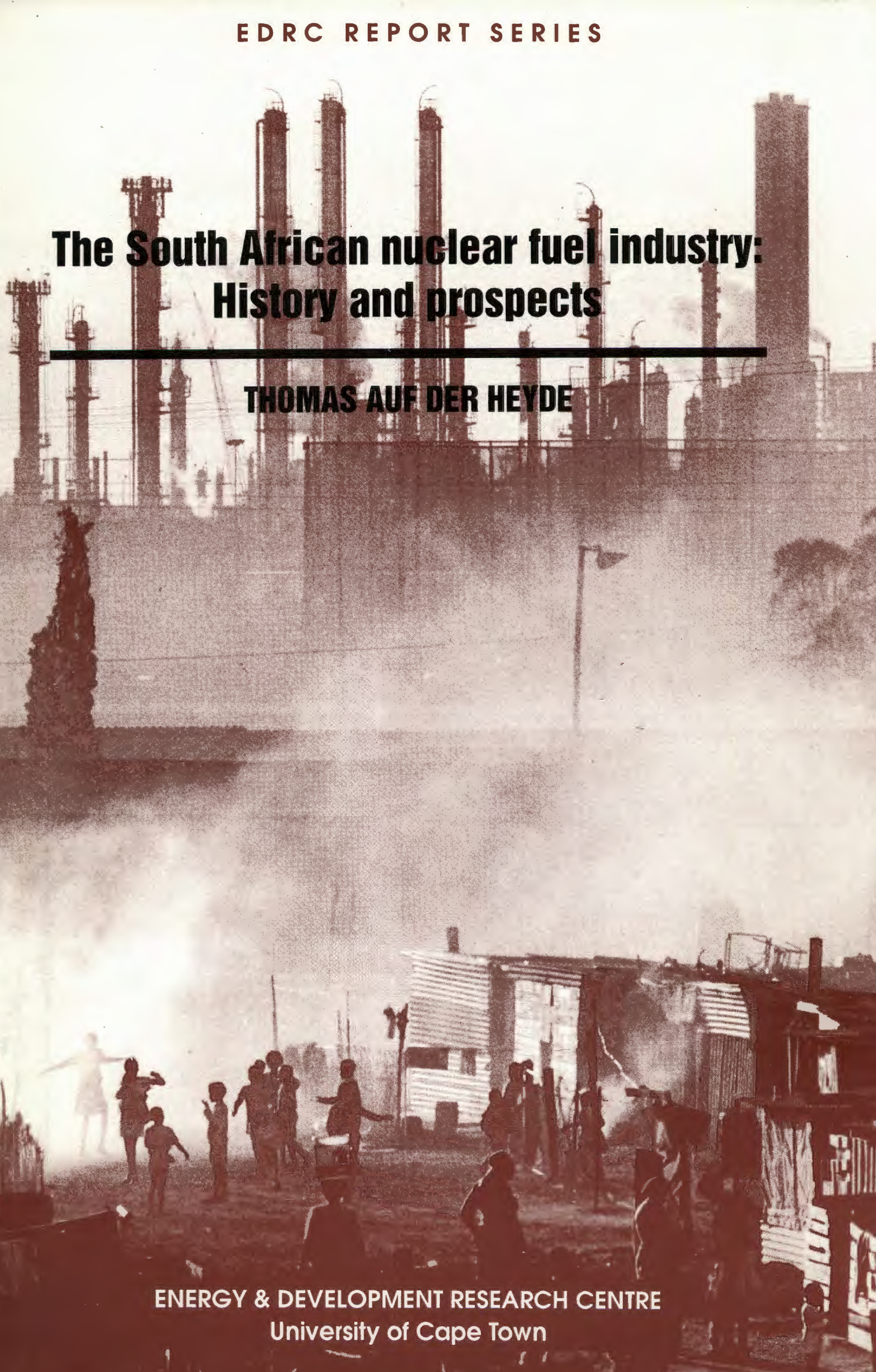

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