

# Techno-economic analysis of nuclear project management in South Africa

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## **Abstract**

This research report is a techno-economic analysis of the nuclear project management capacity in South Africa. It will focus on the project development phases of the nuclear expansion programme. The author has nuclear engineering training background and also currently involved in the Eskom new build programme (Medupi & Kusile) and the coal refurbishment projects. The following thinking philosophy is used to structure this research report:

- Project management practise for nuclear projects globally
- Project management practise for major Eskom projects in South Africa
- The differences between South Africa and international project management practises
- Guideline for project management in the nuclear environment for possible implementation of the nuclear expansion programme.

The project life cycle has different phases, namely, project setup and planning phase, project design and engineering phase, and project execution phase. The first two phases were discussed and analyzed in detail. The project execution phase was also discussed, however, due to the limited time, the execution phase will not be analyzed in detail. Further research is recommended on the execution phase.

At the end of this research report, a guideline for nuclear project management is developed and associated with some recommendations. This guideline can certainly assist Eskom or other potential NPP developer to understand all the critical aspects in a nuclear expansion programme.

Keywords: Nuclear, Project Management, Project Finance, EPC, EPCM, South Africa

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## List of Abbreviations and Acronyms

AIA	Approved Inspection Authority
BIS	Bid Invitation Specification
BNI	Balance of Nuclear Island
BOO	Build, Own and Operate
BOOT	Build, Own, Operate and Transfer
BWR	Boiling Water Reactor
CCGT	Closed Cycle Gas Turbine
CFPP	Coal Fired Power Plant
COL	Combined Operating Licence
DoE	Department of Energy
DoF	Department of Finance
DFL	Direct Field Labour
EIA	Environmental Impact Assessment
Employer	Eskom or IPP
EPC	Engineering Procurement Construction
ESBWR	Economic Simplified Boiling Water Reactor
FEED	Front End Engineering Development
FIDIC	Fédération Internationale des Ingénieurs-Conseils
FOAK	First Of A Kind Project
HLW	High Level Waste
HR	Human Resources
HVAC	Heating, Ventilating and Air Conditioning
IAEA	International Atomic Energy Agency
ILW	Intermediate Level Waste
IPP	Independent Power Producer
IRP 2010	Integrated Resource Plan 2010

LLW	Low Level Waste
LSTK	Lump Sum Turn Key
LWR	Light Water Reactor
MWe	Mega Watt Electrical
NDT	Non Destructive Testing
NEC3	New Engineering Contract 3 <sup>rd</sup> Edition
NIL	Nuclear Installation Licence
NOAK	N <sup>th</sup> Of A Kind Project
NPP	Nuclear Power Plant
NSSS	Nuclear Steam Supply System
NWU	North West University
OEM	Original Equipment Manufacturer
PHWR	Pressurized Heavy Water Reactor
PLCM	Project Life Cycle Model
PPA	Power Purchase Agreement
PPP	Private Public Partnership
PV	Photo Voltaic
PWHT	Post Weld Heat Treatment
PWR	Pressurized Water Reactor
QA/QC	Quality Assurance / Quality Control
REIPPPP	Renewable Energy Independent Power Producer Procurement Programme
ROI	Return of Investment
RPV	Reactor Pressure Vessel
SOW	Scope of Work
SWU	Separative Work Unit
WBS	Work Breakdown Structure
USD	United States Dollars

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## 1. Introduction

The recent inclusion of South Africa in the elite club of developing countries, the BRICS (Brazil, Russia, India, China and South Africa), may potentially allowing South Africa to have a higher economic growth in the coming years. This in turn will increase the electricity demand to meet this exceptional growth. In South Africa, nuclear energy plays a small role in our current energy mix, despite the fact that South Africa is one of the pioneers in the nuclear energy field in the past. The South African government has the will to re-establish this role in the future by rolling out the massive nuclear expansion programme.

There are public announcements made by the South African Government relating to the construction of new nuclear power plants in South Africa (NNR, 2008B). This would be a huge challenge to the South African engineering industry as the program will be enormous and can cause a massive drain on project management capacity in South Africa. Eskom is also building two of the largest coal fired power plants in the world at the moment. These mega projects are already draining the project management capacity within Eskom and also by the contractors.

The Integrated Resources Plan 2010 stated that in order to provide sufficient electricity for South Africa to grow in the future, an additional 9600 MWe of nuclear generation capacity is required to be added to the power generation capacity before the year 2030 (DoE, 2011). The Department of Energy is most likely to use Eskom (a State Owned Enterprise) to facilitate the procurement process and also manage the project on the Government's behalf. In terms of the South African power generation market, there is still no other significant role player as a power producer except Eskom. This is mainly because the existing government policy restricts the private sector to participate in the power generation industry (Newbery, D. et al., 2007). However, in other parts of the world, the power generation industry has been privatized and it is a very effective sector, for example in the United States and Hong Kong.

There are different types of power generation technology that are in use, such as, coal fired, gas fired, oil fired, nuclear, solar PV, concentrated solar, wind, geothermal, hydro power, etc. However, in South Africa, the base load option is only viable for coal fired and nuclear (Pather, V., 2000). Gas fired is a potential option as well, if the hydraulic fracturing in the Karoo region becomes an economically viable option and when it obtains the government approval. The recent gas field discoveries in Kenya and Mozambique also add uncertainty in the future of gas. On the other hand, coal is abundant in South Africa and the fuel cost will remain cost effective for South Africa for a very long time. However, carbon emission tax, in the form of R200/Ton, may become a problematic issue for the South African industries and Eskom in the not too distant future (DoF, 2013). Recently, carbon emission tax has become a powerful tool and on-going international pressure on governments to reduce the carbon foot print, this may restrict investments in coal fired power plants (Alton, T. et al., 2012). The foreign investors will invest in countries where carbon emission tax is not implemented, hence, maximize their return of investment. This might potentially affect the South African economy in a negative way.

This leaves the only other viable option to choose from: the nuclear energy. This is a technology which South Africa has been mastered in the past. Although nuclear expertise in South Africa still exists, however, most of the nuclear experts are approaching retirement age (DoE, 2011). Following a relatively long periods of disinvestment in nuclear technology in South Africa, the technical knowledge from the older generation was not transferred to the younger generation. Also, another contributing factor is that a lack of career opportunity existing in the South Africa nuclear engineering fraternity, it results in less young nuclear professionals emerging from the universities during the recent years. This caused the current shortage of skills in the nuclear sector.

Energy security is one of the key focal points for nuclear energy, this being a strong advantage to South Africa. There are uranium deposits in the Southern Africa region, hence,

developing the fuel enrichment plant can be foreseeable as the region continues to develop nuclear energy. The good track record of nuclear security is placing South Africa in a favourable position if this opportunity materializes.

### **1.1. Problem Statement**

South Africa is planning to expand its nuclear energy generation capacity in the near future. However, due to this nuclear expansion programme is very important to the South African economy and its reputation, the programme has to be implemented successfully. **Hence, the problem is that South Africa is in need of a project management guideline for the nuclear expansion programme.**

The below are the rationales for the problem statement indicated above:

- Eskom certainly has good project management capacity and capability in developing coal fired power plants. However, developing nuclear power plants is fundamentally different.
- The developing strategy shall be focused on the nuclear portion and supplement the strategy with the coal fired experience. It shall not be structured as coal fired focus and supplement the strategy with nuclear knowledge.
- Developing a project management guideline for implementing the nuclear expansion programme is necessary and beneficial to the local engineering industry.

### **1.2. Aim and Specific Objectives**

The aim of this research is to analyze the nuclear project management capacity of South Africa and develop an IAEA (International Atomic Energy Agency) based framework for implementing a nuclear expansion programme in South Africa.

The following are the specific objectives for this research:

1. Analyze and discuss the current status of international project management practise
2. Analyze and discuss the current status of South African project management practise
3. Analyze and discuss possible nuclear development strategies
4. Understanding of the requirements of a nuclear project and its unique project management skills

### **1.3. Scope of Work**

This research report will discuss the following elements which are considered to be essential for a successful nuclear programme:

- Conceptual Studies
- Procurement Strategies
- Project Financing
- Ownership Model
- Economic Aspects of Nuclear Power Plant
- Human Resources
- Engineering Phases
- Work Breakdown Structure
- Bid Invitation and Adjudication
- Estimating for Nuclear Power Plant
- Project Control
- Risk Management
- Construction Management
- Quality Control / Quality Assurance
- Construction Schedule

The above elements will be spread across in four major chapters, literature survey, project setup & planning phase, project design & engineering phase and project execution phase. The literature survey chapter entails the history of nuclear project management, where it discusses nuclear programmes of different countries and it also discusses some of the technology providers in brief and their reactors on the market for Eskom to consider. Under the South African context, it gives an overview of the stakeholders in the nuclear expansion programme of South Africa.

In the project setup & planning phase chapter, the research project discusses the project development process, in terms of conceptual studies and feasibility studies. It also discusses the procurement strategies for the NPP, and analyzes the EPC LSTK and EPCM Cost-reimbursable contracts. The research project also provides other major procurement strategies which are currently used in the project management industry. The recommended procurement strategy for the South African programme is also discussed. The economic aspects are discussed in order to give a full picture of a NPP in terms of cost implication of utilizing the nuclear technology. The research project gives an overview of human resources for nuclear project and highlights some of the lessons learnt from the Medupi and Kusile projects of Eskom.

Under the project design & engineering phase chapter, it continues with the discussion on the project development process, from the conceptual studies, into the basic engineering and detailed engineering phases. Construction support engineering is also discussed here. Work breakdown structure for a NPP is analyzed. The research project analyses the bid invitation & adjudication process. Estimating for NPP is highlighted in this chapter, where the research project gives an overview of the top-down and bottom-up approaches. In addition to this, it also analyzes the estimating experiences gathered in the current projects of Eskom.

Project control, risk management, construction management, quality assurance and construction schedule forms part of the chapter of project execution phase. Under project control, the research project discusses the three main functions, namely, cost control, progress management and change management. Risk management is discussed and an analysis was given to understand the risk process and all the risk associated with the NPP project. Construction management was also discussed, due to the vast amount of topics in the construction management. This research report only discusses briefly on the site establishment and construction equipment topics and further research is recommended for the rest of the topics in construction management. At last, quality assurance and construction schedule is also discussed.

In the final chapter, conclusion will be drawn and recommendation will be made to complete this research. These will collaborate with the specific objectives identified in the section of aims and specific objectives.

#### **1.4. Work Excluded**

Due to time constraint, the following topics will not be discussed in this research report:

1. Utility Responsibility
2. Site Selection
3. Environmental Engineering
4. Safety Management on Site
5. Nuclear Fuel Procurement
6. Information Management
7. Earned Value Control
8. External Costs for a Nuclear Project
9. Policy and Regulation Development

10. Expediting

11. Software systems for Construction Management

12. Labour Social Issues

## **1.5. Outputs and Deliverables**

The outcome of this research project will be a framework or a project management guideline for developing a nuclear expansion programme in South Africa.

The framework shall have the following:

- Project Setup & Planning Phase
- Project Design & Engineering Phase
- Project Execution Phase

The above is also depicted as the structure of this research report with specific reference to Chapter Three, Four and Five.

## **1.6. Structure of the Research Report**

The structure of the research report is split into a five major sections. The first chapter is the introduction of this research report. The second chapter is the literature survey. The third, fourth and fifth chapters are the detail analyses and the guideline for the nuclear project management in different phases. In the last chapter, it detailed the recommendations for the nuclear expansion programme.

## **2. Literature Survey**

### **2.1. Introduction to Chapter Two**

Under Chapter Two, the literature survey section is divided into four sections. The Section 2.2 researched on the history of nuclear project management internationally, i.e. the United States, China, Argentina and Korea are the four countries that are researched. After that, it gives an overview of a nuclear power plant and also the international nuclear industry. Section 2.3 discussed the nuclear project management in South Africa, such as stakeholders of a nuclear expansion programme and their functions and relationships. Then the report researched the South African capacities and capabilities and also discussed on the work done by the South African academic sector.

### **2.2. Nuclear Project Management at the International Level**

#### **2.2.1. Nuclear Project Management in other countries**

Project management is critical in order to achieve success in all types of projects where the main three pillars are in cost, quality and time (Steyn, H., 2012). The project management function has to interface with all the supporting functions, such as, engineering, safety, quality, construction, procurement, accounting, finance, commercial and legal. The project manager shall have the knowledge on all the above mentioned fields, although in-depth knowledge is not needed, the project manager shall understand what is the other department is working on and their responsibilities as well. There are 435 nuclear reactors in the world and have an installed capacity of 374 108 MWe at the moment with 65 reactors are under construction (IAEA, 2011C). The nuclear industry is not a small industry at any given survey report. There are countries that have completed the nuclear expansion programme before. Although some countries are successful in the programme, but there are also countries that did not achieve the same outcome as the others. The following are some examples of a nuclear power programme.

### **2.2.1.1. The United States Story**

In the 1960s, the nuclear boom occurred in the U.S., they constructed 100 NPP between 1970 and 1990 in order to provide cheap electricity to the public (Alexander, L., 2009). However, most projects were over budgeted or delayed, the major contributing factor was because of lack of proper project management structure, non-standardized design, etc. In the U.S., since the beginning of electricity market privatization in the 90s, the focus shifted to short term Return of Investment (ROI), long term vision being neglected. Based on the above, the gas market boomed since the capital cost is low and construction time is short, it is relatively easier to the financier to invest in the gas market. As a result of the above, long term projects like nuclear and hydro were losing favour in the investment market, mainly due to their huge capital burden and returns could only be generated after years of construction (Caplan, M., 2009). However, the US government is trying to rejuvenate the nuclear sector in the past few years.

### **2.2.1.2. The Argentinean Story**

Argentina started their nuclear power programme in the 60s, and its first NPP is the Atucha 1 nuclear power plant which entered commercial operation in 1974. Shortly after that, the Argentinean government decided to build the second (Embalse) and the third (Atucha 2) nuclear power plant, however, the Atucha 2 unit was not a successful project. Construction was started in 1981 and it was suspended in 1994 due to lack of funding (IAEA, 2008B). Another contributing factor is that the Siemens group dis-invested in the nuclear industry and Siemens was the technology provider of Atucha 2 (WNA, 2013A). The construction work was restarted in 2006 and it is scheduled to be completed in the mid-2013 which is delayed in decades.

### **2.2.1.3. The Chinese Story**

China embarked on the nuclear power programme since 1970. The first nuclear power plant was the Qinshan NPP which started commercial operation in 1991. In recent years, the Chinese government is building various nuclear power plants using different technologies, such as EPR, AP 1000 and VVER 1000 from the French, American and Russian respectively. These catalyzed the Chinese to develop its own nuclear power reactor technology. The CPR 1000 is the Chinese design and most of the new plants that are in the construction phase or planning phase which have CPR 1000 units. There is a development plan for the CAP 1400 which is a Generation III plant utilized the AP1000 as the reference design base. Localization was also a big driving factor in the Chinese programme, the localization factor is reaching 80% for the latest CPR 1000 project (Wang, J., 2011). The biggest lesson learnt in the AP1000 project was to complete the detailed engineering work before construction work shall commenced (IAEA, 2012).

### **2.2.1.4. The Korean Story**

South Korea has a +30% of electricity generated from nuclear power and it has 20 nuclear reactors in operation in 2012. South Korea is the 5th largest country in the world in terms of nuclear generating capacity (IAEA, 2012). South Korea started their nuclear programme in the 70s as well. This programme was facilitated by the government and supported by the US. The first nuclear power plant, Kori-1, is actually a PWR from Westinghouse built in the late 70s. After the first NPP, the country was in a massive nuclear expansion programme. There were eight nuclear power plants under construction in the early 80s. This progression in construction of the nuclear power plants drove the localization programme as well. The South Korean developed its own nuclear technology by offering the APR 1400 in the international market (Whang, J.D., 2011). This was proven to be successful as the Abu Dhabi government selected four KEPCO's APR 1400 units over the Areva and Westinghouse technologies (ENEC, 2009). This surprised the nuclear industry, and later on

the South Korean government stated that they were aiming at exporting the nuclear technology in a large scale and would like to position themselves as the number three nuclear technology provider in the world (Whang, S.D., 2011).

## **2.2.2. Overview of Nuclear Power Plant and the Nuclear Industry**

### **2.2.2.1. Systems Structures and Components of a Nuclear Power Plant**

A nuclear power plant can be divided into three areas, namely, Nuclear Island (NI), Conventional Island (CI) and the Balance of Plant (BOP). The NPP requires all three areas to function and ultimately produce electricity to the grid (Guénon, Y., 2011).

The NI consists of the NSSS system, where the reactor core, pressurizer, steam generators, control rod systems forms part of it. The reactor pressure vessel, reactor internals, core catcher, reactor containment building, In-containment refuelling water storage tank (IRWST), pressure relief valves, etc. forms part of the NI (Guénon, Y., 2009). The NSSS is the most important system of the whole NPP which generates steam to drive the turbine located in the CI. The quality of these equipment has a direct impact of the structural safety of the plant. Hence, the strict quality control in constructing a NPP.

There is also a BNI portion in the NI. BNI stands for Balance of Nuclear Island which consists of various systems which are not responsible for steam generating, such as, diesel generators, nuclear waste treatment, HVAC, civil work, polar cranes, elevators, etc. (Guénon, Y., 2009).

The CI consists of the steam turbine generator set, cooling water systems, electrical supply system, HVAC, etc. (Siemens, 2009). The CI is typically contracted to Siemens of Germany or Alstom of France in South Africa. The MHI of Japan can also offer the CI service to South Africa (MHI, 2007).

### 2.2.2.2. The International Nuclear Industry

There are several technology providers in the world that specialize in developing NPP. The following table listed the major technology providers and its country of origin (Skoda, R., 2012).

Item	Technology Provider	Country of Origin
1	Areva	France
2	Westinghouse	America
3	General Electric-Hitachi (GE-Hitachi)	America – Japan
4	Mitsubishi Heavy Industry (MHI)	Japan
5	Korea Electric Power Corporation (KEPCO)	Korea
6	Atomic Energy of Canada Limited (AECL)	Canada
7	China Guangdong Nuclear Power Corporation (CGNPC)	China
8	Rosatom	Russia

**Table 2-1: Technology Providers in the Market**

All the above reactor suppliers have their own reactor design. It can be divided into three major groups, Pressurized Water Reactor (PWR), Boiling Water Reactor (BWR) and Pressurized Heavy Water Reactor (PHWR). All of these have a different process to generate steam, but all utilize the nuclear fission reaction. The following is the table of reactors in the market (Mangena, J., 2007):

Item	Reactor Name	Type	OEM	Output
1	ABWR	BWR	GE-Hitachi	1350 MWe
2	AP1000	PWR	Westinghouse	1200 MWe
3	EPR	PWR	Areva	1650 MWe
4	ESBWR	BWR	GE-Hitachi	1520 MWe
5	APWR	PWR	MHI	1700 MWe
6	APR 1400	PWR	KEPCO	1450 MWe
7	OPR 1000	PWR	KEPCO	1000 MWe
8	Enhanced CANDU 6	PHWR	AECL	700 MWe
9	ACR 1000	PHWR	AECL	1200 MWe
10	CPR 1000	PWR	CGNPC	1080 MWe
11	VVER 1200	PWR	Rosatom	1078 MWe

**Table 2-2: Different Reactors on the Market**

Since South Africa favours the PWR technology, the reactor types of PHWR and BWR are not currently considered by Eskom. Hence, only the AP1000, EPR, APR1400, CPR1000 and VVER1200 are suited for the nuclear expansion programme of South Africa.

i. Areva

Areva is a French company who are also a state owned enterprise. They currently provide the majority of the reactors used in the world, in the form of the 900 MWe three loop reactors. Areva is also participating in the entire nuclear cycle, from mining of uranium in Namibia, to fuel fabrication in France and decommissioning of NPP in the United Kingdom (Guénon, Y., 2010). The latest offer is the EPR which is currently being built in Finland, France and also in China. The Figure 2-1 detailed the different buildings in the Areva EPR which has 1650MWe capacity.

