Министерство образования и науки Российской Федерации
Федеральное государственное автономное образовательное учреждение
высшего образования
**«НАЦИОНАЛЬНЫЙ ИССЛЕДОВАТЕЛЬСКИЙ
ТОМСКИЙ ПОЛИТЕХНИЧЕСКИЙ УНИВЕРСИТЕТ»**

Институт Физико-технический
Направление подготовки 14.04.02 Ядерные физика и технологии
Кафедра Физико-энергетические установки

МАГИСТЕРСКАЯ ДИССЕРТАЦИЯ

Тема работы
Вопросы формирования ядерной программы Ганы

УДК 621.039.9(667)

Студент

Группа	ФИО	Подпись	Дата
0АМ5И	Гбину Джошуа		

Руководитель

Должность	ФИО	Ученая степень, звание	Подпись	Дата
Доцент каф. ФЭУ ФТИ	Степанов Б.П.	к.т.н.		

КОНСУЛЬТАНТЫ:

По разделу «Финансовый менеджмент, ресурсоэффективность и ресурсосбережение»

Должность	ФИО	Ученая степень, звание	Подпись	Дата
Доцент каф. МЕН ИСГТ	Рахимов Т. Р.	к.э.н.		

По разделу «Социальная ответственность»

Должность	ФИО	Ученая степень, звание	Подпись	Дата
Ст. преподаватель каф. ПФ ФТИ	Веригин Д.А.			

ДОПУСТИТЬ К ЗАЩИТЕ:

Зав. кафедрой	ФИО	Ученая степень, звание	Подпись	Дата
ФЭУ ФТИ	Долматов О.Ю.	к.ф.-м.н., доцент		

Томск – 2017 г.

ПЛАНИРУЕМЫЕ РЕЗУЛЬТАТЫ ОБУЧЕНИЯ ПО ООП

Код результата	**Результат обучения (выпускник должен быть готов)**
	Профессиональные компетенции
Р1	Применять глубокие математические, естественнонаучные, социально-экономические и профессиональные знания для теоретических и экспериментальных исследований в области использования ядерной науки и техники
Р2	Способность определять, формулировать и решать междисциплинарные инженерные задачи в ядерной области с использованием профессиональных знаний и современных методов исследования
Р3	Уметь планировать и проводить аналитические, имитационные и экспериментальные исследования в сложных и неопределённых условиях с использованием современных технологий, а также критически оценивать полученные результаты
Р4	Использовать основные и специальные подходы, навыки и методы для идентификации, анализа и решения технических проблем в ядерной науке и технике
Р5	Готовность к эксплуатации современного физического оборудования и приборов, к освоению технологических процессов в ходе подготовки производства новых материалов, приборов, установок и систем
Р6	Способность разрабатывать многовариантные схемы для достижения поставленных производственных целей, с эффективным использованием имеющихся технических средств
	Общекультурные компетенции
Р7	Способность использовать творческий подход для разработки новых идей и методов проектирования объектов ядерного комплекса, а также модернизировать и совершенствовать применяемые технологии ядерного производства
	Общепрофессиональные компетенции
Р8	Самостоятельно учиться и непрерывно повышать квалификацию в течение всего периода профессиональной деятельности.
Р9	Активно владеть иностранным языком на уровне, позволяющем работать в иноязычной среде, разрабатывать документацию, презентовать результаты профессиональной деятельности.
Р10	Демонстрировать независимое мышление, эффективно функционировать в командно-ориентированных задачах и обладать высоким уровнем производительности в профессиональной (отраслевой), этической и социальной средах, а также руководить командой, формировать задания, распределять обязанности и нести ответственность за результаты работы

Министерство образования и науки Российской Федерации
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Институт Физико-технический
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Кафедра Физико-энергетические установки

УТВЕРЖДАЮ:
Зав. кафедрой
_____ __________ О. Ю. Долматов

ЗАДАНИЕ
на выполнение выпускной квалификационной работы

В форме:

Магистерской диссертации

Студенту:

Группа	ФИО
0АМ5И	Гбину Джошуа

Тема работы:

Вопросы формирования ядерной программы Ганы	
Утверждена приказом директора (дата, номер)	Пр. №959/с от 16.02.17

Срок сдачи студентом выполненной работы:	

ТЕХНИЧЕСКОЕ ЗАДАНИЕ:

Исходные данные к работе	– технические данные реактора ВВЭР-1000; – мощность реактора 100 Вт; – план объекта – ВВЭР-1000; – программный продукт DYNCO.
Перечень подлежащих исследованию, проектированию и разработке вопросов	– анализ основных направлений развития ядерной программы Ганы; – выделение роли компетентного органа по вопросам регулирования безопасности при использовании атомной энергии на основе рекомендаций международных организаций; – расчет интегральных и дифференциальных характеристик, определение критических позиций групп поглощающих стержней;

	– расчет концентрации борной кислоты в реакторе ВВЭР-1000; – формирование требований к безопасному развитию ядерной программы Ганы.
Перечень графического материала	Схема ядерного объекта – обязательный чертеж

Консультанты по разделам выпускной квалификационной работы

Раздел	Консультант
Финансовый менеджмент, ресурсоэффективность и ресурсосбережение	Рахимов Т. Р.
Социальная ответственность	Веригин Д. А.

Названия разделов, которые должны быть написаны на иностранном языке:

Реферат
Введение
Теоретическая часть
Практическая часть
Результаты
Финансовый менеджмент, ресурсоэффективность и ресурсосбережение
Социальная ответственность
Заключение

Дата выдачи задания на выполнение выпускной квалификационной работы по линейному графику	

Задание выдал руководитель:

Должность	ФИО	Ученая степень, звание	Подпись	Дата
Доцент каф. ФЭУ ФТИ	Степанов Б.П.	к.т.н.		

Задание принял к исполнению студент:

Группа	ФИО	Подпись	Дата
0АМ5И	Гбину Джошуа		

ЗАДАНИЕ ДЛЯ РАЗДЕЛА
«ФИНАНСОВЫЙ МЕНЕДЖМЕНТ, РЕСУРСОЭФФЕКТИВНОСТЬ И РЕСУРСОСБЕРЕЖЕНИЕ»

Студенту:

Группа	ФИО
0АМ5И	Гбину Джошуа

Институт	Физико-технический	**Кафедра**	Физико-энергетические установки
Уровень образования	Магистратура	**Направление/специальность**	14.04.02 Ядерные физика и технологии

Исходные данные к разделу «Финансовый менеджмент, ресурсоэффективность и ресурсосбережение»:
– стоимость генерации электроэнергии с использованием тепловых электростанций на разном виде топлива и атомных электростанций; – Формирование бюджета НТИ проекта (основные статьи расходов)
Перечень вопросов, подлежащих исследованию, проектированию и разработке:
– анализ факторов, влияющих на стоимость электроэнергии; – оценка сравнительной ресурсоэффективности атомных электростанций; – проведение SWOT-анализа; – расчет стоимости проведения научного исследования .

Дата выдачи задания для раздела по линейному графику	

Задание выдал консультант:

Должность	ФИО	Ученая степень, звание	Подпись	Дата
Доцент каф. МЕН ИСГТ	Рахимов Т. Р.	к.э.н.		

Задание принял к исполнению студент:

Группа	ФИО	Подпись	Дата
0АМ5И	Гбину Джошуа		

ЗАДАНИЕ ДЛЯ РАЗДЕЛА
«СОЦИАЛЬНАЯ ОТВЕТСТВЕННОСТЬ»

Студенту:

Группа	ФИО
0АМ5И	Джошуа Гбину

Институт	ФТИ	Кафедра	ФЭУ
Уровень образования	Магистратура	**Направление/специальность**	Ядерные физика и технологии

Исходные данные к разделу «Социальная ответственность»:	
1. *Описание рабочего места (рабочей зоны, технологического процесса, механического оборудования) на предмет возникновения:*	• вредных факторов производственной среды: повышенный уровень электромагнитных излучений, ионизирующее излучение; • опасных факторов производственной среды: вероятность возникновения пожара, вероятность поражения электрическим током.
2. *Знакомство и отбор законодательных и нормативных документов по теме*	• требования охраны труда при работе на ПЭВМ; • электробезопасность; • пожаровзрывобезопасность; • радиационная безопасность.
Перечень вопросов, подлежащих исследованию, проектированию и разработке:	
1. *Анализ выявленных вредных факторов проектируемой производственной среды в следующей последовательности:*	• действие фактора на организм человека; • приведение допустимых норм с необходимой размерностью (со ссылкой на соответствующий нормативно-технический документ); • предлагаемые средства защиты • (коллективные и индивидуальные).
2. *Анализ выявленных опасных факторов проектируемой произведённой среды в следующей последовательности*	• электробезопасность (в т.ч. статическое электричество, средства защиты); • пожаровзрывобезопасность (причины, профилактические мероприятия, первичные средства пожаротушения)
3. *Защита в чрезвычайных ситуациях:*	• *перечень возможных ЧС на объекте;* • *выбор наиболее типичной ЧС;* • *разработка превентивных мер по предупреждению ЧС;* • *разработка мер по повышению устойчивости объекта к данной ЧС;* • *разработка действий в результате возникшей ЧС и мер по ликвидации её последствий*
Перечень графического материала:	
При необходимости представить эскизные графические материалы к расчётному заданию	Нет

