Framework for the cost of policy implementation of the South African nuclear expansion program

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List of Abbreviations

CCGT	Combined Cycle Gas Turbine
DME	Department of Minerals and Energy
EPR	European Pressurized Reactor; Evolutionary Power Reactor
HEU	Highly Enriched Uranium
HVAC	Heating, Ventilation and Air Conditioning
IAEA	International Atomic Energy Agency
IRP	Integrated Resource Plan
LCOE	Levelised Cost of Electricity
LEU	Low-Enriched Uranium
LWR	Light Water Reactor
MIT	Massachusetts Institute of Technology
MtU/a	Million tons of uranium per annum
NECSA	South African Nuclear Energy Corporation
NFC	Nuclear Fuel Cycle
NNR	National Nuclear Regulator (South Africa)
NPIA	Nuclear Power Implementation Agency
NPP	Nuclear Power Plant
NRB	Nuclear Regulatory Body (IAEA)
NRC	Nuclear Regulatory Commission (USA)
NSSS	Nuclear Steam Supply System
PBMR	Pebble-Bed Modular Reactor
PWR	Pressurized Water Reactor
SAPP	Southern African Power Pool
SWU	Seperative Work Unit
WNA	World Nuclear Association
WNN	World Nuclear News

Executive summary

Determining the cost of implementing a nuclear energy policy is very important due to the high costs associated with nuclear programs. Such programs may be unattainable to certain countries due to the many requirements that ensure a safe and secure nuclear sector. The IAEA has a large number of publications that indicate the requirements for implementing nuclear energy sectors. By using these publications, a framework was developed costing each of the main sectors of a nuclear energy program. These sectors correspond to the sectors that the South African government proposed for its nuclear energy policy. The main sectors are:

- Basic infrastructure development
- Nuclear power plant (NPP) sector
- Nuclear fuel cycle (NFC) sector
- Industrial involvement

An outline of the framework is attached as Appendix A. A more elaborative development of the framework is given in Chapter 2.

The Government proposes the development of 20 GWe (Eskom Holdings Limited, 2010:3) of nuclear power over the next 20 to 25 years along with the development of the entire nuclear fuel cycle and an industrial base that will ensure that South Africa is independent of other countries and has the capability to develop nuclear power plants and associated technology. By applying the framework it was possible to estimate the costs of the different sectors.

It was found by the author that the basic infrastructure and power plant sector will cost approximately R 889 billion (2008 Rand value), excluding financing costs.

The fuel cycle sector is very sensitive to global resistance and will require considerable planning to ensure that international bodies and countries are satisfied with the local intention of pursuing fuel cycle implementation. To ensure that costs are minimized the implementation of the different fuel cycle steps is crucial and will depend on the rollout plan of the power plants and the local demand for fuel and the influence of security of fuel supply. To implement the entire front end and reprocessing step it was estimated that the cost will amount to approximately R 52,3 billion.

The cost of implementing the industrial sector development was not determined, due to the many factors involved. The different requirements in the sector may be supplied by similar industries currently active in South Africa. Most of the current industries will require further accreditation and may have to increase capacity if South Africa is to become a global supplier of nuclear technology. Sources indicated that the different sectors will require trained personnel numbers in the region of 77 000 (direct jobs). The amount of indirect jobs that will be created will be in the regions of 300 000. Government therefore has a huge responsibility to ensure that training and education programs are developed that can supply the demand of trained personnel. The different industries involved should also ensure that the relevant personnel are trained in advance, to obtain the required accreditation and experience.

The final outcome of the revised Integrated Resource Plan (IRP2) was not yet available when this dissertation was completed. The outcomes of the future nuclear programs may therefore be different from the extent of developments and investments estimated by this study. The cost of reactors and basic infrastructure will have to be scaled to the revised objectives while the costs of the fuel cycle may change considerably due to a possible decrease in local demand. These changes will affect the economy of scale on many of the sectors of development.

The framework is generic and may be applied to different nuclear development programs and countries.

Chapter 1. Introduction

The South African government plans to generate a significant amount of energy from nuclear power as well as develop the nuclear fuel cycle and industrial support base. These goals are set out in the Nuclear Energy Policy of South Africa (Section 2.3). Reaching the proposed goals will require specific developments to ensure that South Africa is competent to handle the increased responsibility of an extended nuclear energy sector.

The IAEA has produced a range of different publications which could be used by member states interested in developing a nuclear program. Guidelines help interested countries to develop their nuclear programs within a set of constraints that help to alleviate tensions due to the sensitive nature of nuclear energy. By using the IAEA guidelines a country will assure the global community with regard to the intentions of its nuclear program. They further help to ensure that the resultant nuclear program is safe, secure and up to standard.

South Africa is currently planning to enlarge its nuclear power plant fleet. The Koeberg power station provided South Africa with an initial opportunity to establish a capable nuclear infrastructure. It is now essential that attention be given to the different requirements of implementing the different sectors. As will be shown, each of the requirements ensures a competent and efficient nuclear program in an interested country.

1.1. Problem statement

In 2007 Eskom proposed an increase in South Africa’s nuclear capacity, but after the program was shelved in 2008 due to financial constraints (WNN, 2008). Nuclear power is known for its capital intensive nature and this fact necessitates the development of sound financial planning to ensure a successful nuclear building program. To ensure sound financial planning the costing of the program needs to be thorough and has to take all the necessary factors into account.

For the extensive and ambitious development plans for the nuclear sector of South Africa, it is necessary to **develop a framework according to which the cost of implementing a nuclear energy policy can be determined**.

The following section covers further background into the need for the study.

1.2. Background

The study is concerned with the proposed future nuclear energy sector of South Africa. The background is therefore separated in two sections. The first section covers the reasons for developing an expanded nuclear energy sector in South Africa; the second section will elucidate the need for a framework development as presented in the dissertation.

1.2.1. Reasons for Nuclear Energy in South Africa

In the Nuclear Energy Policy (2008:4) the government of South Africa formulates ambitious goals to develop the country's nuclear energy program. The nuclear program is in part necessary as South Africa has an energy supply shortage which has already forced large mining and smelter companies to curtail on their electricity usage. The electricity shortages have placed economic pressure on the country. Coal power plants are being constructed to ensure a sufficient supply of electricity for the future needs of these large companies and the growing population of South Africa.

However, the planet is under huge pressure from the production of greenhouse gases, to a large extent from fossil fuelled power plants, and this factor plays a role in deciding the type of power plants to be constructed in the future. President Zuma (2009) stated at the Copenhagen Climate Conference that with financial and technical support from developed countries, South Africa could reduce CO_2 emissions by up to 34 % by 2020, and 42 % by 2025. Throughout the lifecycle of the different energy sources, nuclear and renewable energy sources emit the least amount of Greenhouse gases (Erdogdu, 2006:3064).

By diversifying energy sources greater security of energy supply is achieved. As South Africa has indigenous uranium resources, nuclear energy is seen as a viable option to alleviate the current energy and climate change issues (Department of Minerals and Energy, 2008:7).

1.2.2. Motivation for this study

South Africa is planning to install 20 GWe of nuclear energy, develop a local industrial support base as well as expand and localise the entire nuclear fuel cycle (Department of Minerals and Energy, 2008:4). Before such large scale developments can take place the country must ensure that the necessary infrastructure, organizations and resources are in place.

The costs associated with nuclear energy, with the relevant industrial support base and with other facets are fairly well known. However, such projects involve large capital investments and long construction times (IAEA, 2008a:6), which increases the financial risks to investors and makes such investments sensitive to market changes and to local and global conditions (IAEA, 2008a:1).

Extensive funding and financing resources will be required due to the size of the planned expansion program. Financial demands will be required for the development of a skilled workforce, a strong industrial base, other necessary infrastructure and the expansion and development of the proposed Nuclear Fuel Cycle, as well as for acquiring and constructing the power plants, among others.

Due to the sensitive nature of nuclear developments and the risk of nuclear arms proliferation it is important that a transparent development process is used, under the guidance of international organizations such as the IAEA. Therefore the framework and cost analysis will predominantly be based on IAEA information and best practices for nuclear programs. This will also lend credibility to the analysis and aid in decision making.

Developing a framework for such a cost analysis will help to make the country concerned aware of the financial requirements for such expansion projects, thereby ensuring that relevant policies are and remain feasible. If all the necessary infrastructure requirements, including funding and financing, are met, South Africa will know that it has the necessary ability to operate the nuclear energy sector safely in a sustained fashion. This also creates a base for further development and expansion of the nuclear energy sector, easing international concerns and attracting support from international organizations and vendors, which could increase a further influx of knowledge, experience and resources.

1.3. Objectives and possible beneficiaries

The following research objectives were thus formulated:

- Develop a general IAEA-based implementation framework for each nuclear sector.
- Determine the main objectives of South Africa’s Nuclear Energy Policy.
- Determine the cost of implementing the nuclear energy policy.
- Propose possible implementation strategies.

The following beneficiaries can then be identified:

- Stakeholders in the development of the South African nuclear energy sector.
- Other countries interested in implementing nuclear energy. The cost of policy implementation framework may be applied to the specific country’s needs.

1.4. Structure of the dissertation

The dissertation contains five chapters, including the introductory chapter. The second chapter covers the background required to develop a costing framework. Chapter 2 also outlines the nuclear energy policy's objectives. The third chapter proposes a method to determine the cost of policy implementation after applying the framework to the South African nuclear energy policy's objectives, both of which were outlined in Chapter 2. The method is then applied in Chapter 4 to establish the cost of implementing a South African policy. In the final chapter conclusions are drawn concerning the application of the framework.

The following sections cover each of the chapters individually to give a broad outline of the project.

1.4.1. Chapter 2: Background and Framework development

Chapter 2 develops a framework for each of the main nuclear energy sectors, namely: basic infrastructure, nuclear power plant sector, nuclear fuel cycle sector, and the industrial involvement sector. There are different requirements necessary to implement the different sectors, each of which will require funding and financing. Short discussions are included in the chapter to give some background on each of the requirements.

The framework for each of the sectors is developed within a three-phase implementation strategy. Each of the phases, or degrees of implementation, requires an increasing amount of resources.

Before applying the framework to the case of the South African government's proposals, it is necessary to determine the scale of the development proposed in the Nuclear Energy Policy of South Africa. The main goals are therefore summarised during the latter sections of Chapter 2.

1.4.2. Chapter 3: Framework application method

A method is proposed of arriving at the objectives of this study, which were proposed in Section 1.3. Each of the policy's goals corresponds to a sector in the framework, and it is therefore possible to determine the degree of development for each of the sectors as well as which of the sector's requirements apply to South Africa.

1.4.3. Chapter 4: Framework application

Having developed the framework and establishing government's goals, it is now possible to apply the framework to determine the cost of implementing the policy. While determining the cost, the extensive complexity and the amount of resources required for the implementation of the policy and nuclear energy projects are clearly illustrated. To apply the framework to South Africa in a meaningful manner, the current situation within each of the sectors had to be determined.

Possible implementation strategies are proposed by positioning the requirements within the relevant phase of the nuclear program's development.

The costs are then determined by assuming that the sector is implemented in total.

1.4.4. Chapter 5: Conclusions

The final chapter provides a summary and the associated conclusions of the entire dissertation and the different findings of Chapter 4. The cost of the sectors will be indicated as well as possible strategies in regard of implementation.

In Chapter 2 a costing framework is developed from IAEA-based principles and other literature sources.

Chapter 2. Framework development and Nuclear Energy Policy review

2.1. Introduction

South Africa, through Eskom, is currently expanding its energy generation capacity due to economic and population growth. To ensure security of energy supply, multiple generation sources are proposed. South Africa is mostly dependent on fossil fuels and due to the decrease in these resources, other alternatives are also sought after. One of these alternatives is nuclear energy. Due to the extensive funding and financing requirements of nuclear energy, it is important to determine whether the country is capable of implementing nuclear energy strategies and policies.

To develop a framework for the cost of policy implementation, the different requirements of implementing nuclear energy sectors are established in Section 2.2. A framework is established from the literature, based predominantly on IAEA practices, for application in later chapters to the determination of the cost of South Africa's strategies. The Nuclear Energy Policy of South Africa is also summarised, to determine the extent to which the framework should be applied and what the future nuclear plans of the South African government are.

2.2. Implementation framework

In this section a framework is developed which indicates the requirements for establishing the main sectors associated with nuclear energy. A framework is important as it indicates the main aspects that determine the cost of implementing the different sectors. In Chapter 4 the framework is applied to the South African conditions with reference to the objectives proposed in Chapter 1.

The International Atomic Energy Agency (IAEA) is a United Nations body tasked with assisting countries in the safe use of atomic energy. The IAEA is recognised as the leading agency for promoting the safe use of nuclear energy (DME, 2008:21). The following section is therefore closely related to IAEA practices regarding nuclear programs and their safe use.

Implementing a nuclear energy sector involves the following main development aspects (IAEA, 2006a:5):

- Basic infrastructure development
- Nuclear power plant (NPP) sector
- Nuclear fuel cycle (NFC) sector
- Industrial involvement

The possibility of developing the latter three aspects is dependent on the development and implementation of certain parts of the basic infrastructure, such as a nuclear regulator. The basic infrastructure (Section 2.2.1) is specifically related to the power plant implementation, but most of the infrastructure aspects are also critical to both the fuel cycle and industrial developments.

Development phases are proposed, for each of the aspects, by the International Atomic Energy Agency (2007a:6). Each of these phases is associated with its own specific milestone. These phases were mainly developed for the basic infrastructure and power plant implementation developments. The NFC and industrial involvement aspects can be developed coincidentally or separately, depending on the country's situation and policies concerning these aspects.

The phases are:

- Phase 1 – The considerations before the decision to launch a nuclear power program.
- Phase 2 – After policy decisions, this phase is associated with the preparation to construct the nuclear power plants.
- Phase 3 – This phase involves different activities to implement the nuclear power plants.

The following milestones, associated with the respective phases, should be reached before the next phase is considered:

- Milestone 1 – After considering the different facets of nuclear energy the country should be ready to make a knowledgeable decision and a commitment for nuclear energy in the country.
- Milestone 2 – The different issues associated with inviting bids for the nuclear power plants should be resolved and the country should be ready to invite bids from vendors.

- Milestone 3 – The country should be ready to commission and operate the nuclear power plants.

Each of the main sectors is covered in the following section to determine the requirements of implementation.

2.2.1. Basic infrastructure development

The following sections will cover the basic infrastructure developments during each of the phases as well as a short description of each of the basic infrastructure aspects.

2.2.1.1. Milestone/Phase 1

Phase 1 is associated with the economic assessment of the expansion or implementation project as well as with exploring the different financing options available (IAEA, 2007a:27). A country should become familiar with the different issues associated with nuclear energy and develop strategies to fund the basic infrastructure requirements (IAEA, 2007a:26). Due to the capital intensity of nuclear energy developments, government participation is almost always required. The necessity for a nuclear expansion project should be weighed against other possible development programs planned by the government. It should be determined whether the nuclear project should receive priority, since its funding and financing requirements may prohibit other simultaneous development projects (IAEA, 2007b:33).

Organisations necessary for policy development and strategy development are mainly active during this phase. Funding is therefore required for the founding and operation of these agencies (IAEA, 2007b:33). Funds will further be required for the development of the required legislation (IAEA, 2007a:26).

2.2.1.2. Milestone/Phase 2

The basic infrastructure requirements determined in the first phase are implemented and those aspects which are crucial to start of the bidding process are completed (IAEA, 2007a:10).

After the country has made a knowledgeable decision regarding nuclear energy and its necessity to the country, funding for basic infrastructure should be provided (IAEA, 2006a:19). The local participation in the nuclear energy program should be covered by mainly local financing, which should be provided by government and/or local owners of the proposed nuclear energy infrastructure and facilities. Government funds for such developments will mostly arise from the allocated budget, while the owner’s funds include equity as well as local bonds and loans (IAEA, 2007b:33).

The different basic requirements are briefly discussed in the following sections. The extent of the development will have a large influence on the costs associated with each requirement.

a) Nuclear policy development

The first step in implementing nuclear energy in a country requires the development of government policy. This portion of implementing the basic infrastructure requires the expert advice of policy advisors and parties interested in the whole process of nuclear development. Before a policy is implemented, especially concerning nuclear power, the general public should be involved in discussions. This allows the different parties involved to ease the concerns of the public regarding the safety of the proposed project and the necessity thereof in the energy generation mix. The necessity will be determined with regard to energy requirements, economy and the role of nuclear energy as an agent of development in the country (IAEA, 2006a:2).

Government should specify the role it will play in the funding and financing of the different development stages and further identify the different sectors in which the country should participate as well as the degree of localisation that should be implemented within these sectors (IAEA, 2007a:71).

The announced policy should clearly indicate the commitment by government to the development project. This ensures that investor or creditor concerns, regarding policy and political changes, do not affect the project and place the investments at risk (IAEA, 2009a:5).

b) Nuclear legislation and nuclear regulatory body

As nuclear energy and nuclear materials are such sensitive and volatile issues, it is important that countries comply with the correct laws and regulations. These laws and regulations have to cover the following aspects (IAEA, 2006a:8).

- Countries should have laws in place that assign power to regulatory bodies, to ensure that the implementation and operation of nuclear facilities as well as the use of nuclear substances are safe and secure.
- There must be laws in place to regulate the quantities and types of nuclear material used and the associated technology, to ensure their peaceful use.
- Laws and regulations should prohibit the illegal use of radiation sources as well as ensure protection against the dangers associated with the misuse of such materials.
- Laws assigning liability to the different parties involved in nuclear activities.

- Laws on radioactive waste and spent fuel, as well as on the decommissioning of the nuclear power plants at the end of their lifetimes. These laws provide for the necessary funding and capability to deal with these issues safely and successfully.
- The treaty of non-proliferation acts as safeguard against countries using material to develop nuclear explosive devices.
- National laws should bind and force countries to implement international conventions and treaties.
- Environmental protection laws should stipulate that environmental assessments must be performed before nuclear projects are implemented.
- Laws should be developed to ensure the early notification of nuclear accidents and of the associated conditions and effects of the accident.
- In the case of privately owned nuclear facilities using foreign investments, it is important to have regulations and laws covering all the different parties.
- Developing laws and regulations ensuring the safe operation and safety of nuclear facilities.

The nuclear regulatory body (NRB) ensures that the above mentioned laws are complied with and therewith has the following functions (IAEA, 2006a:10):

- Developing the necessary safety requirements and enforcing the implementation thereof.
- Developing the different codes and standards required.
- Ensuring the safe operation of nuclear facilities by assessing the safety and reviewing the safety analysis reports.
- Authorising, licensing and inspecting nuclear projects and activities, ensuring the standard of development proposals and their precise implementation.
- The enforcement of the different regulations, laws, codes and standards which are essential to a healthy nuclear sector.
- Ensuring that the country and its nuclear sector comply with international standards for the safe use and development of nuclear activities.
- Informing the public about nuclear activities and providing assurance regarding safety and other factors of concern.

The NRB as well as the laws and regulations ensure that all concerned parties are protected. These issues form part of the basic infrastructure; their omission would result in an unsafe nuclear energy sector without guarantee for the protection of the public and environment.

c) Physical facilities

The following physical facilities are required for the implementation of a nuclear power sector, and the size of the nuclear power program will determine the extent of physical infrastructure development and the importance of each of these facilities.

i) Site

The site, on which a nuclear power plant will be constructed, is critical in ensuring the efficiency of the power plant as well as providing protection to the plant and public. The following factors are important in this regard:

- Water supply

Water is essential in the production of electricity for most generation systems using a steam cycle. This is also the case for nuclear energy, and in the case of Light Water Reactors (LWR's) water is further required as moderator and coolant. The water sources also act as final heat sink, which has a major effect on the efficiency of the cycle. Where water bodies such as rivers, lakes or the ocean are not available, cooling towers act as final heat sinks (IAEA, 2006a:12).

- Power supply

Electricity is required during construction and in the initial phases of development. After construction, some reactor designs require offsite power for diversity in their safety systems. During normal operation, onsite power is provided by the reactor itself (IAEA, 2006a:12).

- Transport and access

Rail, road or water transport facilities are essential during construction, for the delivery of equipment and for the access required by the construction teams and other personnel. After construction such infrastructure remains important for provisions and access. For the current reactors, which are developed in modules, it is important to ensure that the transport systems are capable of allowing access to the plant. This is especially important for road transport; the roads have to provide sufficient capacity for large sections of the plant and equipment (IAEA, 2006a:12).