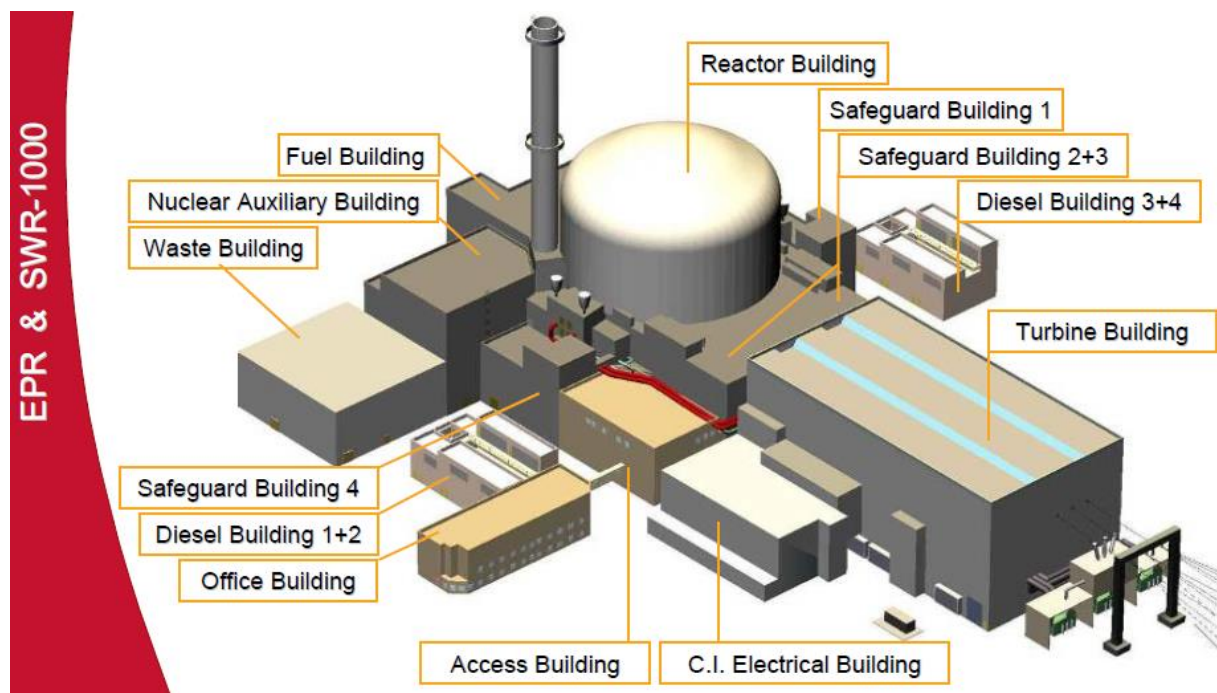
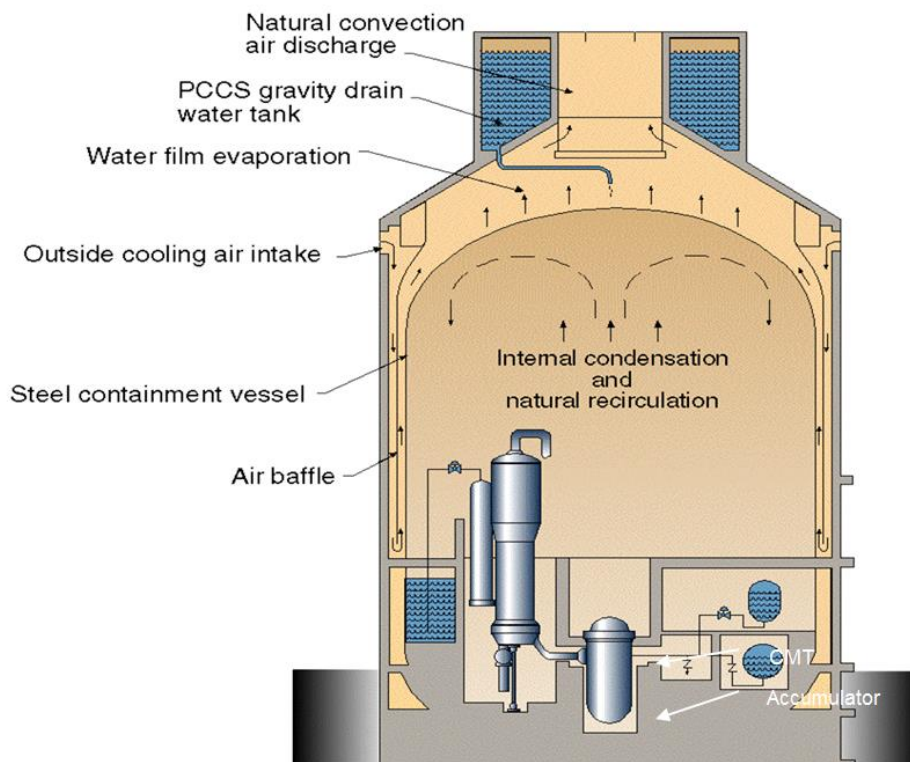


Figure 2-1: Areva EPR (Sourced by Y Guénon - Areva)

## ii. Westinghouse

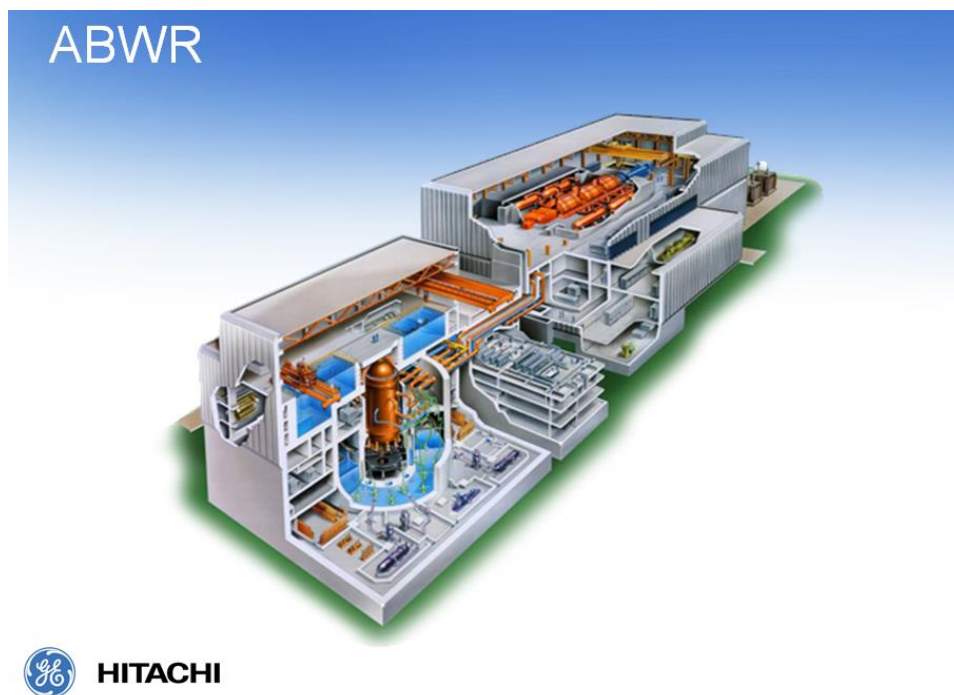
Westinghouse is also a major player in the nuclear industry which has got a big market share in the United States. The company specialize in developing new reactors for the market. Westinghouse also facilitated the AP1000 technology transfer programme in China. The AP1000 is capable of generating 3415 MWth from its NSSS and the electrical output is at 1200MWe (Westinghouse, 2008). The Figure 2-2 shows the passive containment cooling system of the AP1000. The technology transfer was part of the contract and it is proven to be very successful (Westinghouse, 2008). The recent holding share transferred from the Shaw Group to the Toshiba Group might have an impact on the company's direction in the future. However, Westinghouse is still very respectable in the nuclear engineering fraternity.



**Figure 2-2: Westinghouse AP1000 Passive Cooling System (Sourced by Y Brachet - Westinghouse)**

iii. GE-Hitachi

GE-Hitachi is the joint venture by the two energy giants, General Electric from America and Hitachi from Japan. The sole intention of this joint venture is to obtain the biggest market share in the BWR market. The highly successful ABWR is the only Generation III reactor which is in operation. Four ABWRs are in operation in Japan and also four ABWRs are in construction in both Taiwan and Japan (McDonald, D., 2011). The GE-Hitachi subsequently developed the ESBWR which is an advanced version of the ABWR for the BWR market.



**Figure 2-3: GE-Hitachi ABWR (Sourced by D McDonald - GE-Hitachi)**

iv. Rosatom

Rosatom is a Russian state owned enterprise, it also covers the entire nuclear cycle which is similar to Areva of France. Rosatom has offered the VVER design to the world with proven technology. The VVER has been built and all the previous versions of the VVER are in operation across Russia. The latest offering is the VVER 1200 which is a Generation III

design and shall be very competitive against the EPR of Areva and AP 1000 of Westinghouse.



**Figure 2-4: Rosatom VVER 1200 Reactor Building (Sourced by S Svetlov - Rosatom)**

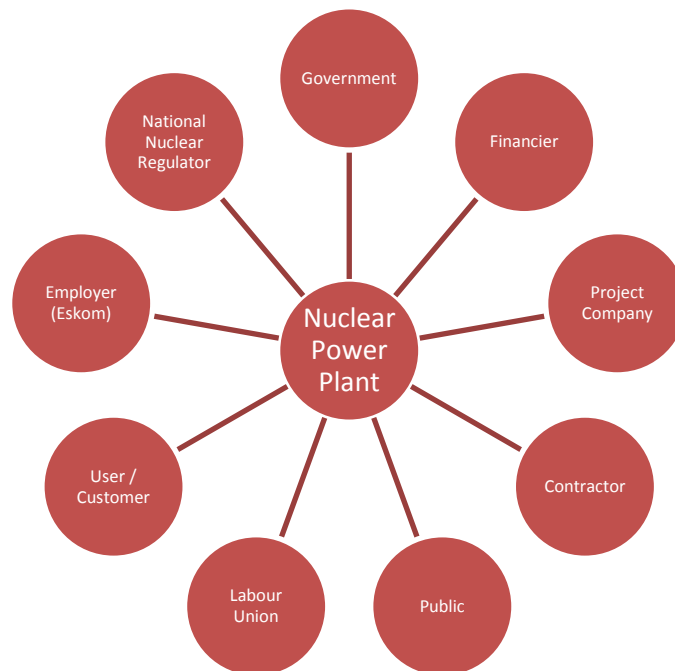
Table 2-2 listed most of the reactors available to the market and they all have their own advantages and disadvantages, mainly due to the power output, reliability, philosophy of safety systems, etc. All of these NPPs utilize PWR technology, which means the water will not turn to steam at the reactor core. This is different to the BWR technology where the steam is generated inside the reactor core. In the PWRs, although the design might be different, there is some mechanical equipment in the plant which has the same function, such as the reactor, control rod driving system, reactor coolant pumps and turbine. The pressurizers and steam generators are unique to the PWR technology, since the steam

which is driving the turbines is from the steam generators rather than the reactor core (in the case of BWR). Hence, the steam is not radioactive for the PWR units.

## 2.3. Nuclear Project Management in South Africa

### 2.3.1. Stakeholders of a Nuclear Power Plant Project in South Africa

In a nuclear environment in South Africa, it is necessary to understand the stakeholders on a NPP project. For the success of the nuclear expansion programme, it is essential to establish the stakeholder management process and structure.



**Figure 2-5: Stakeholders of a NPP in South Africa (Primary Source from Murray & Roberts)**

#### **Government:**

The Government shall develop and implement the national energy policy, in order to establish a long term vision plan, i.e. Integrated Resources Plan (IRP 2010). It needs to establish a stable environment in the energy sector, due to the fact that a nuclear energy programme requires a 100 years (from planning, construction, operation to decommission) commitment from a nation (ENEC, 2009).

**Regulator:**

The regulator in South Africa, National Nuclear Regulator (NNR), shall have two major functions in terms of regulating nuclear energy, such as, issuing licenses to operate nuclear facilities and maintain/ensure a quality standard of the nuclear facilities. The daily activities of the NNR shall be reviewing and assessing safety cases, ensuring compliances of nuclear facilities and enforcement actions on non-compliance facilities. The NNR shall be responsible for the protection of the public safety and at the same time to allow the project to proceed.

**Employer:**

The employer is the legal plant owner and in the case of South Africa, it would be Eskom. Eskom would also operate the plant, as it is clearly stated in the Nuclear Energy Policy of 2008 (DME, 2008). It assumes all the legal liability to the public after the commercial operation milestone. Eskom shall be responsible to develop the NPP project as well.

**User / Customer:**

In the South African context, the user / customer shall be the residential users, municipalities and industrial users. They are the customers for Eskom and they shall be prepared to pay a fair price for the electricity. In the case of IPPs, it is possible that the NPP is only supplying the generated electricity to a group of industrial users. However, a PPA shall be in place before the project can be commenced.

**Financier:**

The financier, sometimes referred to as the project sponsor, is the entity that supporting the project financially. The financier would have a calculated return of investment in accordance

to an adequate risk profile and in some cases, would be legally binding with a PPA. However, there are various types of financial models for a NPP project.

### **Project Company:**

The project company is normally the company representing the employer to manage the construction project. The company shall protect the interest of the employer in the project and shall have the authority to make decisions on behalf of the employer. In other projects, if the employer has the capacity and capability, a team will be assembled to manage the project. Hence, the function of the project company is performed by the employer.

### **Contractor:**

The contractor shall be the legal entity, usually a consortium in a NPP project, to perform the design and construction work. The consortium typically comprises of technology provider and main construction contractors. The scope of work shall include engineering, procurement, construction and commissioning of the NPP. The contractor is responsible to ensure the NPP will achieve commercial operation by a set date and in compliance to the user requirement specification.

### **Public:**

Public means the general citizen in South Africa, and it shall also include all the environmental groups. The public shall be allowed to comment on the nuclear energy policy and voice their concerns during the public hearing sessions. This involves sensible discussions with the government and Eskom. Ultimately, the public safety is the first priority in any nuclear project, in fact in any engineering project.

## Labour Union:

The labour unions are the voices of the workers. They shall be allowed to comment on the nuclear energy policy. However, sensible discussions shall be used rather than industrial actions. The current situation with the labour unions are divided, since the Solidarity supports the nuclear expansion programme and the COSATU and the NUM are against the programme (Maharaj, S., 2010). The nuclear industry shall discuss this issue with the labour unions because a nuclear expansion programme requires support from all stakeholders.

### 2.3.2. South African Capacities and Capabilities

In the nuclear industry, there is a defined line of engineering competency levels. The below table classified the complexity of engineering products in terms of nuclear engineering.

Complexity	Items
Advanced	Ultra Heavy Forging Turbine
High	ASME III Components Fuel Cycle
Intermediate	Pipe Fabrication Pumps and Valves
Low	Construction Structural Steel

**Table 2-3: Industrial Complexity for NPP Components**

Based on the estimate prepared by Rosatom, almost 50% of the total contract value for the construction of a nuclear power station will involve civil work (Kalinin, A., 2012), and this is typically where the local industry can participate. Local contractors like, Murray & Roberts, Aveng Group, WBHO, Group Five and Basil Read can all benefit from the localization of the programme with regards to the civil portion of the nuclear expansion programme.

There are other contractors in South Africa who specialized in boiler installation and have good experience in the high pressure and low pressure piping systems. They are Babcock, Steinmüller and DB Thermal.

Most nuclear power projects have localization requirements set as one of the commercial criterion. Local contractors can form part of the localization strategy with the bidders. Bids will be evaluated by the procurement committee from the Government in terms of the level of localization. Local contractors are more than capable of executing the civil scope. The challenges with the civil work might be the thickness of the concrete that is involved in a nuclear power plant that may need assistance from foreign technical experts. However, only a handful of the local contractors are active in the mechanical installation of an industrial project especially in the field of mega projects that requires high precision and high quality, such as the petrochemical sector and the power generation sector. However, only Aveng Group and Group Five are actively involved in the nuclear power construction sector and to a lesser extent Murray & Roberts. Aveng Group is currently analyzing the fundamental differences between constructing coal-fired power plants and nuclear power plants in the power generation sector. Aveng Group also has a nuclear construction division within the company (Quan, D., 2011). The same strategy can be said for Group Five. Group Five also has a nuclear construction division and they are currently investigating in the construction method of NPP, i.e. modular construction method (Greyling, M.S., 2012). This posed a huge constraint in the localization strategy due to the experience and capabilities of the local contractors who are therefore in doubt.

### **2.3.3. Researches from the South African Academic Sector**

Since the nuclear expansion programme is detailed in the IRP 2010, the private sector has researched the nuclear project management capacity in South Africa. However, there is not a vast amount of work being performed by the South African academic sector. There are only a few researches that were completed by the North West University and the University of Pretoria.

Mr Mangena has completed a research in the availability of resources for a nuclear power plant (Mangena, J., 2007). Mr Ballack has also completed a research in the cost of policy implementation for the nuclear expansion programme (Ballack, P.A., 2010).

The current focus in the South African academic sector is research on the renewable energies, rather than the nuclear energy. **Hence, there is no research focus on guidelines for project management in developing a nuclear expansion programme. Hence, this report is being developed in order to fill the gap.**

## **2.4. Summary for Chapter Two**

In Chapter Two, the literature survey section, it researched the nuclear project management at an international level that discussed different countries, i.e. United States, Argentina, China and Korea. In the chapter, it also gave an overview on a nuclear power plant and the nuclear industry. After this, the literature survey discussed the nuclear project management in South Africa, it discussed the different stakeholders in a nuclear power plant project and also the South African nuclear industry. At the end, it also looked into the researches performed by the academic sector.

In Chapter Three, this research report will look into the project setup & planning phase of the nuclear expansion programme, as it is the first stage in the programme.

### **3. Project Setup & Planning Phase**

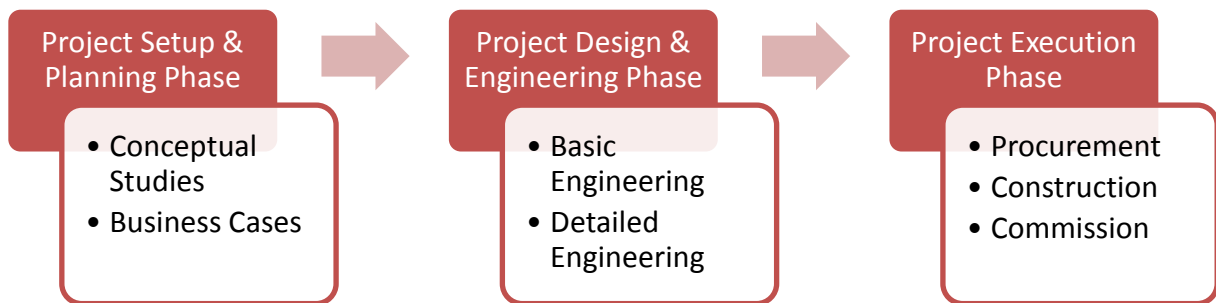
#### **3.1. Introduction to Chapter Three**

Under Chapter Three Project Setup & Planning Phase, it is divided into five sections in order to discuss all the aspects in this early phase of the nuclear project. The Section 3.2 Project Development will discuss the engineering phases in the project, especially on the conceptual studies. Section 3.3 Procurement Strategies will research on the EPC LSTK and EPCM Cost-reimbursable options. Major procurement strategies that are used in Eskom will also be analysed in this section. Section 3.4 will discuss the project financing options and ownership models for nuclear power plants. Section 3.5 will discuss the economic aspects of a nuclear power plant, including overnight cost, operation & maintenance cost, specific cost and nuclear fuel cycle cost. Operating efficiency will also be discussed in the same section. Lastly, Section 3.6 will focus on the human resources for nuclear projects and its South African context. Section 3.7 is the guideline for Project Setup and Planning Phase. Section 3.8 is a brief summary of Chapter Three.

#### **3.2. Project Development**

Eskom stated that due to the Nuclear Energy Policy in South Africa, they are the only operator of the commercial power reactor (DME, 2008). Hence, Eskom has a very strong chance that they will procure the NPP fleet as well. Due to the financial nature of nuclear power plants, the expansion programme is capital intensive and the total investment value will be in the region of billions of Rand. To implement such massive plans, best practise of project engineering has to be utilized. In the Eskom PLCM, it stated that projects have to be developed from conceptual studies to business cases and then feasibility studies (Murray, M.F.B., 2010). All these studies are in the planning stage, and they all have a sole purpose that is to define the project whether it is feasible or not in terms of return of investment. It has an industry norm that after the detailed engineering phase, the project cost should be within

+10% and -5% of estimated accuracy, see Section 4.5. This certainly helps the Eskom board to make the decision and also allows the financier to prepare the funding model.



**Figure 3-1: Phases in Project Life Cycle Model (Sourced by Murray, M.F.B. - Eskom)**

After the approval of the bankable feasibility study and the front end engineering design is completed, the employer shall start to prepare for the licensing application to the regulator. At the moment, the NNR is adopting the US NRC system with regards to the COL (Combined Operating License) process. This process requires the design to be certified by the NNR. After that a design certificate is issued as it declares that the design is approved by the NNR. The NNR is currently using both multistage approach and the once off approach with regards to Nuclear Installation License (Bester, P., 2012). The NIL is specific to one design while the other license, Nuclear Installation Site License is issued to a nuclear installation without a specific design. Once the employer has obtained the NIL, the early site work can proceed. The employer could in the meantime raise the capital for the project.

