South African Nuclear Fuel Cycle Profile

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Abstract. In this paper the South African approach to the implementation of the Nuclear Fuel Cycle is briefly described. Nuclear currently forms only 5% of the National electricity generation mix in South Africa, with the majority being coal based. An additional 40 GWe electrical power needs to be added to the current electricity supply system, of which amount 50% is planned be nuclear. In order to facilitate the implementation of this programme the government produced a Nuclear Energy Policy in 2008[1], with the main drivers being: 1) energy security through diversification of energy sources, 2) mitigating global warming and climate change and 3) alleviating constraints regarding distribution of coal reserves, mineral resources and demographics in South Africa.

The factors which favour nuclear power in South Africa are its sizeable uranium reserves exploited as a by-product of gold production, the potential for ramping up local uranium production, the fact that South Africa already has an existing nuclear power plant, South Africa's previous nuclear fuel cycle experience, the existing regulatory nuclear framework, as well as its non-proliferation credentials. South Africa has strong ties with the international nuclear community through various international and regional treaties, conventions and bilateral agreements. In this regard South Africa has demonstrated its adherence to the principle of peaceful use of nuclear energy.

In terms of the Nuclear Energy Policy[1], the South African Nuclear Energy Corporation is presently investigating the options for the re-implementation of the nuclear fuel cycle in South Africa. The feasibility of establishing a local uranium conversion, enrichment and fuel fabrication capability in South Africa is being evaluated. South Africa is presently on the verge of creating a new nuclear energy sector based on the beneficiation of the country's uranium reserves with a clear view to being fully commercially viable in the future.[Click **here** and type your abstract.]

1. Background

Almost 95% of all electricity in South Africa is produced by the state owned electricity utility Eskom. South Africa experienced serious power shortages during the past two years due to a lack of electricity generating capacity in the national grid. The current installed capacity is nearly 40 000 MWe, with peak demand being at roughly 36 000 MWe, yielding an inadequate reserve margin of 8 – 10%.

Nuclear currently forms only 5% of the national electricity generation mix in South Africa, with coal at 87%, and the remainder from diverse sources. Nearly 4% of South Africa's electricity supply is imported from neighbouring Mozambique. South Africa is expecting an economic growth rate of 6%, which translates into a 4% electricity growth rate per year, implying that the country's electricity demand will be roughly doubled by 2025. This means that an additional 40 GWe electrical power needs to be added to the current electricity supply system, of which amount 50% is planned be nuclear. At that stage the contribution of coal to the overall electricity mix will be less than 70%.

2. South African Institutional Nuclear Framework

South Africa has an institutional nuclear framework which incorporates the necessary legislation, policies, strategies and regulations.

The relevant nuclear legislation is embodied in the two principal acts of Parliament, viz. the Nuclear Energy Act, (Act No 46 of 1999) (NEA) and the National Nuclear Regulator Act, (Act No 47 of 1999) (NNRA). The NEA provides *inter alia* for 1) the establishment of the South African Nuclear Energy Corporation (Necsa), which is wholly owned by the State and mainly responsible for nuclear research and development, 2) ministerial responsibility for the implementation of the Safeguards Agreement with the IAEA under the Nuclear Non-Proliferation Treaty and Addition Protocols, 3) ministerial authority to regulate acquisition and possession of nuclear material and equipment in consultation with the South African Council for the Non-proliferation of Weapons of Mass Destruction and 4) ministerial responsibility over the management and disposal of radioactive waste and the storage of irradiated nuclear fuel. The NNRA establishes the National Nuclear Regulator (NNR) responsible for the protection of persons, property and the environment against nuclear damage.

Policies are approved by Cabinet and enforced by the responsible government departments, principally the Department of Minerals and Energy, as supported by the Department of Environmental Affairs and Tourism and the Department of Water Affairs and Forestry. The nuclear relevant policies are the Nuclear Energy Policy (2008) and the Radioactive Waste Management Policy and Strategy (2005) [2]. Nuclear policies and strategies, in conjunction with their supporting regulations, need to be implemented by the organizations active in the local nuclear industry, viz. principally Necsa, Eskom, PBMR (Pty) Ltd, the mining and milling industry and others, under the regulatory control of the NNR.