- Earthquake monitoring system

To evaluate seismic activity, micro-earthquake monitoring systems should be constructed or placed on the site location and neighbouring regions, to determine whether the seismic licensing analysis was correctly and accurately performed. This is required before construction starts (IAEA, 2006a:12).

- Meteorological and hydrological station

A meteorological and hydrological station is very important physical infrastructure requirement. It has to be erected before site approval is awarded. A meteorological station is important as it determines factors such as average wind speed and direction as well as dispersion factors. In cases of accidents and radioactive release analysis, these factors have an impact on the area covered by radioactive fallout and the risk associated to the public and environment. Hydrological stations are important for accident scenarios and assessing possibilities of floods and tsunamis (IAEA, 2006a:13).

- Town site and administrative facilities

The workforce and other personnel, important to construction and operation, should be provided with accommodation and other necessary facilities (IAEA, 2006a:13).

ii) Grid

The grid size is critical in the choice of whether to implement nuclear power. A single nuclear power plant produces a large amount of energy and therefore the IAEA (2007c:3) proposes that a single power plant should not exceed 10% of the total grid capacity. This ensures security of supply and stability in the case of refuelling and shut down. If this percentage is exceeded lots of pressure will be placed on the other generation sources to ensure supply while the NPP is off-line. The grid should also be able to supply offsite emergency power to the plant safety systems (IAEA, 2006a:13).

iii) Physical protection facilities

Although most Generation 3 power plants are designed and constructed to withstand missiles and airplane crashes and to continue controlling the plant by diversity and separation of safety systems, it is further important to ensure the availability of security features to protect against unlawful access to the plant and surroundings (IAEA, 2006a:13).

iv) Component manufacture and material supply

If the policy allows for local manufacturing of certain plant components or of the entire plant, the facilities for such purposes will have to be constructed, either before plant construction starts or during this process, as part of technology transfer contracts. This is therefore very dependent on government policy, regarding localisation and scope of manufacturing activities. The country may start by providing contracts to local civil contractors and suppliers of non-nuclear material. This could reduce expenses in these sectors of the construction process. Viability of such developments will play a role in the decision-making process (IAEA, 2006a:13). Knowledge transfer in regards to the construction of the nuclear island is essential.

This requirement is discussed in Section 2.2.4.

v) Standard calibration laboratory facilities

Calibration is essential for instrumentation used in nuclear power plants. These instruments are used in the measurement of important parameters which are critical for the accurate construction and operation of the plant. These instruments are calibrated periodically (IAEA, 2006a:14).

vi) Storage/disposal of low or and medium level radioactive waste.

Waste storage facilities should be provided for low-level and medium-level radioactive waste. It is important that these facilities are managed correctly to ensure that the public and the environment are protected from misuse or the release of radioactive substances (IAEA, 2006a:14).

vii) Spent fuel storage and disposal facilities

Different stages of storage are implemented. During the first stage, part of the power plant building is used for the storage of spent fuel in spent fuel pools. These pools ensure decay heat removal and allow for adequate storage of spent fuel for a number of years, depending on design. The second stage is interim storage of the spent fuel. Reprocessing, for the reuse of fissile material, may be a major process during this stage in the future. Such processes would have a major impact on the final stage of disposal. Currently it is hard to ensure the effectiveness of disposal facilities due to the presence of elements with extended half-lives and their continued activity. If processes are implemented which reduce these active periods, continued security could be guaranteed. These facilities are mostly located in stable geological locations (IAEA, 2006a:14).

Spent fuel management is discussed further in Section 2.2.3.

viii) Safeguards plan and equipment

This infrastructure requirement is essential in ensuring the protection, accountability and peaceful use of nuclear material. Having these structures in place instils public and international confidence in the country’s ability to partake in the peaceful use of nuclear materials and technology (IAEA, 2006a:14).

ix) Emergency response facilities and notification of nuclear incidents

In case of incidents, the regulatory body and/or other organisations should have provided procedures for the evacuation of plant personnel and surrounding population. To ensure appropriate action, the personnel, public, and other affected parties should be notified about the incident and its details (IAEA, 2006a:15).

x) Communication

Communication facilities are necessary during construction and operation. These systems are also important for the above-mentioned requirement of notification in case of an incident (IAEA, 2006a:15).

d) Human resource development

As nuclear energy and its associated fields are such exact sciences, the development of qualified and competent personnel is important. Different sectors of expertise are important to the nuclear development in a country, as discussed in the following sections.

i) Government policy

The departments required in the development of the nuclear energy policy must have competent personnel to ensure the development of a viable policy and associated strategies. Due to the long term commitments associated with nuclear power and issues such as storage of nuclear waste, it is important that the policy developers are adequately trained in the field of nuclear energy and related fields (IAEA, 2006a:15).

ii) Nuclear regulatory body

As this regulatory body is responsible for assessing the safety of designs and operation it is imperative that its personnel should have a wide knowledge base. Trained personnel are required to ensure that the regulations and codes developed are sufficient for the safe licensing, construction and operation of nuclear facilities.

The knowledge base should provide for the following functions (IAEA, 2006a:17):

- Establishing the correct regulations, codes and standards.
- The evaluation of the different facilities and their designs, such as reactors, fuel cycle and waste management facilities, as well as design and manufacturing facilities. These facilities and the design thereof should comply with all relevant standards and regulations prior to licensing and operation.
- The issuance of licences to facilities and operators.
- Developing sufficient emergency measures in case of incidents.

iii) Radiation and workforce awareness

Knowledge and awareness among the workforce concerning radiation and its dangers are very important, to ensure that personnel are capable of assessing situations and react in a safe and sensible fashion (IAEA, 2006a:17).

iv) Financial knowledge

Due to the uniqueness of nuclear energy and its associated financing issues, it is important that personnel concerned are trained in the different financing strategies and risks of nuclear projects.

v) Human resource development programs

Certain sectors of the nuclear industry require similar skills to those of other construction and industrial sectors, while the remaining skills are more exact and specific. It is important that these nuclear specific skills should be developed locally. While the nuclear power plant project is underway expertise should be developed locally to localise the design, construction, installation, commissioning and management of nuclear projects. This allows project operator(s) the opportunity to develop skills, create jobs and decrease costs of future projects (IAEA, 2006a:22).

The contract with the vendor can include on-the-job-training. Before such training occurs, study courses should be made available to ensure that the required theoretical knowledge base is up to standard. On-the-job-training will ensure that a sufficiently large group of experts are available who are capable of running and maintaining the plant during operation. These trainees can either be from the private or public sector or both. By the use of simulators the operators can be trained to control and operate the reactor safely (IAEA, 2006a:23).

Personnel in the Quality assurance and Quality management sectors should be provided and/or trained by the utility, vendor or independent body, to create a cadre of responsible people who are familiar with the risks of nuclear energy and will ensure that all facets of the processes involved comply with the highest standards. They will further ensure that all tests and inspections are up to standard and sufficient to ensure safety and quality (IAEA, 2006a:23).

There should be trained personnel with the capability of managing a nuclear project ensuring that the project is completed on time, within budget and in accordance with the relevant quality standards (IAEA, 2006a:24).

vi) Public consultation and environmental assessments

The public consultation process is conducted in two phases: the first phase is concerned with the public's opinion on implementing nuclear energy in the power generation mix and the second phase deals with the environmental impact of the chosen site and the intended construction. At this stage an environmental assessment should be complete for the chosen sites (IAEA, 2006a:224).

The consultation process should allow all parties sufficient time and provide the necessary project proposals, to develop their cases and concerns. Main drivers for acceptance are the benefits to the community and country. The main objective is to relieve concerns regarding nuclear projects and to assure the public about the safety and benefits involved. The project leaders should compare the project to different alternatives to prove that such a project is the most viable and beneficial. Cross-border consultation should also take place if several countries are affected (IAEA, 2006a:25).

Environmental management plans and systems should be developed, ensuring that the project complies with the environmental assessment and regulations. This includes an environmental action plan in case of an accident (IAEA, 2006a:26).

2.2.1.3. Milestone/Phase 3

During this phase certain of the basic infrastructure aspects are finalised although others such as the regulatory body and legislation should have been completed before this phase can commence.

2.2.2. Nuclear power plant sector

This section discusses the three stages of NPP development as well as the associated method of cost calculation.

2.2.2.1. Milestone/Phase 1

An understanding of the obligations and commitments that arise from the use of nuclear power is developed, along with an investigation whether nuclear power plants are economically and practically viable in regard to the grid capacity as well as possible implementation strategies. Therefore the main costs considered, during this phase, are associated with the strategy and policy development agencies, as is the case for the basic infrastructure development (IAEA, 2007a:9).

2.2.2.2. Milestone/Phase 2

The development of a financial plan is essential during this phase. Such plans will attract vendor attention and should include issues such as financial risk management and the funding and financing strategies. The requirements for construction and implementation of the development strategies should be completed while the owner should have the structures and personnel in place for competent management of nuclear power plants. At the completion of this phase the country should be able to invite bids from possible vendors (IAEA, 2007a:27).

The owner and operator of a NPP will have between 200 and 1000 personnel. These include scientists, engineers and people from other technical fields necessary for the safe operation of the reactors. As mentioned before, experience and on-the-job training for the relevant personnel, such as operators and other essential personnel, are critical for the safe operation of nuclear power plants. Such opportunities, of obtaining expertise, can be included in the contract with the relevant vendor of the power plants (IAEA, 2007c:7). Training of plant operating personnel should commence during this phase (IAEA, 2007a:43).

2.2.2.3. Milestone/Phase 3

During this phase all the strategies and plans for the construction and commissioning of the NPP are implemented. This phase is associated with the highest capital expenditure (IAEA, 2007a:11). Most of the previous phases' costs, in the NPP implementation, are covered by the costs associated with the development of the basic infrastructure.

The main construction cycle involved:

a) Licensing

This includes the licensing of the site, plant, operators and obtaining construction permits (IAEA, 2007a:66)

b) Site preparation

Preparing the site for construction to start includes the development of transport access, communication systems and other facilities, such as offices and on-site medical centres (IAEA, 2007b:75). The site preparation is covered in Phase 2 of the basic infrastructure development of the previous section (Section 2.2.1).

c) Construction of plant buildings and structures

The main requirements are the provision of sufficient concrete and construction equipment for the erection of the plant structures (IAEA, 2007b:76).

d) Installation of the equipment, components and systems

This section requires personnel with experience in the installation of nuclear components. During the installation of the core components the utility's maintenance staff should participate, gaining experience in the installation of important components (IAEA, 2007b:77).

e) Plant commissioning

This is the phase associated with the testing of the plant and its systems before commercial operation starts (IAEA, 2007b:78).

The capital cost of constructing the power plant is divided into direct and indirect costs, each with the following cost aspects (IAEA, 1993:22):

- Direct costs
    - Structures and facilities
    - Reactor equipment
    - Turbine plant equipment
    - Electric plant equipment
    - Miscellaneous plant equipment
    - Cooling systems, etc.
- Indirect costs
    - Construction management, equipment and services
    - Home office engineering and services
    - Field office engineering and services
    - Personnel training

The fore-cost or overnight cost is determined by adding the direct and indirect costs as well as the owner's cost (licensing costs and administration and associated buildings costs (WNA, 2010b)), cost of acquiring spare parts for operation and contingency costs (unforeseeable costs (IAEA, 1993:145)). To determine the total capital investment cost, interest during construction and escalation as well as interest on the escalation are taken into account and added to the fore costs (IAEA, 1993:22).

The following table indicates the spread of costs, over the construction period, and the overnight cost. The overnight cost gives an indication of the total cost of developing the plant if such an amount would be required all at once, while not taking interest during construction into account.

Table 1 – Construction outlays per construction year (2002 dollar value)

Year	-5 $/kWe	-4 $/kWe	-3 $/kWe	-2 $/kWe	-1 $/kWe	Total Outlay (mixed $/kWe)	Overnight Cost (2002 $/kWe)	Total Cost (2002 $/kWe)
Nuclear	165	444	566	471	185	1831	2000	2557
CCGT	0	0	0	236	243	478	500	549

Source: MIT, 2003:142

The nuclear costs are compared to the combined cycle gas turbine (CCGT). From the table it is clear that nuclear energy has a significantly higher overnight cost and longer construction time. This is one of the main factors influencing investor confidence.

The cost estimations in the MIT study (2003:145) were updated in 2009 (MIT, 2009:7) and the comparative figures are indicated in the following table.

Table 2 – Cost comparisons different generation alternatives (2009 dollar)

			LCOE		
	Overnight Cost	**Fuel Cost**	**Base Case**	**w/carbon charge $25/tCO$_2$**	**w/same cost of capital**
Unit	$/kW	$/mm Btu	c/kWh	c/kWh	c/kWh
MIT (2003)					
$2002					
Nuclear	2000	0.47	6.7		5.5
Coal	1300	1.20	4.3	6.4	
Gas	500	3.50	4.1	5.1	
Update					
$2007					
Nuclear	4000	0.67	8.4		6.6
Coal	2300	2.60	6.2	8.3	
Gas	850	7.00	6.5	7.4	

Source: MIT, 2009:6

From the table it is clear that overnight and other costs have risen sharply from 2003. Although the overnight cost of nuclear power doubled, the fuel price did not rise as sharply as the comparative generation alternatives and therefore the electricity price of nuclear power increased comparatively less than the alternatives. It should further be clear that a country planning to invest in nuclear power should have the necessary resources or investor incentives to ensure the required financing.

Approximately 200 of the utility's personnel can be on-site to receive training while the plant is constructed. These will mainly be the operation and maintenance personnel (D'Olier, 2005:31). The construction personnel requirements are indicated in Section 2.2.4.3.

2.2.3. Nuclear fuel cycle sector

This section discusses the relevance of the implementation phases to the NFC.

2.2.3.1. Milestone/Phase 1

The fuel cycle should be evaluated to determine the feasibility of different implementation strategies. Developing a complete nuclear fuel cycle with the first NPP is in all likelihood not economically viable. The implementation of the different stages will be determined by the natural resources available and whether the country has the capability of developing or obtaining the subsequent processes. Back end strategies have to be developed concerning spent fuel (IAEA, 2007a:57).

The different sectors within the fuel cycle are hereafter discussed as well as their current operations worldwide. Worldwide supply and demand will also have an effect on whether a country decides to implement its own nuclear fuel cycle activities.

STEP 1. Mining

Open pit or underground mining is used to extract the ore. Uranium is also extracted as by-product in other mining operations.

The world is currently producing less uranium than required, due to external supply. Countries such as the USA and Russia supply military HEU (highly enriched uranium), which is blended down to form LEU (low enriched uranium). This has been a source of nuclear fuel that has filled the gap between supply and demand. In 2007 the demand was 69 110 t while the supply was 43 300 t.

With the current surge in interest in nuclear energy, the demand is projected to rise to between 70 000 t and 122 000 t of uranium per annum by 2030 (IAEA, 2009b:14).

STEP 2. Concentration/ processing

- Uranium is extracted from the ore and pulverised before leaching takes place, dissolving the U_3O_8.
- Solvent extraction or ion exchange is used to remove the U_3O_8 from the leachant.
- Calcination produces yellow cake, and further processing produces almost pure UO_3 (Duderstadt & Hamilton, 1976:589-591).

The current worldwide production capacity of the uranium concentration processes is 56 946 t of uranium. If nuclear energy expands as proposed, production capabilities will have to increase to supply the demand. (IAEA, 2009b:14).

STEP 3. Conversion

- The hydrogenation process converts UO_3 to UO_2.
- UO_2 reacts with hydrogen fluoride to produce UF_4.
- By the addition of fluorine salt, UF_4 is converted to gaseous UF_6 (Duderstadt & Hamilton, 1976:589-591).

The current UF_6 conversion capacity is estimated at 74 000 t of uranium per annum. The demand for UF_6 was 60 000 t per annum. The expected demand in 2025 is estimated at between 60 000 t and 90 000 t of uranium per annum. To supply this, the world supply capacity will have to increase with increasing demand. The current plants are also ageing and will have to be replaced or upgraded to keep up with demand (IAEA, 2009b:14).

STEP 4. Enrichment

There are different techniques to enrich the U^{235} isotope in the natural uranium mixture. These include:

- Electromagnetic separation.
- Gaseous diffusion.
- Ultracentrifuges.
- Laser excitation (Duderstadt & Hamilton, 1976:589-591).

There are new gaseous centrifuge plants being constructed around the world to replace the gaseous diffusion plants. Gaseous diffusion is an older technology which is more energy intensive and requires more separation stages to achieve a desired enrichment. The demand in 2007 was estimated at 40 million SWU (Separative Work Unit) while worldwide capacity is estimated at 56 million SWU. Another 5,5 million SWU is added by the down-blending of HEU.

Future demand is estimated between 50 and 85 million SWU in 2025. Therefore increased capacity might be necessary, depending on the degree of nuclear development worldwide (IAEA, 2009b:14).

STEP 5. Fabrication

- Enriched UF_6 is chemically converted to UO_2 or UC (this is the form used in the fuel pellet).
- Ceramic (UO_2 or UC) is compacted into small pellets.
- Manufacturing of mechanical components and tubing.
- Pellets are loaded into tubing and into final assembly (Duderstadt & Hamilton, 1976:589-591).

In 2007 the demand for LWR fuel was approximately 7500 tons of heavy metal while the production capacity is estimated at 11500 tons of heavy metal. The demand will range between 6000 and 12000 tons of heavy metal per annum in 2025 (IAEA, 2009b:14).

STEP 6. Fuel burnup

During this section of the fuel cycle the fuel is added to the reactor and used to generate energy.

STEP 7. Spent fuel management

Different approaches exist in this regard. Certain countries choose reprocessing while others directly dispose of the used fuel without reprocessing. Reprocessing entails the recycling of fissile material not spent during the fuel burnup stage for further use (IAEA, 2009:9).

Due to the economic barrier to nuclear energy, the nuclear market has become more efficient in the different sections of the fuel cycle, developing into a market which can compete with other energy sources (IAEA, 2005:3).

2.2.3.2. Milestone/Phase 2

Fuel cycle strategies should be completed before invitations to bid are issued as they will have an effect on the initial fuel purchase and future reloads (IAEA, 2007a:57). If the country has an aggressive implementation policy and wants to provide for the proposed power plants, development and construction should start during this phase or as soon as the relevant basic infrastructure is in place, such as the NNR and relevant legislation as well as the consent of the broader nuclear community.

2.2.3.3. Milestone/Phase 3

The different sectors will have to be developed if the country decides to pursue its own fuel cycle activities. If implementation started during the second phase, it will continue during this phase.

If the NFC policy provides for the implementation of single or multiple stages in the fuel cycle, the following life cycle steps are followed. The costs of implementation for each of the fuel cycle sectors will be divided into these life cycle steps.

a) Licensing documentation

The licensing documentation shall establish the safety of the facility by including a safety analysis report as well as operating limits and conditions. These documents will be reviewed by the nuclear regulatory body, leading to a license being granted if all the laws and regulations are adhered to (IAEA, 2008b:7). It is therefore important that the regulatory body has the necessary expertise to develop the required legislation and regulations to ensure the safety of all nuclear fuel cycle facilities (IAEA, 2008b:9).

b) Siting

The siting should take into account the impact of external hazards and natural phenomena, to ensure the safety of the public and environment during all forms of release, either authorised or during accidental releases. Public acceptance and the safety risks associated with the specific fuel cycle facility will have an influence on the siting (IAEA, 2008b:17).

c) Design

If a country decides to develop its own fuel cycle processes the designs will have to comply with nuclear and other safety specifications. The type of facility will determine the degree of safety required in regard of the possibility of nuclear accidents and other accidents related to the chemical and industrial sectors (IAEA, 2008b:21).

This life cycle step includes costs that will not normally be recovered in the price of the product. These costs include (Shropshire *et al.*, 2007:8):

I. Planning costs
II. Research and Development costs
III. Prototype or pilot plant costs
IV. Generic licensing costs

These costs are known as the **early life cycle costs**.

d) Construction

Before construction commences the owner should ensure that the necessary licensing is obtained from the nuclear regulator. Construction shall ensure the safety of the workers and surrounding population (IAEA, 2008b:32).

e) Commissioning

Testing procedures will be implemented to ensure that the safety features in the design satisfy the requirements, before operation is commenced (IAEA, 2008b:33).