### **3.2.1. Conceptual Studies**

Conceptual studies are used as the very first step in the planning stage. It is used to determine whether the technology is best suited for the country (IAEA, 2012). In the case of power generation projects, the Eskom board normally made the decision to pursue a new capital project and sponsor the capital planning department to facilitate a conceptual study.

The capital planning department in conjunction with the engineering team will begin to investigate available technologies to add new capacity to the grid. The study is also referred as “desktop studies” which only require research from available sources, initial high level meeting with potential suppliers and review studies from other countries. The outcome of this study shall be a specific technology which can fulfil the requirements from the Eskom board. The study will be presented to the Eskom board and either approval to pursue a business case is granted or the conceptual study is rejected.

It is logical that conceptual studies should be done by engineers who possess planning skills and have macroeconomic thinking skills. Details are not important in this type of study, it should satisfy the requirement set by the Eskom board and also highlight the major advantages and disadvantages of such a project.

The spent fuel management and the nuclear liability shall form part of the conceptual studies in a nuclear power project. These two topics are nuclear project specific and shall be taken seriously (IAEA, 2012). The conceptual study could be used to measure the following criterion against the feasibility of the nuclear programme:

1. Capacity
2. Location
3. Benefits
4. Potential Capital Investment
5. Return of Investment
6. Safety

The outcome of such studies shall allow the decision maker to understand all the potential risks and opportunities associated with the project. Alternative benefits shall also be highlighted in order to fully understand the project even at a social economical level.

### **3.3. Procurement Strategies**

#### **3.3.1. Understanding EPC LSTK Contract**

Traditionally, the EPC LSTK contract type is what the employer preferred in terms of contractual mode for mega projects. This type of contract can provide greater cost and time certainty to the employer or the financier (McNair, D., 2011A). The EPC LSTK type is structured so that the main contractor assumes the overall responsibility of the project. This includes the design, engineering, procurement, construction and commissioning of the NPP. The employer shall only be focusing on the final product in terms of agreed performance of the NPP and the completion date of the project. The employer will typically issue a set of employer's requirements which shall be referenced to the EUR (European Utility Requirements) requirement. It has four volumes:

- Volume 1 – Main Policies and Objectives
- Volume 2 – Generic Nuclear Island Requirements
- Volume 3 – Application of EUR to Specific Designs
- Volume 4 – Power Generation Plants Requirements

However, the employer needs to fulfil certain deliverables prior to the commencement of the EPC LSTK contract. These items normally include the provision of the land, EIA, geotechnical survey and shall include the services establishment. Services establishment shall include the water connection, sewage connection and power connection for the construction site including the lay down areas. These shall be discussed later in the Section 5.4.1.

The scope of work shall be clearly defined in the EPC LSTK contract, this can avoid ambiguity as to "who performs what" scenarios, where these disputes are often results in arbitration or litigation (Clark, C., 2009). A drafted Scope of Work for the nuclear expansion programme is in Appendix A.

The employer shall also be updated with the project progress during the construction period and the main contractors shall submit progress reports to the employer for acceptance. Overseeing the quality control of the plant is also needed to ensure the finished NPP shall achieve the same reliability performance as agreed. Safety is also important from the employer's point of view to ensure life is not lost in the project. This contractual mode allows the employer to have a well-defined cost and duration for the project. However, due to this high risk nature of the EPC LSTK contract, the main contractor will have a high contingency budget to overcome unforeseen risks (Nevin, T., 2013). For the main contractor, this type of contract represents high risk, but also high reward. There are different contract forms in the industry to cover this type of contractual mode, such as the FIDIC EPC/Turnkey Contracts, commonly known as the "Silver Book" or the NEC3 Engineering and Construction Contract (ECC).

### **3.3.2. Understanding EPCM Cost-reimbursable Contract**

EPCM cost-reimbursable projects were used in the petro-chemical and mining sectors, however, in the recent years, the power generation and the water desalination sectors also utilize this contractual mode for their mega projects (McNair, D., 2011A).

As mentioned above, in the recent development of the mega-project fraternity, the use of EPCM cost-reimbursable contractual mode is increasing. The main driver for this is because in the petro-chemical industry, there are only a few contractors that have the know-how, strong balance sheet and the resources to execute mega-project (Loots, P., et al, 2007). Due to the fact that there are only a few of these players in the market, the competition is not high. The margin for these contractors is high and the employer is forced to look into a different contracting strategy, such as the EPCM cost-reimbursable contract.

The EPCM contractor shall not be mistaken as they will execute the construction itself. The acronyms CM in the EPCM shall mean construction management. EPCM contractors act as

the engineer for the employer, and it manages the construction on behalf of the employer. Procurement is performed on behalf of the employer. An EPCM cost-reimbursable contractor normally executes the design engineering work and appoints subcontractors to execute the work packages. This arrangement is a major risk to the employer, as the EPCM cost-reimbursable contractor can prolong the duration of the contract to gain contract value. To counter this practice, an employer shall implement incentives to allow the EPCM cost-reimbursable contractor to complete the project as soon as possible. The following is one of the incentive schemes used in the EPCM industry:

The employer will determine the target cost for the EPCM cost-reimbursable contractor. If the project is under budget and also completed sooner than the agreed date, then the EPCM cost-reimbursable contractor will receive a performance bonus to recognize its achievement.

### **3.3.3. Major Procurement Strategies**

There are three major types of procurement strategies at the moment:

- EPC Turnkey
- Multi Contract
- Split EPC

In the current Medupi and Kusile projects, Eskom utilized the Multi Contract contractual model, and it has proven to be cost ineffective. It creates a lot of interfaces between these smaller contracts and the project priorities are changed as soon as delays occurred in one of these contracts. This phenomenon has significantly stretched the existing Eskom project management resources, as it cannot cope with all the priority changes and it creates confusion and ultimately results in standing time and delay claims from the contractors towards the employer. However, if the employer is experienced in building NPPs, then, this method should be used in order to allow the employer to have control over the project. For example, EDF (Électricité de France) is very experienced in building NPPs, hence, the EPR

unit referred as Flamanville 3 being built in France is also utilizing the Multi Contract mode. The four AP1000 units being built in China are also using the Multi Contract mode. This practise is only successful if large contracts have been awarded to large experienced organizations with extensive capabilities in nuclear construction (IAEA, 2012).

However, in the current nuclear project environment, it is unlikely to have one EPC LSTK contractor to deliver the entire NPP project. This is the reason that there are hybrid contracting strategies, such as the split EPC and the multi contract.

Split EPC has a higher commercial risk than the other two approaches, the interfaces between the work packages shall be well-defined by the project engineering team and it should be reviewed by the project director of the employer. The project director has the responsibility to ensure the work packages cover all the interfaces and allow no grey areas. This process is very important and the project director should pay attention to this process and excuses shall not be used to delegate this responsibility.

On the other hand, the EPC LSTK approach is sometimes used by a country that has very little or no experience of managing nuclear projects. It is also the conventional way of delivering projects in the power generation industry. Although, the cost of using this strategy is normally higher than the other two, but the employer's risk is limited. Downstream commercial claims can be limited due to the contractor has assumed the total responsibility of the project (Hammonds, 2010). Nevertheless, it is not recommended to use the EPC LSTK strategy for the nuclear expansion programme, as the South African contractors are matured and cannot be compared to countries that have never completed mega projects before. In Section 3.4.3, it will discuss the Olkiluoto 3 project in Finland where it is being constructed on an EPC LSTK strategy lead by Areva and Siemens.

### 3.4. Project Financing for Nuclear Power Plant

Investing in a nuclear power generation facility was never an easy option. The exceptionally high capital cost and a long waiting period before revenue can be generated are some of the biggest obstacles in developing NPP. Understanding project financing in the nuclear environment will be critical for potential investors who are looking for stable return for a long period of time. This becomes especially attractive in the current economic climate.

#### 3.4.1. Project Financing Options

There are three options to provide finance to such large infrastructure project: (IAEA, 2008A)

1. Government
2. Corporate
3. Limited Resource Finance

The above are the project financing options and should not be mistaken as ownership models or vice versa. There are a few ownership models used by the nuclear industry. The following is the table that includes but does not limit to the ownership models (IAEA, 2008A).

#### 3.4.2. Ownership Models

Ownership Model		
Type		Share Holding
State Owned	Utility Owned	100% Public
IPP	Independent Power Producer	100% Private
PPP	Private Public Partnership	Percentage shares in Public and Private
BOO	Build Own Operate	100% Private
BOOT	Build Own Operate and Transfer	100% Private then 100% Public

Table 3-1: Types of Ownership Model

##### 3.4.2.1. State Owned

State Owned NPPs are fairly common due to the financial structure is purely based on finance from the government. As discussed above, the government can provide either cash injection or guarantee to the utility to facilitate the project (McNair, D., 2011B).

### **3.4.2.2. Independent Power Producer**

IPP is an ownership model where the private sector owns the power plant and sells the generated electricity to the grid operator. Normally this would have a power purchase agreement (PPA) in place between the IPP and the grid operator. For example, the South African REIPPP programme facilitated by the Department of Energy is the prime example of utilizing IPPs. The PPA is effective for 20 years in the case of REIPPP programme.

### **3.4.2.3. Private Public Partnership**

PPP is another method when the ownership structure consists of both the private sector and the public sector. This type of method is used, so that the financial burden of the government can be eased and the project cost can be shared with the private sector. The government can also retain a percentage of the shareholding for the infrastructure (Murray & Roberts, 2008). The Gautrain is a prime example of a PPP project. However, this type of ownership model usually requested the government to guarantee a certain income threshold for the private sector. The Gautrain project has a clause in the agreement between the private shareholders and the government as if the revenue does not reach a threshold agreed by both parties (GMA, 2013). The Government will subsidise the private shareholders in order to achieve a reasonable return.

### **3.4.2.4. Build Own Operate and Build Own Operate Transfer**

BOO and BOOT are the newly found ownership models for the nuclear market in the recent years. These ownership models operate as the IPP, Independent Power Producer, which improve the liquidity of the utilities or even at the government level.

BOO stands for Build Own and Operate and BOOT stands for Build Own Operate and Transfer. These are used primarily in countries where nuclear infrastructure is not established, hence, the biggest market for these ownership models is the developing nations. Under the BOO model, the contracted party will build the NPP, assume the

responsibility of the NPP which means provide insurance and also operate the plant to provide electricity to feed into the grid. The BOOT model is in fact only add the “Transfer” on to the BOO model. The transfer of the plant shall take place after a pre-agreed duration, it is typically in the region of 10 to 20 years (McNair, D., 2011B). The BOO and BOOT developers will finance the plant and will normally have a targeted tariff, such as the example in Turkey \$0.1235 /kWh for 60 years with escalations mechanism (Rosatom, 2013). Turkey is the one of the first few countries that utilizes this ownership model to establish the NPP fleet with Rosatom (Rosatom, 2013).

### **3.4.3. Example of Failed Project Finance Option**

The failure example of the Finnish Olkiluoto U3 NPP, the project was agreed on a fixed price lump sum (EPC LSTK) contract with Areva as the main contractor, as Siemens pulled out of nuclear service, and subsequently became a sub-contractor to Areva. The agreed lump sum price is €3 billion, and as of December 2012 it has a forecasted price of €8.5 billion. Numerous factors are held responsible to this cost overrun problem, but mainly a lack of preparation from both sides in terms of quality workmanship being the main contributing factor (WNA, 2013B).



**Figure 3-2: Olkiluoto U3 NPP Construction Site (Source by Areva)**

This expensive project should serve as an alarm to any country that is embarking on a nuclear programme. Project development phase should not be neglected in any nuclear programme, as the cost implication can be astronomical. It was proven by the Finnish Olkiluoto U3 NPP project, as the original estimate is of €3 billion and by December 2012 it was estimated to be at €8.5 billion which is a €5.5 billion difference or 183% to the original cost.

### **3.5. Economic Aspects of a Nuclear Power Plant**

The economic considerations of a nuclear project are probably one of the most important criteria for the employer or even the public to determine whether to develop nuclear energy in the country. This section will provide an insight into the financial advantages and disadvantages for the South African programme.

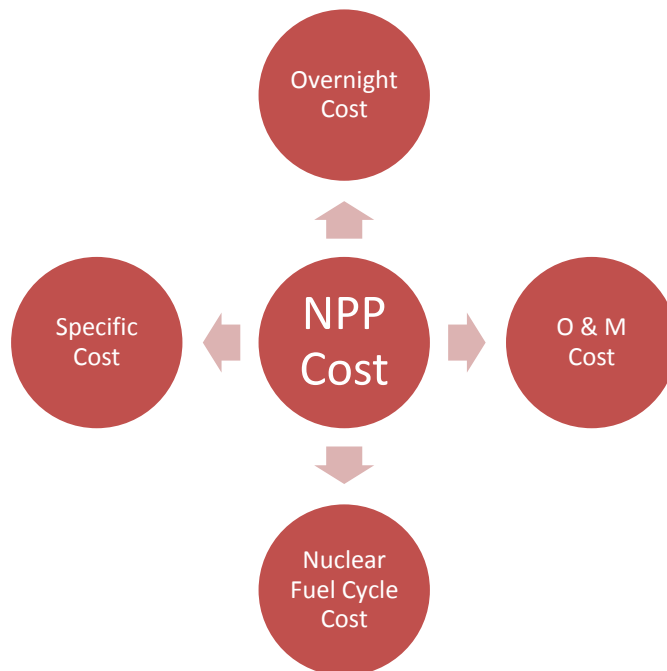
<b>General Shares</b>	<b>Nuclear</b>	<b>Gas CCGT</b>	<b>Coal</b>
<b>Investment Cost</b>	50-60%	15-20%	40-50%
<b>O&amp;M Cost</b>	20-35%	5-10%	15-25%

<b>Fuel Cost</b>	15-20%	70-80%	35-40%
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**Table 3-2: Cost Breakdown for Base Load Energy Options (Source by Caplan, M., 2009)**

In South Africa, it is known that the majority of the electricity is from coal fired power plants (CFPP). Eskom has a selling rate of R 0.6551 / kWh to the municipalities and to the public in 2013 (NERSA, 2012).

The total cost of a NPP can be analyzed and it is typically split into four major cost areas, namely, overnight cost, operation & maintenance cost, specific cost and nuclear fuel cycle cost.



**Figure 3-3: Associated Costs for NPP (Sourced from IAEA, 2008A)**

### 3.5.1. Overnight Cost

The overnight cost is the cost of construction if no interest is incurred during construction. They are commonly used to compare with different construction cost of power generation technologies. The overnight cost should consist of the direct portion and the indirect portion. The overnight cost is known to be very intensive on a NPP project, the typical figure is in the

region of \$5000/kWe (Mnqandi, Z., 2012), and interest on financing the project is excluded from this cost.

The overnight construction cost can be calculated as follows (Gen IV Forum, 2007):

$$\text{Overnight Construction Cost} = \text{Direct Cost} + \text{Indirect Cost} + \text{Supplementary Cost}$$

**Equation 3-1: Detail of Overnight Cost**

The total capital investment cost can be calculated as follows (Gen IV Forum, 2007):

$$\text{Total Capital Investment Cost} = \text{Overnight Construction Cost} + \text{Capital Financial Costs}$$

**Equation 3-2: Detail of Total Capital Investment Cost**

### 3.5.1.1. Direct Cost

The direct portion can be defined as the Direct Field Labour, DFL, it shall include the rate of the labour, accommodation and transport cost and also the tools and consumables cost (Murray & Roberts, 2012).

DFL productivity should also be defined. This DFL productivity can vary and it is always dependent on the location of the NPP. It is because the skill level of the labour varies from region to region. This is an important factor to be used in formulating the man-hour estimates for the NPP construction project.

### 3.5.1.2. Indirect Cost

The indirect portion can be defined as Preliminary and General, P&Gs, and it is typically as a cost component which has a direct proportional relationship with the DFL cost. It should be divided into Time Dependent, Value Dependent and Fixed Cost (Murray & Roberts, 2012). Time Dependent P&Gs are the cranes, site supervision and management, etc. For a NPP project this time factor shall be per month. Hence, this forms the basis of site indirect cost.

The P&Gs cost can be split into three different costs:

1. Fixed P&G Cost
2. Value-dependent P&G Cost
3. Time-dependent P&G Cost
  - a. Fixed Preliminary and Generals

The Fixed P&G cost is the cost that is charged only once to the employer for the project. The typical cost components are the purchase and erection of the on-site fabrication facility, warehouse, site establishment cost, de-mobilization cost, etc.

- b. Value-dependent Preliminary and Generals

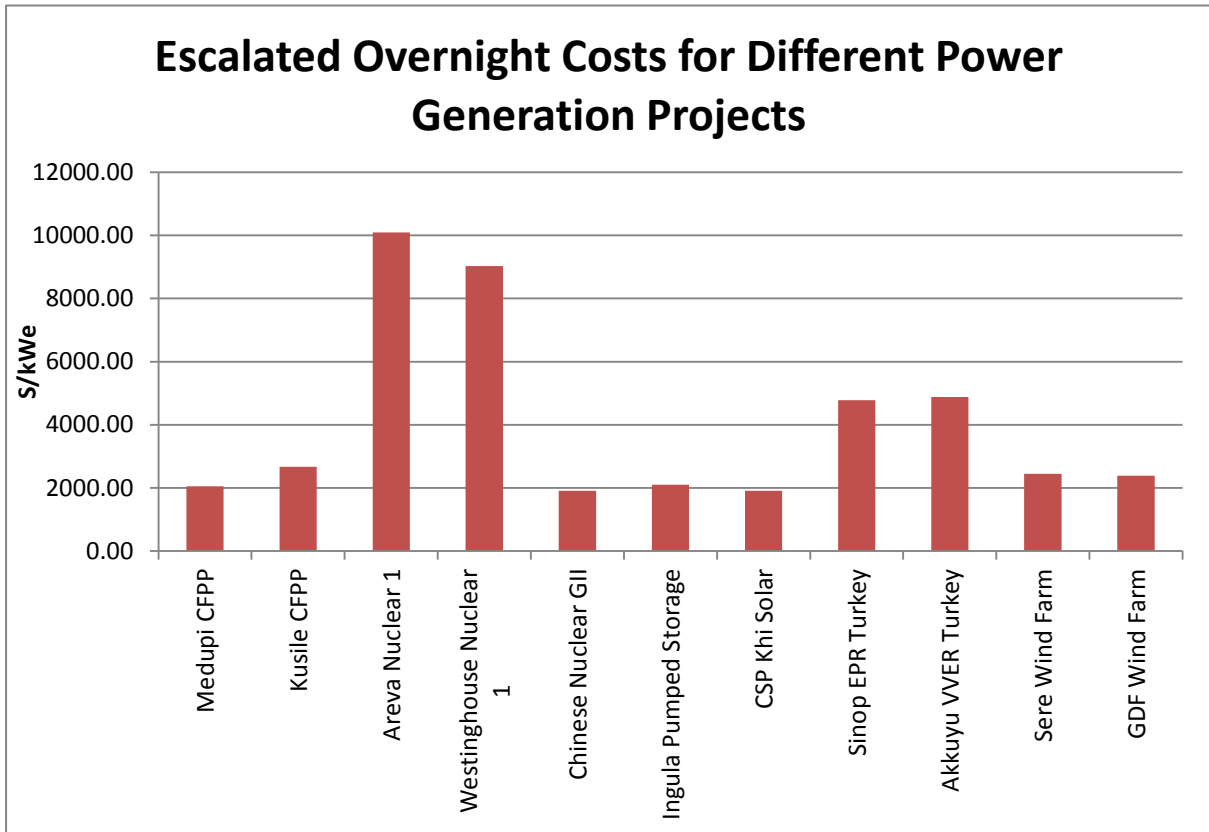
The value-dependent P&G shall mainly comprise of the bond cost and the equipment cost (if not hired). This type of P&G cost shall be adjusted if the contract value increases and decreases substantially. This is especially important for the employer to understand as the design maturity is the key determination factor for the value-dependent P&G cost.

- c. Time-dependent Preliminary and Generals

This is essentially all the costs incurred by the contractor on a monthly basis. The employer shall be aware that when the extension of time is claimed by the contractor, this time-dependent P&G shall be used as a basis for the incurred cost.

Site supervising cost, engineering and project management costs, equipment rental costs are all the typical costs for the time-dependent P&G cost.

Often, the value-dependent cost may be shared with the time-dependent P&G cost. The ratio shall be determined by the contractor. For an experienced contractor, they will assess the design maturity of the NPP project, and it is very often that the time-dependent portion is “heavily loaded” due to the contractor expecting the project to be prolonged to accommodate design changes. The fine balance between the P&Gs is a dedicated and well-studied function of the contractor’s estimating department.



**Figure 3-4: Escalated Overnight Costs for Different Power Generation Projects**

The details of the above costs can be found on Appendix B. The Figure 3-4 shows the escalated overnight costs on various projects using 2013 USD Value. It is important to note that this confirmed the high overnight costs for nuclear power plants compared to the other electricity generating technologies.