Legislation is presently being prepared for the establishment of a Radioactive Waste Disposal Institute which will in future assume the responsibility for the operation of the National Radioactive Waste Disposal Facility for LILW at Vaalputs, presently still falling under Necsa.

3. Nuclear Energy Policy

Policy Objectives

In response to the national shortage of electricity generation capacity the government produced a Nuclear Energy Policy in 2008 that defines the overall institutional terms of reference for the nuclear industry in South Africa. The main energy policy objectives are 1) promotion of nuclear energy as part of the diversification of energy sources for securing energy supply, 2) establishment of the necessary governance structures for an extended nuclear programme, 3) creation of a framework for safety and the protection of the environment, 4) contributing to the country's socio-economic development and 5) serving as a guide to enhance the nuclear energy sector in South Africa.

The factors which favour nuclear power in South Africa are its sizeable uranium reserves, the potential of ramping up local uranium production in response to market demand, the fact that South Africa already has a nuclear power plant, South Africa's previous experience in the nuclear fuel cycle, the existing nuclear regulating framework, as well as South Africa's non-proliferation credentials.

Cardinal Policy Aspects

More specifically, the aspects which are dealt with in the Nuclear Energy Policy include:

- Security of energy supply
- Security of uranium supply
- Employment
- Public Awareness
- Human resource development

- Environmental protection
- Funding: re Institutional, technological & industrial
- A reserve of nuclear sites.

From the above list it is clear that the Nuclear Energy Policy goes beyond the purely techno-economic, environmental and public awareness considerations that are normally associated with energy policy. The socio-economic needs of the country also have to be effectively woven into the nuclear energy policy. As the latter involves large capital investments the broadest possible impact on the overall development of the country thus needs to be assured.

Nuclear Fuel Cycle Implementation

The Nuclear Energy Policy defines the role of Necsa as the agent acting on behalf of government to investigate, develop, establish, support and/or participate in uranium mining and milling, uranium conversion, uranium enrichment, fuel fabrication, spent fuel management, reprocessing and radioactive waste management.

The activities that need to be performed by Necsa in regard to each of the above steps of the nuclear fuel cycle are clearly defined in the Nuclear Energy Policy. Necsa is well-placed to perform this task on the basis of its previous nuclear fuel cycle experience gained during 1970's and 1980's. These nuclear fuel cycle facilities at Pelindaba were permanently closed during the1990's as a result of unfavourable economic circumstances. Necsa is presently engaged in the decommissioning of these redundant nuclear facilities as well as in the concomitant radioactive waste management at the Pelindaba site.

Nuclear Reactor Construction and Operation

Nuclear power is produced by Eskom's Koeberg Nuclear Power Plant (KNPP) situated 40 km north of Cape Town on the Atlantic Coast. This power plant consists of 2 PWRs of French design having a combined capacity of 1800 MWe. Nuclear power is the only viable baseline electricity option for the Western Cape which lacks adequate coal reserves.

The Nuclear Energy Policy defines Eskom's role in extending the national nuclear generation capacity, in respect of which Eskom will be acting on behalf of government.

It is stated in the Nuclear Energy Policy that the type of reactors to be constructed in South Africa in the future will be limited to PWRs and PBMRs. The deployment of the PWRs is made subject to the requirement that technology should be transferred as part of the reactor construction phase. A further requirement is to establish a viable investment program in support of the localization of design, manufacture and construction.

No decision has yet been taken in respect of the future deployment of the Pebble Bed Modular Reactor (PBMR) system in South Africa. This decision would depend on the results obtained from the PBMR demonstration module to be constructed at Koeberg as well as the performance of the PBMR fuel production plant being constructed at Pelindaba. It is not yet clear whether the PBMR would be used for electricity generation and/or for process heat applications.

Public Awareness

The Nuclear Energy Policy recognizes the need to inform the public about the risks, benefits and safety of nuclear energy. To this end the government will "initiate and sustain public awareness campaigns, education programmes and information dissemination by conducting public seminars and consultative meetings amongst others, as and when appropriate" [1].