The costs associated with siting, construction and commissioning are combined in the following aspects:

I. Capitalised preconstruction costs (Shropshire *et al.*, 2007:8):
    - Land and land rights
    - Site permits
    - Plant licensing
    - Plant permits
    - Plant studies (safety studies)
    - Plant reports
    - Other costs
    - Contingency costs

II. Capitalised direct costs (Shropshire *et al.*, 2007:8):
    - Structures and improvements
    - Process equipment
    - Auxiliary equipment
    - Electrical equipment
    - Heat addition/rejection system
    - Miscellaneous
    - Special materials (nuclear materials and special shielding material (Shropshire *et al.*, 2007:37))
    - Simulator (Training (Shropshire *et al.*, 2007:37))
    - Contingency costs

III. Capitalised support services (Shropshire *et al.*, 2007:9):

- Field indirect costs (temporary buildings, hiring of construction equipment, etc. (Shropshire *et al.*, 2007:37))
- Construction supervision
- Commissioning and start-up costs
- Demonstration test run costs
- Design services offsite (design reports from design “home” office (Shropshire *et al.*, 2007:37))
- Project manager or construction manager offsite service costs (management activities costs (Shropshire *et al.*, 2007:37))
- Design services onsite costs (engineering services from designers (Shropshire *et al.*, 2007:37))
- Project manager or construction manager onsite service costs
- Contingency

IV. Capitalised operations (Shropshire *et al.*, 2007:9)

- Staff recruitment and training
- Staff housing
- Staff salary related costs
- Other owner’s costs
- Contingency costs

V. Capitalised supplementary costs (Shropshire *et al.*, 2007:9)

- Shipping and transportation
- Spare parts
- Taxes
- Insurance
- Decommissioning (will depend on policy)
- Contingency

The **total overnight cost** is the sum of the costs associated with points **I** to **V**.

VI. Capitalised financial costs (Shropshire *et al.*, 2007:9)

- Escalation
- Fees
- Interest during construction
- Contingency

The sum of points **I** to **VI** is the **total capital investment costs**.

f) Operation

To ensure sufficient and safe operation, competent personnel should be trained in accordance with the different skills required (IAEA, 2008b:56).

g) Decommissioning

As in the case of the NPP the owners shall ensure that the required funding and resources are available for decommissioning (IAEA, 2008b:49).

2.2.4. Industrial involvement

Industrial involvement requires companies to comply with very high standards and codes to ensure high quality equipment (IAEA, 2007a:61). The following sections provide a breakdown of the different phases of development as well as the different sectors which may be implemented. The requirements of the sectors are also indicated.

2.2.4.1. Milestone/Phase 1

The strategy development agencies should determine the country's capabilities with regard to the possibility of local industrial participation, especially in view of the high quality standards associated with nuclear equipment. Short and long term policy, concerning local participation, should be developed after the assessment of the country's current position (IAEA, 2007a:61).

2.2.4.2. Milestone/Phase 2

The degree of local participation should be specified in the bidding process and such participation should satisfy the requirements stipulated by the vendor to ensure the necessary level of quality and reliability. If the nuclear safety graded components are beyond the capabilities of local industries, equipment or areas with lower safety requirements may be pursued.

2.2.4.3. Milestone/Phase 3

If industrial involvement is part of the development policy the industrial sectors can be developed during any of the development phases. If development only starts during this phase and depending on the strategy, the resulting support base may provide operational support, such as spare parts and maintenance, to future operations of completed power plants. If the industrial involvement has developed sufficiently, subsequent power plant constructions may to a larger degree, or entirely, be covered by local industries.

The different resources required for nuclear power plant industries are described under the following headings. These will constitute only the main sectors within the NPP industrial involvement.

a) Manufacturing

This point covers the main system and safety-related components, including (D’Olier, 2005:25):

- Reactor pressure vessels
- Steam generators/ moisture separator reheaters
- Control rod drives and fuel elements
- Steam turbine generators and condensers
- Pumps
- Valves
- Class 1E switchgear and equipment
- Control equipment

If the country wants to pursue the manufacture of one or more of these components, the relevant facilities and personnel will have to be developed or acquired. If similar components are manufactured for other industries, the facilities will have to be modified to ensure that the prescribed quality standards, for nuclear safety grade components, are met.

b) Fabrication

Modern reactors use prefabricated modules to decrease construction time and enhance accuracy during the development of the equipment or sections, as they are constructed in construction facilities and not on-site.

The modules include (D’Olier, 2005:26):

- Mechanical equipment modules
- Piping, electrical and valve modules as well as piping assemblies
- Structural modules
- Electrical equipment modules
- Reinforced steel modules

This sector is dependent on the type of reactor system chosen. If older second-generation plants are constructed, less off-site fabrication might be required.

c) Labour

If the country wants to develop its ability to construct power plants by using local personnel, the following crafts should be developed and, if related, personnel from similar construction crafts could be trained in specific nuclear applications, to ensure the higher quality standards (IAEA, 2007a:41).

- Construction craft labour

Table 3 indicates the different construction crafts as well as the approximate number of personnel required to construct a single unit.

Table 3 – Craft description and requirements

Craft description	Craft Percent	Peak Personnel Average Single Unit
Boilermakers	4	60
Carpenters	10	160
Electricians/Instrument Fitters	18	290
Iron Workers	18	290
Insulators	2	30
Labourers	10	160
Masons	2	30
Millwright	3	50
Operating engineers	8	130
Painters	2	30
Pipefitters	17	270
Sheetmetal Workers	3	50
Teamsters	3	50
Total Construction Labour	100	1600

Source: Adapted from D'Olier, 2005:30

- Craft supervision – approximately 80 supervisors are required per generation 3+ reactor (D'Olier, 2005:30).
- Site indirect labour – these personnel are required to support the craft personnel and account for a total of approximately 10% or 160 personnel (D'Olier, 2005:30).
- Quality control inspectors – approximately 40 inspectors required (D'Olier, 2005:30).
- Nuclear steam supply vendor and subcontractor staffs – at least 140 administrators, engineers and loss control personnel per unit (D'Olier, 2005:30).
- Engineer, Procure and construction contractors – approximately 100 per unit including management, engineers, schedulers and clerical personnel (D'Olier, 2005:31).
- Owner's operating and maintenance staff – these would account for 200 personnel (D'Olier, 2005:31).
- Start up personnel – 60 personnel per unit (D'Olier, 2005:31).
- NRC inspectors – at least 20 inspectors will be on and offsite during construction to monitor different activities (D'Olier, 2005:31).

From the above mentioned crafts, it is clear that the number of personnel required is quite extensive. Due to the high quality requirements of nuclear system construction, certain of the mentioned crafts would require highly trained craftsmen with specific skills related to nuclear systems ((D'Olier, 2005:82). These high standard techniques or skills can be obtained through skills development courses and training.

Table 4 is a summary of the different personnel requirements in the construction of a single NPP.

Table 4 – Summary of personnel requirements per single NPP unit

Personnel Description	Peak Personnel Average Single Plant	Peak Personnel Multiple Plants
Craft Labour	1 600	8 000
Craft Supervision	80	400
Site Indirect Labour	160	800
Quality Control Inspectors	40	200
NSSS Vendor and Subcontractor Staffs	140	700
EPC Contractor's Managers, Engineers and Schedulers	100	500
Owner's O&M Staff	200	1 000
Start-up Personnel	60	300
NRC Inspectors	20	100
Total	2 400	12 000

Source: Adapted from D'Olier, 2005:31

Personnel cost is one of the main costs associated with nuclear developments which include the areas of design, construction, installation and commissioning and project management. Localising these fields of expertise will decrease costs for the implementation of nuclear power plants (IAEA, 2006a:22).

By using semi-skilled labour the number or people required during the nuclear development program will be different than the numbers proposed in the Table 4. The numbers were developed for the USA where the workforce is made up of mostly skilled personnel.

d) Construction equipment

During construction the country may provide the following equipment, if such equipment is available (D'Olier, 2005:32). This will decrease the cost of hiring and importing the equipment from other countries:

- Very heavy lifting cranes
- Pipe bending machines
- Automatic welding machines
- Automatic rebar assembly machines

e) Material

Large amounts of material are used in the construction of a NPP. If the country has limited capability in providing components or fabricating modules, materials may be provided for the construction. Vendors will have to be satisfied that the materials meet the required quality standards. Table 5 indicates the main materials used and the approximate amounts used in the construction of Generation 3+ nuclear power plants.

Table 5 – Material requirements

Material	Approximate Quantity
Concrete	352 000 m^3
Reinforced steel and embedded parts	46 000 tons
Structural, Miscellaneous and Decking steel	25 000 tons
Large bore pipe	80 000 m
Small bore pipe	132 000 m
Cable tray	67 000 m
Conduit	370 000 m
Power cable	427 000 m
Control wire	1 650 000 m
Process and instrument tubing	230 000 m

Source: Adapted from D'Olier, 2005:33

From Section 2.2 it should be clear that the requirements for each of the nuclear energy sectors are extensive and capital intensive. It is therefore very important for countries to develop feasible nuclear energy policies with regard to the specific country's capacity and capability. The following section (Section 2.3) is a summary of the South African nuclear energy policy.

2.3. Nuclear energy policy review

The South African government has an ambitious development program planned for nuclear energy and also plans to develop the nuclear fuel cycle as a whole. Nuclear energy is seen as an important option for the reduction of greenhouse gases. South Africa plans to become globally competitive in the nuclear energy sector as well as in the nuclear fuel cycle arena. All these expansions are planned while ensuring the safety of the public and environment as well as complying with global standards and legal requirements for the peaceful use of nuclear energy (DME, 2008:3).

Security of energy supply is achieved by diversifying energy sources as well as by assuring that the sources are locally produced and sustained. This means that a country is not totally reliant on a single source of energy or on a specific country for the supply of energy or energy producing capabilities (Greenhalgh & Azapagic, 2009:1061). Hence nuclear energy is seen as a source of energy to achieve diversity. South Africa has the capability to produce nuclear energy, in all its facets, thus achieving a locally sustained energy source. The country is rich in uranium and other resources and, with development, could be self-sufficient in the supply of all that is required for sustaining a nuclear reactor fleet (DME, 2008:7).

To achieve this, government has developed a nuclear energy policy which is summarised in the following sections. The policy is used as reference to establish the main sectors proposed for development. The relevant main sectors and their requirements of the framework will be applied to the current situation in South Africa and its nuclear program.

2.3.1. Policy objectives (DME, 2008:9)

The following objectives were outlined by government in the policy:

- Government wants to promote nuclear power by developing industrial support to design, manufacture and construct nuclear energy systems.
- Establish governance structures that create a framework for the continued use of safe, secure and environmentally friendly nuclear energy.
- Nuclear energy should be a source of development for South Africa and its people both socially and economically.
- The policy should create a climate for development and act as guide for promoting, supporting, enhancing, sustaining and monitoring the nuclear energy sector.
- Create a globally competitive and self-sufficient nuclear energy sector in the future.

- Obtaining economical benefit by controlling un-processed uranium ore for export purposes.
- To ensure that adequate land is available for the generation of nuclear power in South Africa.
- Create an environment for the participation of the private sector in nuclear energy.
- Ensure security of energy supply.
- Improve the lives of the South African public and promote skills development in nuclear energy while ensuring the advancement of science and technology.
- Ensure that the emission of greenhouse gases is limited or decreased.

2.3.2. Policy principles (DME, 2008:15)

The policy principles are:

P1. Nuclear energy will serve as a diverse primary energy source to ensure security of supply.

P2. Developing nuclear energy in South Africa will require developments in infrastructure, creation of jobs and development of skilled workers. By developing these fields nuclear energy will contribute to the growth of the South African economy and facilitate technology development.

P3. Nuclear energy will be part of the solution towards decreasing the effects of climate change.

P4. The development of nuclear energy will take environmental impact into account.

P5. The different sectors of nuclear energy will operate under a legal regulatory framework and comply with international standards.

P6. Nuclear energy will only be used for peaceful purposes complying with national and international laws and obligations.

P7. By ensuring that nuclear and radiation safety remains the highest priority, property, the public and the environment will be protected.

P8. The use of uranium will be optimised to ensure sustainability thereby including the use of recycled uranium.

P9. Institutions will be developed to introduce or develop the human resources necessary to manage nuclear infrastructure.

P10. The skills necessary to enable the design, development, construction and marketing of a locally developed nuclear reactor and fuel cycle system will be acquired. Depending on the extent of nuclear development in South Africa, an industrial support base will have to be developed. To attain certain technology for the nuclear energy sector, technology transfers will be optimised.

P11. The South African nuclear energy sector will comply with international obligations concerning safeguards and security measures.

P12. The research, development and innovation in nuclear technology will be supported by government. Government will also support nuclear energy innovation programmes worldwide.

P13. South African innovative technology as well as intellectual property rights, in the nuclear energy sector, will be protected and upheld by government.

P14. The South African public will be informed and made aware of the nuclear energy program.

P15. To ensure that the objectives of the policy are reached, government will make sure that the necessary funding is available to develop nuclear technology. Further to ensure that other important technologies continue operations, price support mechanisms may be implemented.

P16. To ensure that economy of scale is achieved and to optimise the introduction of the nuclear industry on a large scale, the power reactors will be acquired according to a fleet approach.

Government will ensure that the policy is implemented and will make sure that the necessary support is available in attaining the goals as set out in the policy. The support necessary will include financing, human resources and competency development as well as managing and acquiring uranium stockpiles. Government will further cooperate internationally and regionally to ensure markets exist for future nuclear products and services and also for their procurement from other states. Government will also support global nuclear initiatives. This will take place within local and global legal frameworks (DME, 2008:18).

Private investments in all aspects of the South African nuclear fuel cycle will be promoted (DME, 2008:19). To develop a commercial nuclear industry in South Africa an industrial support base will have to be established, as it currently does not exist. The support base will design, develop, manufacture, commercialise, sell and export the products developed by the nuclear industry (DME, 2008:24). Participation of the private sector will be encouraged. In the case of public-private partnerships Eskom will be the controlling shareholder and main owner and operator of nuclear reactors (DME, 2008:23).

2.3.3. Nuclear fuel cycle development and current status

This section covers the plans for development of the different fuel cycle sectors.

- Uranium mining and milling

Government will ensure that uranium remains a sustainable source of secure nuclear fuel supply for South Africa. The resource will also be exploited and processing capacity should be increased to match global demand tendencies (DME, 2008:25).

- Uranium conversion

South Africa is dependent on other countries for the conversion process. Therefore to develop an active nuclear fuel cycle in South Africa the country should obtain conversion capabilities to benefit from indigenous uranium resources (DME, 2008:26).

- Uranium enrichment

There are no active enrichment capabilities in South Africa. Government plans to determine whether such capabilities will be viable and also wants to obtain access to active enrichment programmes worldwide to ensure security of supply.

Economically viable technology will have to be developed or acquired from countries with active enrichment programmes.

It will also have to be established whether security of supply can be obtained if South Africa remains dependent on other countries for enriched fuel and whether these countries will be able to ensure continued supply with the currently planned nuclear expansion programs worldwide (DME, 2008:26).

- Fuel fabrication

This sector of the fuel cycle is not currently active in South Africa. Fuel fabrication capabilities will have to be developed to support the proposed fuel cycle industry in South Africa (DME, 2008:26).

- Waste management

Waste will be handled in accordance with the Radioactive Waste Management Policy and Strategy for South Africa (DME, 2008:27).

- Reprocessing of used fuel

The viability of reprocessing capabilities will be evaluated by Necsa and government. This is important if the sustainability of uranium resources is to be ensured (DME, 2008:27).

2.3.4. Nuclear reactor construction and operation

South Africa plans to build a large fleet of Pressurised Water Reactors. The implementation of the building process will be used as an opportunity to develop the industrial support base, the technology and competency necessary to be self-sufficient in the design, manufacturing and construction of nuclear reactors.

2.3.5. General

The export of un-processed uranium will be restricted to ensure adequate reserves for the needs of the South African nuclear energy sector and security of energy and uranium supply (DME, 2008:30).

The nuclear energy sector is seen as an industry with lots of job opportunities for the population. The development of the sector will further increase opportunities. To ensure that the workforce is skilled and competent, government will ensure the recruitment or development of the necessary personnel (DME, 2008:31).

Funding will be required for the different institutions involved, for the research and development of current and innovative technologies and for the development of an industrial support base. Government will investigate the possible funding mechanisms to realise and implement the nuclear energy policy (DME, 2008:32).

2.4. Chapter summary

Chapter 2 indicates the different requirements of implementing nuclear energy sectors in a specific country. The main sectors of development are: basic infrastructure, nuclear power plant sector, the nuclear fuel cycle and the industrial involvement of a country in nuclear energy. The Nuclear Energy Policy of South Africa was summarised to be used in determining the main sectors proposed for South Africa.

To apply the framework developed in Section 2.2 to the South African Nuclear Energy Policy, the procedure used is explained in the following chapter.

Chapter 3. Framework application methodology

This chapter describes the method used to determine the cost of implementing the nuclear energy policy of South Africa, and the knowledge gained from such studies. The framework developed in Chapter 2 is quite general and applies to any nuclear development program. To determine the cost of implementing South Africa's policy, the framework should be applied to the South African situation.

An outline of the framework, developed in Chapter 2, is attached in Appendix A, which indicates the main cost factors for each of the main sectors of nuclear developments.

3.1. Application advantages

The application of the costing framework verifies its relevance to nuclear programs.

By developing and applying the framework the following insights are gained:

- The requirements for each of the main nuclear sectors are indicated and briefly explained. This gives an indication of the extensive commitment required for the implementation of nuclear programs.
- Costing studies provide insight into the viability of policies and their objectives. The development of nonviable policies does not instil confidence in investors and places the country and its government in a bad light. The framework may serve as guide in policy development.
- By indicating which factors require the most capital, countries and/or utilities may develop feasible strategies in reaching the project objectives.
- Implementation frameworks currently exist although such frameworks have not been developed for the fuel cycle and industrial sectors. These frameworks have also not been developed in terms of the implementation costs of the different sectors.

The application of the framework in regards to the South African situation should attain the above-mentioned perspectives.

3.2. Framework application

From the development of the framework in Chapter 2 it is clear that there are four main sectors in nuclear programs. These main sectors are (IAEA, 2006a:5):

- Basic infrastructure development
- Nuclear power plant (NPP) sector
- Nuclear fuel cycle (NFC) sector
- Industrial involvement sector

Before applying the framework it is important to determine which of the main sectors are included in the nuclear development program of South Africa. By analysing the nuclear energy policy and its objectives it is possible to categorize the objectives into the relevant main nuclear sectors. The policy is used as reference for future strategy as it is the main action plan proposed by the government in regard of nuclear developments.

After determining which main sectors are relevant, it is possible to focus on each of these sectors to determine the cost of complying with the necessary requirements.

The main strategy in regard of framework application is then described as follows:

- Determine the current situation of each of the framework requirements

Applying the framework requires information on the current situation of the main sectors, included in the development program.

Determining current circumstances will clearly indicate the capacity of the different main sectors as well as the availability of the associated requirements in South Africa, which apply to the country due to the active nuclear program. The assessment is necessary since some requirements may already be fulfilled and will not contribute to the cost of implementation, unless these sectors are not at the required capacity.

- Expand or implement each of the requirements to obtain the future objectives

Each of the main sectors has different phases, each with its own requirements and associated costs. The policy and other sources are clear on the proposed goals for most of the main sectors in South Africa. The phases and associated requirements are discussed in terms of financial influence and extent of required developments to reach the policy’s goals. Development scenarios will be proposed for the sectors for which development strategies are not clear.

- Expansion and implementation require funding and financing and will amount to the costs of implementing the policy and its objectives

Within each of the sectors there will be main cost drivers which have the largest influence on the cost of implementing that specific sector. Determining the main cost drivers will help to indicate which aspects have the largest influence on the success of the proposed developments. By using available data it is possible to determine the cost of implementing each of the main requirements. If required, these data have to be adapted to represent the cost of the developments proposed by the policy.

Determining the main cost factors will also help to develop implementation strategies to ensure that the objectives are reached with the least amount of risk to the different stakeholders involved. By adding the costs of the different requirements, it is possible to calculate the cost of each of the main sectors, which in turn may be used to calculate the cost of implementing the nuclear energy policy.

3.3. Summary

The main steps of the study are therefore as follows:

- Determine the South African nuclear energy policy’s main sectors of development.
- Determine the current status of the nuclear program in South Africa.
- Determine, from the policy, the extent of developments proposed within each sector.
- Determine which of the requirements in the framework are met and may be excluded from cost calculations.
- Apply the framework and projected degree of developments to the sectors proposed by the policy.
- Determine the main cost drivers within each main sector of developments.
- Determine the implementation costs.

Chapter 4 indicates the results after applying the above mentioned methodology, as well as a discussion of the main results.