### 3.5.1.3. Supplementary Cost

Supplementary cost shall include the following as indicated in the IAEA Code of Accounts (COA) for Account number 51-59 (Gen IV Forum, 2007).

- Shipping and Transportation
- Spare Parts

- Taxes
- Insurance
- Initial Fuel Core Load
- Decommissioning
- Contingency for Supplementary Costs

#### 3.5.1.4. Capitalized Financial Cost

Capitalized financial cost is the cost that incurred during construction of the NPP, which is specifically due to financial reasons. The following are the costs included in the Capitalized Financial Cost (IAEA, 2008A):

- Escalation
- Fees
- Interest During Construction (IDC)
- Contingency on Supplementary Cost

Escalation is the cost that is associated with the general inflation during the construction period. It can be easily calculated in a country where Consumer Price Index (CPI) is always kept track of.

Interest During Construction, IDC, is the cost which is payable between the period of construction commencement and the commercial operation. It is the interest accumulated on the loan, investors or banks where the fund is raised from. IDC can be estimated by the following formula (Gen IV Forum, 2007):

$$IDC = \sum_{j=1}^{j=J} C_j [(1 + r)^{t_{op}-j} - 1]$$

**Equation 3-3: Estimating Interest During Construction**

Where

- $j$  = period  
 $J$  = number of periods (years of construction)  
 $C_j$  = cash flow for year  $j$ , reflecting beginning-of-period borrowing  
 $r$  = real discount rate expressed annually  
 $t_{op}$  = year of commercial operation

### 3.5.2. Operation & Maintenance Cost

The operation & maintenance (O&M) cost is the cost that comprises of the labour cost for operating and maintaining the NPP, spare parts and consumables, off-site technical support. The plant management cost shall be included as well. It shall be noted that the fuel cost shall not be part of this O&M cost. However, the cost for major refurbishment of the NPP shall not be included, these are typically the replacement of steam generators, and other plant upgrades. The O&M cost for a NPP is significantly lower than an equivalent CFPP (Delene, J.G., 1990).

### 3.5.3. Specific Cost

Specific cost for a NPP is also a specialized cost, this typically includes the decommissioning cost, cost for non-proliferation and accident cost.

The decommissioning cost is generally included into the electricity tariff, as a rate per kWh. This cost will be kept in a decommissioning fund for the future decommissioning projects. This can assure that when the NPP approach its end of design life, there is funding for decommissioning. The below is the formula used by the NRC of USA to calculate PWR decommissioning cost in 1989 USD value (Delene, J.G., 1990):

$$PWR \text{ decommissioning cost} = 107 + 0.015(P - 1200MW_{th})$$

**Equation 3-4: PWR Decommissioning Cost**

Cost should be in USD millions.

$P$  = Power block thermal power  $MW_{th}$

Cost for non-proliferation is used to capture the cost for the security to protect the facility and also the radioactive materials against terrorism.

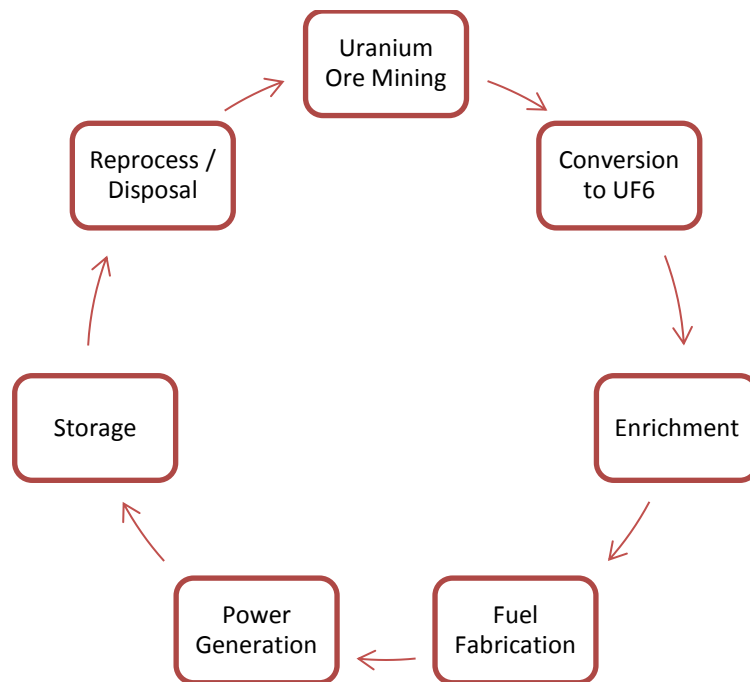
The accident cost is also included into the electricity tariff, as a rate per kWh. It is normally collected into a fund, which can be used if a serious nuclear accident has occurred. Currently, there is no insurance company in the world that can and is willing to insure a NPP, in terms of an accident. This type of guarantee normally comes from the government, as in the case of Ukraine and Japan.

### 3.5.4. Nuclear Fuel Cycle Cost

The nuclear fuel cycle cost used to calculate nuclear fuel is significantly different to the fuel costs of Coal and Gas. The nuclear fuel cycle cost can be divided into several areas, such as, mining cost, conversion cost, enrichment cost, fuel fabrication cost and the waste disposal cost, in order to cover the full nuclear fuel cycle. It is generally divided as front end and back end fuel cycles. The following is a detailed table showing all the costs involved in producing nuclear fuel in 1998 USD value (Yanko, L.T., 2012).

<b>Mining</b>	8.9 kg $U_3O_8$ x \$146	US \$1300
<b>Conversion</b>	7.5 kg U x \$13	US \$98
<b>Enrichment</b>	7.3 SWU x \$155	US \$1132
<b>Fuel Fabrication</b>	per kg	US \$ 240
<b>Total</b>		US \$ 2770

Table 3-3: Cost Breakdown for the Fuel Cost



**Figure 3-5: Fuel Cycle (Primary source from Areva)**

Mining cost should include the cost of mining uranium ore. Uranium mining is typically achieved using the following methods: open cast, underground and in-situ leaching. The in-situ leaching (ISL) is used mainly in Kazakhstan and the United States. The ISL is a chemical process of leaching the uranium ore and the product is the  $U_3O_8$  or often called the “yellow cake”. It involves strong chemicals such as sulphuric acid and it undergoes precipitation, filtration and drying to form the “yellow cake”. The other uranium producing countries are using open cast and underground mining methods. There are different costs attached to these different mining methods, but the typical cost is used as \$65/kg U in 1998 USD value (Yanko, L.T., 2012).

Conversion cost is the cost attached to the process which converts the  $U_3O_8$  to  $UF_6$ . The process of hydro-fluorination to convert  $U_3O_8$  to  $UF_4$  and the fluorination to convert  $UF_4$  to  $UF_6$  are included in the total conversion cost. The cost of this process is around \$98/kg  $UF_6$  in 1998 USD value (Yanko, L.T., 2012).

The enrichment process is measured by the SWU. The below two formulae described the value function and the SWU calculation function (Kugeler, K., 2012):

$$V(e) = (1 - 2e) \times \ln\left(\frac{(1 - e)}{e}\right)$$

**Equation 3-5: Value Function for SWU**

$e$  = the enrichment in weight fraction

$$SWU = M_P \times V(e_P) + M_T \times V(e_T) - M_F \times V(e_F)$$

**Equation 3-6: SWU for enriched uranium**

$M_T$  = mass of tail

$M_F$  = mass of feed

$M_P$  = mass of product

This part of the fuel cycle is extremely costly, due to the fact that it mainly uses the centrifugal process to enrich the uranium. This is accomplished by a mechanical spinning process and it consumes a lot of electricity. An additional cost is that this process is under heavy surveillance by all the governing bodies. Firstly, not to be able to enrich weapon grade uranium and secondly in order to minimize the risk of a terrorist attack to the facility. These two issues require extra security measures and therefore, increase the cost of enrichment.

The fuel fabrication is the final step to produce a fresh fuel assembly. The fuel pellet is the standard form of nuclear fuel in PWR. It is then placed into the zirconium tube to form a fuel rod. A multiple arrangement of these fuel rods will form a fuel assembly, in the case of VVER1200 of Rosatom it has 312 fuel rods in a fuel assembly (Yanko, L.T., 2012). The fuel fabrication process should include the fabrication process of the fuel assembly using the zirconium alloy.

Waste disposal cost is the cost associated with the disposal of all the nuclear wastes, such as, LLW, ILW and HLW (Scott, A., 2013). The LLW and ILW can be disposed to a

geologically stabled facility. The constructing and maintaining costs for this facility are part of the waste disposal cost. The waste disposal cost should include the waste transportation as well.

The HLW, mainly in the form of spent fuel, is normally stored on the NPP site, the maintenance cost for the spent fuel pool shall also form part of the waste disposal cost.

### 3.5.5. Operating Efficiency of Plant

Efficiency of the plant also plays an important role in the economic aspect of a NPP. Obviously, the higher efficiency of the NPP, the lower the operating cost. Another important criterion to measure the performance of a NPP is the availability factor, it shows the operating duration against a year (Lamarsh, J., et al., 2001).

$$\text{Availability Factor} = \frac{\text{Operating Hours}}{8760 \text{ hrs}}$$

**Equation 3-7: Availability Factor for NPP**

The higher of this availability factor, represents a lower down time of the nuclear power plant, hence, it can generate profit for the utility for a longer period. In the US, the availability factor is above 90% (Alexander, L., 2009), by comparison to the Koeberg NPP in South Africa is at 83% (Eskom, 2011). This actually means that there is a 7% difference in terms of the availability factor and it will equal to around R 723 million losses in revenue in 2013 Rand value, see Appendix C for the detail analysis.

### 3.6. Human Resources

In this chapter, the discussion will revolve around the skills of South African professionals, their management effectiveness, decision making ability, quality and experience.

The modern advanced technological reactors, manufacturing quality and construction quality cannot be compromised. The mindsets of the South African construction workforce will have

to change to focus on excellence. The mentality of “n Boer maak n plan” attitude should not be allowed in the construction of a nuclear power plant, especially on the primary system.

The development of an effective organisational structure for the construction of a nuclear project is vital (IAEA, 2008B). While the project director will be ultimately responsible for the compiling of such an organogram as well as defining the competence and skills requirement, the recruitment will be a human resource function. The skills level of artisans should not be overlooked, as it will significantly affect the construction schedule. An entry exam is suggested and implemented to avoid un-skilled labour being employed at the wrong position, hence, productivity can be predicted.

Human resources development is important for the key success factor for the implementation of the nuclear new build programme. There are six sets of skills needed for the programme (DoE, 2011), they are as follow:

1. Construction Skills
2. Plant Operation Skills
3. Skills for Government Departments
4. Regulatory Skills
5. Supporting Industry Skills
6. Decommissioning Skills

As mentioned in the opening chapter Introduction, to build 9600 MWe nuclear energy, it requires three nuclear plants which consist of two reactor units of 1600MWe each. By building three plants, there is a need in skilled workforce which ideally should be South African. The shortage of skilled artisans is a major problem with the current Eskom Medupi and Kusile projects (Sofijanic, M., 2011). The productivity from the existing artisans is not satisfactory and is not comparable to the EPC contractors' expectation. For example, the weld repair rate has increased from the Eskom required level of 3% to the unacceptable

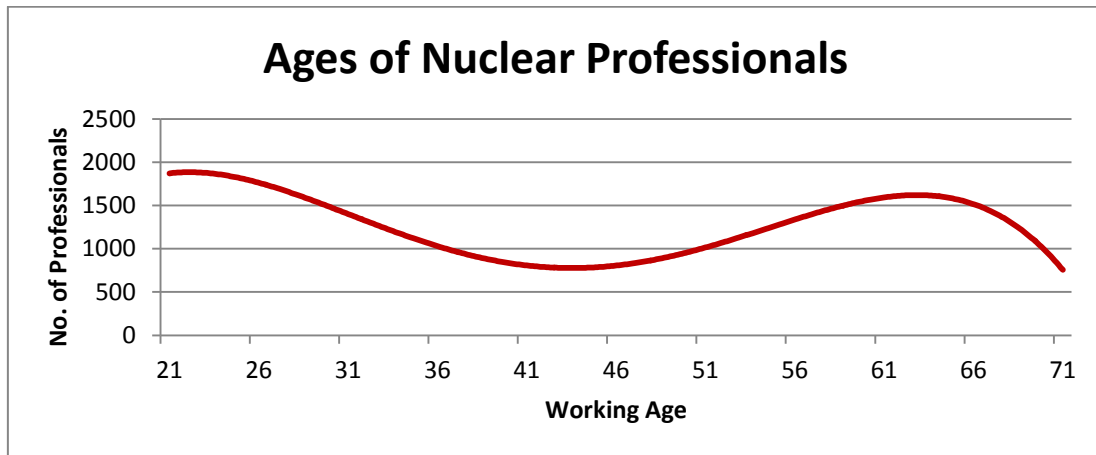
level of 10%. This results in major delays in the progress of these projects (Petrick, L., 2013).

Nuclear industry requires the most stringent quality of construction skills to complete the project. This results in top quality welding skills which, sadly, South Africa does not have at the moment (Greve, N., 2013). In order not to delay the roll out of nuclear energy, education & training programme have to be prepared to mitigate this risk. The following should be in place before the start of mechanical erection taking place:

- Training of welding skills on super alloy, i.e. X10CrMoVNb 9-1, Incol 800, etc.
- Training of concrete workers on high strength concrete for unusual concrete thickness

Another method of mitigating the shortage of skilled artisans is to absorb the artisans trained at the Medupi & Kusile projects. The artisans used in these projects should also attend training to convert them from a fossil fuel plant to a nuclear plant accredited, which is predominately the ASME IX accreditation.

In various assessments by the suppliers, Dr Yves Guénon from Areva suggested that 6000 engineers are needed for the nuclear programme (Guénon, Y., 2010). However the age profile for the nuclear engineering skills, see Figure 3-6, is not very promising for the future nuclear expansion programme (IAEA, 2011C). Please note that the graph is for indicative purposes only. The huge gap in the age group of 35 to 45 years old can have a detrimental effect of the programme.



**Figure 3-6: Working Ages of Nuclear Professionals**

The management team of the nuclear expansion programme should not be ignored. Since, the nuclear industry is quality and safety focused, the management team should attend training courses to allow them to understand the difference between the conventional fossil fuel plant and the nuclear plant. This allows them to understand the stringent quality and safety requirement before they enter into the nuclear workplace.

The proposed human resources strategy is that initially the technology provider could bring foreign skills to South Africa to start the programme with Unit 1. However, South African should be supplementing the foreign skills in order to learn from them. Later on with Unit 2, South African should be given a greater responsibility and be involved with higher levels of decision making. With the second plant the skill set should be fully developed and it should be possible to manage the project on its own. Although this is the ideal strategy of the human resources plan, resistance from local professionals or management teams should not be ignored in the starting stage of the execution phase. Local management teams shall have a mindset of learning rather than rebelling. This should be coordinated and managed by senior executives on the project to ensure this risk is mitigated.

Unions should also be notified and involved before the implementation phase to avoid disputes which would ultimately delay the project or cause industrial unrest. Due to the

specific conditions of South Africa, union coordination shall be discussed and researched in future studies.

### **3.7. Conclusion for Chapter Three: Guideline for Project Setup & Planning**

Under project setup & planning phase, there is a vast amount of decisions to be made in this phase to decide whether to proceed with the project or not. Eskom shall understand and also apply the well-developed PLCM. It stated that Eskom projects shall be developed from conceptual studies to business cases and then feasibility studies, and eventually to the execution phases. It is the same for any other major engineering project. Although the cost spent at this stage is not enormous, the impact is high, especially on the nuclear expansion programme. The conceptual study should be initiated when the Eskom board or the government decided to pursue a nuclear expansion programme. Below is the list that included but not limited the outcome of the conceptual study:

1. Capacity of the nuclear expansion programme
2. Potential location of the NPP(s)
3. Benefits of the nuclear expansion programme both economically and socially
4. Potential capital investment cost of the nuclear expansion programme
5. Safety of the nuclear power plants
6. Spent fuel management strategy
7. Nuclear liability

However, the most important factor shall be the return of investment of the nuclear expansion programme. These could allow the decision maker to decide whether to implement the programme, or not.

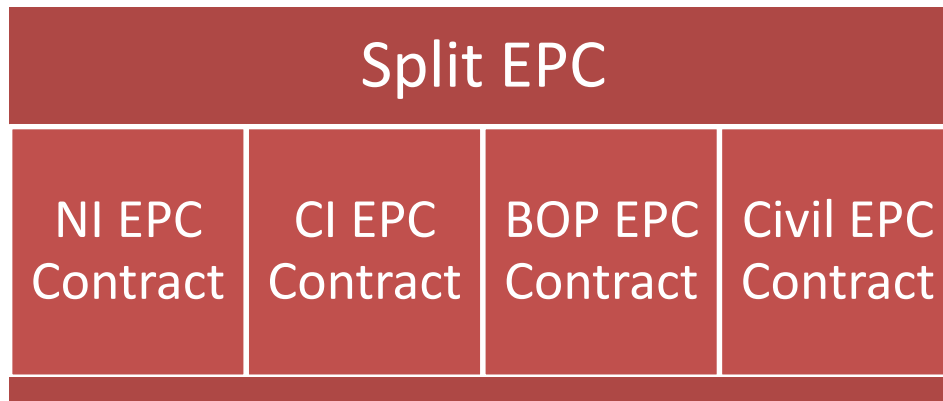
Once the conceptual study is approved, the engineering work shall commence, i.e. basic engineering and detailed engineering. The basic engineering phase is typically completed by

the reactor vendor. On the other hand, the detailed engineering phase can be completed by the main contractor in conjunction with the reactor vendor. By using this strategy, the NPP will be designed to suit the South African operation condition. However, these will be discussed in detail in Chapter Four.

Eskom shall consider the procurement strategy of the nuclear expansion programme after the conceptual study is approved. The procurement strategy is particularly important. The decision to proceed with EPC LSTK or EPCM cost-reimbursable contracts will impact on the financing side of the nuclear expansion programme. From the employer's point of view, the decision made during this stage, should take into consideration the level of skill in South Africa. The employer should also have a thorough understanding of its project management capability and capacity, in order to find the best suited procurement strategy and reduce the risk on the NPP project. The EPC LSTK contract is one of the two contract types that allow the contractor to take full ownership of the nuclear power plant. This option also allows the employer to have less risk, due to the risks for construction and commissioning is allocated to the contractor. From the contractor's point of view, it can be concluded that the EPC LSTK contract will have a higher risk, however, the reward would be higher as well. On the other hand, there is another option which is the EPCM cost-reimbursable contract. This contract allows an experienced employer to develop the plant and only use the contractor to complete the detailed engineering design. The construction work is also closely monitored by the employer. This allows the employer to monitor and control the cost. However, the risk of the employer is significantly larger due to the engineering influence by the employer. From the contractor's point of view, the EPCM cost-reimbursable contract will have a lower risk, but the reward will also be less.

The recommended procurement strategy is to utilize a split EPC package. This is ideally suited for the South African condition. Four major EPC contracts shall be awarded by Eskom

to the main contractors and the following shows the recommended procurement strategy of Split EPC:



**Figure 3-7: Proposed Split EPC Contracts**

This shall allow the NI to be contracted to one EPC LSTK contract. The same contracting mode shall apply to the CI as well. This shall allow the contractor to bear the majority of the risks. These contractors are responsible for the NI and the CI will be the technology providers. On the other hand, the BOP can be constructed by the local contractor on the EPC LSTK contractual mode. The local industries are capable of engineering and constructing the BOP of the nuclear power plant but due to its complexity it is not of the same level as the NI and the CI. The BOP of the NPP does not have a big difference compared to the BOP of the CFPP. However, the local contractor shall be aware of the nuclear grade quality requirement, in order to construct the BOP of the NPP. In order to maximize the local content of the nuclear expansion programme, the civil work shall be contracted to the local industries as well. It is recommended that this shall be contracted as the same as the NI, CI and BOP, hence, utilize the EPC LSTK mode. By placing the major EPC LSTK contracts, Eskom is only required to manage four EPC LSTK contracts. This allows Eskom to manage the contracts relatively easier than the multiple packages contract and allows Eskom to have effective control to the contractors. The contractors shall have full

control over the construction activities and the overall quality of the plant is also within the contractor's responsibility.

In the project finance section, most of the options were discussed, the advantages and disadvantages were also listed. The decision made at this stage solely depends on whether the government would like to fund the project or not, if so, what level of involvement shall the government be responsible for. However, the success of the REIPPPP for the renewable energy roll out, set the framework on how to procure energy from IPP. This project financing phase shall not be neglected, especially in the nuclear environment, where high capital cost and a long waiting period before revenue can be generated, are the well-known factors in the industry. Understanding the nuclear project is very critical in order to achieve success in the nuclear expansion programme.