Дата выдачи задания для раздела по линейному графику	

Задание выдал консультант:

Должность	ФИО	Ученая степень, звание	Подпись	Дата
Ст. преп. каф. ПФ	Веригин Д.А.			

Задание принял к исполнению студент:

Группа	ФИО	Подпись	Дата
0АМ5И	Джошуа Гбину		

Министерство образования и науки Российской Федерации
Федеральное государственное бюджетное образовательное учреждение
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ТОМСКИЙ ПОЛИТЕХНИЧЕСКИЙ УНИВЕРСИТЕТ»**

Институт Физико-технический
Направление подготовки 14.04.02 Ядерные физика и технологии
Уровень образования Магистратура
Кафедра Физико-энергетические установки
Период выполнения (весенний семестр 2016/2017 учебного года)

Форма представления работы:

Магистерская диссертация

КАЛЕНДАРНЫЙ РЕЙТИНГ-ПЛАН
выполнения выпускной квалификационной работы

Срок сдачи студентом выполненной работы:	

Дата контроля	Название раздела (модуля) / вид работы (исследования)	Максимальный балл раздела (модуля)
15.05.2017	*Выдача задания*	
19.05.2017	*Анализ основных направлений развития ядерной программы Ганы*	
22.05.2017	*Выделение роли компетентного органа*	
25.05.2017	*Расчет интегральных и дифференциальных характеристик, определение критических позиций групп поглощающих стержней*	
29.05.2017	*Расчет концентрации борной кислоты в реакторе ВВЭР-1000*	
01.06.2017	*Анализ полученных результатов*	
07.06.2017	*Сдача работы*	

Составил преподаватель:

Должность	ФИО	Ученая степень, звание	Подпись	Дата
Доцент каф. ФЭУ ФТИ	Степанов Б.П.	к.т.н		

СОГЛАСОВАНО:

Зав. кафедрой	ФИО	Ученая степень, звание	Подпись	Дата
ФЭУ ФТИ	Долматов О.Ю.	к.ф.-м.н., доцент		

Summary

This master dissertation consists of 103 pages; 19 figures; 15 tables; 40 references and 3 appendixes.

Key words: Ghana's nuclear program, VVER, nuclear safety, reactivity, physical protection, nuclear materials control and accounting.

The main aim of this work is to develop safety requirements for the construction and operation of nuclear power plants.

The objectives of this project include: conducting an analysis of the main directions for the development of Ghana's nuclear program; highlighting the role of the competent government authority on safety regulation in the use of nuclear energy based on the recommendations of international organizations; formation of requirements for the safe development of the nuclear program of Ghana; analyzing the safety of control and protecting system of VVER-1000 reactor and the use of asymptotic period method to determine the reactivity of the VVER-1000 reactor.

The results of this work are based on the formation of Ghana’s nuclear industry and the requirement of IAEA on installation of nuclear facility. The safety and control system as well as the reactivity of VVER-1000 was analyzed using the DYNCO simulator. The critical position of the tenth group of CPS and critical concentration of Boric acid was then calculated. Based on IAEA requirement for PPS of nuclear facility (IAEA Nuclear Security series No. 13, 2011), a layout was designed for the physical protection of the VVER-1000. A second layout was sketched for NMAC based on IAEA nuclear security series No. 25-G., Use of NMAC for nuclear security.

Level of implantation: fully working on this thesis during 1 semester.

Cost-effectiveness and value: high feasibility, does not require much cost.

Applied areas: this research can be well applied in a variety of areas, such as requirements for installation of nuclear power plant and safety during operation of nuclear reactor. Contributes some new experienced data to the standard data libraries of safety and security of nuclear facilities.

Future plans: apply to requirement and safety and security of a nuclear reactor.