Chapter 4. Applying the Framework Application Methodology

This chapter discusses the results after determining the main development sectors proposed by the nuclear energy policy's objectives. The relevant sectors of the framework are applied after determining the extent of proposed developments as well as the current situation of each of the sectors. The cost of implementing the different sectors is calculated and discussed.

The following section determines the main sectors proposed by the policy.

4.1. South African nuclear energy policy objectives

The overall objective of the nuclear energy policy is to ensure that South Africa becomes globally competitive in the design, manufacture and deployment of nuclear energy systems, power reactors and the nuclear fuel cycle (DME, 2008:6). Implementation will only occur after the viability of such developments has been proven (DME, 2008:4). In the long term the South African government proposes self-sufficiency and global competitiveness in the different nuclear energy sector (DME, 2008:10).

The following main sectors are covered within the government's long-term vision:

4.1.1. Basic infrastructure development

Development of the basic infrastructure, which is required for nuclear power plants and other nuclear sectors, will be included in the nuclear build program. Many of the requirements have already been established for the Koeberg nuclear power station.

The degree of development of the basic infrastructure is dependent on the implementation strategy of the South African nuclear expansion program. The current basic infrastructure should be evaluated to ensure sufficient capacity for the extended program.

The basic infrastructure requirements proposed by the IAEA, for member countries interested in implementing nuclear programs, is discussed in Section 2.2.1.

4.1.2. Nuclear power plant sector

Government proposes the use of technology transfer in the conventional nuclear building program. The proposed technology is that of Pressurised Water Reactors (DME, 2008:28). A fleet approach is to be used in the procurement of the reactors (DME, 2008:17). The country further wants to develop its own nuclear reactor (DME, 2008:16).

The development of a domestically designed reactor will not be included since local technology development lies in the distant future, due to the current limited technology expertise in the reactor design sector and the nuclear component development industry. Benefits may arise from technology transfer contracts and minor changes to designs, although such developments are dependent on the development of the industrial support base sector. The locally developed PBMR project has also been shelved by the government, and large-scale beneficiation from this project is not expected in the near future.

The degree of development of the nuclear power plant sector is mostly determined by the requirement for increased energy generation over time, as well as by the availability of resources and alternative generation methods. The proposed target is to expand the nuclear generation capacity by 20 GWe (Eskom Holdings Limited, 2010:3).

The requirements for general nuclear power plant development, proposed by the IAEA, are discussed in Section 2.2.2.

4.1.3. Nuclear fuel cycle (excluding power plants)

South Africa will strive to implement, or obtain interest in, the entire nuclear fuel cycle (DME, 2008:25). Implementation will be associated with the development of local fuel cycle systems and the use of technology transfer (DME, 2008:16).

Government, through NECSA, will:

- undertake and develop uranium conversion capabilities (DME, 2008:26);
- investigate the viability of enrichment capability development (DME, 2008:26);
- design development strategies on nuclear fuel fabrication capability (DME, 2008:27);
- investigate the viability of a reprocessing capability (DME, 2008:27).

The above-mentioned objectives indicate the proposed development strategies for the different sections of the fuel cycle.

Waste will be handled according to the waste management policy and strategy (DME, 2008:27).

The different sectors and their requirements are discussed in Section 2.2.3.

4.1.4. Industrial involvement

Technology transfer and a fleet approach will be used for the power plant sector, ensuring that industrialisation processes are optimised (DME, 2008:17). Industrial involvement lies in the design, manufacture and construction of nuclear energy systems (DME, 2008:28). By developing local fuel cycle capabilities, industrial support and expertise will be developed and may be applied to the implementation of the different sectors.

The industrial involvement and the associated general requirements are discussed in Section 2.2.4.

The above-mentioned main sectors are covered in this study. The other outcomes named by Government in the Nuclear Energy Policy are directly or indirectly included in these main sectors. The main sectors are interrelated and interdependent, in regard of the degree of implementation of each of the sector. The framework therefore sheds light on the cost of implementing these proposed sectors individually and as a whole.

4.2. Framework application

The following sections indicate the results found after applying the general framework to the South African scenario. Each of the main sectors is covered. The framework provides a clear indication of cost factors which are relevant to such nuclear developments. The different sectors and their related aspects are discussed in accordance to the framework presented in Section 2.2.

4.2.1. Basic infrastructure development

Many of the issues discussed in the basic infrastructure development have been established due to the active nuclear power plant in South Africa. The established aspects are indicated and discussions follow on whether these aspects are at the sufficient capacity. Infrastructure requirements will only be regarded as previously implemented if clear proof thereof was found during research.

4.2.1.1. Milestone/Phase 1

Phase 1 of the Basic infrastructure development is the phase wherein the country acquires all the relevant knowledge to make a knowledgeable decision regarding nuclear energy.

a) Assessment of nuclear energy

The issues involved in nuclear power plant operations are well known to South Africa due to the safe operation of Koeberg over the past 20 years (DME, 2008:13). The nuclear fuel cycle sector was active in South Africa and therefore a certain extent of awareness of the relevant issues is assumed. It is further assumed that the high quality standards and other factors required for the industrial involvement are clear to all the relevant parties.

The fact that the government has made a decision and developed a policy on nuclear energy and its role in the country, would suggest that such requirement assessments have been completed to a certain extent and therefore very little costs will further be incurred. As developments continue and new issues come to light, further assessments and choices will have to be made, which will require guidance from policy and strategy agencies.

b) Economic assessment

Economic assessment is a very important facet of the basic infrastructure development. It is important due to the high capital intensity associated with nuclear energy sectors. Policy in favour of nuclear programs should not be accepted if a country is not able to raise the required funding and financing. From the policy itself it seems that certain assessments have not been completed in South Africa. Although the future goal is self-sufficiency and global competitiveness, it is stated in the policy, for many of the sectors, that feasibility should be proved. Although these feasibility studies will include factors other than economics, it remains one of, and possibly the most important determining factor.

There will therefore be cost assessments, within the relevant agencies, determining the economic feasibility of the different sectors, especially in the nuclear fuel cycle and industrial involvement sectors. Such assessments indicate to the public whether nuclear energy is a viable generation alternative. Expansion projects should not place pressure on the availability of funds for future development projects, especially if government will be a financier of the nuclear projects.

c) Finding and operation of agencies for policy and strategy development

Different agencies will be part of the nuclear expansion program, each with a contribution towards the development of policy and strategies.

Table 6 – Different agencies required as basic infrastructure

Division of Responsibilities for the Establishment of Basic Nuclear Power Infrastructure			
Infrastructure Issue	Responsible	Funding and Implementing Organisation	
		Primary	Supporting
Nuclear Power Implementation Agency (NPIA)	Government	Ministry of Energy	Other Ministries and Existing Nuclear R&D Institutes
Nuclear Power Policy	Government	NPIA	Ministry of Energy
Nuclear Related Laws	Government	NPIA	Ministry of Justice
Nuclear Regulatory Body	Government	Government	NPIA
Educational Institutions	Government	NPIA	Ministry of Education
Economic Assessment	Utility	Utility Finance and Commercial Department	NPIA
Financing Assessment	Utility	Utility Finance and Commercial Department	NPIA, Ministry of Finance, Consultants
Public Consultation	Utility	Utility Public Relations Department	Consultants, Ministry of Environment
Siting and Site Infrastructure	Utility	Utility Technical Department	Consultants, Ministries of Energy and Industry
Grid Strengthening	Utility	Transmission Utility	Department of Energy
Transportation Means	Utility	Utility Technical Department	Ministry of transport
Environmental Assessment	Utility	Utility Technical Department	Consultants, NRB, Ministry of Environment
Bid Request, Evaluation and Vendor Selection	Utility	Utility Technical and Commercial Department	Consultants, Ministry of Energy
Licensing	Utility	Utility Technical Department	NRB, Consultants
Emergency Planning	Utility	Utility Technical Department	NRB, Consultants
National Laboratories	Government	NPIA	Ministries of Industry, Science and Technology
Engineering	Utility	Private Sector Companies	Utility, Ministries of Industry and Energy
Project management and Commissioning	Utility	Private Sector Companies	Utility, Ministries of Industry and Energy
Fuel Supply	Utility	Utility through International Suppliers	NRB, Ministries of Energy and Foreign Affairs
Waste management	Utility	Utility	NPIA, NRB, Waste Management and Decommissioning Authority

Source: Adapted from IAEA, 2006a:32

Table 6 indicates the different agencies required during the implementation of nuclear energy in a country. These different agencies include:

- Nuclear Power Implementation Agency (NPIA) – provides assessments regarding the implementation of nuclear power and gives feedback to the government. These assessments include the basic infrastructure requirements and the possible implementation strategies, fuel cycle and industrial support base strategies as well as possible power plant sites and waste management strategies (IAEA, 2006a:4). Strategies help to develop policies regarding the proposed nuclear sectors.
- Nuclear regulatory body
- Nuclear research and development institutes
- Waste management and decommissioning authority

The nuclear energy policy provides some guidance concerning the different bodies in South Africa, currently active or which still have to be formed. These agencies are listed below.

- Government proposes the formation of a National Nuclear Energy Executive Coordination Committee which will have a similar function to the NPIA. The committee will provide oversight and ensure the implementation of the policy (DME, 2008:22).
- NECSA is an active public company empowered in the fields of research, development and innovation (DME, 2008:13). NECSA is also responsible for the processing of nuclear waste and other nuclear materials. NECSA should further participate in the uranium beneficiation and is responsible for storing uranium purchased by government, for future fuel security (DME, 2008:25). For each of the nuclear fuel cycle steps, NECSA will be responsible for determining the viability as well as developing strategies for the implementation of fuel cycle processes in South Africa, including decommissioning and reprocessing of used fuel (DME, 2008:25-27).
- ESKOM will be the main owner and operator of the nuclear power plants, while Public-Private Partnerships will be promoted (DME, 2008:23). The utilities will be responsible for ensuring the sites, site facilities and ensure that the proposed power plant is compatible with the grid.
- The National Nuclear Regulator (NNR) is responsible for licensing and establishing a safe nuclear energy sector, including the mining sector, due to natural radiation exposure at these facilities.
- A National Radioactive Waste Management Agency is responsible for the management of radioactive material (DME, 2008:24). Once the agency is

operational, it will assume control of waste management where after NECSA will no longer perform this function.

From the list it should be clear that most of the agencies required for the implementation of the nuclear energy policy are already active. The National Radioactive Waste Management Agency Bill (41/2008) was published by the government, concerning the establishment of a National Radioactive Waste Management Agency. There was, at the time of this research, no proof of the implementation of a National Nuclear Energy Executive Coordination Committee.

The main costs associated with the implementation or expansion of the different agencies, derive from the acquisition and development of skilled and competent personnel. If the required expertise is not available the personnel should be trained locally or recruited from countries with the relevant skills base (IAEA, 2007a:42).

d) Determine Legislation requirements

Most of the required legislation for nuclear power plants and the associated issues is in place due to the active program. South Africa is a member state of the IAEA and is therefore bound by the requirements of the agency. These requirements ensure the safe and effective operation of nuclear facilities. Legislation regarding the fuel cycle and industrial involvement sector is discussed in the following section.

4.2.1.2. Milestone/Phase 2

During phase 2 the country will prepare to receive bids for the power plants.

a) Nuclear policy development

The South African government has already produced its Nuclear Energy Policy. A specific policy regarding the fuel cycle will have to be developed in the future, to indicate the plan of action with regard to the different fuel cycle sectors.

b) Nuclear legislation development

The legislation required for the fuel cycle and industrial involvement sectors will have to be established, if these sectors are proven feasible. Such laws are very important to the fuel cycle sector, because such laws have to ensure that the requirements of the treaty of non-proliferation and other safeguard requirements are met. The cost associated with establishing legislation for these sectors will therefore be incurred in the future, depending on developments.

c) Nuclear regulatory body development

South Africa has an active National Nuclear Regulator (NNR). The Regulator is currently developing strategies to ensure that it is capable of handling the implications of the changing nuclear climate worldwide and in South Africa (NNR, 2009a:10). The main implications imposed on the NNR concern the effectiveness of the regulations and legislation as well as the extension of the scope of oversight and activities, to all the different sectors proposed for development (NNR, 2009a:12).

These developments will require that the NNR increase the capacity of its personnel. The primary cost driver within the NNR is the personnel cost (58 % of the budget), and increasing the number of staff members will lead to further increases in costs (NNR, 2009a:44). Due to the diversity of the nuclear industry and shortage of skilled personnel within the NNR, consultation fees represent a large portion of its annual expenses (8 % of the budget). Costs are covered by income related to the government budget, allocated to the NNR, and by annual authorisation fees (NNR, 2009a:45). Although the expansion of the NNR’s capacity involves extra costs, the developments will also increase revenue from licensing operations and annual authorisation fees, on a larger number of facilities. Further consultation fees should decrease due to the growing knowledge base within the NNR. If the agency is run commercially, expansion costs will be covered by revenue.

The NNR has 90 employees for its current nuclear regulatory oversight requirements (NNR, 2009b:62). The following table indicates the additional staff requirements of the NNR taking into account the new building program and the expansion of other sectors (NNR, 2009a:42). The NNR will have to ensure that its current capacity and the proposed added recruitment provide sufficient staff during the different stages of development and later operations of the nuclear facilities.

The NNR could use the existing licensing process from the vendor of choice to reduce the personnel and licensing requirements imposed on South Africa by the nuclear build program.

Table 7 – NNR new staff requirements

NNR	Required new Staff Numbers Per Financial Year			
	2008/09	2009/10	2010/11	2011/12
Nuclear Reactors	1	5	1	0
PBMR	4	10	0	0
Nuclear Technology	4	5	1	0
Norm	3	3	3	1
New Build	10	10	0	0
Emergency Planning	3	0	2	1
Security	2	0	1	1
Quality Assurance	3	4	0	0
Regulatory Research	3	4	0	0
Supporting Services	5	2	1	2
Total	38	43	9	5

Source: NNR, 2009a:42

Due to the termination of the PBMR project, the personnel increase proposed for this sector may be spread over the other sectors of the NNR.

Ensuring a competent regulator will require the training and hiring of staff for all the different sectors within the nuclear industry. On-the-job training could be used in establishing a larger regulatory knowledge base, by training the necessary personnel through the NNR and the regulator of the country from which the power plants and other facilities will be purchased, since they have experience in the licensing of such plants and facilities (IAEA, 2006a:10).

d) Physical facilities development

The discussion of this section refers specifically to the basic infrastructure of the nuclear power plant sector.

i) Site

Section 2.2.1.2 specifies all the necessary requirements for a nuclear power plant site. Depending on the situation of the country, the costs of acquiring a site and developing infrastructure on and to the site will differ. South Africa has the advantage that the Koeberg site can accommodate a few more power reactors, which will decrease the effect of grid and site readiness costs (DME, 2008:33). Eskom has identified five possible new sites, allowing for a reserve of nuclear sites for future expansions. The following figure shows four of the possible locations. The potential sites are indicated by the symbol shown in the legend of

Figure 1 (ESKOM, 2010b). The fifth possibility is the Duynefontein site adjacent to the Koeberg site (NNR, 2009a:11).

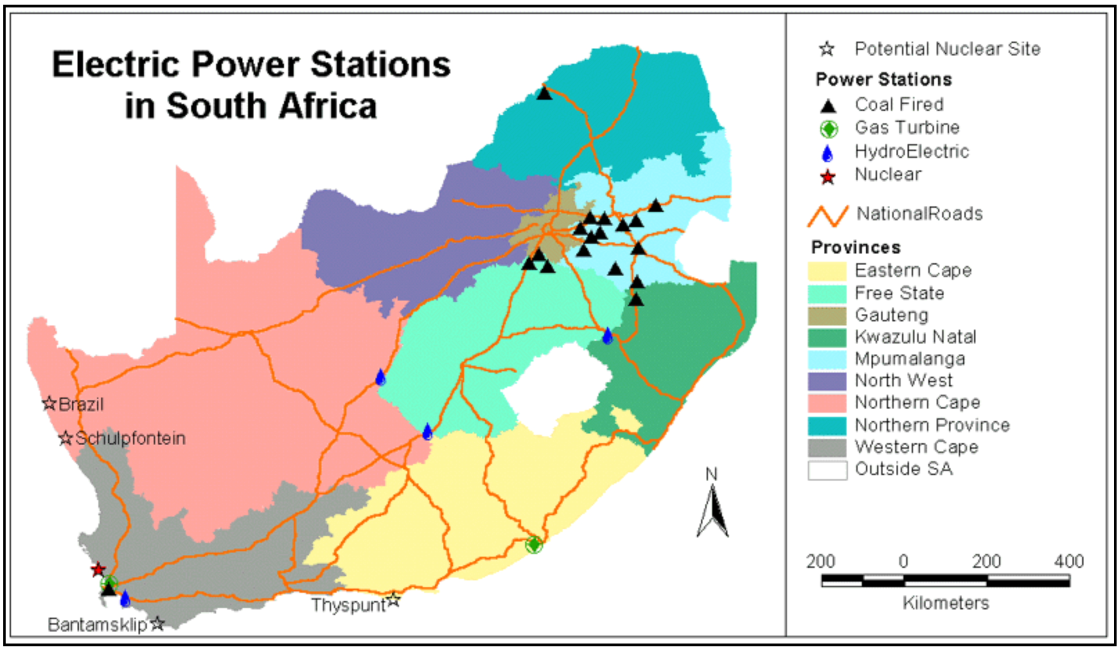

Figure 1 - Alternative nuclear sites (ESKOM, 2010b)

Figure 1 clearly indicates how generation sources are mostly located in the north eastern parts of South Africa. Compared to coal-fired power stations, nuclear power plants do not have to be located close to their fuel source and may therefore be located closer to the areas of demand, taking into account the different requirements for the nuclear sites as mentioned in Section 2.2.1.2. Other than the requirements mentioned, the safety of the public and of the environment is critical in the choice of site location.

From the five proposed sites, Bantamsklip, Duynefontein and Thyspunt are the most suited sites for the initial building program (Eskom Holdings Limited, 2010:3).

The Bantamsklip and Thyspunt sites have been acquired by Eskom (Eskom, 2010d) while the Duynefontein site is within the Eskom-owned property of the Koeberg site (Eskom Holdings Limited, 2010:5). The cost of outstanding land is indicated in Table 8. Only small sections of land were outstanding and had to be purchased.

Another site is proposed for the Kwazulu Natal coastline, although proof of the exact location has not been found.

The main site requirements are summarised and discussed under the following headings.

- Water supply

Due to the coastal locations of the sites, fresh water will be available from desalination of sea water (Eskom Holdings Limited, 2010: 6), while the sea water may be used for process cooling, associated with the tertiary loop of the steam cycle.

- Power supply

Emergency power will be supplied by an Open Cycle Gas Turbine Plant (Eskom Holdings Limited, 2010:4).

- Transport and access

Costs for the upgrade of the transport systems are included in the financial costs of constructing the plant (Eskom Holdings Limited, 2010:10) and for each of the proposed sites is indicated in Table 8.

- Earthquake-monitoring, meteorological and hydrological station

All three sites have been found clear of major geological, seismological, geotechnical and hydrological risks (Eskom Holdings Limited, 2010:5). Therefore earthquake monitoring as well as meteorological and hydrological stations or systems would have been or are active on the sites.

- Town site and administrative facilities

During power plant construction, temporary residence will be constructed to house the relevant personnel (Eskom Holdings Limited, 2010:9). The cost of the housing is indicated in Table 8.

The main site requirements and their capital costs are included in Table 8 below (Eskom Holdings Limited, 2010b:47). These costs were developed nuclear power plants generating 4 GWe (Eskom Holdings Limited, 2010b:2).

Table 8 – Site infrastructure cost, 2008 Rand

Factor	Thyspunt site (R million)	Bantamsklip site (R million)	Koeberg site (R million)
Land cost (outstanding land)	7	4	0
Construction village	2 024	2 024	1 513
Construction camp	265	265	265
Access Roads	660	150	250

Source: Eskom Holdings Limited, 2010b:47

ii) *Grid*

Table 9 indicates the cost and extent of the grid infrastructure required for each of the proposed sites. Grid requirements are one of the main factors that led to the preliminary elimination of the Bantamsklip site (although it may still be used in the future).

Table 9 – Grid infrastructure costs

Factor	Thyspunt Site	Bantamsklip Site	Koeberg Site
Line length required	500km 0f 400kV lines	990km (400kV and 765kV combined)	190km (400kV line combined with Cable)
Infrastructure Cost (R' billion)	5.3	12.72	5.1

Source: Adapted from Ngcobo, 2008:9

From Table 9 it is clear that the Bantamsklip site has a higher cost due to the larger transmission requirements. The Northern Cape sites were excluded due to the limited local electricity demand and the lack of transmission system availability (Eskom Holdings Limited, 2010:2).