Although the Nuclear Energy Policy does not specifically mention this, there is a need for public information and participation in nuclear issues that is built into the relevant nuclear related legislation. Nuclear operators, as prospective licensees, need to satisfy essentially two independent sets of legal requirements, viz. the environmental requirements as laid out in the National Environmental Management Act (Act No 107 of 1998) (NEMA) and the nuclear safety requirements as defined in the National Nuclear Regulator Act (Act No 47 of 1999), (NNRA).

- In the case of the NEMA, environmental impact assessments (EIA's) need to be submitted to the Department of Environmental Affairs and Tourism (DEAT) for permission (Record of Decision) to proceed with the development of land earmarked for nuclear purposes. Public scoping is part of this procedure which involves a formal process whereby the interested and affected parties, as well as the public at large, are invited to attend public meetings where information is provided about the proposed projects.

- In the case of the NNRA a somewhat different process is followed with regard to public involvement in the sense that public hearings are held at the stage when the prospective licensee has submitted its safety case to the NNR. The public is then given an opportunity to comment on the documents submitted for public scrutiny.

There is provision in the NNRA for cooperative governance between independent regulators (in this case the NNR and DEAT) according to which the above two processes may be combined for ease of implementation.

International Cooperation

South Africa has strong ties with the international nuclear establishment through various international and regional treaties, conventions, bilateral and multilateral cooperation, international initiatives, etc. In the Nuclear Energy Policy the government states its intention to cooperate and collaborate internationally within the constraint of protecting intellectual property in its national programme.

South Africa signed the Treaty on the Non-Proliferation of Nuclear Weapons in 1991 and also entered into a Comprehensive Safeguards Agreement with the IAEA in the same year. The Additional Protocol was subsequently signed in 2002. The African Nuclear-Weapons-Free-Zone Treaty (Pelindaba Treaty) was opened for signature on 11 April 1996. South Africa will host the Treaty's African Commission on Nuclear Energy (AFCONE) once the Treaty comes into force. In this regard South Africa has demonstrated its adherence to the principle of peaceful use of nuclear energy.

South Africa is a signatory of the convention on Nuclear Safety and the Joint Convention on the Management of Spent Fuel and the Management of Radioactive Waste.

South Africa will pursue bilateral cooperation with states that have relevant nuclear programmes from which South Africa can: 1) learn and benefit, 2) acquire technology, material or equipment transfer and 3) can gain opportunities for export of domestically produced nuclear services.

Regarding multinational cooperation the Nuclear Energy Policy states that South Africa will pursue such cooperation in terms of the national policy approach to multinational institutions. The IAEA is recognized as the leading multinational institution responsible for promoting the peaceful uses of nuclear energy.

With regard to initiatives on international nuclear fuel cycle activities, South Africa has for example joined INPRO (International Project on Innovative Reactors and Fuel Cycle) and GIF (Generation IV International Forum), but is still considering the benefits and obligations potentially flowing from joining GNEP (Global Nuclear Energy Partnership) and other similar initiatives.

South Africa will actively seek to promote uranium beneficiation on a regional basis. Because any future nuclear fuel cycle enterprise needs to be established on a fully commercially viable basis it is particularly important to establish partnerships where possible with international organizations in the nuclear field. Such partnerships are presently being explored by Necsa with regard to uranium conversion, uranium enrichment and fuel fabrication.

South Africa does not only cooperate on the front-end of the nuclear fuel cycle with internationally recognized companies, but also on the back-end in order to establish in this regard an integrated radioactive waste management system for the country.

4. Radioactive Waste Management Policy

South Africa adopted the Radioactive Waste Management Policy and Strategy in 2005 [2], which needs to be read in conjunction with the Nuclear Energy Policy. The Radioactive Waste Management Policy and Strategy sets out the principles on which the national radioactive waste management system needs to be established. It also defines the institutional structures necessary for policy and strategy implementation, which are: 1) the National Committee on Radioactive Waste Management, 2) the Radioactive Waste Disposal Institute, and 3) the Radioactive Waste Management Fund.