ACRONYMS

PIV - physical inventory verification

PIT – Physical Inventory Taking

MBA – Material Balance Area

NPP – Nuclear Power Plant

FA – Fuel Assembly

NM – Nuclear Material

CPS – Control and Protecting System

NMAC – Nuclear Material Accounting and Control

OECD - Organisation for Economic Co-operation and Development

PPS – Physical Protection System

LCO - Light Cycle Oil

DFP - Distillate Fuel Oil

IPP - Independent Power Producers

ADD - Access display device

WAGP - West African Gas Pipeline

CPPNM - Physical Protection of Nuclear Materials

TID - Tamper-indicating device

ADD - Access display device

KMP - key measurement points

Table of Content

Introduction

The excellent safety and environmentally friendliness of a nuclear power plant as an electric generating facility raised interest for its construction all over the world. Nuclear energy is seen as one of the cleanest source of energy because it produces almost no carbon dioxide, and no sulphur dioxide or nitrogen oxides. The low stored energies, benign reaction products, absence of climate-changing emissions, and automatic termination of power excursions are some of the features that naturally give nuclear power plant a safety advantage over other sources of energy [1]. The numerous advantages of nuclear energy over other sources of electricity does not mean that its safety is assured. Safety and environmental concerns associated with a nuclear power plant are centred on risk of radiation exposure, security of nuclear facility and nuclear waste management. The main safety concern is the release of radioactive material into the environment with the possible radiation exposure to organisms.

For a nuclear facility to meet the levels of safety and requirements necessary for licensing, attention must be paid to a number of challenges to safety associated with hazards that commonly arise. Design during construction to mitigate the likelihood of occurrence of these challenges are essential. And to license the construction and operation of a nuclear facility, a high degree of assurance of the security and safety performance will be required from the applicant, with a robust demonstration that the safety provisions in the design meet the requirements in all foreseeable conditions, normal and abnormal.

Safety and storage of nuclear fuels is an essential factor in Nuclear power plant. Nuclear fuel contains fissile material and, after irradiation, highly radioactive fission and activation products. The most significant design features of fuel handling and storage systems in nuclear power plants are those that provide the necessary assurances that the fuel and core components can be received, handled, stored and retrieved without undue risk to health, safety or the environment. All design features of the fuel handling and storage systems are thus related to the objectives of: maintaining subcriticality of the fuel; ensuring the integrity of the fuel; cooling irradiated fuel; ensuring radiation protection and safety in accordance with the Basic Safety Standards and preventing unacceptable releases of radioactive material to the environment [2]. Recommendations on the design of fuel handling and storage systems for nuclear power plants and how to fulfil the requirements established are outlined in this thesis. Fresh fuel, including mixed oxide fuel may emit significant amounts of radiation if it contains fissionable material recovered by reprocessing. Although such fuel can be handled without cooling, applicable recommendations are included in this thesis on safe handling of those fuels. Recommendations on the design of storage facilities for fresh and spent fuel from nuclear power plant are as well stated. Spent fuel storage facilities provide for the safe storage of spent nuclear fuel after it has been removed from the reactor pool and before it is reprocessed or disposed of as radioactive waste.

In this paper, some of the key challenges to the safety and security of nuclear facilities are reviewed, and the design options to meet these are identified. The Ghanaian nuclear industry and the prerequisites to construct a nuclear power plant is outlined [3]. Also, development of international requirements to ensure the safe handling of nuclear materials are reviewed. International obligations to obtain license and construct a nuclear power plant are discussed as well [4]. The likely expectations of a nuclear regulator are discussed, leading to the implied safety requirements.

Finally, the approaches to nuclear and radiation safety that have evolved over the stages of the nuclear development program are reviewed, with focus on the ongoing evolution for nuclear facilities of the future.

Goal

- Development of safety requirements for the construction and operation of nuclear power plants.

Objectives

- conducting an analysis of the main directions for the development of Ghana's nuclear program;
- highlighting the role of the competent government authority on safety regulation in the use of nuclear energy based on the recommendations of international organizations;
- formation of requirements for the safe development of the nuclear program of Ghana.
- Analyzing the safety of control and protecting system of VVER-1000 reactor.
- To determine the reactivity of VVER-1000 by asymptotic method using the DYNCO simulator.