Figure 2 gives an indication of the grid in South Africa as well as the connections associated with the Southern African Power Pool (SAPP). A possible advantage of the alternative nuclear power station sites in the Northern Cape would be the strengthening of the current generation and transmission of electricity into Namibia, Angola and Zaire, as indicated by the proposed transmission lines. This could open the doors to a multilateral generation project.

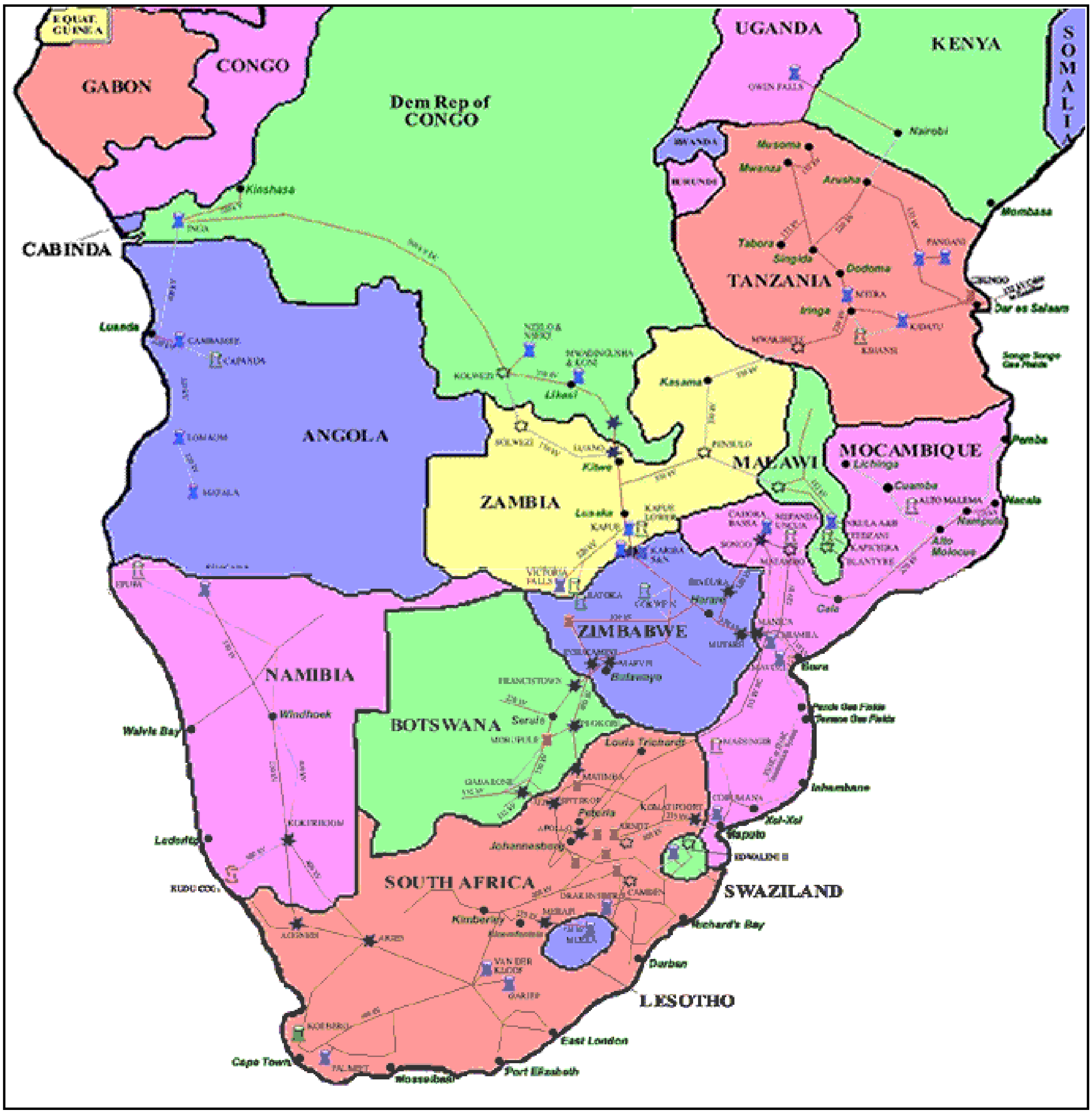

Figure 2 – SAPP grid (SAPP, 2010)

Due to the high cost of the additional infrastructure and the pressure nuclear developments place on a country's resources, cooperation between countries could alleviate the infrastructure and economic burdens (IAEA, 2006b:1). Mr Kahuure (2009), at the General Conference of the IAEA, stated that Namibia planned to generate electricity from nuclear energy, powered by Namibian natural resources, and that a regulatory body had been founded to develop and implement the regulatory infrastructure. Most of the Namibian electricity requirements are currently imported from South Africa, and Namibia has a relatively small grid, generating approximately 360 MW of its own electricity (NamPower, 2010). Due to the small size of the Namibian grid it would not be practical to install a large nuclear power plant that would generate most of the Namibian grid capacity and place huge pressure on the remaining facilities. An alternative would be a joint venture, between South Africa and Namibia as well as their public utilities, installing a nuclear power plant in the Northern Cape, close to the Namibian border. Such a joint venture could be based on the following arrangements:

- Namibia could provide a share of the capital required for the erection of the power plant and infrastructure, thus reducing the burden on Eskom’s financing requirements.
- The licensing and regulatory burden would be carried by the NNR, while the Namibian, newly formed, regulator could use the opportunity to arrange on the job training for its personnel, creating the expertise required for future nuclear programs in Namibia.
- Other human resource development options exist, such as the training of operational personnel at the power plant itself as well as in the construction and commissioning phases of the project.
- Waste storage facilities could jointly be set up in either of the countries to ensure that future waste produced by either the country’s nuclear programs is safely stored.
- Due to the large uranium reserves in Namibia the governments could jointly store reserves for future use as well as have joint ownership in possible fuel cycle facilities, thus benefiting from the natural uranium reserves possessed by both countries. Erecting multi-country facilities will also promote the South African ideas about the promotion of uranium beneficiation on a regional basis (DME, 2008:21).

Agreements could be entered into by other African countries who want to benefit from similar joint ventures.

iii) Physical protection of facilities

During the biding preparation phase, the sites should be secured by security personnel and systems or strategies should be developed for implementing such requirements. The role of local and national law enforcement agencies should be established (IAEA, 2007a:70).

The development of the physical protection system and its features are the responsibility of Eskom, to the degree determined by the contract between the utility and vendor. These include (Westinghouse Electrical Company LLC, 2004:13-4):

- security organisation;
- classification of vital security areas;
- control points of personnel, vehicles and materials;
- central alarm station and separate alarm stations;

- communication between security stations;
- provision for testing and maintenance of alarms, communications and physical barriers;
- development of a security plan.

The following are site-specific requirements and current security infrastructures:

- The Duynefontein site is located within the Koeberg power station protection zone. Minimal additions will be required, including new access control points (Eskom Holdings Limited, 2009a:ii).
- Thyspunt and Bantamsklip have fencing and access limitations in place. Control access points will have to be established. Costs of additions are assumed to be insignificant (Eskom Holdings Limited, 2009a:iii).

Although such systems are critical, their costs are low compared to the grid or transport infrastructure.

iv) Component manufacture and material supply

Requirements are developed in Section 4.2.4.

v) Standard calibration laboratory facilities

Koeberg has a calibration laboratory facility (SA Five Group, 2010). Calibration facilities can be erected at each of the sites due to the large number of reactors and associated systems on each site.

vi) Storage/disposal of low or and medium level radioactive waste.

Low-level and intermediate-level radioactive waste is firstly stored on site, in interim storage facilities. Interim storage facilities should be built allowing for expansion during the lifetime of the power plant (IAEA, 2006a:46). The management steps taken for these levels of waste are:

- Pre-treatment – during this step collection, segregation, chemical adjustment and decontamination take place. Characterisation and segregation of the waste entails the separation of the different levels of waste and their classification in terms of handling requirements. Storage of certain low level waste, with short-life radioactive elements, is performed to allow for decay during storage and disposal by simple methods, due to decreased radioactive limits (IAEA 1995, 13).
- Treatment – such processes improve the safety of the waste and change its characteristics. Treatment involves processes such as volume reduction, removal of radionuclides, and changing the composition of the waste. Volume reduction ensures

that the handling and storage requirements are simplified. Removal of radionuclides and change of composition change pertains mostly to liquid waste (IAEA 1995, 14).

- Conditioning – involves the preparation of the waste for handling and disposal. Preparation includes solidifying liquid waste in cement or glass matrixes or the placement of waste in steel drums (IAEA 1995, 14).
- Disposal – the waste, in their conditioned form, is stored in waste facilities with sufficient barriers to maintain the safe state of the waste and prevent excessive release or exposure (IAEA 1995, 14).

As part of waste management transport is very important. Koeberg's low-level and medium-level wastes are treated and conditioned on-site and then transported to the Vaalputs waste storage facility (ESKOM, 2010c). Due to the existence of the active waste storage facility (Vaalputs), for low and medium level wastes, there will be no extra development costs required for such facilities, in the short to medium term.

If the expansion program is implemented and depending on the extent of development, Government may have to start acquiring alternative sites to secure future waste storage capacity. Vaalputs receives approximately 475 steel drums and 158 concrete drums per year from Koeberg power station (ESKOM, 2010c). The Vaalputs facility has the capacity to store all the low and medium level waste of five nuclear power plants the size of Koeberg throughout their lifetime (NECSA, 2010).

vii) Spent fuel storage and disposal facilities

The relevant requirements are developed in Section 4.2.4.

viii) Safeguards plan and equipment

The necessary safeguards plan and equipment will have to be supplied and developed for each of the new nuclear sites and facilities. The IAEA has developed and published different sets of safety and safeguard standards to help Member States that are implementing nuclear programs (IAEA, 2006a:4).

The relevant legislation and safeguard procedures should be in place, while information should be provided to the IAEA as overseeing agency (IAEA, 2007a:68). Due to the active nuclear power program in South Africa, legislation already exists with regard to the accountability for nuclear materials and facility safeguard standards (DME, 2008:10). Therefore, financing will be required during the development of safeguard standards specific to each facility and nuclear sector under development. Legislation and safeguards concerning nuclear fuel cycle facilities will have to be developed to ensure that the use of such facilities and relevant materials is safe and complies with IAEA standards. The NNR, as overseeing body in South Africa, will play an important role by ensuring compliance with all the relevant laws, regulations and treaties (DME, 2008:14).

ix) Emergency response facilities and notification of nuclear incidents

The NNR is responsible for ensuring that nuclear emergency planning is in place (DME, 2008:14). Each facility, within each of the sectors, will have varying safety and emergency safeguards in place due to the differences in materials and processes used and therefore in associated risks. The nuclear power plants will have the highest safety precautions and response actions. Emergency procedures and the infrastructure required for their enactment will have to be in place at the relevant facilities and sites.

The Duynefontein site has the possibility of using the Koeberg emergency response infrastructure, although expansions may be required to cope with the increased nuclear capacity (Eskom Holdings Limited, 2009b:ii). Due to a high population density within the 16 km range, this is the least preferred site (Eskom Holdings Limited, 2009b:23).

Both Bantamsklip and Thyspunt currently have little emergency response capacity due to underdeveloped infrastructure. Emergency infrastructure will be sufficient after construction of the access roads and communication infrastructure. These sites have low population densities within the 16 km range and are therefore better suited for nuclear power stations (Eskom Holdings Limited, 2009b:22).

The main requirement is transport infrastructure for the evacuation of the relevant population and personnel. The main costs will therefore be covered during the construction phase of the transport and other site infrastructure.

x) Communication

Due to the modern communication infrastructure in South Africa and the relative centrality of the sites, communication system availability will not pose significant problems or incur large costs.

e) Human resource development

The following lists the different knowledge bases required in nuclear energy sectors:

- government policy;
- nuclear regulatory body;
- radiation and workforce awareness;
- financial knowledge;

- industrial support (design, construction, installation, commissioning, project management);
- operations and maintenance;
- quality assurance and quality management.

The required educational institutions, such as universities, will have to be developed or expanded to allow for a basic knowledge base, after which specialist training in the relevant sector can proceed. Increasing the degree of knowledge localisation will lead to economic and social uplifting of the country and its people.

To benefit maximally from technology transfer contracts, the relevant basic knowledge should be developed prior to such building programs. Developing basic local knowledge will ensure that the relevant personnel may receive specialized on-the-job training, by the vendor's experts (Csik et al., 1987:66).

f) Public consultation and environmental assessments

The environmental assessment of the different sites has been completed and the associated public participations have been held, as required (Eskom Holdings Limited, 2010:4). During the licensing phases further public participation events should be held. If other sites are proposed the environmental impact assessments must be performed.

4.2.1.3. Milestone/Phase 3

During Phase 3 it is ensured that the necessary infrastructure is in place for construction and later commissioning of the different facilities. The costs will therefore include the operation and completion of previously mentioned aspects.

4.2.1.4. Summary of main cost factors

Within the basic infrastructure development, the site and grid infrastructure will be the most costly. Many of the basic infrastructure development issues will have positive effects on and benefits for the development of the country.

Table 10 summarises the main cost factors and their values. The cost factors are relevant to the basic infrastructure of the Nuclear Power Plant sector.

Table 10 – Main basic infrastructure costs (4 GWe plant)

	Thyspunt site (R million)	Bantamsklip site (R million)	Koeberg site (R million)
Land cost (outstanding land)	7	4	0
Construction village	2 024	2 024	1 513
Construction camp	265	265	265
Access Roads	660	150	250
Grid infrastructure	5 300	12 720	5 100
Total (4 GWe)	8 256	15 163	7 128

Source: adapted from Eskom Holdings Limited, 2010b:47

From the table it should be clear that the costs take similar factors into account compared to the factors developed in the framework of Chapter 2. The similarities serve to a certain extent as validation of the cost factors of the basic infrastructure development framework.

The power plants required to generate the 20 GWe will be built in batches. Due to the economy-of-scale strategy proposed by government, it is assumed that the plants will be built as 4 GWe power plants over the next few decades.

Thyspunt and Bantamsklip are superior options for larger numbers of reactors, due to the low population densities in surrounding areas. The Northern Cape sites may be used, but the requirements are very extensive due to the low local demand for electricity and the remoteness of the sites from current major infrastructure. The isolated nature of the latter sites will require major grid and transport infrastructure additions. If such sites are chosen, economy of scale will be a major factor to ensure viable developments (Eskom Holdings Limited, 2008:11-3). While the situation in the Northern Cape remains similar to current conditions, significant growth in electricity demand is not expected. The proposed sites of Duynefontein, Bantamsklip and Thyspunt will therefore remain favourites for future construction.

It would require five 4 GWe power plants to generate the target of 20 GWe. The costs will therefore have to be re-evaluated to determine the costs for the five power plants. This will require a strategy of power plant placement on different sites to generate the target of 20 GWe.

The following strategy, regarding generation capability per site, is proposed:

- 8 GWe at Thyspunt
- Three other sites each generating 4GWe (possibly Bantamsklip, Duynefontein and a Kwazulu Natal site)

In the present investigation it was assumed that the economic assessments, and associated costs, of Bantamsklip, Duynefontein and Thyspunt, may be applied to all the sites, even if some of the sites have not yet been announced. This assumption will make it possible to determine the cost of constructing the total 20 GWe nuclear power plant fleet.

From Table 4 (Chapter 2) it is clear that the demand in labour differs between one and eight nuclear units. For 8 units, the labour requirement increases five times from the required amount of a single unit (D'Olier, 2005:69). The costs associated with Thyspunt will have to be adapted to allow for the 8 GWe power plant labour requirements, which will have an effect on the construction camp and village costs. From the 6848 workers of a 4 GWe plant, 5500 will be accommodated in the construction camp. Therefore 1348 labourers are local labourers and don't require accommodation (Eskom Holdings Limited, 2010b:27). Therefore from the 8000 labourers of the 8 units, 6700 (8000-1348) will require accommodation in the construction camp. The camp proposed for the 4 GWe plant will increase capacity by 1,5 times, as will the costs, assuming a proportional increase. A similar assumption is made for the construction village.

The cost of constructing the construction camp and village will further have to be adapted in case the effect of using semi-skilled labour has large effects on the labour requirements.

Adapting the Thyspunt electrical grid to 8 GWe will incur large costs. The current 4 GWe has a relatively low cost grid (R 5,3 billion) due to its close proximity to the main load centre of Port Elizabeth as well as the future grid infrastructure planned for the area (Leask, 2010). But generating a further 4 GWe at the Thyspunt site will increase grid costs significantly. The increase is due to the fact that all the transmission capacity will be occupied by the first 4 GWe. Transmission of the added 4 GWe will require long-distance lines to either KwaZulu-Natal or Gauteng. The costs will therefore range between R15 billion and R20 billion (Leask, 2010). The latter will be used as conservative estimate in the study.

The costs of the fourth site are assumed to be similar to the site with the most costly infrastructure requirement (Table 10). This is assumed due to the uncertainty of the proposed site's conditions and available infrastructure. Land costs will be a major cost driver for the fourth site, if the land has to be purchased by Eskom.

Environmental assessments as well as economic viability will be important factors in determining the generation capacity per site and the spread of reactors.

The following table indicates the costs for the number of reactors proposed per site.

Table 11 - Main basic infrastructure costs (20 GWe total)

	Thyspunt site (R million) (8 GWe)	**Bantamsklip site (R million) (4 GWe)**	**Koeberg site (R million) (4 GWe)**	**Site 4 (R million) (4 GWe)**
Land cost (outstanding land)	7	4	0	7
Construction village	3 036	2 024	1 513	2 024
Construction camp	397.5	265	265	265
Access Roads	660	150	250	660
Grid infrastructure	25 300	12 720	5 100	12 720
Total	28 256	15 163	7 128	15 676

Source: adapted from Eskom Holdings Limited, 2010b:47

4.2.2. Nuclear power plant sector

This section applies to the construction of the proposed power plants and the different cost requirements associated with such developments.

4.2.2.1. Milestone/Phase 1

The following are the main requirements during the first phase:

- understanding the obligations and commitments;
- operation of the strategy and policy development agencies.

Most of the requirements and issues involved with nuclear power plants will be well known to the country and especially Eskom, as owner and operator of the current power plant. The main Environmental Impact Assessment has been completed and public participation sessions have been held and therefore the various issues of the proposed sites and surrounding areas have been identified as well as the associated strategies and mitigating safeguards.

4.2.2.2. Milestone/Phase 2

Phase 2 of the Nuclear power plant sector pertains to the preparations before the bidding process can start. The following points have to be completed before bidding commences.

- Development of the financial plan

The financial plan is crucial to ensure that strategies exist to obtain the required funding and financing for the proposed power plants. Funding strategies will result from the economic assessments performed in line with the proposed development strategies.

- Human resource development of owner

Eskom will require 1385 employees for the operation of the 4 GWe power plants. The number increases over time, from the time that construction starts, to the total number of employees when operations start. Of the 1385 staff members, 1000 will be professionally or technically qualified (Eskom Holdings Limited, 2010b:59). The following table indicates the increase in the number of Eskom employees during construction.