In the past, there are three major project financing options in the nuclear sector, such as, Government, Corporate and Limited Resource Finance. In the recent years, there are some new ownership models appears in the nuclear sectors, i.e. State Owned, IPP, PPP, BOO and BOOT. Eskom shall assess each option and select the best one that allows the company to maximize its benefit and ultimately ensure the burden on the consumers is not overly excessive. It is recommended that the PPP option shall be used for the nuclear expansion programme. The PPP option allows the private sector to be involved in the development of the NPPs. This shall improve the efficiency of constructing the NPPs and also improves the liquidity of Eskom. The risk is being shared to both the private sector and the public sector. Another deciding factor is that a NPP is of a great security interest to a nation, if it is controlled by a foreign company can potentially comprise on national security. It is for the same reason that the IPP is not recommended for the nuclear expansion programme.

Once the project financing option is decided, Eskom shall understand the costs involved in the nuclear expansion programme. This allows Eskom to control the costs better if a thorough understanding of the nuclear industry is known. From Table 3-2, it is understood that for a NPP, the Capital Investment cost is around 50% to 60% which is significantly more than a Gas CCGT or a CFPP. However, the fuel cost of nuclear power plant is only 15% to 20% compared to the 70% to 80% of the Gas CCGT.

In the more detailed cost analysis for a nuclear power plant, it can be concluded that the overnight cost, operation & maintenance cost, specific cost and nuclear fuel cycle cost are the major four cost factors. The overnight cost can be split into direct, indirect, supplementary and capitalized finance. The operation & maintenance cost can be defined by the labour cost, spare parts, etc., which are cost associated with the operation of the NPP.

The specific cost and the nuclear fuel cycle cost are unique to the nuclear power generation sector. The specific cost can be summarized to as cost for nuclear specific activities, such as decommissioning, accident provision and nuclear non-proliferation measures. The nuclear fuel cycle is also unique, the cost of mining, conversion, enrichment, fabrication, disposal and reprocess are all summarized and discussed in the above sections. This gives a rough guideline for Eskom to understand the full nuclear fuel cycle and its potential cost implication. Operating efficiency for a NPP is often neglected, the efficiency can be measured by the availability factor. It can be compared to other power generating technologies, the availability factor of nuclear is usually the highest, due to the fact that the fuel usage is very low and the fuel stays in the reactor for 18 to 24 months between refueling. Wind and Solar might have a smaller availability factor due to wind not blowing the whole day and the sun not shining the whole day as well.

Human resources are critical in the nuclear industry due to the fact that there were not many newly built nuclear power plants in the 1990s and 2000s. The average age in the nuclear

engineering sector is very high as well. It can be concluded that the type of people in the nuclear industry shall be quality focused, in order for the NPP to be built to the agreed specification and hence, achieve the goal for public safety.

The existing project management team for the Medupi & Kusile CFPP project and the CFPP maintenance projects might not be very quality focused. However, the “nuclear-ized” project management team can be developed through training. Nevertheless, the mentality of quality management being a nuisance shall not be allowed in the nuclear construction industry. The workforce shall also attend a nuclear conversion programme. The welding skills developed for the Medupi and Kusile CFPP project shall be upgraded to nuclear grade. Hence, reduce the reliance of foreign artisan skills to construct the NPP. It can be concluded that a training plan shall be put in place in order to maximize the South African involvement in the nuclear expansion programme.

### **3.8. Summary for Chapter Three**

In Chapter Three, it concluded the project setup and planning phase, which detailed the contracting strategies, project financing options, ownership models, economic aspects of a NPP, overall costs in NPP and human resources. Once all of the above are considered and the decision has been made, the project can move onto the next phase, which is the project design and engineering phase. Chapter Four will discuss and analysis this design and engineering phase of the nuclear expansion programme.

## **4. Project Design & Engineering Phase**

### **4.1. Introduction to Chapter Four**

Under Chapter Four, Project Design and Engineering Phase, this chapter is divided into four sections. The first section is 4.2 Engineering Phases, this section discusses the engineering functions in a nuclear power project. The second section is Work Breakdown Structure in Section 4.3, in this section the research project will analyze the function of Work Breakdown Structure and the formulation of it. The next section is Bid Invitation and Adjudication in Section 4.4. This section will detail the process of performing bid invitation for a NPP. The detail of bid adjudication will also be discussed. The last section is Estimating for Nuclear Projects in Section 4.5. It will analyse and discuss the two estimating techniques and also detail the estimating experience on a NPP. Section 4.6 is the guideline for the Project Design and Engineering phase. Section 4.7 is a brief summary of Chapter Four.

### **4.2. Engineering Phases**

After the conceptual studies, see Section 3.2.1, the engineering phases will be activated to further develop the project. Engineering consists of the following three phases in the project environment:

1. Basic Engineering
2. Detailed Engineering
3. Construction Support

#### **4.2.1. Basic Engineering**

Basic Engineering, sometimes refer as FEED. The ideas in the conceptual studies are now translated into Process Flow Diagrams (PFDs) and will be continued to the final stage of developing P&IDs for the plant. In order to complete the basic engineering phase, plant layout, building arrangement, number of mechanical equipment shall be identified, flow rate of mediums, structural beams sizing shall be calculated (Bradbrooke, R., 2009). For an NPP,

basic engineering and detailed engineering shall be done prior to construction commencement. The basic engineering is normally completed and verified by the design certificate and the obtainment of the Combined Operating Licence, COL which is equivalent to the NIL of NNR in South Africa.

#### **4.2.2. Detailed Engineering**

The main function of detailed engineering is to convert process design developed during the basic engineering phase into a “buildable” design. Work packages are developed and forms part of the structure of the scope of work. The detailed engineering phase develops further engineering solutions from the basic engineering phase, such as the connection detail of structural steel, pipe support, load support, etc. These are particularly important as basic engineering may not have developed to a level that will be accepted to relevant codes and standards for a particular design.

The outcome of this phase of engineering shall be specifications for the NPP, which shall include but not limited to the following:

- Operating Parameters
- Test Requirements
- Maintenance Programme
- Materials Requirements
- Reliability Requirements
- Corrosion Protection Requirement
- Design Life of Plant
- Modularization Requirements
- Stress Analysis
- Bill of Materials
- System Isometrics

The detailed engineering shall be completed as much as possible before the commencement of construction work, in order not to delay the project during the project execution phase. This is proven to be essential in the Medupi and Kusile projects and also in the Chinese AP1000 project. In the Chinese AP1000 project, the engineering work is still incomplete after the first concrete being poured eighteen months ago. This placed enormous strain in the other contractors to complete their SOW in time (IAEA, 2012). This shows that the completeness of engineering design before commencement of work on site is critical to achieve success in a nuclear power plant construction project.

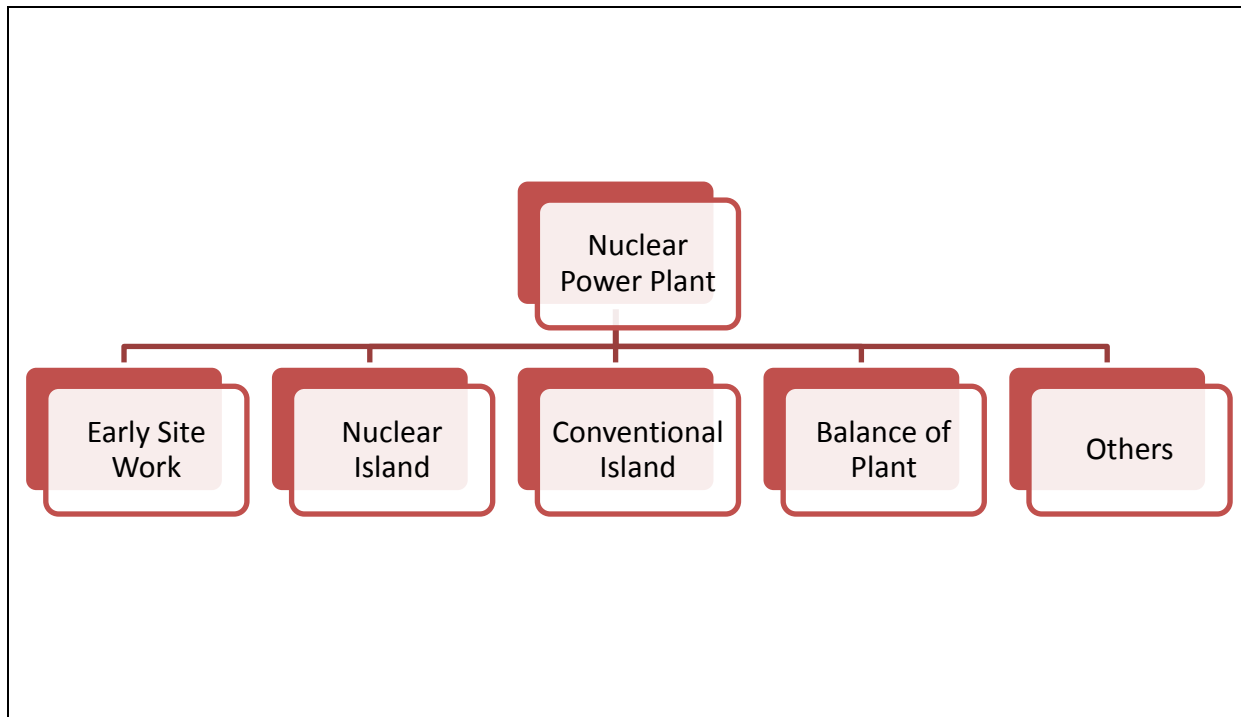
#### **4.2.3. Construction Support**

Construction support shall be the last function of the engineering phase. There shall be resident engineers on site during construction, because the construction team may require support or clarification during construction of the NPP. In a NPP project, like all the other mega projects, design changes are unavoidable. The design changes needed to be implemented on site. These late changes are required to be implemented on site, and the resident engineer shall coordinate this with the construction department to see the intended function is maintained after the implementation. The above is the main job objective for the resident engineer. However, construction engineers are different to the resident engineer on site, the construction engineers shall be looking at the constructability of the NPP, and its function shall be streamlining the construction process so that interfaces with different areas are coordinated.

#### **4.3. Work Breakdown Structure**

In a mega project, i.e. nuclear power plant construction project, it is often very complex and involves all the engineering disciplines. The interfaces are vast and complicated. For the project management team to break down the project, WBS is often used (IAEA, 1988). WBS is a tool to breakdown a project into systems and sub-systems. Hence, the project can be

managed at a reasonable level. From the basic engineering stage, work packages shall be defined. These work packages form the work breakdown structure (WBS). The following is the typical WBS for a nuclear power plant (Siemens, 2009).



**Figure 4-1: Typical WBS for NPP**

The EPC/EPCM contractor shall develop the detailed engineering design base on these work packages. The employer's project management team shall have a good understanding of the basic engineering, so that they can interpret the progress made by the EPC/EPCM contractor.

For example, the detailed engineering design shall identify the wall thickness of the main pipeline in the NSSS. These are critical details for the procurement of the pipeline, since the materials of these pipes may not be available in South Africa and needed to be imported from overseas. For example, an outer diameter of 800mm and wall thickness of 50mm or above with exotic materials is not very common in South Africa (Chan, K.F.J., 2012). From these work packages, procurement of the NPP can take place.

## **4.4. Bid Invitation & Adjudication**

Bid invitation & adjudication is a very important phase in the programme, affecting not only technical offerings in the bids, but also the importance of the financial implications of the bids. The thorough understanding of the bid details will minimize downstream scope changes which normally impact negatively on the costs and schedules of the programme.

### **4.4.1. Bid Invitation**

Bid invitation process for procuring a nuclear power plant should be very similar to any other mega industrial project. However, the nuclear quality aspect should not be ignored since the procurement team started the process of acquiring a nuclear power plant. Due to the stringent quality requirement of the nuclear industry, quality should be fundamental through all the phases of the project. This will be elaborated in the Section 5.5. The employer will have to develop the BIS (Bid Invitation Specification) from the employer engineering team in order to procure a NPP to suit the employer's requirement. The BIS shall include but not limit to the following:

- Background and arrangement of the bidding process
- Technical and commercial requirements
- Conditions and circumstances under which the contractor will have to perform the tasks
- Expected structure and contents of the bids
- Bid evaluation criteria

To prepare the BIS, generally it will take more than 6 months and sometimes it can go up to 12 months (IAEA, 2011A). However, this is highly dependable on the contract strategy and the quality of professionals that are utilized in the BIS preparation process. If a split packages strategy is used, the engineers need to define well for the interface and the project

manager shall review the BIS's so that all aspects of the plant are covered. This activity can avoid downstream scope changes when the construction takes place.

Bid invitation shall also be planned in advance and the employer shall not rush through this process. The information and technical detail shall be defined and ambiguity shall be avoided. The BIS shall also be compiled by experienced professionals that have project development experience. It is recommended that the employer involve experienced professionals that have experience from the contractor side to structure the BIS. By doing so, the employer can eliminate possible unclear requirements and, hence, the contractor can estimate the project accordingly with minimal risk of unclear requirements.

#### **4.4.2. Bid Adjudication**

Bid adjudication can be done on two different approaches (IAEA, 2011A):

The first approach is to have qualitative approach where the technical evaluation team only evaluate the technical acceptability of the bids. The outcome result can be classified in either non-acceptable or acceptable.

The second approach is to have quantitative approach where the technical evaluation team has to evaluate the bids in detail and also compare them, in order to define the advantages and disadvantages of each bid. The technical evaluation team has to rank the bids in order to provide the best solution.

For bid evaluation strategy is dependent on a few factors, the monetary value of the project, the number of bidders, the quality of the bidders, the contracting strategy, etc.

If there is only one bidder, bidding for the project, then, the bid evaluation process should remain short and only confirm the technical compatibility of the bid to the employer's BIS.

However, for a nuclear power plant, it is normally more than one bidder and the investment value is very high. Hence, an alternative strategy should be employed in order to procure a nuclear power plant that will suit the employer's need. Normally, when the employer issues a Request for Proposal/Tender to a few contractors, then when the bids are returned, these bids shall proceed through the preliminary bid evaluation process. For this process, there should be a team of engineers and procurement professionals to evaluate the initial compliance of the bids. This process only evaluates into the basic technical detail and the commercial clauses, in order to shortlist the bidders to two to three bidders only.

The evaluation team shall issue a list of additional questions to the bidders in order to clarify their bids. All the shortlisted bidders shall be subject to the same questions and all the clarification responses from the evaluation team shall be forwarded to the bidders. This practice is to ensure all the bidders will receive the same information and gain no unfair advantages to each other. The shortlisted bidders shall be required to attend a bid clarification meeting individually to further clarify the detail of the bid or require the employer to clarify the scope in detail. After the bid clarification meetings with the bidders, the shortlisted bidders shall revise their bids with updated information with regards to the technical details and/or the commercial details. The procurement officer shall set a timeline which is reasonable to the bidders to revise their bids. For a nuclear power project, the duration can be from a minimum of one month to three months. The revised bids shall be submitted back to the procurement office in due time.

The revised bids shall be reviewed in the second phase of the bid adjudication process. The technical team shall comprise of multi-disciplined engineers to assess the bids in the following areas:

1. Technical capability
2. Technical capacity

### 3. Safety Analysis

The sections can be divided into major sections of the nuclear power plant, such as Nuclear Island, Conventional Island, Balance of Plants, Civil Foundation, Switchyard and Auxiliary Structures.

The leader of the technical evaluation team shall combine all the evaluation report back from the different disciplines and insert it into a matrix that will ultimately provide a result in a ranked structure. On the other side, the commercial team shall develop a similar approach and also rank the bids in terms of commercial analysis.

In a nuclear project, a committee shall be assembled to coordinate this activity and also make a judgment call to present the best bid to the Eskom board and obtain the approval for the nuclear project. As described in the IAEA technical report, this bid adjudication period can be as long as two years in order to assess the bid comprehensively (IAEA, 2011A).

## **4.5. Estimating for Nuclear Power Plant**

Project cost estimating is one of the key steps in the project design and engineering phase. The following two sections will discuss the two estimating techniques used in the industry.

### **4.5.1. Top-Down Approach**

The top-down estimating technique requires a reference plant data (Steyn, H., 2012). It usually used the past project data to assist on the cost estimate. However, due to the last NPP built in South Africa was more than 30 years ago. The past project data cannot be fully used. For the Eskom nuclear expansion programme, the reference plant data can be obtained from countries like Finland, China and Japan on the Generation III NPP. This shall provide an adequate database for the reference plants. However, none of the above are built in South Africa, if the top-down approach is utilized, the productivity and commodity prices

shall use the Medupi and Kusile CFPPs as a reference. The cost data from the reference plant data shall be the source to estimate costs for the proposed NPP (Wiote, G., 1979).

The top-down technique is often used by the employer to estimate a project. Due to the complexity of a NPP, if the employer uses the bottom-up technique, it may consume a great deal of time and also utilize excessive engineering man-hours to complete the estimate. This is unachievable, especially when a country is lacking nuclear construction experience. Another reason for not using the bottom-up technique is the employer normally does not have a detailed engineering design for the NPP at the tender stage, hence, a lot of systems may be omitted. If the bottom-up technique is used by the employer, then when the design changes, the bottom-up estimate needs to be changed to suit the design changes. This would create a lot of unnecessary work since the design may vary in the project at its initial stage.

Another advantage for the top-down technique is that normally the top-down technique will have a higher estimated value than the bottom-up technique. This will assist the employer to facilitate a budget with enough margin built in, this is usually called the bottom line.

The top-down approach has a number of factors affecting the estimating process, factors such as complexity, productivity, etc., are based on expert judgement. The local contractor may not have these experts and the normal estimator from either the petro-chemical sector or coal fired power generation sector will be responsible for the tender. The results will be that the tender may neglect some of the nuclear quality aspects. This is often the case and the submitted tender price is low and the local contractor struggles to proceed with the project and results in delay or cost overruns.

If the top-down approach is utilized to estimate a NPP, this has to be done by experienced professionals. Eskom shall utilize the top-down approach to estimate the cost of the NPP.

Foreign experts shall also be used to estimate the project cost and shall be used as a reference.

For the cost of processing equipment using a top-down approach, the new process component can be estimated using the following formula (Gen IV Forum, 2007).

$$C = A + (B \times P^n)$$

**Equation 4-1: Cost of Process Equipment by Top-Down Estimate**

Where

C = Cost of the new plant component

A = Fixed Cost of the reference plant component

B = Variable cost of the reference plant component

P = Ratio of the new plant component to the reference plant component

For example, Koeberg U1 NPP Thermal Output = 2775 MWth and Westinghouse NPP Thermal Output = 3415 MWth, so that the ratio shall be 1.23.

n = exponent that reflects the size benefit of rating for the component

The above shall be able to give a relatively accurate estimate on the major systems of the NPP. For indirect cost, commonly referred as P&Gs, there are formulae developed for Generation III+ plants 1200 MWe by the Gen IV Forum, the costs are 2007 USD value. The first value is for the fixed cost P&Gs, the second value is for the value-dependent P&Gs and the last value is for the time-dependent P&Gs.

$$NI = 6.85 \times 10^6 \times (P/1200 \text{ MWe})^{0.33} + 0.48 LN + 4.30 \times 10^5 \times (P/1200 \text{ MWe})^{0.5} \times M$$

**Equation 4-2: Indirect Cost for NI**

$$BOP = 6.85 \times 10^6 \times (P/1200 MWe)^{0.66} + 0.34 LF + 4.30 \times 10^5 \times (P/1200 MWe) \times M$$

**Equation 4-3: Indirect Cost for BOP**

P = Plant Rating in MWe

LN = Labour Cost for NI

LF = Labour Cost for BOP

M = Construction Duration in Months

#### **4.5.2. Bottom-Up Approach**

The bottom-up technique is normally used by contractors and maybe even by the second level contractors who are used to do the construction work. The bottom-up estimating shall only be used when the design is mature enough. It is necessary for the construction contractor to define their estimate in a structured manner (Steyn, H., 2012). Due to their work nature which has no design responsibility, their work can be estimated from bottom up. It creates a basis for the employer to understand the construction contractor's tender price. It is very rare that a NPP project does not result in delays. The basis established by the construction contractor can be utilized to formulate claims from delay or design changes or any "force majeure" events.

The bottom-up estimate also gives the construction contractor a better understanding of the project risk. For large nuclear projects, the main contractor normally performed the bottom-up estimates in conjunction with the utility (Gen IV Forum, 2007). In a NPP project, construction works are typically performed by a group of construction companies or a consortium. This creates a better environment for the NPP project as the risk is spread

across different companies. The estimate can be verified by all the companies in the consortium, so that all of their past project data can be used.

The bottom-up approach will be effective if all the construction commodities, plant equipment and labour man hours are defined in great detail. See Appendix D for an example of the bottom-up estimate.