To date only the National Committee on Radioactive Waste Management has been established. The National Radioactive Waste Disposal Institute (draft Act) is currently being tabled in Parliament and is expected to be promulgated early next year, as a consequence of which the Waste Disposal Institute will be created. The Radioactive Waste Management Fund will be established at a later stage.

The radioactive waste generators need to submit their waste management plans to the National Committee on Radioactive Waste Management for recommendation to the Minister of Minerals and Energy. As part of this procedure the interested and affected parties need to be informed. This is done through the Public Safety Information Forums that nuclear licensees need to set up as part of their emergency safety measures.

Once the Radioactive Waste Disposal Institute has been duly established by legislation [3] the radioactive waste disposal facility at Vaalputs in the Northern Cape will be transferred from Necsa to the new Institute. Furthermore the Institute will also be responsible for selecting the site for, and the development of a future national deep geological disposal facility for high level waste. For its part, the future Radioactive Waste Fund will collect funds from the waste generators for eventual waste disposal. At the moment the option of direct disposal of spent fuel versus that of reprocessing and recycling is kept open by the policy.

The aim is to enable the respective role players, i.e. the waste generators (Necsa, Eskom), the pre-disposal waste operators (Necsa, Eskom, others), the disposal operator (Institute) and the Waste Fund, to function effectively within a fully integrated back-end system. An integrated national waste management system will be necessary as a result of the different types of high level waste that have to be managed to the point of disposal. Spent fuel will arise from PWRs, PBMRs as well as the Safari-1 MTR reactor.

5. Nuclear Infrastructure

South Africa was a major uranium producer during the three decades leading up to the 1980's producing as much as 6 000 tons uranium per annum. With the decline in uranium prices worldwide during the 1990's and early 2000's many South Africa gold mines producing uranium as a by-product terminated their uranium extraction activities. Currently South Africa produces less than 1 000 tons uranium per annum, but with the substantially higher market prices this figure is expected to ramp up to 5 000 tU per annum by 2015. Much of the existing mining and milling infrastructure, however, would have to be upgraded in order to attain these higher production levels. The three active producers in South Africa are presently Anglo Gold Ashanti, Uranium One and First Uranium. Others have announced intentions of commencing production in the near future.

Necsa established the historical nuclear fuel cycle programme during the 1970's and 80's. This programme was closed down during the 1990's for economic reasons following the normalization of South Africa's relations with the rest of the world. Many of these redundant facilities have been decommissioned with a view to being reused in the future for new fuel cycle facilities where possible. With the nuclear renaissance Necsa is presently planning to re-establish R&D facilities as a precursor to possible future fuel cycle facilities. This approach is in line with its responsibility in terms of the Nuclear Energy Act, 1999. The Safari-1 research reactor, a 20 Megawatt MTR Oakridge type reactor commissioned in 1965 is presently still in operation and is almost exclusively used for the production of radioisotopes.

The National Radioactive Waste Disposal Facility for LILW at Vaalputs commissioned in 1986 is currently still operating as a fully licensed facility using near-surface trenches for disposal. This facility is presently used exclusively for Eskom's LILW from Koeberg, but Necsa plans to send its waste there as well. As already stated, the Waste Disposal Institute is expected to take over the operation of Vaalputs during 2009.

The two PWRs established at Koeberg and commissioned during 1984 and 1985 are fully operational, with the option of a life extension of 10 years over and above the licensed 40 years. Considerable nuclear infrastructure therefore exists at this site. Eskom has succeeded in making a case for the establishment of the PBMR demonstration unit at Koeberg after a number of alternative sites had been investigated for this purpose. The PBMR fuel production plant will be built at Necsa's Pelindaba site which offers sophisticated infrastructure ideal for this purpose.