Table 12 – ESKOM employee requirements per 4 GWe plant

Month	Jun	Jan	Jun	Jan	Jun	Jan	Jun	Jan	Jun
Year	**1**	**2**	**2**	**3**	**3**	**4**	**4**	**5**	**5**
Senior Management/ Executives	6	7	8	8	9	9	9	9	9
Middle Management	3	5	5	11	12	18	18	28	29
Professionals	6	33	34	39	39	111	124	132	138
Engineers/technicians and other semi professionals	60	86	90	146	160	199	219	226	222
Technicians	0	5	6	10	34	46	56	70	70
Artisans level	0	1	2	8	8	8	9	22	27
Clerical staff	0	0	1	2	7	12	12	17	17
Total	75	137	146	224	269	403	447	504	512

Month	Jan	Jun	Jan	Jun	Jan	Jun	Jan	Jun	Jan	Jun	Jan
Year	**6**	**6**	**7**	**7**	**8**	**8**	**9**	**9**	**10**	**10**	**11**
Senior Management/ Executives	9	9	9	9	9	9	9	9	9	9	9
Middle Management	32	32	40	40	40	40	40	40	40	40	40
Professionals	185	204	239	249	263	263	266	272	288	293	293
Engineers/technicians and other semi professionals	191	192	162	173	186	198	219	224	229	239	244
Technicians	86	91	138	212	297	329	399	414	445	464	464
Artisans level	39	46	54	76	195	200	218	228	238	253	253
Clerical staff	24	27	32	44	50	55	60	72	72	82	82
Total	566	601	674	803	1040	1094	1211	1259	1321	1380	1385

Source: Adapted from Eskom Holdings Limited, 2010b:60

Many of the technical and professional personnel must be trained on the specific type of reactor chosen for the development. Such training programs should be included in the contract between the vendor and utility. The maximum amount of utility personnel required for the entire nuclear power plant build program add up to approximately 7 000. This is a conservative number assuming that the five power plants, each generating 4 GWe, are built on separate locations and require their own specific personnel. Personnel requirements decrease by having the plants built on similar sites due to sharing of personnel between the different units. 7 000 employees is therefore the maximum number that would be required and is a conservative assumption. Of the 7 000, 5 000 will have to be qualified. It should be clear that the utility's human resource requirement is rather significant and therefore the government should be clear on its strategies concerning the nuclear power program. Clear-cut strategies will ensure that human resource development can proceed without the risk, to the trainees and investors, of uncertainty regarding project implementation.

Education and training of local employees should progress during the construction period, ensuring sufficient personnel capacity as soon as operations commence. Koeberg power station could be used to create a certain level of operational experience. Eskom should provide courses for the establishment of a basic LWR operational experience, which can further be honed by the vendor to the specific type of reactor constructed. This will allow for a shorter training period with the vendor company and increase the measure of local experience in the field of nuclear power plant operations.

- Bidding for procurement

Bidding may commence once sound financing possibilities have been identified and the essential basic infrastructure requirements are at the required capacity or currently under development.

4.2.2.3. Milestone/Phase 3

Certain aspects of site preparation are covered in the basic infrastructure development section. The following is a list of basic nuclear power plant construction costs:

- Licensing
- Site preparation
- Construction of plant buildings and structures
- Installation of equipment, components and systems
- Plant commissioning
- Human resource development

Table 13 summarises all the construction costs of a power plant, generating 4 GWe, on each of the proposed sites (Eskom Holdings Limited, 2010b:47).

Table 13 - Breakdown of total plant construction costs (4GWe plant)

	Thyspunt (R million)	Bantamsklip (R million)	Duynefontein (R million)
Land	7	4	0
Sand removal and disposal on site	127	201	130
Advantage for St Francis (Beach Repair)	-50	0	0
Water removal	1.3	0.9	1.1
Bedrock removal and disposal	57	96	5 103
Reactor – constant cost	160 275	160 275	160 275
Construction support services, transport	231	247	81
Construction steel – transport cost	142	180	170
Concrete and bricks – transport	133	234	82
Import material, port to site (abnormal loads)	793	2339	567
Import material, port to site (normal load)	52	39	11
Construction village – capital	2 024	2 024	1 513
Construction village – transport cost	503	201	317
Construction camp – capital	265	265	265
Construction camp – transport cost	199	79	1347
Labour – difference in numbers	0	0	-173
Capital cost of access roads	660	150	250
Capital cost of connection – national grid	5 300	12 720	5 100
Tourism impact	65	-124	38
Value of job creation	-1 399	-655	0
Total	169 385	178 276	173 864.1

Source: Eskom Holdings Limited, 2010b:47

Some of the above-mentioned costs were discussed in the basic infrastructure development and for the sake of completeness have been added in Table 13. Table 13 determines the total project cost of constructing a 4 GWe plant on any of the sites. From the table it is clear that the cost is mostly dependent on the constant cost of the reactor.

Adjustments have to be made to these figures to determine the cost of constructing five 4GWe nuclear power plants.

By assuming that two 4 GWe plants are constructed on the Thyspunt site it is possible to determine the cost of constructing the 8 GWe plant. The site preparation in terms of sand removal, water removal and bedrock removal will be separately done for each of the 4GWe power plants that add up to the required 8 GWe. Similarly, the constant reactor cost as well as the material transport costs and import material transport costs will be incurred for each of the power plants. It was assumed that the impact on tourism will not increase due to increased generation per site. The tourism impact cost factor will therefore remain the same. It was further assumed that there will be no further benefit during the construction of the power stations on Thyspunt, with respect to job creation.

Table 14 – NPP construction costs

	Thyspunt (R million) (8 GWe)	Bantamsklip (R million) (4 GWe)	Duynefontein (R million) (4 GWe)	Site 4 (R million) (4 GWe)
Land	7	4	0	7
Sand removal and disposal on site	254	201	130	201
Advantage for St Francis (Beach Repair)	-50	0	0	0
Water removal	2.6	0.9	1.1	1.3
Bedrock removal and disposal	114	96	5 103	5 103
Reactor – constant cost	320 550	160 275	160 275	160 275
Construction support services, transport	462	247	81	247
Construction steel – transport cost	284	180	170	180
Concrete and bricks – transport	266	234	82	234
Import material, port to site (abnormal loads)	1 586	2 339	567	2 339
Import material, port to site (normal load)	104	39	11	52
Construction village – capital	2 024	2 024	1 513	2 024
Construction village – transport cost	1 006	201	317	503
Construction camp – capital	265	265	265	265
Construction camp – transport cost	398	79	134	199
Labour – difference in numbers	0	0	-173	0
Capital cost of access roads	660	150	250	660
Capital cost of connection – national grid	25 300	12 720	5 100	12 720
Tourism impact	65	-124	38	65
Value of job creation	-1 399	-655	0	0
Total	351 898.6	178 276	173 864.1	185 075.3

Source: adapted from Eskom Holdings Limited, 2010b:47

The totals in Table 14 make it clear that the funding and financing requirements of the proposed project are very extensive. The strategies developed, to obtain the required capital, are therefore crucial to ensure that the policy objectives are reached.

4.2.3. Nuclear fuel cycle sector

This section discusses the third main sector proposed for development. Government has proposed the long-term goal of becoming self-sufficient and globally competitive. Only the mining, milling and concentration processes are currently active in South Africa, and therefore the development of a self-sufficient, independent fuel cycle will become a very expensive and sensitive project. Global and regional support will be essential for the different fuel cycle steps, especially enrichment and reprocessing, due to the fear of proliferation.

The following sections indicate the phases of development within the fuel cycle sector.

4.2.3.1. Milestone/Phase 1

During the first phase of the fuel cycle developments the following points should be covered.

- Strategy and policy development

Basic strategy and policy have been developed in the Nuclear Energy Policy which outlines the main and long term goals of the nuclear fuel cycle sector. A clear-cut policy and a strategy concerning the degree of implementation and development have not been completed as yet.

To optimise the economics and effectiveness of the fuel cycle sector, implementation of the different cycle steps will have to develop parallel to the Nuclear Power Plant sector. The strategies, of fuel cycle implementation, will have to be developed.

- Human resource development

Chemical industry knowledge may be used directly or adapted to nuclear requirements. If nuclear specific training is required the relevant personnel will have to undergo training at the relevant institutions. If such institutions are not available in South Africa, personnel will either have to undergo training outside the country or these courses will have to be developed and implemented in South African institutions. Research into the different requirements will have to take place as soon as the government’s strategies become clear.

4.2.3.2. Milestone/Phase 2

Implementation of the different fuel cycle steps may start during the reactor bidding phase, although such aggressive fuel cycle strategies are not expected. One of the main factors determining the implementation strategy is whether the development will be economically viable. During the early stages of power plant development, the demand for fuel will only be limited and security of fuel supply will not be a major factor, while during later stages, when demand becomes higher and fuel security more important, the implementation of the different fuel cycle steps may be sensible and viable.

4.2.3.3. Milestone/Phase 3

In this study it is assumed that implementation of the inactive sectors start after the construction of the power plants; it is therefore discussed in Phase 3 of the developments.

Due to the increased amount of fuel that will be required for the expanded reactor program, the requirements on the fuel cycle will have to be determined to ensure sufficient supply. In the following sections it is assumed that South Africa implements the entire fuel cycle, although economies of scale preclude certain sectors in the short or medium term. Taking the entire fuel cycle into account will ensure that the framework requirements and costs determined are at the maximum influence and values. Whether total implementation will be the case still has to be determined and will depend on the security of supply and its economics, as well as on other factors.

The modern PWR reactors (Generation 3+) have higher burnup and therefore increased enrichment requirements. From the Generation 3+ reactors the European Pressurised Reactor (EPR) has a higher burnup and power output. The EPR enrichment requirement will be used in the enrichment calculations to allow for conservative estimations with regard to enrichment facility costs. The Ap1000 requires marginally larger amounts of fuel due to the lower power output which requires more reactors to generate the 20 GWe. The AP1000 is therefore used as reference reactor to determine the maximum fuel requirements per year.

The characteristics of the EPR and AP1000 are indicated in the tables below.

Table 15 – EPR characteristics

Characteristic	**Value**
Thermal Power	4 500 MWt
Fuel cycle	18 Months
Availability	94 %
Burnup	62 000 MWd/tU
Enrichment (Maximum)	5 %

Source: Framatome ANP, 2005:18

Table 16 – Ap1000 Characteristics

Characteristic	Value
Thermal Power	3 415 MWt
Fuel cycle	18 months
Availability	93 %
Burnup	60 000 MWd/tU
Enrichment (Maximum)	4.8 %

Source: Westinghouse Electric Company LLC, 2003:4

The above mentioned information is used to determine the heavy metal requirements per year for the total number of reactors. From the calculations (Appendix B.1) the uranium requirement per reactor per year was determined at 19,32 tons. For the 20 reactors (assuming 1 000 MWe each) the total requirement adds up to a maximum value of approximately 430 tons of Uranium per year, including Koeberg's requirement.

In each of the fuel cycle steps there are uranium losses which increase the demand on the total amount of natural uranium mined. The waste streams are made up of possibly reusable extract, and unrecoverable waste. The approximate losses, through each of the steps, are indicated in the following table.

Table 17-Uranium loss per cycle step

Cycle step	Loss (%)	Mass balance (feed to each step) tU/year
Mining	0	4 366
Concentration process	20	4 366
Conversion	0.5	3 493
Enrichment	87.5	3 475
Fabrication	1	435
Total Reactor requirement		430

Source: Developed from Lamarsh & Baratta, 2001:187

From Table 17 it is clear that the largest amount of uranium is lost during the enrichment process. The loss percentages will be used to determine the feed requirements during each of the steps.

The current situation and requirements of each of the fuel cycle steps is discussed in the following sections.

STEP 1. Mining

South Africa mines approximately 2 472 tons of Uranium per year (IAEA, 2009b:53). By using the value of reactor fuel required and backtracking through the uranium losses the amount of heavy metal required in the natural uranium, for the South African reactors, will add up to approximately 4 366 tons per year. This is equivalent to almost 1,8 times the current production by South African mines. If security of fuel supply is to be achieved, the country should be able to supply local demand as well as current contracts and/or future export demands.

Mining expansion projects could perhaps facilitate the government's vision of including local investors in uranium beneficiation. Before further mining contracts are undergone, the government should assess whether the local reserves will be sufficient to provide for local needs as well as external demand. The fuel cycle strategy should therefore be set and should be the main factor determining the future and strategy of uranium mining in South Africa. Due to the large number of reactors being built, throughout the world, the demand for uranium will increase, which will increase the possibilities of export opportunities. The government should be wary of large-scale uranium exports as such actions could hamper the security of local fuel supply in the future.

According to Mining Weekly (Swanepoel, 2010), Extract Resources is planning to develop a uranium mine in Namibia at a cost of $ 704 million. The mine will produce 6 800 tons (15 million pounds) of U_3O_8 per year. The cost per ton of uranium was determined at R 1,23 million. Although it is not stated in the article it was assumed that the cost includes the construction of a concentration plant. Developing a single uranium mine with the capacity to produce the entire uranium requirement will cost R 5,4 billion. The proposed mine in Namibia would become the world's second largest uranium mine, with a fairly low capital cost per ton of uranium produced. From the next section it will be clear what the costs are of constructing processing facilities. By implementing a larger mine as well as the associated processing facility, costs will be decreased compared to a few smaller mines and facilities.

Most of the South African uranium is mined as a by-product of gold processing. As the quantity of uranium processed is dependent on the gold production, uranium specific mines may have to be developed, if the gold production or other secondary sources does not allow for sufficient uranium processing. If most of the uranium is produced from other mining operations the cost of the mining sector will be minimal and will only require the construction of concentration facilities. Other relatively low mining cost sources of uranium in South Africa include the processing of gold mine tailings.

It is assumed that the uranium will be mined as a by-product and that costs will only require the construction of processing facilities.

STEP 2. Concentration/processing

All of the uranium currently mined is processed locally to produce yellowcake. Due to limited losses during the mining process the uranium feed to the processing facility is equal to 4 366 tons per year. During concentration 20 % of the feed is lost, leaving a uranium quantity of 3 493 tons per year. The current capacity will therefore have to be increased to support the increased demand.

Before uranium specific sectors in the nuclear fuel cycle are developed, it should be determined whether such operations will be viable in the South African market. The fuel cycle beneficiation strategy will determine the actions taken and the tempo at which developments take place. As the number of reactors increases the importance of security of fuel supply will also increase. The mining and processing production rates will be dependent on the subsequent fuel cycle sections and/or on export demand. If the latter sections of the fuel cycle are not developed, demand for the mining and processing steps will only depend on external demand.

Concentration facilities are normally located on-site as part of the mining facilities. Therefore the siting of the plant is bound to the siting of the mine. No additional site purchasing will be required unless the facility is constructed of-site, which may be the case if a facility is constructed to service a few mines and is therefore constructed in a central off-site location.

According to the Mining Weekly (Davenport, 2010), Rand Uranium is planning to construct a processing facility which will produce approximately 1 000 tons (2,3 million pounds) of U_3O_8 per year. The estimated cost of erecting the facility was determined at R 3,5 billion. The figure is supported by the figures proposed by Equinox Minerals Limited (2008:3) for a similar plant in Zambia. The following table indicates the proposed figures for the Lumwana plant in Zambia.

Table 18 – Lumwana Project costs

Lumwana Uranium Project – Capital costs estimate (±15% accuracy)

Area	Pre-Production (US$M)	Deferred (US$M)	Total (US$M)
Process Plant	80.3	12.3	92.6
Onsite and Offsite Infrastructure	31.7	0.0	31.7
Tailings and Water Management	8.5	15.1	23.6
Indirects (EPCM)	30.8	0.0	30.8
Process Plant and Infrastructure	**151.3**	**27.4**	**178.7**
Owner's Costs	14.4	0.0	14.4
Mining	7.8	5.2	13.0
Contingency	26.0	0.0	26.0
Total Below the Line Costs	**48.3**	**5.2**	**53.5**
Closure Costs	0.0	19.8	19.8
Overall Capital Costs	**199.6**	**32.6**	**232.2**

Source: Equinox Minerals Limited, 2008:3

The Lumwana plant will produce 900 tons (2 million pounds) of U_3O_8 per year. The plant will therefore produce 770 tons of uranium per year. The cost per ton of uranium was calculated at approximately R 3,1 million. The total capital input for the South African market will reach an amount of approximately R 11 billion, assuming that current capacity production will continue to be exported and will not contribute to the local demand.

To produce the 3 493 tons of uranium per year, 4,6 plants will be required, assuming that the plants will have a similar size to the Lumwana or Rand Uranium plants. The costs may be lowered if larger plants are developed. The size of the plants will be dependent on the feed from the mines. If uranium-specific mines are opened the plant capacities will increase which may decrease the capital input per ton of uranium produced.

The mining and concentration steps are linked and the costs will be covered by the mining companies.

STEP 3. Conversion

From Table 17 it is clear that the percentage of uranium lost during conversion processes is small. After the conversion processes, the amount of uranium sent to the following processes equals 3 475 tons per year. Conversion is not currently in operation in South Africa and therefore such processes have to be developed or the technology acquired.

One of the main concerns in conversion facilities is the release of chemicals. Safety has an influence on the site location, as prevailing winds and other factors have to be taken into account to minimize the risk to the population located in the vicinity of the plant. Criticality is only a risk when U^{235} in excess of 1 % is being handled in the plant (IAEA, 2010:6).

Construction of these plants is similar to the chemical industry and the associated safety requirements are similar or stricter (IAEA, 2010:34).

The extent of costs will depend on whether these plants are developed locally or are acquired from the relevant vendors. South Africa had conversion plants in operation and therefore a certain extent of knowledge in this field is available. It will have to be determined if the technology used in the former plants is still relevant and commercially viable and competitive. If this is the case, that local technology may be used, which should decrease the costs.

According to Areva (2007:10) Areva is planning to develop a conversion facility capable of producing 21 000 tons of uranium per annum at a cost of € 610 million. Assuming an exchange rate of R10/€, the price of constructing a 21 000 MtU/a plant is R 6,1 billion. The price per ton of uranium is approximately R 300 000. Therefore a plant producing 3 475 tons of uranium per year will cost R 1,1 billion (2007 Rand). The cost per ton of uranium is expected to be higher than the proposed R 300 000 due to the fact that the plant proposed by Areva is approximately 6 times larger, which decreases the cost per ton of uranium.

Due to ageing facilities and a stagnation of investments in the conversion step of the fuel cycle, it is possible that a shortage in future supply may occur (Areva, 2007:10). NECSA has been tasked with developing a local conversion capability which, if implemented, would ensure the supply of local demand and further creates export opportunities.

STEP 4. Enrichment

Enrichment is the most expensive and also, from the proliferation point of view, the most sensitive sector of the fuel cycle, within the front end. Due to the large amount of losses during this process the amount of enriched heavy metal leaving the process is approximately 435 tons per year.

The tails (or loss stream) amount to 3 040 tons per year. Due to the large fraction lost there are alternative processes used to re-enrich the tails. The tails streams may in future also be used as fast breeder reactor fuel. Re-enrichment is not currently a viable option due to the cost associated with enrichment. If made viable, such processes could in future ensure that the uranium reserves are used in a more sustainable fashion (Shropshire *et al.*, 2007:78).

From the above-mentioned data it is possible to determine the required Seperative Work Units (SWU) required per year to obtain the desired enriched product. The overnight cost of an enrichment plant is in the order of $500 per SWU (Cabrera-Palmer & Rothwell, 2008:2572). This cost estimate may then be used to determine the cost of constructing a plant sufficient to provide for the country's needs.

The above SWU value was calculated at approximately 3,05 million kg/year. Assuming an exchange rate of R10/$ this yields a construction cost of R 16 billion.

The overnight cost of $500/SWU was determined from large enrichment plants (n^{th} of a kind). From the Cabrera-Palmer and Rothwell (2008:2575) study it is clear what influence the economy of scale has on these projects. For a 114 000 SWU/year plant the overnight cost is equal to $1 800/SWU. It is therefore clear that the implementation strategy chosen by the government should take such factors into account. The parallel development of both the reactor fleet and enrichment capabilities should be well defined to ensure that the need of the reactors is sufficient to allow for a large enrichment plant to be developed, which would decrease the costs considerably. The enrichment plant may then be scaled up to allow for the need of subsequent reactors.

The main risks associated with enrichment plants are the release of chemicals and the possibility of criticality accidents (IAEA, 2010:6). The safety aspects within these plants are more critical than those of the conversion facilities. Safety risks are mainly associated with the on-site personnel, although such plants should avoid being in the nearby vicinity of populated areas, as the risks may also extend to these nearby areas (IAEA, 2010:8). Costs will include the purchase of land in areas suitable for enrichment plants with the associated waste and risks.

STEP 5. Fabrication

South Africa has no fuel fabrication activities active. Fuel fabrication was active in South Africa before the 1990s (IAEA, 2005:75). Local knowledge regarding the fuel fabrication step should therefore be available, although it should be determined whether the techniques used in previous years are still relevant for the current needs and for the modern reactors.

During fabrication, approximately 1 % of the uranium is lost equivalent to 430 tons of uranium within fabricated fuel.

Rothwell (2010:543) provides an indication of capital investment costs associated with fuel fabrication facilities. A linear function dependent on the size of the facility is proposed, namely: $K = \$67\ 000\ 000\ +\ \$330\ 000\ *\ (Size\ of\ facility)$

The Size term is measured in metric tons of uranium while the first term accounts for licensing, design and site preparation. It is suggested in the study that the licensing, design and site preparation costs could exceed the $67 million mark (Rothwell, 2010:543). The facility required for South Africa requires a capacity of 430 tons of uranium per year.