This type of estimate is very detailed. The drawings that are used shall be at the stage of “Issued for Tender”, together with the BOQ, bill of quantities, of all the components. From the above information, the main contractor will then be able to allocate man-hours to the systems. After this step the main contractor will apply the unit rate to the man-hours. This unit rate depends on the country and also the location of the work, such as at Works or on Site.

However, the bottom-up estimate by the construction contractors can be significantly different to the top-down estimate by the employer. Even for the same nuclear power plant, the two estimates may differ by 50 ~ 100% (IAEA, 2008A).

The bottom-up approach is normally used at the contractor level, it is generally suitable because the scope of work is well defined and the bottom-up approach can give a fair accuracy level for the contractor to tender the project. However, the contractor shall not misuse the industry norms in their man-hour estimate.

### **4.5.3. Estimating Experiences**

Estimating is an essential part for the contractors that are ready to participate in the nuclear expansion programme. However, the importance of the in-house estimating ability of the employer shall not be overlooked. The employer shall understand the bids submitted by the main contractors, hence, the bids can be evaluated fairly.

The following is the table indicated the estimating accuracy during different engineering phases (Fleming, M., 2009). It shows the upper limit and lower limit of the accuracy.

Phase	Upper Limit	Lower Limit
Conceptual Studies	+30%	-15%
Basic Engineering	+20%	-10%
Detailed Engineering	+10%	-5%

**Table 4-1: Estimating Accuracy for Projects in different phases**

It is well known that estimating an activity in a project is completed by man-hours, however, productivity shall not be overlooked. The man-hours of modern day's construction projects compare to the man-hours used in the late 70s / early 80s in South Africa shall not necessarily be compared in the same context.

The climatic data of the proposed site shall be understood by the contractors due to the fact that heavy rain, strong wind, etc., can affect the construction schedule, hence, affecting the cost of the project.

A thorough understanding of welding / NDT / PWHT requirements in the nuclear environment shall also be a crucial factor to formulate the man-hours estimate.

Estimating for the construction of a NPP is an enormous task. The duration for the estimating exercise shall not be overlooked or underestimated. However, a unique advantage of constructing a NPP is that the design is fixed and completed in most cases, due to the fact that the EPC LSTK contractor has to obtain the "Design Certificate" from the regulator before construction can commence (NNR, 2008A). The cost estimate shall be accurate enough for construction. The only problem for the local construction companies is the complexity level of the NPP can be significantly different to the projects that the local construction companies have completed before. This might result in underestimating the project. However, this is also a common practice in the construction industry for under

quoting, it has two driving forces. The first reason is that the construction companies usually under quoted a project intentionally and submitted a lower tendering price to secure the project. The second reason is that the company does not have the productivity norms of today's workforce. Hence, a wrong estimate is performed, which results in under quoting the project. One of the reasons is because the industrial actions supported by the labour union can have a significant impact on the productivity of the workforce, where this is proven in the Medupi & Kusile projects (Chan, K.F.J., 2011). This is unpredictable and it is also unique to each project, Section 5.3.1.5 will discussed this labour risk in detail.

#### **4.5.3.1. Civil Work**

For the civil work portion, estimation for the work shall be split into the earth work and the concrete work. The earth work can be identified in the volume of soil to be excavated and to be backfilled and re-compacted. It used a unit of  $R/m^3$  as the estimating basis.

From the employer's point of view a geotechnical report shall be assembled by an experienced company and the geological detail of the Greenfield site identified. The employer shall then identify the geological level of the planned site. The difference shall be recorded and a BOQ shall be developed which forms part of the civil contractor's tender enquiry. The concrete work is predominantly, pouring concrete and placing reinforcements. By the nature of concrete work, the unit used as the basis of estimate is  $R/m^3$ . The concrete work can only be finalized when a specific reactor design is identified. The civil contractor shall be able to assemble the BOQ for the concrete work for the NI. However, if the procurement strategy is to have an EPC LSTK package for the NI, then the concrete work shall form part of the NI contractor's scope of work.

#### **4.5.3.2. Structural Steel Work**

For structural steel work, it is essential to know that there are three type of structural steel work, namely, light, medium and heavy structural steel works. They all have different

complexities and it will affect the final outcome of the estimate. For example, the Medupi and Kusile projects contracted to Hitachi Power Africa, System 07 is the structural steel part of the boiler projects (Hitachi Power Africa, 2006). Structural steel is estimated in a unit of R/ton. This cost shall include the portion of fabrication and erection. The design cost shall also be included into the fabrication portion.

#### **4.5.3.3. Mechanical Work**

Mechanical work, on the other hand, can also be split into the main areas as turbines, rotating equipment and pressure vessels, other mechanical equipment such as heaters, fire protection, HVAC, cranes and elevators shall also be defined in the estimate. This mechanical equipment is also using the R/ton as a unit for estimating purposes.

In most cases, storage tanks shall form part of the mechanical work, i.e., IRWST (In-containment Refuelling Water Storage Tank). This being one of the tanks inside a NPP.

#### **4.5.3.4. Pipe Work**

Due to the complexity of pipe systems in a NPP, pipe work is normally forms part of the NI, CI and BOP. The pipe work can be defined in large bore piping and small bore piping. On these two sections, it can also be divided into the cost of welding and the cost of material handling.

The cost of welding is normally completed on a technique called Weld Diameter Inches, WDI. WDI is a unit used in the industry to monitor the performance of welders and also the estimating of welding hours in the pipe system.

The norm used is shown below (Broich, I., 2013):

	South Africa	European Countries
Field Weld	8 WDI	20 WDI
Shop Weld	25 WDI	55 WDI

**Table 4-2: Welding Norms for Pipe Systems**

When the contractor receives the piping isometric drawing and the weld map from the main contractor, the contractor can identify the diameter of the piping. For example, 4 welds on the 8 inches pipe is equals to 32 WDI. If the weld is a field weld, one South Africa welder can do 8 WDI per day shift. It means the Contractor has to allow for 3 day shift for the welder to complete that section of welding. However, if a European welder can do 20 WDI on a Field Weld, then it means it will only use 1.6 day shift. It is a gain of around 50% schedule saving on this activity (Broich, I., 2013). However, the contractor shall be cautious about the wage differences between a South African welder and a European welder.

It is normal that the employer will restrict the use of foreign labour in any South African major project. However, from past project experience, the employer will relax on this restriction once the delay is impacting the baseline construction schedule. The accelerated programme usually do allow for the foreign workers to perform tasks that were previously exclusive to local workers.

The cost of material handling is simply using the unit of R/ton for the piping. The weight of the piping can be easily identified from the piping isometric drawings generated in the detailed engineering design.

#### **4.6. Conclusion for Chapter Four: Guideline for Project Design & Engineering**

Under Chapter Four, the project design and engineering phase has been discussed in detail. In Section 4.1.1, the basic engineering design process was discussed and it is understood

that the outcome of this design process will result in a set of documents which includes the P&IDs, plant layout, etc. These shall be sufficient for the reactor technology provider to obtain the design certificate from the NNR. The detailed engineering process is the next step after the basic engineering stage. This stage of engineering requires all engineering discipline to be involved to design a constructible nuclear power plant. It is important that this phase is nearly finished before entering into any contractual relationship with the construction contractors. This will minimize scope change to the construction contractors which is often results in massive claims. When the detailed engineering process is completed, the procurement department can then issue the “Request For Quotation” to the market in order to obtain quotation to construct the NPP. When the construction contractors received these engineering documents, they shall be allowed to have sufficient time to assess and estimate on construction man-hours and material costs. These estimates shall be based on the requirements from the engineering documents.

The bid invitation and adjudication process shall not be overlooked. This is often the case when the government is criticized of corruption due to an un-transparent procurement process. Following the proper procurement process discussed in section 4.4 will minimize this risk. The Eskom project development team shall compile the Bid Invitation Specification, BIS. The BIS shall entail the following:

- Background and arrangement of the bidding process
- Technical and commercial requirements
- Conditions and circumstances under which the contractor will have to perform the tasks
- Expected structure and contents of the bids
- Bid evaluation criteria

The technical and commercial requirements shall be clearly identified in the BIS. Eskom shall define the above in detail so that the bidders can formulate a meaningful bid for Eskom to evaluate.

The bid adjudication method shall also be carefully followed, although there are two adjudication methods, namely, the qualitative method and the quantitative method. It is recommended to use the two stages approach. Firstly, utilize the qualitative method to eliminate the bids that are not compatible to the conditions outlined in the BIS. This shall result in two to three bids while still in the bid adjudication process. Then, secondly, the quantitative method shall be used to fully detail the bids in terms of the following:

1. Technical capacities
2. Technical capabilities
3. Safety Analysis
4. Commercial advantages
5. Commercial disadvantages

An evaluation matrix shall be used with weight factors defined in the beginning to suit the South African conditions. For example, percentage of localization may weigh 15% in the evaluation matrix due to the South African government wanting to develop a nuclear industry in South Africa.

The final outcome shall be based on the evaluation matrix and transparent as well, so that the bidders understand the decision making process, in order not to have other dispute which may delay the nuclear expansion programme.

It is understood that the employer or the reactor technology provider will use the top-down approach to complete their estimate and the construction contractors will use the bottom-up approach. The difference in these estimates can be significant. These differences shall be addressed in the bid clarification meeting between the employer and the contractor.

It can be concluded that there are four major parts of work in a NPP, the estimating activity shall be split accordingly into, civil work, structural steel work, mechanical work and pipe work. The civil work shall include earth work and concrete work. The table below is a guideline of units used as the basis of estimating for each major part of work.

Item	Work	Description of Work	Units
1	Earth Work	Excavate, Backfill and Re-compact	R/m <sup>3</sup>
2	Concrete Work	Placing Reinforcement & Pouring concrete	R/m <sup>3</sup>
3	Structural Steel Work	Fabricate and Erect Steelwork	R/ton
4	Mechanical Work	Fabricate and Erect rotating equipment and pressure vessels.	R/ton
5	Pipe Work	Fabricate and erect piping, including welding and material handling	R/Weld or R/ton

**Table 4-3: Summary of unit used for Estimating**

It can be concluded that in the project design and engineering phase, the main three steps are to complete the basic and detailed engineering, and then perform the bid invitation & adjudication process. At last, cost estimating shall be performed in either top-down or bottom-up methods.

#### **4.7. Summary for Chapter Four**

In Chapter Four, it summarized the project design and engineering phase of the nuclear expansion programme. It detailed the engineering phases, work breakdown structure, bid invitation process, bid adjudication process and the estimating techniques for a nuclear power plant. When all of the above processes are completed in the project design and engineering phase, the project execution phase shall begin in order to construct the nuclear power plant. The project execution phase is discussed in Chapter Five.

## **5. Project Execution Phase**

### **5.1. Introduction to Chapter Five**

The Project Execution phase is discussed in this chapter. The chapter starts with Project Control in Section 5.2 which consists of cost control, progress management and change management. Section 5.3 discusses Risk Management in a nuclear power plant project. The risk cycle and the various project risks are investigated. Section 5.4 discusses the construction management. Then, in Section 5.5, the function of quality assurance & quality control is also discussed. Finally, Section 5.6 discussed the construction schedule. Section 5.7 is the guideline for the Project Execution phase. Section 5.8 is a brief summary on Chapter Five.

### **5.2. Project Control**

The project control function shall not be ignored as it is a crucial part of the project management. This function can be categorized into the following:

- Cost Control
- Progress Management
- Change Management

#### **5.2.1. Cost Control**

Cost control is not a simple task in a mega project like constructing a NPP. It is also one of the important functions in the project control department. This function shall be implemented from the project design and engineering phase, but it is used extensively during the project execution phase. There are tools which can be used for cost control. They can be divided into planning tools and controlling tools (Burke, R., 2008). In the Medupi & Kusile projects, the cost control function used the same tools as indicated below which are in-line with the global best practice.

Planning Tools	Controlling Tools
1. Cost Breakdown	1. Expenditure Report
2. Activity Budget	2. Committed Cost
3. Department Budget	3. Cost-to-complete

**Table 5-1: Planning & Controlling Tools for Cost Control**

### **5.2.1.1. Cost Breakdown**

It is a planning tool utilized to define a project and used monetary terms to breakdown a project. It helps the project management team to understand all the cost components.

### **5.2.1.2. Activity Budget**

In some other cases, it may refer to a work package budget (Murray & Roberts, 2010). It is a planning tool facilitated by the cost controllers and the quantity surveyors. The activity budget shall comprise of man-hours and material, presented in monetary values. This tool allows the project manager to understand what resources he has for his project.

### **5.2.1.3. Departmental Budget**

It is also a planning tool used by the discipline managers, i.e. engineering manager, project control manager, procurement manager, etc. These managers are the head of departments and shall be responsible for the department budget. These departments will also be allocated a budget for them to function. For example, the engineering manager may decide to use this department budget to hire engineers or utilize a consulting service to achieve a project departmental goal.

### **5.2.1.4. Expenditure Report**

It is a controlling tool. The main function for this tool is to capture all the expenditure against a cost code, hence, on a specific work package. The data capturing process is critical on this

controlling tool. If the data was incorrectly captured, then the expenditure report will not be accurate. The project management team depends on this controlling tool to provide information on the project and hence, make the correct decision based on this information.

#### **5.2.1.5. Committed Cost**

Committed cost is also a controlling tool. It details the costs that the project has committed to pay to the suppliers or the subcontractors. It assists the project management team to monitor the costs on the project even when the bill has not been paid.

#### **5.2.1.6. Cost-to-Complete**

It is a controlling tool as well. The cost-to-complete tool shall be used by the project control department in a regular period. This shall forecast the final cost to complete each work package. Hence, in order to forecast the project will be overspent or under budget.

### **5.2.2. Progress Management**

Progress management is important, as it monitors the progress of the project. However, accurate feedback is needed from the construction managers, in order to compile a meaningful progress report. However, some of the construction managers are focused on the construction activities and neglected the importance of feedback. A common excuse used by these construction managers is that they are too busy and do not have time to allocate man-hours to the construction team (Chan, K.F.J., 2013).

An accurate recording of construction man-hours spent is essential to monitor the project progress. From the man-hours measurement, construction productivity can then be measured. Productivity is measured as a ratio between planned man-hours to actual man-hours spent on site. This figure is normally given as a percentage (%). If man-hours are not correctly recorded by the construction department, then the productivity figures may be misinterpreted by the project manager and corrective action might not be taken as required.

### **5.2.3. Change Management**

The change management team shall be assembled as early as possible in the project life cycle. There shall be estimators in the change management team who should have extensive knowledge in the contract as to what was agreed on, especially on the mutually agreed scope of work. Hence, changes can be captured with great accuracy and also avoid unqualified claims which can damage the relationship between the contractors and the employer. Although the change management team is crucial to the EPC LSTK contractor, this shall not be an exclusive function to the contractor and the employer shall also have a similar team. The current development is that the commercial quantity surveyors from the employer shall also possess the knowledge to deal with changes and they managed the changes together with the project managers. Regular meetings are recommended to ensure the communication between the employer and the EPC LSTK contractors are facilitated. The cost-to-complete shall be used as a tool to monitor the progress on the project in terms of monetary value (Bradbrooke, R., 2010).

In terms of change management, the responsible change manager shall ensure all the drawings and specifications are captured by his/her attention. The change manager shall have a good connection with the engineering department, who shall provide support to the change manager and advise the impact on the construction activities of the final NPP. The estimator shall then use the engineering information to translate these changes into monetary value and man-hours. The change manager shall then formulate claims in order to facilitate the compensation due to these design changes. For a nuclear power plant, design changes shall be minimal as the technical design is already approved by the regulator. Although major changes may not occur, changes such as piping routing, location of weldments on the high pressure/low pressure piping, etc., can still be occurred during the project. The configuration of the plant, especially on the BOP can change to suit a specific site. Some of the BOP changes might result in price change due to the extra piping and civil

work may be needed. Extra mechanical equipment and workers are also required during construction for these changes to be implemented.

An effective change process is required to verify changes on the project. Typically, design changes shall be assessed by the change management team and there shall be a graded level to indicate the significances of the changes. The design changes during construction shall be avoided as these activities are proven to delay the project and also have cost implications. A design freeze milestone shall be set to avoid these activities. However, if changes are needed for the plant safety, then, the changes shall be implemented as soon as possible.

In the Medupi & Kusile projects, the change management function was not implemented effectively. The change process was in place, however, there is lack of training for the area managers in this regard. Most area managers were not aware of what was expected from them to identify changes (Chan, K.F.J., 2012).

### **5.3. Risk Management**

#### **5.3.1. Risk Cycle**

Risk management is one of the most important aspects in the modern world business model, this is no different in the nuclear industry. It is important that all the risks identified in the conceptual study are allocated to the parties that can best handle that particular risk, i.e. schedule delay risk shall be allocated to the construction contractors, etc. In fact, this might be even more important in the NPP project, due to the monetary value invested in a NPP project. The decision for an investor to participate in a nuclear project comes down to risk-reward ratio (IAEA, 2008A). The typical risk cycle can be illustrated as below: (Murray & Roberts, 2010)



**Figure 5-1: Typical Risk Cycle**

Risk Assessment is the function to firstly identify the opportunities and the threats, and to establish an assessment which will measure each opportunity and threat in severity and likelihood.

Opportunities and threats management is a process to discuss and analyze how to change the exposure to risks.

Risk mitigation is the function to implement measures to reduce the likelihood and impact of threats. On the other hand, realise opportunities as well.

Risk audit is a process to evaluate the effectiveness of the measures that identified in the risk mitigation process, and also ensure the measures have been carried out as intended.

The following is the major risks that are identified for a NPP project:

1. Schedule Delay risk
2. Technology risk
3. Financial risk

4. Safety risk
5. Labour risk
6. Political risk
7. Quality risk

### **5.3.1.1. Schedule Delay Risk**

The risk mitigation measures that are used to counter the schedule delay risk are new improved design, and design standardization from the technology providers. The use of advance project planning tools, improved nuclear project management skills are the two measures that can be used by the contractors against the schedule delay risk. The regulator also improved on the license application process to include NIL, in order to lower this risk (NNR, 2008A).

The employer shall also select high quality and experienced contractors to mitigate the risk of delay due to poor quality during construction which might result in re-work and subsequently delay the project. Incentives and penalties shall be used by the employer to control the contractors. In a typical construction project, Performance Liability Damages (PLD) and Delay Liability Damages (DLD) are used, but both should be capped to avoid the contractor including the inflated risk provision in their tender price (McNair, D., 2011A). On the other hand, if the contractor performed well in their contract, they shall be suitably rewarded, but it depends on which contractual mode is used and vice versa.

In the Medupi and Kusile projects, all the contractors performing construction work on the projects have DLD as part of their contract. However, PLD are not always carried down to the subcontractors' level and is not imposed into their contract. This is one of the contributing factors that the subcontractors have performed below their expectation. Hence, the schedule delays in the construction work of Medupi and Kusile.

### **5.3.1.2. Technology Risk**

The improved plant performance in the recent years shows that the nuclear energy technology has a high availability factor compared to the other power generation technologies. It results in good return on investment once the NPP has started commercial operation.

Nuclear energy is a proven power generation technology and it is very successful in the US, France, Korea and even in Japan, despite the Fukushima disaster. A FOAK project risk is high in the nuclear industry, and demonstration is needed to provide certainty to the market. Standardization is also a measure used to lower the technology risk (IAEA, 2008B). Global fleet approach is also used to share learning in order to reduce the impact of technology risk.

For a NPP project to be successful a completed basic engineering design is essential. This will significantly reduce the risk of delaying the construction activities, hence, reduce the risk of cost overruns and schedule delays.

### **5.3.1.3. Financial Risk**

The financial risk is exposed to the financier and impacted on their expected ROI. Due to the fact that a NPP project is a capital intensive project, some of the risk mitigation measures are used below (McNair, D., 2011B):

1. Strong credit rating for the Employer
2. Government Guarantee for NPP
3. Demonstrated project success in the past

The above three measures provide certainty to the financier, hence, the funding can then be allocated to the nuclear expansion programme. It is important to note that new risk mitigation measures can be developed and it is especially easy to develop financial mechanisms to mitigate financial risks. Normally, if the government provides guarantee to the project, the

employer will receive favourable funding terms. This is essential for lowering the total investment cost for a NPP project. Hence, the financial risk is reduced.

In the IPP scenario, PPA is used to provide certainty to the investor with regards to ROI. However, if the project has cost overruns and schedule delays, these will change the overall risk profile on the NPP project in terms of financing.

#### **5.3.1.4. Safety Risk**

Public Safety is paramount to any NPP project, safety measures are incorporated into the reactor design of NPP. Hence, the nuclear industry has the strong focus of "Defence in Depth" and "Diversity and Redundancy". A strong nuclear regulator is needed to ensure the safety of the public is the first priority of any utility in the world.

In South Africa, the Koeberg Nuclear Power Plant has been in operation for more than 20 years. Hence, the nuclear safety culture is already developed in the industry. The construction industry is also well developed in terms of safety due to all the recent mega construction projects that took place in the last few decades. Hence, the safety risk is not a top concern in the nuclear sector. However, risk mitigation measure for safety is to reference the best practice for other nuclear construction projects around the world.