6. Eskom's Plans

Eskom's nuclear expansion plans are detailed below in the accompanying table. It shows the two options regarding the choice of PWR reactor type, i.e. the AP1000 (Westinghouse) and the EPR (Areva). To date Eskom has not yet made public its choice of reactor vendor. PBMRs are included in the future generation mix on the assumption that they are economically viable and suitable for electricity generation, as opposed to process heat generation. Eskom has subdivided its overall programme into two parts: The first part *Nuclear 1*, having a capacity of approximately 3 300 MWe. The second part, the so-called *Fleet*, contributes the balance of the approximately 18 000MWe nuclear generation capacity that needs to be added to the grid. The entire programme was originally scheduled to be completed by 2025, but in the light of present economic circumstances the programme may have to be revised.

TABLE 1. ESKOM'S NUCLEAR *NEW-BUILD* SCENARIOS

Item	**Low**	**Reference**	**High**
Generation capacity: (MWe)	13 000	16 000	20 000
EPRs (10x1600)		2 145	
PBMRs (13 x 165)		18 145	
Generation capacity: (MWe)	13 000	16 500	20 000
AP1000 (15 x 1100)		2 145	
PBMRs (13 x 165)		18645	

7. Necsa's Plans

Due to the nuclear renaissance worldwide, as well as in South Africa, Necsa decided to create a nuclear fuel cycle department in 2007 to investigate the feasibility of re-establishing the nuclear fuel cycle or aspects thereof in this country. As its main aim this department embarked on a series of pre-

feasibility studies involving uranium, conversion, enrichment and fuel fabrication for PWR and PBMR systems with the aim of examining available fuel cycle options for future implementation. The criteria which are used in this evaluation are based on technical, economic, commercial, institutional, socio-political and ethical considerations.

Based on the evaluation of fuel cycle options a provisional strategic plan was developed taking into account the following parameters:

- South African uranium resources and potential supply
- Minimum process plant size for enterprise viability
- South African demand for nuclear fuel cycle services
- Realistic timeframes for the implementation of the SA fuel cycle facilities
- Access to international markets
- Availability of technologies in South Africa
- Eskom's support for local fuel cycle services
- Development of a local technical skills-base

In overall terms, the initial results of this investigation indicated that South Africa would need, for security of supply purposes, a nuclear fuel cycle capability around 2020. This implies that uranium conversion, enrichment and fuel fabrication facilities would need to be established from 2018 onwards in South Africa provided they are commercially viable. In general the approach is that such facilities, being commercially viable, would supply services to the local nuclear power plants, as well as export to overseas markets. Furthermore, given the time frame until 2025 when such facilities are required, South Africa would be in a position to pursue certain of the localization options regarding uranium conversion, enrichment and fuel fabrication.

8. Conclusions

The following conclusions can be drawn from the present situation in South Africa as far as nuclear power generation is concerned, taking into consideration the country-specific nuclear profile as outlined in this paper:

- The major driving forces for re-introducing the nuclear fuel cycle are clearly defined and understood, i.e. commercial uranium beneficiation, security of supply and industrial development
- Commercial and economic considerations are the decisive criteria for long-term sustainability
- Lessons learned from the previous South African nuclear fuel cycle experience which lacked commercial viability have duly been taken into account
- Time frames for implementation of local nuclear facilities have been clearly delineated. (Conversion 10 years, enrichment 13 years and fuel fabrication 10 to 15 years)
- Human resources development (capacity building) needs to be given top priority in the fuel cycle strategic planning
- Environmental and nuclear licensing requirements need to be addressed at an early stage of the programme with concomitant capacity building having to be done at the regulator
- Relationships with reputable overseas nuclear services companies need to be strengthened and pursued to the point where partnerships can be established
- An undertaking is needed from Eskom to source a major portion of its nuclear fuel requirements from local service providers such as Necsa
- The need for a strong nuclear regulatory capability is a prerequisite for successful fuel cycle implementation.

REFERENCES

[1] Department of Minerals and Energy, Nuclear Energy Policy for the Republic of South Africa, June 2008.

[2] Department of Minerals and Energy, *Radioactive Waste Management Policy and Strategy for the Republic of South Africa*, 2005.

[3] Department of Minerals and Energy, *Radioactive Waste Disposal Institute Bill for the Republic of South Africa.*.