By using the proposed size it is therefore determined that the capital investment cost of a fuel fabrication facility is approximately R 2,2 billion, assuming an exchange rate of R10/$.

The nuclear energy policy proposes that NECSA should develop fuel fabrication facilities. The implementation strategies will play an important role in determining the final capital investment cost per ton of uranium. The strategy should optimise the influence of economy of scale to decrease parametric costs. Implementation is further dependent on supply and demand. There are currently many fabrication facilities and the market is competitive (Rothwell, 2010:538). Supply assurance will become a major concern to South Africa as the number of reactors increases and will act as driver towards developing local fabrication capacity.

Fuel fabrication facilities develop fuel for a certain type of power plant. A standardised fleet of power plants will therefore have a large influence on whether local fabrication services are implemented. By standardising the choice of power plant design the economy of scale resulting from implementing a fleet of similar reactors will reduce implementation costs.

STEP 6. Fuel burnup

The sixth step in the fuel cycle takes place inside the reactor. The fuel is burned to produce the required energy for electricity production. During burnup fission products and other elements are produced. These products are a primary concern in terms of proliferation and waste management.

STEP 7. Spent fuel management

Nuclear power plants provide storage capacity for spent fuel. These used fuel assemblies continue to produce heat due to the decay of fission products and are therefore stored in spent fuel pools where water cooling takes place.

After decommissioning, intermediate storage capacity must be provided for the spent fuel assemblies. There are two main intermediate storage techniques, namely, wet or dry storage (IAEA, 2009c:5).

Wet storage involves the storage of the used fuel in water pools. This is a proven process that necessitates engineered systems to maintain the cooling and water chemistry as well as monitoring and leak detection, among others (IAEA, 2009c:5).

Dry storage uses either metal casks, concrete casks, vaults or other configurations (IAEA, 2009c:8). The main advantage is the decreased number, if any, of engineered systems to keep the fuel cool. This is mainly achieved by conduction and natural convection (IAEA, 2009c:9).

Intermediate storage can be on-site or at a separate location. The advantage of having such facilities on-site lies in the availability of safeguard systems whereas a separate site would require a duplicate implementation of such safeguards. Having the space available onsite will therefore decrease the costs associated with the environmental assessments required for separate sites as well as the implementation costs of the safeguards. If however other African countries decide to implement nuclear power, a multiregional storage facility could be set up. The advantage of having such a single site for multiple countries is the simplified proliferation control as well as accountability and management of nuclear materials.

After the intermediate storage phase, management processes such as reprocessing and final storage of reprocessing effluent, or direct storage of the spent fuel can be implemented. These factors will have influences on the repository and the volume of waste intended for long-term storage.

Opinions concerning final long term storage of high-level waste are diverse. Many countries are sitting back, in regards to strategy development, to evaluate whether more efficient options arise. Reprocessing is one of the options to decrease the radioactive time frame to more manageable periods by the removal of plutonium and uranium from the spent fuel. Final storage in underground geological formations or mine shafts are proposed strategies for the storage of the reprocessing waste or the direct storage of spent fuel (NECSA, 2010).

Government and Eskom have the advantage of a few years grace before a strategy needs to be implemented. Reprocessing is proposed by government to meet the objective of sustainability and to implement the waste management policy (DME, 2008:27).

STEP 8. Reprocessing (optional step)

Reprocessing will only be an option if its viability is proven. It is another very sensitive aspect of the fuel cycle, due to the separation of plutonium from the spent fuel. Global cooperation and consent are important in implementing reprocessing.

The capital cost of a reprocessing facility is very high. The capital cost of a plant with a capacity of 500 tons of heavy metal per year is approximately $2,29 billion (2002 Dollar) (Spencer *et al.*, 2003:2). It was estimated that the cost in South Africa would therefore amount to R 22,9 billion (R10/$).

The effect of scale plays a significant role in the capital cost. A plant with a 2000 ton heavy metal capacity per year will only cost $1 645/kg while the 500-ton-per-year plant costs $4 680/kg (Spencer *et al.*, 2003:2). The disadvantage, in terms of costs, with implementing reprocessing in South Africa is the limited local demand for reprocessing. Unless government plans to become a global reprocessing role player the implementation costs will be very high and make the short or medium term implementation of a reprocessing plant remote.

If Africa becomes a role player in the nuclear industry, South Africa may choose to reprocess the spent fuel of the relevant African countries. Increasing plant capacity will improve the chances of decreasing the capital cost per ton of uranium processed.

Reprocessing facilities employ a large amount of people. The La Hague facility, with an annual capacity of 1 100 tons of uranium, employs 6 000 people (Schneider & Marignac, 2008:30). The personnel for South African plants, if implemented, will have to be trained to the required standards of a reprocessing plant. Throughout the different sectors it is clear that lots of job opportunities will arise during the implementation of the nuclear energy policy.

Final storage may take place in a facility such as Vaalputs, although that facility currently only handles low-level and intermediate-level waste. The main costs include purchasing the land, wherein storage will take place, as well as operational equipment. Purchasing land will only be necessary for future disposal sites and if the Vaalputs facility is not able to safely store high level waste. Land and equipment costs will have to be included in the total cost estimations although it is not expected that these costs will compare with the costs of other fuel cycle facilities and steps.

4.2.3.4. Summary

All of the fuel cycle cost calculations assume similar costs of construction in South Africa compared to the countries of origin. Such an assumption may not be correct since the required skills or technology may not be available in South Africa and may have to be imported, which will increase the costs further. Factors such as productivity of labourers and salaries will also have an influence on the cost of construction and operation. Costs are further developed from cost information for large plants, which will not necessarily apply in South Africa. Unless otherwise mentioned economy of scale was not taken into account in cost calculations.

The framework in Chapter 2 provides a breakdown of the costs included for each of the fuel cycle steps. Due to the sensitive nature of fuel cycle facilities it is very difficult to obtain costing information for the different aspects. The cost information provided is therefore general and only provides the total capital costs.

The following table provides a breakdown of the expected costs for the entire fuel cycle.

Table 19 – Fuel cycle cost implementation cost

Fuel cycle step	Capital cost (R million)	Assumption
Mining		Mined as by-product
Concentration/Processing	11 000	3 493 tU/year
Conversion	1 100	3 475 tU/year
Enrichment	16 000	435 tU/year
Fuel fabrication	2 200	430 tU/year
Reprocessing	22 000	430 tU/year
Total	**52 300**	

From Table 19 it is clear that the cost of implementing the entire fuel cycle will be very high. These factors do not take indirect costs into account, and these figures might therefore increase further. The assumptions made will also have a drastic effect on the costs.

It has to be emphasised that the implementation strategy will be essential in allowing economy of scale to play a role in the cost per facility and sector.

The following section covers the local industrial involvement and associated requirements.

4.2.4. Industrial involvement

This section considers the different industrial sectors that South Africa will have to develop to reach the goals of becoming self-sufficient and a supplier of nuclear technology. The self-sufficiency will ensure that South Africa can service the local sectors while further creating export opportunities for the local technology.

The different phases of development as well as the associated industries are discussed. Where necessary the availability of local suppliers of the different products or services was established.

4.2.4.1. Milestone/Phase 1

The nuclear industry has very strict codes and standards which ensure high quality products. During the initial phase of the nuclear program, strategies should be developed to ensure that the policy goals are obtained by a sensible and economical approach. The goals, regarding localisation, as set out in the nuclear energy policy, state that South Africa should have the ability to design, manufacture and construct nuclear energy systems (DME, 2008:28). It is further proposed that the implementation strategy of the power plant sector should promote industrial development (DME, 2008:17). It therefore appears that the government is proposing the development of the entire or a large section of the nuclear industry, while further stating that industrialisation will depend on the scale of the power plant sector (DME, 2008:16). The strategy is similar for the nuclear fuel cycle sector (DME, 2008:32).

Phase 1 of the industrial involvement further requires that the local industry in South Africa should be assessed. The assessments will determine the extent of local support to the initial phases of power plant implementation.

4.2.4.2. Milestone/Phase 2

During Phase 2 the different stakeholders, in the industrialisation process, should determine whether the facilities and processes, of the different nuclear industries, are at the required standards for participation in the manufacturing, fabrication, construction and implementation. Should it be found that the industry is not up to standard but stakeholders wish to participate in the future, strategies would have to be developed to ensure an improvement in the capability and development towards compliance with the high standards.

The contract between the vendor and the utility is crucial in ensuring that the degree of technology transfer allows for industrialisation at the scale proposed by government.

South Africa's electricity industry is well developed and may therefore participate in the construction of non-nuclear sections of the plant, such as the turbine island. According to Westinghouse (Nel, 2008), South Africa could supply the following equipment:

- containment vessel assembly;
- non-ASME III pumps and compressors;
- tanks;
- electrical transformers;
- material for and assembly of service water cooling towers;
- heat exchangers;
- module construction;
- switchgear, MCCs, panels;
- material-handling equipment;
- electrical panels and load centres;
- civil & MEI construction;
- cable and electrical raceway;
- electrical fittings;
- concrete;
- rebar;
- formwork;
- structural steel;
- BOP piping;
- HVAC ductwork and supports.

From the list it is clear that South Africa has a base from which to localise a nuclear industry. Many of the equipment requirements, which will be discussed in the following sections, may be supplied locally, if the correct accreditation for the different facilities is obtained. There are South African companies with experience in general construction management, and with specialised training and/or guidance from vendor personnel, local management of nuclear construction projects will be possible. On the other hand, there are companies such as Aveng which have expertise in nuclear power plant construction (Aveng, 2010). Other companies such as LESEDI Nuclear Services also have experience in aspects of nuclear power plant development (LESEDI, 2010b).

South Africa should identify local non-nuclear industries which could service the needs of the proposed nuclear program (Nel, 2008). Such parallel operations will decrease the costs of implementing certain of the sectors and will further allow the development of current industries to higher and more competitive standards.

It is expected that the fuel cycle will only be implemented during the latter stages of the nuclear power plant development, as soon as demand justifies implementation. Therefore, industrialisation will initially only pertain to the nuclear power plant sector, although it is possible that early developments for the fuel cycle industry may take place, if aggressive fuel cycle goals are initiated by government. Local participation in the fuel cycle sector is expected to occur on a larger scale than the power plant sector, due to the fact that most of the front-end fuel cycle activities were previously active in South Africa and the processes are currently being re-developed locally, which allows the growth of local knowledge in the development and manufacturing of these processes and equipment.

4.2.4.3. Milestone/Phase 3

It was assumed that the localisation, of the main nuclear industry sectors, would be implemented during the construction phase of the power plants and thereafter. The assumption specifically pertains to the local manufacturing of the nuclear components and other major plant components. The other less stringent industries should be developed prior to construction, to ensure local participation from the onset of the construction phase.

The resources required during construction of the power plants are quite extensive. The resource requirements include manufacturing, fabrication, labour, construction equipment and associated construction material. If the resources are not locally available the requirements will have to be met by other suppliers in different parts of the world.

To ensure total self-sufficiency, all of the following sectors must be developed and implemented locally.

a) Manufacturing

The main power plant equipment includes:

- reactor pressure vessels;
- steam generators / moisture separator reheaters;
- control rod drives and fuel elements;
- steam turbine generators and condensers;
- pumps;
- valves;
- class 1E switchgear and equipment;

- control equipment.

If South Africa wants to become self-sufficient in the industrial sectors, the above mentioned equipment will have to be manufactured locally. To ensure the sustainability of the industry, South Africa will have to become part of the global supply chain. There are opportunities in the manufacturing of these components due to the limited amount of suppliers and the current worldwide construction of nuclear power plants. The implementation strategy will have to take into account that many other countries want to participate in the global supply chain, and if local implementation does not evolve rapidly, South Africa may later step into a market with a sufficient amount of role players. Therefore it is important that, if implemented, the local nuclear industry should be run by industries producing similar components, to ensure that the demand, for the different products, is sustained.

Many of the above-mentioned components require that manufacturing companies are accredited according to nuclear standards. Nuclear power plants have safety rated and non-safety rated equipment. Certain components of the plant, which are not safety rated, may be supplied by South African manufacturers, while the remainder will have to be imported or the manufacturing capabilities developed locally. Equipment which may be supplied locally includes the components mentioned by Westinghouse in the previous section.

DCD-Dorbyl, a South African company, has the possibility of manufacturing the main nuclear components. Westinghouse has interests in using the company to manufacture steam generators and pressure vessels for export purposes (WNA, 201d). It is unclear whether the company currently has the correct accreditation to manufacture nuclear components although certain components of the PBMR project such as storage vessels and valve blocks were manufactured by DCD-Dorbyl (DCD-Dorbyl, 2010).

DB Thermal is a manufacturing company covering different industries, including the Power Generation industry. The company manufactures boilers, pressure vessels and pressure piping and has been certified according to different ASME codes (DB Thermal, 2010a). The accreditations do not include nuclear component manufacturing capability. The company further manufactures heat exchangers, cooling systems, pre-heaters and other components which may allow localised production during the initial construction stages (DB Thermal, 2010b).

Heaton Valves is a South African company which supplies nuclear and power industry valves, among others. The nuclear valves have the required ASME N-stamp. Heaton Valves has two branches in South Africa and may be used for the supply of valves. The valves are not manufactured locally, but such high standard valves may thus eventually be manufacturing locally.

If the manufacturing of the components can be covered by current industries in South Africa, the cost of implementation will decrease, unless these industries do not yet have the capacity and need to establish new production facilities.

b) Fabrication

The following modules are required:

- mechanical equipment modules;
- piping, electrical and valve modules as well as piping assemblies;
- structural modules;
- electrical equipment modules;
- reinforced steel modules.

Module fabrication decreases construction time and increases the standard of construction. Many of the modules could be fabricated by local companies, although it will have to be determined whether the local fabricators have the ability to supply the modules at the correct standards. Due to the recent construction activities associated with the FIFA World Cup 2010, construction standards and capacities should have improved, which could assist South Africa in the construction of modules and civil work at the power plants and other fuel cycle facilities.

Different companies in South Africa have the ability to become role players in the nuclear fabrication supply chain, and some of these companies and services are discussed in short in the following paragraphs. South Africa therefore has the possibility to participate in construction and fabrication of plant modules, although the necessary accreditation should be obtained where relevant.

According to World Nuclear News, DCD-Dorbyl may be responsible for the development and fabrication of certain modules of the AP1000 (WNN, 2010).

LESEDI is an affiliate of Areva NP and offers services in the nuclear and non-nuclear sectors, including maintenance and welding and fabrication of piping and other components (Lesedi, 2010a). The welding and fabrication department operates under nuclear quality standards and has experience in nuclear and non-nuclear operations. The company further has experience in the mechanical erection of generators and other components, piping manufacture, turbine hall erection and isolation as well as control and instrumentation system implementation, among other non-nuclear services (Lesedi, 2010b). The LESEDI Nuclear Services section offers services in (Lesedi, 2010b):

- Preparation – Feasibility studies and the required input data
- Execution – Mechanical, electrical, instrumentation and control projects
- Operations – Mainly the commissioning and support of operational plants
- Technical Support – At the completion of the project after service support is supplied

LESEDI also offers services in nuclear and non-nuclear electrical projects and may therefore play a role in the electrical equipment modules.

Companies such as Aveng may partake in the construction of the structural and reinforced steel modules due to the company’s experience in construction projects, in both nuclear and non-nuclear projects (Aveng, 2010).

There are local companies which have ASME accreditation for welding and non-nuclear pressure vessel fabrication, such as (SAIW, 2010):

- Stainless Fabricators
- Engski Manufacturing
- Babcock Fabrication
- Lesedi Nuclear Services
- SHM Engineering
- Carbon Steel Fabricators

These companies may therefore, after obtaining ASME nuclear accreditation, participate in the fabrication of piping modules and assemblies as well as mechanical equipment modules and the manufacturing of the main nuclear components, as mentioned in the manufacturing section.

It would therefore seem that South Africa has the potential to participate in large-scale local fabrication activities.

c) Labour

To ensure localisation, local personnel should be trained to comply with the standards of the different nuclear industry sectors. The safety grade of the sector will determine the qualifications required for the relevant personnel.

Table 4 indicates that a peak number of 12 000 on-site personnel are required for the construction of multiple units (8 units). The tempo at which the power plants are constructed will influence the number of personnel required. If the construction strategy is developed to optimise the sharing of personnel between sites, labour requirements may be minimised, which will also decrease labour costs. The eight units, proposed in Table 4 for the USA, are constructed in multiple American states. Due to the size of the American continent, sharing of personnel between states will be difficult. The proposed sites in South Africa are located in relative close proximity to each other, which will allow optimal sharing and combined construction between the different units. It is therefore expected that the peak on-site labour demand in South Africa, during the entire construction program, will not exceed 12 000, assuming a strategy of constructing less than 8 units simultaneously.

The labour requirements for Thyspunt should not exceed 12 000 due to the fact that there will be a maximum of eight units on the specific site. From the data in Table 4 it is clear that the personnel for the remaining three sites (4 GWe each) should be slightly more than half of the requirement for the 8 GWE plant and therefore the figures support the 6 848 labourers proposed by Eskom. An important consideration that could influence the labour requirements is the fact that the numbers presented were developed for the American labour market. South Africa will use semi-skilled labour and will therefore require more personnel.

Many of the necessary skills are similar to other power plant construction requirements. Taking into account that South Africa is currently constructing coal fired and other power plants, which will be completed between 2015 and 2020, there could be pressure on local craft requirements due to the multiple projects. If this is the case, foreign teams will have to be hired or larger numbers of local personnel trained, increasing the costs associated with the construction of the plants. Increased local training may be seen as a benefit to the country due to job creation and skills development.

The on-site personnel will be made up by the following crafts:

- construction craft labour;
- craft supervision;
- site indirect labour;
- quality control inspectors;
- nuclear steam supply vendor and subcontractor staffs;
- engineering, procurement and construction contractors;
- owner’s operating and maintenance staff;
- start up personnel;
- NNR inspectors.

According to Dr. Yves Guenon, Business Director at Areva and quoted by 25 Degrees.Net (2010), 77 000 local people will be trained during the construction of the 20 GWe power plants. A breakdown of the number is given in Table 20:

Table 20 – Job creation by localisation

Craft	**Number of people**
Engineering	6 000
Technicians	18 000
Artisans	53 000
Total	77 000
Indirect job creation	>300 000

Source: 25 Degrees.Net, 2010

The 77 000 people will be responsible for building and operating the nuclear power plants. It is unclear what percentage of industrial localisation the numbers in Table 20 represent.

The manufacturing and fabrication facilities which currently have the possibility of participating in the supply of components and modules might have to increase the number of trained personnel to supply current needs as well as the increased demand due to the development of the nuclear energy sector. The increase in current personnel numbers will contribute to the figures proposed in Table 20.

d) Construction equipment

Many of the companies supplying equipment and services to the nuclear sector might have to increase fabrication and production capabilities due to the increase in demand as a result of the construction of the power plants and other facilities. Increased capacity will also be necessary when supplying export markets.

The following equipment and possible suppliers are important for the construction of the power plants:

- Very heavy lifting cranes

Sarens South Africa has the capacity to mobilise 2 000 metric ton lifting equipment within a month (Sarens South Africa, 2010). Very heavy lifting cranes are required for the different modules and the components of the power plant. Several of the cranes will be required during the construction of the power plants. It is imperative, during all the nuclear sectors, that the government should clearly state its intent and timing strategies to ensure that companies secure the supply of the crucial equipment.

- Pipe-bending machines

Pipe bending reduces welding time and labour requirements. Pipe bending machines are not essential in the construction, although construction time and labour requirements will decrease. LESEDI has pipe fabrication capabilities and should be able to supply the need for pipe-bending equipment. Currently only cold bending technology is available in South Africa, which limits the size of the pipes. Bending technology required for larger sized pipes will have to be acquired.

- Automatic welding machines

There are companies that supply automatic welding machines in South Africa such as EngNet South Africa, while others such as LESEDI already uses automatic welding machines in their operations.

- Automatic rebar assembly machines

Rebar, Mesh & Construction Supplies is a South African company that specialises in rebar equipment, which will decrease construction time and ensure higher quality civil work (Rebar, Mesh & Construction Supplies, 2010). The company took part in projects associated with the construction of the Medupi Power Station and the Gautrain Project.

South Africa therefore has local suppliers of modern construction equipment which will greatly assist in the construction of the plants.

e) Material

The material industry is one in which South Africa will play a key role. The power plant constructions will ensure sustainability of the different material industries such as the cement industry. These industries increased capacity to supply the increased demand of material during the construction of the World Cup stadiums.