#### **5.3.1.5. Labour Risk**

Labour risk is one of the key risks to the investor in South Africa. In the recent major projects, labour unrest took place and it seems like it is unavoidable for the nuclear expansion programme. These industrial actions caused the project to be delayed from weeks to months. The delays caused, were impacting on the baseline schedule, and most of the project had to be resolved in an accelerated programme, that increased the cost of the projects. Most of the time, it entered into legal proceedings between the contractors and the

employer due to un-resolved claims. These are the indirect effects due to the industrial actions.

There is a fair chance that the nuclear expansion programme will experience industrial action during the construction phase. In order to mitigate the labour risk, lessons learnt from the existing major projects have to be implemented. This includes the following measures, constant communication with the labour unions, daily talks to the labourer to resolve minor complaints, careful planning of accommodation, timeous transport arrangement, etc. The above seems to be minor issues in the planning stage, however, these minor issues can cost the project dearly if not handled correctly. This is proven in the existing projects, such as the Medupi and Kusile CFPP construction projects (Chan, K.F.J., 2011).

Pre-employment screening is one of the tools used in the past, it is due to the unique nature of the construction industry. Some of the labourers do have criminal records and they do pose a threat to the project. Pre-employment screening is used as a condition in the employer's requirement, however, due to poor enforcement in the contractor's level, some of the "bad blood" had infiltrated into the work force. Most of the labour unrest is caused by these small groups of workers who then intimidated the others to carry out a strike (Chan, K.F.J., 2013).

#### **5.3.1.6. Political Risk**

The major risk of all is the political risk, because a change of government can affect the programme immensely, even discontinue the programme entirely. In a nuclear expansion programme, the duration of the programme including decommissioning, can span across 100 years, hence, government commitment is critical and it has to be sustained. The South African government has a five year cycle for each voting interval, and the NPP project cycle is longer than this government election cycle. This provides significant risk to the programme.

In order to mitigate the political risk, education is always used. For example, in Korea, general public is being exposed to nuclear knowledge when they attend secondary schooling. The nuclear programme is a national policy in Korea, hence, it is not easy to abandon or change (Choi, S., et al., 2009).

Political risk is directly related to the government's level of involvement. If the government is involved in the financial structure of the nuclear power plant project, it may reduce the risk of political uncertainty. Therefore, the government would not easily change the decision to impact on their revenue. This is one of the reasons why PPP is popular in energy projects (IAEA, 2008A).

#### **5.3.1.7. Quality Risk**

Quality in a nuclear power plant is of paramount importance, it cannot be compromised. In the nuclear environment, quality shall be built into each and every single activity, because the consequences of sub-standard work are enormous. The major risk associated with quality is the quality of the suppliers, constructors and even the engineering designers. In order to mitigate these quality risks, the global nuclear industry has adopted a series of standards, such as the ASME III (USA), the RCC-M (France), JSME (Japan), and KEPIC (Korea), etc (Malouines, P., 2013). These standards are the risk measures put in place by the industry in order not to compromise on quality when performing work in the nuclear environment.

#### **5.3.2. Risk in Other Technologies**

Risk is not just appears in the nuclear sector, other technologies also have their own specific risks. Below is a table listing the major risks in other technologies (Mnqandi, Z., 2012, Guénon, Y., 2009 and DoE, 2011).

	Fossil Fuel	Renewable
Risk #1	Volatile fuel price	Intermittent recourse availability
Risk #2	Changing environmental standards	Changing government policies
Risk #3	Carbon Emission Tax	Siting issues with locals

**Table 5-2: Risks associated with Fossil Fuel and Renewable Technologies**

## 5.4. Construction Management

Construction management is one of the key processes in a construction project. The correct implementation of construction management can reduce the cost of the project and also stay on track with the project schedule. On the other hand, ineffective construction management may result in cost overruns and schedule delays. It is especially important in a nuclear construction project, since a NPP is capital intensive, and a good construction management team will almost certainly guarantee success in nuclear projects.

A NOAK project shall be defined as the plant after 8000MWe has been constructed (IAEA, 2008A). A FOAK project has a higher cost than a NOAK project due to its complexity and unfamiliarity of new technology. A FOAK project also experience a lot of design changes, because of its nature as the detailed engineering design is not completed. The situation in South Africa is very similar to this, because South Africa has not built a nuclear facility in approximately 30 years. The experience in the industry has faded away due to there were no new NPP been built. However, South Africa has retained some of its nuclear skills due to other mega projects are also absorbing some of these experts. A training system shall be put in place to “nuclear-ize” these existing experts to perform the development of the nuclear expansion programme.

Construction technologies shall be carefully exemplified by the construction contractor in conjunction with the engineering contractor. By doing this, the project can establish cohesion among the different parties, so there will be less misunderstanding during the construction phase (IAEA, 2011B). The construction contractor shall also actively get involved with the

basic engineering, so that the engineer can design components or modules to suit the construction phase which can significantly reduce the cost and time for the project (IAEA, 2011A).

#### **5.4.1. Site Establishment**

Site establishment plan shall be identified before the construction of the NPP is started. The plan shall include but not limit the following and it shall be detailed by experienced professionals:

- Laydown Areas
- Water Connection
- Construction Power
- Sewage System
- Storm Water Management
- Gas Reticulation
- Fabrication Workshop
- Warehousing
- Batching Plant
- Borrow Pits
- Site Offices
- Marine Berth for Unloading Equipment

The above are normally provided by the employer, however, in the Medupi and Kusile projects, the EPC LSTK contractors undertook some of these responsibilities (Murray & Roberts, 2012).

Lay down areas are important to the EPC LSTK contractors and it allows them to plan their logistics plan and to fit the “Just in time” principle. The lay down areas will then be further developed to have a stabilized ground for the equipment and also to satisfy the loading

capacity for the cranes. For a NPP construction work, the major mechanical equipment, such as reactor core, steam generators, primary circuit pumps, are not going to be stored on site for a prolonged duration. The materials to be stored on site would mainly be the structural steel, piping, valves and other associated mechanical items.

Water connections shall be planned to ensure there is sufficient water supply for both human usage and for construction purposes. A historical data shall be obtained by the EPC LSTK contractors and past projects, this will ensure the usage is realistic and the employer can plan to secure a water source to supply to the NPP project. Water storage facilities on site can be provided by either the contractors or the employer. The water supply is also important for the civil contractors, the concrete forming process involves using water. In the nuclear graded concrete, some very high strength concrete is required, it is in the region of 60MPa to 120MPa (IAEA, 2011B). Water is also required for the hydrostatic test on the piping systems and storage tanks. The quality of the water shall not be neglected as it may cause corrosion if the quality of the testing water is inferior.

Construction power is crucial for the construction phase and the commissioning phase. Due to the fact that the polar crane which is on top of the reactor building is electrically powered, the power supply will determine the erection progress of the main mechanical equipment. For an all-weather approach, the lighting and welding process also draws a significant power from the supply (IAEA, 2011B). The substations are generally supplied by the employer as the electricity distribution shall be the core competency of the employer in the South African context. Construction power lines shall be in the scope of the employer in order to establish the connection to the grid to draw power from.

Sewage System shall be based on the planned DFL (Direct Field Labour) programme, this shall be important for both temporary and permanent use.

#### **5.4.2. Construction Equipment**

Heavy lifting equipment shall be ordered before the construction phase as these are long lead time procurement items. The crane capacity shall be determined by the contractor as they are the parties that are going to execute the work on Site. However, the engineering contractor can make a suggestion and provide a support in the form of information, such as the heaviest load, the highest level of plant, the foot print of plant, etc. These are all important to determine the type and capacity of the heavy lifting equipment to be used on site. On the other hand, mechanical equipment often needs to use spreader beams or lifting aids for the erection process. These construction aids shall be designed and go through a careful selection process, as to the consequence of the loss of life or property damage, having a loss of life accident on site will not just result in a loss of production time, but also a serious de-motivation to the work force. Property damage to the high precision mechanical equipment can cost the project greatly with cost and time.

The use of heavy lifting equipment on a NPP is primarily for the use of erecting the dome of the RPV, the bottom part of the RPV and the reactor core. The steam generators are normally installed by the polar crane on top of the LWR reactor building. These types of cranes have to be designed and manufactured by a specialist company, hence, the lead time for delivery could be long.

#### **5.5. Quality Assurance / Quality Control**

This section will discuss the importance of Quality Assurance/Quality Control in the nuclear industry. This section has also analyzed the QA/QC problem in South Africa with its unique issues with regards to manufacturing and construction.

The construction work in the nuclear project shall only be performed by experienced professionals, as the safety of public via quality cannot be compromised. The components in the NSSS shall be one of the safety critical components, which shall have a very stringent

quality requirement. For example the high pressure piping in the NSSS, requires the highest quality of workmanship from manufacturing to installation. The document detailing the welding process of this high pressure piping shall be prepared by a registered welding engineer who should have experience and knowledge of a nuclear system (Zerger, B., et al., 2011). However, the quality control on these processes is equally important.

Quality forms part of the critical pillars in the outcome of the project management principles, alongside with the cost and the time. All the documentation shall be completed according to prescribed procedures which will ensure that traceability is maintained throughout the project. The QM-58 of Eskom is a document that detailed the quality requirements from the contractor (Tjabadi, S., 2012). Training shall be provided to the QC inspectors to ensure the work of QC is understood, especially to the QC inspectors who are responsible for all the materials within the NSSS circuit.

Having the right people at the job is extremely important, as this will develop the project culture and this kind of culture is important. Project management is supported by three main factors, namely, Quality, Time and Cost (Steyn, H., 2012). For a nuclear project, quality has a far greater priority than the other two, because the consequence of an unsafe nuclear power plant is incomparable and the potential failure can cost the country dearly. The quality department shall appoint qualified QC inspectors, which shall include local QC inspectors and foreign QC inspectors. This can ensure the lesson learnt in the other parts of the world is maintained (IAEA, 2011C). The employer shall appoint its own AIA to oversee the quality aspect of the NPP is maintained. The AIA shall be the final authority on the project and has exclusive right to reject inferior projects or work from the contractors (Tjabadi, S., 2012). The responsibility of the AIA shall not be restricted to the site work only, and it shall have active QC inspectors in the various workshops of the OEMs. They shall continuously monitor the quality of the fabricators, which shall not be limited to the following:

1. Structural Steel
2. Mechanical Equipment
3. Pressure Parts
4. Piping
5. Electrical
6. Control & Instrumentation
7. Earthwork & concrete work

## **5.6. Construction Schedule**

In this section, the discussion is around the planning and scheduling around the NPP construction project. In the case of South Africa, it shall include the master plan of building a fleet of NPPs.

Project schedule shall only be defined after the estimates (Gen IV Forum, 2007). The estimating phase shall provide all the necessary man-hours for the project. This can in turn formulate the resources loading plan in conjunction with the milestones which shall be defined by the employer.

On the structure on project schedule, the NEC3 contract stated very specifically that the following shall be presented in a project schedule: (NEC3, 2006)

1. Start Date
2. Access Date
3. Key Dates
4. Completion Date

Above are the basic milestones used in a NEC3 contract, the NPP construction project shall have more defined milestones.

The following are the typical milestones for a NPP project:

1. Commencement of earthworks
2. First pour of concrete
3. First steel erected
4. Installation of reactor core
5. Installation of Steam Generators
6. Closing of dome
7. Turbine installation
8. Pressure test
9. Safety system test
10. Commissioning the primary system
11. Commercial operation

These milestones are important to track the progress of the project and also will reflect in the commercial payment milestones, but it depends on the contract mode and the agreed payment method.

Provisions are allowed, such as float, time risk allowance, health and safety requirements and the procedures set out in the contract. All the claims and the actual progress shall be documented in the revisions of the project schedule as well.

There are levels of details in the construction schedule of a NPP project, it is typically divided into four different levels of details (IAEA, 2012).

- 1<sup>st</sup> Level: Overview of the whole NPP project
- 2<sup>nd</sup> Level: Master Schedule, major critical paths are identified
- 3<sup>rd</sup> Level: All required tasks shall be completed and the integrated project schedule is done. Engineering, procurement, erection and testing are identified in this level of detail.

4<sup>th</sup> Level: Detailed schedule of each task is identified.

The construction schedule shall be agreed between the employer and the contractor prior to work commencement. Once the schedule is agreed by all parties, the schedule shall be distributed to all levels within the project. Hence, the entire project team can be aware of all the major milestones. The schedule shall be updated in a regular interval to show progress and also be used to monitor productivity and identify issues.

## **5.7. Conclusion for Chapter Five: Guideline for Project Execution**

In Chapter Five, the project execution phase has been discussed. In the execution phase, this is where the entire plan has become a reality. In a nuclear power plant project, the cost component for construction is highly significant compared to the other power generation technologies. Since controlling the cost during construction can make a huge impact into the overall cost of the nuclear expansion programme. Project control techniques are introduced to achieve this. It is necessary to use all the planning and controlling tools to perform the cost control function. All of these tools are well known in the construction industry, these tools shall be enforced in the NPP construction project.

Since the history of constructing nuclear power plants are all associated with schedule delays and cost overruns, progress management shall not be overlooked in a nuclear construction project. The project management team shall monitor the progress on the construction activities in order to address issues before the problem becomes irreversible.

The third component in the project control function is change management. In Section 5.2.3, the change management was discussed. There are lessons learnt from the Medupi and Kusile projects that can be used in the NPP construction project. The late design changes had a massive cost implication to the Medupi and Kusile projects. The nuclear expansion programme shall not repeat the same mistakes, it shall strive for 100% detailed engineering design to be completed before work commencement on site. However, if changes are

unavoidable, the change management process shall be facilitated to capture all the changes and implement the changes to the construction team.

Risk management is also another important function during the execution of the nuclear expansion programme. The risk cycle was discussed which includes the risk assessment, opportunities/threats management, risk mitigation, and risk audit. Major risks associated with the nuclear expansion programme were also identified, they were schedule delay risk, technology risk, financial risk, safety risk, labour risk, political risk and quality risk. These risks shall only be allocated to the parties that can best handle it.

Construction management is undeniably the key function in the execution phase. Due to the time limits in this research project, the analysis of construction management only progress to site establishment and construction equipment. It is recommended that further research to be completed in this regard. However, on the site establishment of the NPP construction project, it is recommended that Eskom appoint the earth work contractor to allow for an early start with the earth work and civil work. The overall basic infrastructure, such as water, sewage and electricity shall be installed and commissioned before the mechanical contractor has been granted site access. These are basic essentials and shall be completed as early as possible in order not to have any delay or claims from the contractors.

Quality Assurance/Quality Control is an extremely difficult and complicated matter in a NPP construction project. The integrity of a nuclear power plant relies on the workmanship during the construction phase. Eskom already utilize AIA to monitor the contractor's work, in order to ensure the construction work is done in accordance to the original design. Nevertheless, quality shall be incorporated into each phase of the project management phases.

Construction schedule is the backbone of the project management plan, it is required during the project setup & planning phase in order to establish the project investment cost for financing. In the project design & engineering phase, the construction schedule is also

important. It provides interfaces for all the work packages and also allows the contractors to estimate the cost for construction. In the project execution phase, the project progress is measured against the construction schedule. All the project delays are captured in the construction schedule and it is necessary to identify and monitor the critical path for the project. The construction schedule also allows the commercial team to identify the major milestones for the project, which is often used as a payment schedule.

In Section 5.6, it discussed that the construction schedule can have different levels of details, where in most projects, it is developed to Level Four detail in order to identify details of each task. This is essential for project control purposes. From a Level Four detailed project schedule, the project management team can understand all the activities involved in the project. It is very important for a nuclear power plant construction project in order to monitor quality, schedule and cost effectively.

## **5.8. Summary for Chapter Five**

In Chapter Five, it concluded the project execution phase. It discussed the cost control process, progress management and change management. It also analysed the risk management process, and discussed all the major risks in the nuclear expansion programme. Construction management was briefly discussed together with the quality assurance/quality control function and the construction schedule. Project execution phase is the last phase that will be discussed in this research report. The next chapter will lead to the recommendations for all three phases that were discussed in Chapter Three, Four and Five respectively.

## 6. Recommendation

The planned nuclear expansion programme of South Africa will be the biggest infrastructure project ever taken in the South African history. The sheer magnitude of the programme can easily equal to R300 Billion or above. The purpose of this research report is to create a project management guideline for the South African nuclear industry with regards to the nuclear expansion programme. Another important contribution is to align the South African industry to the nuclear standard, assisting the existing industry to understand the difference between a nuclear power plant project to a coal fired power plant project. South Africa has the capability to achieve success in this programme, however, there are some alignments to be done, to “nuclear-ize” the existing industries to the required nuclear level. The project guideline for the nuclear expansion programme in South Africa is presented in the above chapters, the chapter below is the recommendation for the nuclear expansion programme.

There are three phases in developing a nuclear power plant, they are namely, project setup & planning phase, project design & engineering phase and project execution phase, as illustrated in Figure 3-1.

### 6.1. Recommendation in Project Setup & Planning Phase

#### **Recommendation One:**

Eskom shall understand and also apply their well-developed Project Life Cycle Model (PLCM) to the nuclear expansion programme. It stated that Eskom projects shall be developed from conceptual studies to business cases and then feasibility studies, and eventually to the execution phases. Below is the list that includes but not limits to the outcome of the conceptual study:

1. Capacity of the nuclear expansion programme
2. Potential location of the NPP(s)

3. Benefits of the nuclear expansion programme both economically and socially
4. Potential capital investment cost of the nuclear expansion programme
5. Safety of the NPP(s)
6. Spent fuel management strategy
7. Nuclear liability

Another important factor that shall be considered is the return of investment in the nuclear expansion programme. These shall allow the decision maker to decide whether to implement the programme, or not. All of the above shall be considered before the programme can be carried into the next phase.

### **Recommendation Two:**

In the procurement strategy, it is recommended that Eskom utilize the Split EPC (Engineering Procurement and Construction) contracting mode, this shall allow the Nuclear Island (NI) to be contracted to one EPC LSTK contract. The same contracting mode shall apply to the Convention Island (CI) as well. This shall allow the contractor to bear the majority of the risks. These contractors responsible for the NI and the CI will be the technology providers. On the other hand, the Balance of Plant (BOP) can be constructed by the local contractor on the EPC LSTK contractual mode, as the local industries are capable to engineering and constructing the BOP of a nuclear power plant. The engineering complexity of the BOP is not of the same high level as the NI and the CI, hence, the local industries shall be able to handle it. Another factor is that there is not a big difference between the BOP of the NPP and the BOP of the CFPP, where local industries are performing this work already. However, the local contractor shall be aware of the nuclear grade quality, in order to successfully construct the BOP of the NPP. In order to maximize the local content of the nuclear expansion programme, the civil work shall be contracted to the local industries as well. It is recommended that this shall be contracted the same as the

NI, CI and BOP, hence, utilize the EPC LSTK mode. By placing the major EPC LSTK contracts, Eskom is only required to manage four EPC LSTK contracts. The contractors shall have full control over the construction activities and overall quality of the plant which is also within the contractor's responsibility. This can ease the project management capacity within Eskom and allows Eskom to have effective control over the contractors.

### **Recommendation Three:**

When the contracting modes are selected and decided, the funding of the nuclear expansion programme shall be considered. This project financing phase shall not be underestimated, especially in the nuclear environment, where high capital cost and long waiting periods before revenue can be generated, are the well-known factors in the industry.

Eskom shall assess all the available options (i.e. State Owned, Independent Power Producer (IPP), Public Private Partnership (PPP), etc.) and select the best one that allows the country to maximize its benefit and ultimately ensure the burden on the consumers is not overly excessive. It is recommended that the PPP option shall be used. The PPP option allows the private sector to be involved in the development of the NPPs. This shall improve the efficiency of constructing the NPPs and also improve the liquidity of Eskom. The risk is being shared to both the private sector and the public sector. Another deciding factor is that a NPP is of a great security interest to a nation, if it is controlled by a foreign company, it can potentially compromise national security. It is for this same reason that the IPP is not recommended for the nuclear expansion programme.

### **Recommendation Four:**

Once the project financing option is decided, Eskom shall understand the costs involved in the nuclear expansion programme. This allows Eskom to control the cost more effectively if a thorough understanding of the nuclear industry is known. From Table 3-2, it is understood

that for a NPP, the capital investment cost is around 50% to 60% which is significantly more than a gas fired Closed Cycle Gas Turbine (CCGT) or a Coal Fired Power Plant (CFPP). However, the fuel cost is only 15% to 20% compares to the 70% to 80% of the Gas CCGT. Hence, it is recommended that Eskom have an analysis of the project costs. This will allow Eskom to understand the full project costs and then a strategy can be developed to control these costs.

## **6.2. Recommendation in Project Design & Engineering Phase**

### **Recommendation Five:**

Under the Project Design & Engineering Phase, the fifth recommendation is towards the engineering phases, i.e. basic engineering, detailed engineering and construction support. Eskom and its chosen technology provider shall follow the above mentioned engineering approach and the lessons learnt in the Medupi and Kusile projects shall be implemented for the nuclear expansion programme. It is recommended that a "design freeze" shall be used as a project milestone. After this milestone, engineering changes shall only be allowed to be implemented if it has a significant impact on the reliability and operability of the NPP. This will limit the number of scope changes in terms of design changes, hence, reduce the cost of construction.

### **Recommendation Six:**

The sixth recommendation is towards the construction support function for the engineering department during the construction phase. It is recommended that the engineering department shall be present on site in order to ensure the systems in the NPP are correctly constructed and commissioned. The site engineers shall also oversee the implementing of design changes on site. At last, the site engineers shall also be responsible to resolve

engineering queries raised on site, in order to minimize the delay of engineering responses and streamline the construction process.

#### **Recommendation Seven:**

The bid invitation and adjudication process shall not be taken lightly in the nuclear expansion programme. Eskom shall allow a team of engineers to develop the Bid Invitation Specification (BIS). The detail of the BIS is discussed in Section 4.4.1. Eskom shall also use the bid adjudication method proposed in Section 4.4.2. The recommended bid adjudication method is to utilize the two stages approach, first stage is the qualitative method and the second stage is the quantitative method. This will allow the bidders and the employer to have a clear strategy for the bidding process which is transparent and also logical.

#### **Recommendation Eight:**

It is recommended that the cost estimating process performed by the contractors to be verified by an experienced consulting company who have completed a NPP construction project before. It is a risk if the estimates are incorrectly performed and caused by inexperienced contractors. Eskom shall have an estimating team verifying these costs and shall point out the cost estimate for the nuclear expansion programme is either underestimated or overestimated. This process can ensure the nuclear expansion programme will be a win-win situation for both Eskom and the contractors and minimize the chances of becoming a discontinued or abandoned nuclear expansion programme.

### **6.3. Recommendation in Project Execution Phase**

#### **Recommendation Nine:**

Under the Project Execution Phase, the ninth recommendation is towards the project control function in the nuclear expansion programme. For the project control section in the nuclear

expansion programme, the following are the main functions from the contractor's point of view:

1. measuring costs used against planned budget
2. measuring man-hours used against planned man-hours

By using the above two measurement, the project control department can generate a regular progress reports for the project management team to identify whether the project is on course or not. Accurate information is also required to generate a meaningful progress report. Hence, the data capturing process is an important part of the whole function of project control as mentioned in Section 5.2. In the nuclear expansion programme, it is recommended that the data capturing process shall be done by the quantity surveyors in the commercial department. The quantity surveyors shall also be responsible for analyzing this information. He/she shall advise the project management team on whether the project is on course or not in terms of both the budget and man-hours used. He shall also perform the cost-to-complete for the project and monitor productivity as well.

#### **Recommendation Ten:**

It is recommended that during the construction of the NPP each department shall generate a monthly progress report to reflect their latest development in the department respectively. The report shall be reviewed by Eskom and action shall be taken if any shortcoming is foreseen. Contingency shall only be used by the project management team if the project control department has identified that certain areas in the project had be intervened in order not to have any delay in the project schedule or safety of plant being violated.

#### **Recommendation Eleven:**

The eleventh recommendation is to implement change management as soon as the project commences. This process can identify all the design changes and its cost implications in the

nuclear expansion programme. However, before change management can be implemented, the cost control process shall be well-defined. There are a number of controlling tools and planning tools to assist in this regard. Budgets for each system shall be clearly identified and the responsible managers shall be informed, in order to have a functioning change management process in place.

**Recommendation Twelve:**

The risk management tool shall be established and the project management team that are responsible for the nuclear expansion programme shall understand and define all the risks (listed in Section 5.3.1) and opportunities before the programme can commence. The political risk and the labour risk are particularly important to South Africa. It is recommended that these risks shall be well-defined and a risk mitigation process shall be put in place before the start of the nuclear expansion programme.

**Recommendation Thirteen:**

Eskom shall appoint the earth work contractor to allow for an early start with the earth work and civil work. The overall basic infrastructure, such as water, sewage and electricity shall be installed and commissioned before the mechanical contractors have been granted site access. These are basic essentials and shall be completed as early as possible in order not to have any delay or claims from the other contractors.

**Recommendation Fourteen:**

The Quality Assurance / Quality Control (QA/QC) aspect of the nuclear expansion programme shall be closely monitored. As explained in the Section 5.5, quality in the nuclear expansion programme shall not be compromised. In order for QA/QC function to perform, the quality control inspectors shall undertake training for nuclear grade inspection. This will allow them to perform the quality control function more effectively. It is also essential to have

an experienced project management team that understands that a nuclear project shall have the top priority in quality and safety.

#### **Recommendation Fifteen:**

It is recommended that Eskom shall develop a detailed project schedule in order for all the parties to understand the nuclear expansion programme and also monitor the progress of the programme. This project schedule shall be developed up to the level four requirements. This will allow all parties to have an idea of the activities and tasks to be performed in a nuclear expansion programme. A project schedule is of paramount importance in a construction project as mentioned in the NEC3 and FIDIC contracts, it is used for both project management and also in commercial management.

#### **6.4. Final Conclusion**

In the final conclusion, the research report has successfully completed all the specific objectives outlined in Section 1.2. This report have analyzed the current status of international project management practise and also discussed the current status of South African project management practise. The guideline developed in this research report also detailed the nuclear development strategies, in terms of project setup & planning phase, project design & engineering phase and project execution phase. The guideline also allows Eskom and other possible NPP developers to understand the unique requirements of a nuclear project and its project management skills.

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## **APPENDIX A**

**Draft Scope of Work document for the nuclear expansion programme**

APPENDIX A

Scope of Work for the Nuclear Expansion Programme

LEGEND	
A	Eskom
B	Main Contractor
C	Civil Contractor
D	Erection Contractor
E	EC&I Contractor
F	Turbine Contractor

Areas	Work	Categories	Basic Engineering	Detail Engineering	Procurement	Construction	Commissioning	Remarks
Early Site Work	Road	Civil	B	C	C	C	A	
	Foundation	Civil	B	C	C	C	B	
	Electricity	Elect	B	E	E	E	A	
	Water	Civil	B	D	D	D	A	
	Sewage	Civil	B	D	D	D	A	
	Communication	C&I	B	E	E	E	A	
	Survey	Civil	B	C	C	C	B	
	Concrete Supply	Civil	B	C	C	C	B	
	Marine Work	Civil	C	C	C	C	C	
Nuclear Island	Reactor Containment Building	Civil	B	C	C	C	B	
	Auxiliary Building	Civil	B	C	C	C	B	
	Fuel Handling Building	Civil	B	C	C	C	B	
	Polar Crane	Mech	B	D	D	D	B	
	Fuel Handling Equipment	Mech	B	B	D	D	B	
	Control & Instrumentation	C&I	B	E	E	E	B	
	High Pressure Piping	Mech	B	B	D	D	B	
	Control Rod Driving System	Mech	B	B	D	D	B	
	Low Pressure Piping	Mech	B	D	D	D	B	
	Electrical Reticulation	Elect	B	E	E	E	D	
	Elevators	Mech	B	D	D	D	D	
	Control Room	C&I	B	B	E	E	B	
	IRWST	Mech	B	B	D	D	B	
Heat Exchangers	Mech	B	B	D	D	B		
Conventional Island	Turbine Building	Civil	F	C	C	C	F	
	Auxiliary Building	Civil	F	C	C	C	F	
	High Pressure Piping	Mech	F	F	D	D	F	
	Turbine Set	Mech	F	F	D	D	F	
	Generator Set	Elect	F	F	E	E	F	
	Control & Instrumentation	C&I	F	F	E	E	F	
	Low Pressure Piping	Mech	F	D	D	D	F	
	Electrical Reticulation	Elect	F	E	E	E	F	
	Elevators	Mech	F	D	D	D	F	
Heat Exchangers	Mech	F	F	D	D	F		
Balance of Plant	Diesel Generator Building	Civil	A	C	C	C	A	
	Spent Fuel Storage Building	Civil	A	C	C	C	A	
	Diesel Generator	Elect	A	E	E	E	A	
	Low Pressure Piping	Mech	A	D	D	D	A	
	Storage Tanks	Mech	A	D	D	D	A	
	Water Treatment Plant Building	Civil	A	C	C	C	A	
	Water Treatment Equipment	Mech	A	D	D	D	A	
	Transformer	Elect	A	E	E	E	A	
	HV Switchyard	Elect	A	E	E	E	A	
HVAC	Mech	A	D	D	D	A		

## **APPENDIX B**

### **Overnight Costs of different power generation projects**

**APPENDIX B**

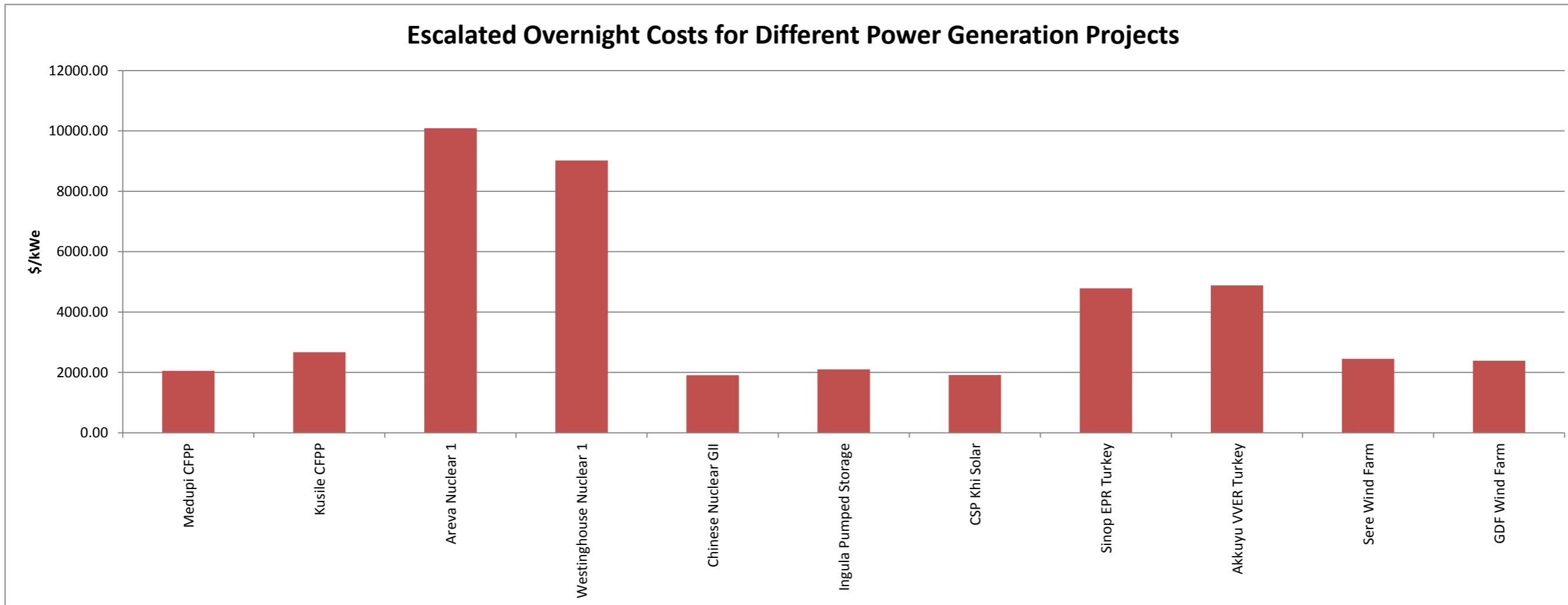
**Escalated Overnight Costs for Different Power Generation Projects**

Rate of Exchange 9.8 R:\$

Projects	TIV R Billions	Year R value	Escalated 2 R Billions	Capacity MWe	Overnight Cost \$/kWe	Type 1st/2nd/nth	Reference
Medupi CFPP	91.2	2012	96.559	4800	2052.70	NOAK	Creamer T, Engineering News
Kusile CFPP	118.5	2012	125.463	4800	2667.16	NOAK	Creamer T, Engineering News
Areva Nuclear 1	245	2008	326.349	3300	10091.19	2OAK	Mnqandi Z, Eskom
Westinghouse Nuclear 1	239	2008	318.357	3600	9023.72	2OAK	Mnqandi Z, Eskom
Chinese Nuclear GII	55	2009	67.324	3600	1908.28	NOAK	Wang J, CGNPC
Ingula Pumped Storage	25.9	2012	27.422	1332	2100.71	NOAK	Creamer T, Engineering News
CSP Khi Solar	1.875	2013	1.875	100	1913.27	FOAK	Carratu I, SPX
Sinop EPR Turkey	215.6	2013	215.600	4600	4782.61	2OAK	World Nuclear News
Akkuyu VVER Turkey	196	2010	229.785	4800	4884.89	FOAK	World Nuclear News
Sere Wind Farm	2.4	2013	2.400	100	2448.98	NOAK	Creamer T, Engineering News
GDF Wind Farm	2.2	2013	2.200	94	2388.19	NOAK	Morthorst, P.E. Denmark

Statistics SA	
Year	CPI
2013	5.876%
2012	6.243%
2011	4.224%
2010	4.410%
2009	8.820%
2008	9.457%
2007	5.964%
2006	1.799%
2005	2.133%
2004	-1.816%

CFPP Norm R 2,812.15 2013 Value R 2,500.00 2011 Value  
 NPP Norm R 5,536.54 2013 Value R 5,000.00 2011 Value



## **APPENDIX C**

**Loss in revenue due to different availability factor**

## **APPENDIX C**

### **Loss in Revenue due to difference in Availability Factor**

US reactors = 90% (Alexander, L., 2009)

Koeberg NPP = 83% (Eskom, 2011)

Koeberg nameplate capacity = 1800 MWe (Eskom, 2011)

Selling Rate = R 0.6551 / kWh (NERSA, 2012)

*$\Delta$  in availability factors*

$$= 90\% - 83\% = 7\%$$

*Electricity loss due to  $\Delta$  in availability factors*

$$= 365 \text{ days} \times 24 \text{ hrs/day} \times 7\% \times 1800 \text{ MWe} = 1.10 \times 10^9 \text{ kWh}$$

*Revenue Loss*

$$= 1.10 \times 10^9 \text{ kWh} \times R0.6551/\text{kWh}$$

$$= R723 \times 10^6$$

$$= R723 \text{ Millions}$$

## **APPENDIX D**

**An example of bottom-up estimate for the IRWST in a NPP**

**PACKAGE - 1401: NUCLEAR ONE PROJECT**

**PRICING SCHEDULE FOR IRWST**

**SECTION : SUPPLY, FABRICATE & INSTALL**

**IN-CONTAINMENT REFUELING WATER STORAGE TANK**

ITEM	DESCRIPTION	UNIT	QUANTITY	RATE	AMOUNT	
<b>1</b>	<b>DIRECT LABOUR COST</b>					
1.1						
	a	CODED WELDER	HOURS	3200.00	R 320.80	R 1,026,560.00
	b	PIPE FITTER	HOURS	3200.00	R 282.20	R 903,040.00
	c	STEEL ERECTOR	HOURS	3200.00	R 282.20	R 903,040.00
	d	RIGGER	HOURS	1000.00	R 282.20	R 282,200.00
	e	STOREMAN	HOURS	3200.00	R 235.80	R 754,560.00
	f	SEMI SKILLED	HOURS	9600.00	R 183.28	R 1,759,488.00
	g	LABOURER	HOURS	9600.00	R 101.28	R 972,288.00
<b>2</b>	<b>PRELIMINARY &amp; GENERALS</b>					
2.1	TIME DEPENDENT					
	a	PROJECT MANAGER	MONTH	8.00	R 120,000.00	R 960,000.00
	b	COMMERCIAL MANAGER	MONTH	8.00	R 100,000.00	R 800,000.00
	c	PROJECT ENGINEER	MONTH	16.00	R 100,000.00	R 1,600,000.00
	d	QUANTITIES SURVEYOR	MONTH	8.00	R 80,000.00	R 640,000.00
	e	SITE MANAGER	MONTH	8.00	R 80,000.00	R 640,000.00
	f	QC MANAGER	MONTH	8.00	R 80,000.00	R 640,000.00
	g	SITE PLANNER	MONTH	8.00	R 56,000.00	R 448,000.00
	h	WELDING SUPERVISOR	MONTH	8.00	R 56,000.00	R 448,000.00
	i	SITE SUPERVISOR	MONTH	8.00	R 56,000.00	R 448,000.00
	j	QC INSPECTOR LEVEL III	MONTH	8.00	R 67,000.00	R 536,000.00
	k	SAFETY OFFICER	MONTH	8.00	R 48,000.00	R 384,000.00
	l	SITE ADMINISTRATOR	MONTH	8.00	R 29,000.00	R 232,000.00
	m	QC ADMINISTRATOR	MONTH	8.00	R 32,000.00	R 256,000.00
	n	MATERIALS CONTROLLER	MONTH	16.00	R 29,000.00	R 464,000.00
	o	DRAWING OFFICE	MONTH	8.00	R 120,000.00	R 960,000.00
	p	POTABLE WATER	MONTH	8.00	R 20,000.00	R 160,000.00
	q	ELECTRICAL RETICULATION	MONTH	8.00	R 15,000.00	R 120,000.00
	r	TRANSPORTATION	MONTH	8.00	R 50,000.00	R 400,000.00
	s	COMMUNICATIONS	MONTH	8.00	R 8,000.00	R 64,000.00
	t	ACCOMMODATION	MONTH	88.00	R 22,000.00	R 1,936,000.00
	u	50 TON MOBILE CRANE	MONTH	16.00	R 120,000.00	R 1,920,000.00
2.2	VALUE DEPENDENT					
	a	ELECTRICAL RETICULATION	SUM	1.00	N/A	INCLUDED
	b	TRANSPORTATION	SUM	1.00	N/A	INCLUDED
	c	COMMUNICATIONS	SUM	1.00	N/A	INCLUDED
	d	ACCOMMODATION	SUM	1.00	N/A	INCLUDED
	e	PERFORMANCE BOND	SUM	1.00	R 80,000.00	R 80,000.00
	f	INSURANCE	SUM	1.00	N/A	INCLUDED
2.3	FIXED COST					
	a	INSURANCE	SUM	1.00	R 200,000.00	R 200,000.00
	b	SITE ESTABLISHMENT	SUM	1.00	R 2,500,000.00	R 2,500,000.00
	c	SECURITY FENCING	SUM	1.00	R 20,000.00	R 20,000.00
	d	SITE DE-ESTABLISHMENT	SUM	1.00	R 50,000.00	R 50,000.00

<b>3</b>		<b>MATERIAL</b>				
	a	PLATE 20MM THK - P91	TON	60.00	R 25,000.00	R 1,500,000.00
	b	STRUCTURAL STEEL - IPE 480	TON	5.00	R 32,000.00	R 160,000.00
	c	STRUCTURAL STEEL - IPE 200	TON	15.00	R 30,000.00	R 450,000.00
<b>4</b>		<b>SERVICES</b>				
4.1		<b>PICKLE &amp; PASSIVATION</b>				
	a	PICKLE & PASSIVATION	TON	26.00	R 25,000.00	R 650,000.00
	b	TRANSPORT	KM	280.00	R 16.00	R 4,480.00
4.2		<b>CORROSION PROTECTION</b>				
	a	CATHODE PROTECTION SYSTEM	EA	1.00	R 500,000.00	R 500,000.00
4.3		<b>NDE SERVICE</b>				
	a	NDT ON THE WELD	WELDS	900.00	R 6,000.00	R 5,400,000.00
4.4		<b>AIA SERVICE</b>				
		TUV SERVICE	MONTH	8.00	R 80,000.00	R 640,000.00
<b>5</b>		<b>EXCLUSION</b>				
	a	CONTROL & INSTRUMENTATION	EA	1.00		EXCLUDED
	b	COMMISSIONING	EA	1.00		EXCLUDED
	c	SUPPLY OF ELECTRICITY	EA	1.00		EXCLUDED
	d	POLAR CRANE	EA	1.00		EXCLUDED
	e	CIVIL & EARTHWORK	EA	1.00		EXCLUDED
<b>TOTAL VALUE OF BILL FOR IRWST</b>						<b>R 32,811,656.00</b>
<b>CONTRACTOR FEES @ 20%</b>						<b>R 6,562,331.20</b>
<b>GRAND TOTAL FOR IRWST</b>						<b>R 39,373,987.20</b>

Note:

- 1 Rates are base dated June 2013
- 2 Price Adjustment Factor applies as 90% to SEIFSA Table C3(a) and 10% Fixed