- Concrete;
- reinforced steel and embedded parts;
- structural, miscellaneous and decking steel;
- large-bore pipe;
- small-bore pipe;
- cable trays;
- conduit;
- power cable;
- control wire;

- process and instrument tubing.

The suppliers of the materials will be inspected by the vendor to ensure that the material and associated facilities are at the correct standard. Although many of the industries increased their production capacity, the number of infrastructure projects has also increased, which may require importing the necessary construction materials.

Table 5 indicates the material requirements per nuclear power plant. The tempo at which the nuclear program is implemented will influence the demand and associated capacity requirements. As soon as the government reveals its implementation strategy, the relevant local material suppliers may start capacity increase projects. The time between the bidding and licensing, up to the point where construction starts, may be used by all the industry sectors to start implementing strategies, to take part in the opportunities presented by the nuclear program.

f) Implementation of facilities for manufacturing, fabrication and material production

The different sectors and associated facilities will each require the following implementation steps, each presenting different challenges and varying capital requirements. The different steps are discussed in short.

- Licensing/permits

Obtaining the stringent licensing and accreditation will require planning and the commitment of resources. Manufacturing the main nuclear components will require the largest capital inputs due to the high standards applied during manufacturing as well as the large facilities and highly accurate processes and equipment required. As the safety standards become less stringent the capital and resource input will follow a similar trend. Many of the sectors will require assistance from government, especially if demand does not justify implementation at the time. Such implementations should only occur if there is clear proof of an increase in future demand, which will, at that time, sustain the industry.

- Siting

Siting will also depend on the safety risks associated with the industry, which will also have an effect on the cost of land. If the plants are developed in remote locations, infrastructure costs will increase. Environmental and other assessments will be important for each of the industries.

- Design or procure

The means by which the technology is obtained will also influence the cost of implementation. To also supply the needs of the nuclear industry, the optimum strategy will be to adapt current industries. Foreign companies may also choose to develop nuclear industries locally.

- Construction

Construction of the facilities will only be necessary if current capacity must be increased and if local industries cannot be adapted, which will require the introduction of new technology. Construction of new facilities and the introduction of unknown processes will decrease the localisation tempo, due to the associated training requirements and construction time.

4.2.4.4. Summary

South Africa has a strong industrial base on which to build and develop world class technologies and products. The main factor influencing the local nuclear industry is the power plant rollout plan, which is dependent on the government. Government therefore has to assess economic and growth strategies to determine whether a strong local nuclear industry is in the best interest of the country. The different requirements for manufacturing, fabrication, construction equipment, labour and local material supply may be viewed in the relevant sections.

During the following chapter conclusions are drawn from the different sector results.

Chapter 5. Conclusions

In this chapter conclusions are drawn regarding the results obtained in the previous chapter. A summary of the results as well as of opportunities for future studies is also included. Each of the main sectors of development will be summarised, followed by relevant conclusions. Due to the complexity of the different sectors the reader should go through Chapter 4, for insight into the requirements and resulting costs of the sectors. This concluding chapter will only serve as a summary of the main results, and of conclusions arrived at during Chapter 4, as well as of recommendations and possible future research areas.

5.1. Implementation framework

During the initial chapters of the dissertation the framework was developed which serves to determine the cost of implementing each of the main sectors. Chapter 4 gives an indication which framework sections are applicable to South Africa and covers the main cost requirements of the main sectors.

A summary of the implementation framework breakdown indicating the different requirements for each of the sectors is attached in Appendix A.

5.2. Policy objectives

The main sectors that the government in its Nuclear Energy Policy has proposed for development include:

- basic infrastructure development;
- nuclear power plant sector;
- nuclear fuel cycle sector;
- industrial involvement.

It is therefore clear that the government has set ambitious development goals for field of the nuclear energy in South Africa. Each of the sectors is dependent on the power plant implementation strategy. Capacity requirements are a primary issue for many of the active components within the different sectors. The cost of implementing each of the sectors was determined in the previous chapter and will be summarised in the next section.

5.3. Sector cost conclusions and recommendations

Each of the sectors will be discussed. The basic infrastructure and power plant sector will be covered together as these sectors and associated requirements are directly related. The remainder of the sectors will be covered individually although these sectors are also dependent on the basic infrastructure and power plant sectors.

5.3.1. Basic infrastructure and power plant sectors

The minor cost activities such as the economic and other assessments have been completed. If further studies are required the costs will not compare to the cost of implementing the power plants and associated infrastructure. Many of the agencies such as the NNR are understaffed and require the training and education of future personnel. The NNR and other agencies and stakeholders have begun increasing personnel capacities. The increased numbers of personnel require extra funding and financing. As soon as the power plant and basic infrastructure developments have been implemented many of the agencies will also obtain an increased influx of capital due to services rendered. The increase in income should cover the expenses.

The following sections cover the costs of constructing the nuclear power plants and the associated site and basic infrastructure development.

The proposed strategy concerning site and associated generation capacity comprise:

- Thyspunt (8 GWe);
- Bantamsklip (4 GWe);
- Duynefontein (4 GWe);
- Fourth site, possibly located in KwaZulu-Natal (4 GWe).

Eskom developed economic assessments for Thyspunt, Bantamsklip and Duynefontein. The data for Bantamsklip and Duynefontein were used directly while the costs developed for Thyspunt had to be adapted to a plant generating 8 GWe. The framework was applied and indicated that the cost elements developed by the Eskom study corresponded to the framework requirements. Each of the components was assessed to determine whether the requirements are at the correct capacity.

Table 21 indicates the total cost for each of the sites as well as the total cost of implementing 20 GWe of nuclear power.

Table 21 – Total power plant construction cost (20 GWe)

Site	Cost (R million) 2008 Rand
Thyspunt	351 898.6
Bantamsklip	178 276
Duynefontein	173 864.1
Fourth site	185 075.3
Total cost	889 113.9

The estimated cost of implementing the 20 GWe will thus be close to the one trillion rand mark. The costs of Table 21 do not take into account financial costs, such as interest and inflation, which will have an effect on the final amount. By assuring the construction time and payback period, the financial costs may be minimised.

The cost per kWe of constructing nuclear power plants generating 20 GWe was estimated in the region of $4 500 (at R10/$). The cost compares to the cost proposed by the World nuclear association's $4 038/kWe (WNA, 2010b) and an MIT study that estimated the cost to be in the regions of $4 000/kWe (MIT, 2009).

Approximately 7 000 utility personnel are required between the different power plants, of whom 5 000 will have to be professionally trained or qualified. The development program will give the country a huge opportunity of creating jobs; the number of indirect jobs will also be significant in alleviating poverty. The number of employees will increase over the construction period and there is therefore time for the training of personnel. The plants will only commence operation from about 5 years after construction. There is therefore time for the government and the different stakeholders to implement their strategies with regard to training and education.

5.3.2. Nuclear fuel cycle sector

The direct application of the framework was not possible for the fuel cycle sector due to the limited costs data available for the fuel cycle steps. The costs used in the study were mainly overnight cost and no breakdown of the financial requirements was obtained. The sensitivity and competitiveness associated with certain of the sectors do not promote the sharing of information.

The concentration step of the fuel cycle had a small breakdown of costs (Table 18). The costs included:

- process plant costs;
- onsite and offsite infrastructure;
- tailings and water management;
- indirect costs;
- owner’s costs;
- mining costs;
- contingency costs.

Many of the costs are similar to the framework breakdown in Section 2.2.3.3. The framework costs included direct costs (equipment costs), indirect costs, owner’s costs and contingency costs. All of the costs mentioned in Table 18 can be divided into the different framework cost sections of the fuel cycle.

The fuel fabrication cost function took licensing, design and site preparation into account. These costs are also included in the cost framework. Although there is no precise verification included in this dissertation, indications were found that many of the cost elements included in the framework are required to determine the cost.

The amount of fuel required for the 20 GWe nuclear power plant fleet will be of the order of 430 tons per year. The size of the different waste streams was indicated in Table 17. The type of reactor used will influence the amount of fuel required. During the study it was assumed that the AP1000 reactor characteristics will determine the fuel requirement, while the EPR characteristics will determine the enrichment requirements. These reactors were chosen as the associated requirements will be maximised, producing conservative results.

The cost data used to determine the total costs was obtained from current projects proposed, or under development, worldwide. The plant sizes and associated costs were adapted to the requirements of the South African program.

The total cost of implementing the entire nuclear fuel cycle were determined as R 52,3 billion. It is not expected that South Africa will enter the reprocessing market in the close future due to a limited local demand, even after implementing the 20 GWe plants, and the sensitive nature of the fuel cycle step. The cost of implementing the remainder of the fuel cycle which has a higher local and international demand is R 30,3 billion. It is possible to give clear justification for the front end steps of the fuel cycle, especially after implementing the 20 GWe. The main reasons are security of fuel supply and the beneficiation of locally mined uranium. The cost of the concentration/processing facilities will be carried by the mining companies, which will either supply only local demand or local and foreign demand. The estimated direct cost to the country, if Necsa becomes the fuel cycle owner, will amount to R 19,3 billion, assuming that the technology implemented will amount to similar costs as those presented in the study.

The different companies, which may bid for the power plant construction, offer different areas of expertise. Areva, for instance, is active in all the nuclear sectors, including the fuel cycle sector. By using such a vendor, local implementation of the fuel cycle steps may be possible if local technologies or processes are not developed. Similar advantages arise for the industrial involvement sector.

5.3.3. Industrial involvement

The industrial involvement was found to depend on a large number of factors, including:

- power plant and fuel cycle role out plan;
- current capacity;
- government strategy;
- global markets.

The framework was not applied during this sector due to the influencing factors, as mentioned above. To obtain sensible cost figures each of these factors has to be assessed and its effects included. It was found that some of the smaller, less safety stringent components may be supplied by South African companies.

The development and manufacturing of the main nuclear components is not expected in the short to medium term. During this period companies may start obtaining the relevant accreditation while increasing their manufacturing and personnel capacity. Many of the other sectors such as module fabrication, construction and balance of plant requirements may be provided by South African companies. The industrial involvement sector will create lots of sustained job opportunities, if implementation is optimised. It was determined that less than 12 000 on-site labourers will be required at the stage of maximum requirement. Approximately 77 000 personnel will be trained and will participate directly in the building and operating of the power plants, while at least 300 000 indirect jobs will be created.

Most of the construction equipment may be supplied locally while construction material capacities will have to be assessed to ensure sufficient supply.

Various companies proposed for early participation were indicated and discussed in the associated industrial sector of expertise.

The various companies which can possibly participate in local manufacturing, fabrication, construction or equipment supply include:

Aveng	(Construction)
Babcock Fabrication	(Manufacturing)
Carbon Steel Fabricators	(Manufacturing)
DCD-Dorbyl	(Manufacturing, fabrication)
DB Thermal	(Manufacturing)
Engski Manufacturing	(Manufacturing)
LESEDI Nuclear Services	(fabrication, construction)
Heaton Valves	(Equipment supply)
Rebar, Mesh and Construction supplies	(Equipment supply)
Stainless Fabricators	(Manufacturing)
SHM Engineering	(Manufacturing)
Sarens South Africa	(Equipment supply)

The costs associated with the industrial involvement will mainly be carried by the companies who wish to participate. Government support will allow local companies the opportunity to enter the nuclear products market in a strong and sustainable fashion. If government support is not viable, foreign companies may cooperate and collaborate with local companies to ensure sufficient resources for the expansions or implementation.

5.4. Recommendations and future research

Recommendations and future research include:

- The method by which the power plants will be financed has to be developed. Government support is essential. The cooperation between private companies and Eskom is also expected in the program.
- The human resource development strategies should start as soon as possible to ensure that the maximum number of local personnel is used. Operator training is essential and it is important that such training programs are implemented and promoted. Government will have to ensure that the relevant training and education courses are locally available to allow a sustained influx of competent personnel to each of the sectors.
- Fuel-cycle plant sizes from which the costs were determined do not account for export markets. If the government proposes such strategies, the plant sizes and

associated costs will have to be re-determined. Increasing plant sizes will have economic benefits due to economy of scale, as indicated in Chapter 4. The reviewed power plant implementation strategy will influence the local demand for fuel cycle activities, which will affect the cost and plant sizes. The figures will have to be reviewed once the strategies have been completed.

- It is expected that there are more companies which are able to participate in local nuclear industries, and it is therefore suggested that such studies should be performed in the near future. In such a study one might also determine the cost of adapting or expanding companies to the required standards and capacity. Each of the industrial involvement sectors will have to be studied, along with the related South African industries. After such studies it will be possible to determine the cost of converting or upgrading the local industries to supply local or export nuclear markets. The industrial sector is therefore a sector in which further study is proposed. Whether local companies can supply construction materials will have to be determined, especially if other large scale infrastructure projects are undertaken simultaneously.
- As mentioned in the executive summary, all the costs will have to be adapted to the reviewed targets proposed by the government in the new Integrated Resource Plan.
- Future research into the different cost factors should include financial costs and may propose strategies to limit the effect of such costs.
- Due to the competitive nature of the nuclear industry it is very difficult to obtain financial, material and personnel estimates. Once a larger number of reactors have been built throughout the world, information will become more accessible, allowing for more accurate costs analysis.

5.5. Main conclusions

The development of the entire nuclear program, which includes all the main sectors, will demand large amounts of resources and intensive planning. Considering the financial resources alone, it is clear that the country will be placed under pressure. The support of the private sector is crucial and will determine the extent of developments. Government and Eskom will not be able to provide the resources on their own as there are other financially demanding infrastructure projects proposed and under development by Government and Eskom. Many countries have required the support of private participation to supply expertise and resources.

Competent human resources are one of the main requirements of the nuclear energy sector. South Africa has need of training and education to ensure that the requirements are met by local personnel, which will decrease costs and benefit the country.

The main factor which will decide the entire nuclear program is the roll-out plan of the nuclear power plants. If the implementation is not aggressive enough, the other sectors and their development will not be viable or sensible. Local demand will be the primary driver for the implementation of the fuel cycle and industrial involvement. If South Africa develops the fuel cycle to ensure fuel security on the basis of sufficient local demand, the chances of global support will also be improved.

The economic and technical coupling of nuclear industries and sectors presents many areas of research and possibilities and economics will be one of the main factors promoting or hindering nuclear energy expansions.

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Appendix A: Costing framework outline

As explained above, this section outlines the main requirements of the implementation framework, discussed in Section 2.2, which makes it easier to apply and develop a South African specific framework. The following sections indicate the framework outline. The source material used in developing the framework of the different sectors is indicated in the relevant sections of Section 2.2.

1. Basic infrastructure development

1.1. Milestone/Phase 1

- Assessment of nuclear energy
- Economic assessment
- Finding and operation of agencies for policy and strategy development
- Legislation development

1.2. Milestone/Phase 2

- Nuclear policy development
- Nuclear legislation development
- Nuclear regulatory body development
- Physical facilities development
  - Site
  - Grid
  - Physical protection facilities
  - Component manufacture and material supply (requirements developed in Section 3.1.1.4.)
  - Standard calibration laboratory facilities
  - Storage/disposal of low or and medium level radioactive waste.
  - Spent fuel storage and disposal facilities (requirements developed in Section 3.1.1.3.)
  - Safeguards plan and equipment
  - Emergency response facilities and notification of nuclear incidents
  - Communication
- Human resource development
  - Government policy
  - Nuclear regulatory body
  - Radiation and workforce awareness
  - Financial knowledge

    - Industrial support (design, construction, installation, commissioning, project management)
    - Operations and maintenance
    - Quality assurance and quality management
- Public consultation and environmental assessments

1.3. Milestone/Phase 3

- Continue or finalise aspects of Milestone 2

2. **Nuclear power plant sector**

2.1. Milestone/Phase 1

- Understanding of the obligations and commitments
- Operation of strategy and policy development agencies

2.2. Milestone/Phase 2

- Develop financial plan
- Bidding for procurement
- Human resource development of owner

2.3. Milestone/Phase 3

- Licensing
- Site preparation
- Construction of plant buildings and structures
- Installation of the equipment, components and systems
- Plant commissioning
- Human resource development

3. **Nuclear fuel cycle sector**

3.1. Milestone/Phase 1

- Strategy and policy development

3.2. Milestone/Phase 2

- May start implementation of strategies

3.3. Milestone/Phase 3

- Different sectors:
    - Mining
    - Concentration/ processing
    - Conversion
    - Enrichment
    - Fabrication
    - Fuel burnup
    - Spent fuel management

- Implementation
    - Licensing documentation
        - Plant licensing
        - Plant permits
        - Plant studies
        - Plant reports
    - Siting
        - Land purchasing
        - Site permits
    - Design
        - Planning
        - Research and Development
        - Prototype or pilot plant
        - Generic licensing
    - Construction and commissioning
        - Structures and improvements construction
        - Process equipment procurement
        - Auxiliary Equipment procurement
        - Electrical equipment procurement
        - Heat addition/rejection system procurement
        - Special materials procurement
        - Simulator procurement
        - Construction supervision
        - Commissioning and start-up
        - Demonstration test run
        - Staff recruitment and training
    - Operation
    - Decommissioning

4. Industrial involvement

4.1. Milestone/Phase 1

- Strategy and policy development

4.2. Milestone/Phase 2

- May start implementation

4.3. Milestone/Phase 3

- The following resource sectors can be totally implemented or subsectors may be provided or developed.

- Manufacturing
    - Reactor pressure vessels
    - Steam generators/ moisture separator reheaters
    - Control rod drives and fuel elements
    - Steam turbine generators and condensers
    - Pumps
    - Valves
    - Class 1E switchgear and equipment
    - Control equipment
- Fabrication
    - Mechanical equipment modules
    - Piping, electrical and valve modules as well as piping assemblies
    - Structural modules
    - Electrical equipment modules
    - Reinforced steel modules
- Labour
    - Construction craft labour
    - Craft supervision
    - Site indirect labour
    - Quality control inspectors
    - Nuclear steam supply vendor and subcontractor staffs
    - Engineer, Procure and construction contractors
    - Owner’s operating and maintenance staff
    - Start up personnel
    - NRC inspectors
- Construction equipment
    - Very heavy lifting cranes
    - Pipe bending machines
    - Automatic welding machines
    - Automatic rebar assembly machines
- Material
    - Concrete
    - Reinforced steel and embedded parts
    - Structural, Miscellaneous and Decking steel
    - Large bore pipe
    - Small bore pipe
    - Cable tray

        - Conduit
        - Power cable
        - Control wire
        - Process and instrument tubing
- Implementation of facilities for manufacturing, fabrication and material production
    - Licensing/permits
    - Siting
    - Design or procure
    - Construction and commissioning
    - Operation
    - Decommissioning
- Implement labour sector
    - Human resource development
- Develop resource from active capability
    - Adapt or improve processes or further train personnel to comply to nuclear quality standards

Appendix B: Calculations

B1 – Fuel cycle mass balance

$$Mass\ of\ Fuel\ \left(\frac{tU}{year}\right) = \frac{Thermal\ Power\ (MW) * 365(days) * Availability}{Burnup\ \left(\frac{MWd}{tU}\right) * 1(year)}$$

$$Mass\ of\ Fuel\ \left(\frac{tU}{year}\right) = \frac{3\ 415 * 365 * 0.93}{60\ 000}$$

$$Mass\ of\ Fuel\ \left(\frac{tU}{year}\right) = 19.32$$

$Mass\ of\ Fuel\ for\ 22\ Reactors\ \left(\frac{tU}{year}\right) = 425.04 \approx 430$ (Including Koeberg)

B2 – SWU calculation

$$SWU = Mp * V(xp) + Mt * V(xt) - Mf * V(xf)$$

$$Mp = Mass\ of\ Product\ \left(\frac{ton}{year}\right)$$

$$Mt = Mass\ of\ Tails\ Stream\ \left(\frac{ton}{year}\right)$$

$$Mf = Mass\ of\ Feed\ Stream\ \left(\frac{ton}{year}\right)$$

$$V(Uranium\ fraction\ of\ specific\ stream) = Value\ function$$

$$Value\ function: V(x) = (1 - 2x)\ln(\frac{1 - x}{x})$$

$$SWU\ \left(\frac{kg}{year}\right) = 435\ 000 * 2.65 + 3\ 040\ 000 * 6.188 - 3\ 475\ 000 * 4.869$$

$$SWU\ \left(\frac{kg}{year}\right) = 3\ 044\ 495$$

$$Cost\ of\ Construction(R) = 500\left(\frac{\$}{SWU}\right) * 3\ 044\ 495(SWU) * 10\left(\frac{R}{\$}\right) \approx R\ 16\ billion$$