1 Plans for the implementation of the nuclear program of Ghana

1.1 Brief overview of Ghana

Ghana became an independent nation on 6th March 1957. Ghana practices a multiparty parliamentary democracy, based on the 1992 constitution. The country is located about 750 km above the equator on the west coast of Africa. It lies between latitudes 4 44' and 11 11' north and longitudes 3 15' west and 112' east. Longitude 0 or the Greenwich Meridian passes through the port city of Tema, which is to the east of the country. The total area of the country is about 238,540 km. The 2010 Population and Housing Census estimated the country's population at about 24.66 million. The backbone of the country's economy has been the agricultural sector. Ghana's landscape is drained by a number of rivers and streams. The major rivers are the following: the Black Volta, which has its origin in Burkina Faso and then flows along the north-western boundary of the country with La Cote d'Ivoire, before entering the country at its midsection; the White Volta, which also has its origin in Burkina Faso, then flows into the country at the middle of the northern boundary; and the Oti River, which flows from Togo and enters the country along the northeast of the country. These rivers, flowing from the north, merge at about the middle of the country to form the Volta River. There are other rivers in the west, like the Pra, Ankobra and Tano rivers, with origins in the highlands of the country. Two hydropower plants have been constructed on the Volta River, at Akosombo and Akuse and a third hydropower plant at Bui on the Black Volta. There are also a number of coastal lagoons: Lake Bosomtwi, created by a meteorite, and the huge manmade Volta Lake, created after the construction of the hydroelectric dam at Akosombo.

Ghana's economy growth decelerated sharply to an estimated 4.2% in 2014, down from 7.4% in 2013. Gas supply interruptions from Nigeria, disruptions in power supply, rising inflation, and decline of the Cedi were the key drivers of the slowdown. Compared to regional countries with similar energy and oil & gas investment opportunities, Ghana is well-ranked as an investment location, as a consequence of its long history as a stable democracy and an attractive investment climate. With the commissioning of Bui hydroelectric plant, Ghana's total system installed capacity is 2,837 MW, with electricity reaching about 74% of the population nationwide. However, the firm or dependable capacity would be 2,515 MW. The generation capacity increased in the third quarter of 2014 by another 240 MW after the commissioning of the Kpone thermal power plant, bringing the total installed capacity to 3,077 MW. Expanding Generation capacity, extension of the distribution network, reliability of the power supply, reduction of technical and commercial losses, and access to natural gas feedstocks are areas of focus in the power and energy sectors for the Government of Ghana (GoG) to maintain economic growth. Total energy generation, consumption, and peak demand are increasing in Ghana due to population and technological advancement. The projected Electricity Coincident Peak Demand for the year 2014 was 2,179.5 MW. This represented an increase of 236.6 MW and a growth of 12.2% over the 2013 actual peak which was 1,942.9 MW. The increase occurred as a result of mines, industrial customers, residential and new loads emanating from rural projects. Hydroelectric generation represents about 55% of dependable capacity, with the remaining 45% largely made up of thermal generation. Solar energy contributes less than half percent of total capacity [5]. The Government of Ghana-owned power generation stations are shown in Table 1.1 below.

Table 1.1 - Government of Ghana installed generation capacity

Facility	MW	% Capacity	Type	Fuel Type
Akosombo	1,02(	37.5%	Hydro	Water
Kpong	160	5.9%	Hydro	Water
TAPCO(T1	330	12.1%	thermal	LCO/GAS/DF
TICO(T2)	220	8.1%	Therma	LCO/GAS/DF

Continuation of Table 1.1

T3	132	4.9%	Thermal	LCO/GAS/DFO
MRP	80	2.9%	Thermal	DFO
Siemens Plant	49	1.8%	Thermal	Gas/DFO
Total	1,993	73.3%		

Table 1.2 - Quasi-Independent Power Producers (IPP)

IPPs	MW	%of Total Capacity	Type	Fuel Type
BUI Power	400	14.7%	Hydro	Water
Sunon Asogli	200	7.4%	Thermal	Gas
CENIT	126	4.6%	Thermal	LCO/Gas
Total IPP	726	26%		
TOTAL GHANA	2,719	100%		

Source: [32]

Reliability of energy supply in Ghana is affected by inadequacy of available generation capacities to meet the projected demand under all system conditions. Also, poor planning and untimely schedule of maintenance and retrofit upgrades to power plants affects the reliability of energy. Security of fuel supplies such as natural gas supply from the West African Gas Pipeline (WAGP), Ghana Gas, and adequate stocks of Light Cycle Oil (LCO) and Distillate Fuel Oil (DFO), Potential of the WAGP not being able to meet contractual quantity of gas, Possible delay in the completion of the Ghana Gas Project and Low water level for the hydro power plants are also factors contributing to the unstable energy in the country [5]. This lead to the shedding of minimal power during off peak and peak periods as a result of worsening in power supply. Economic development in Ghana is constrained by inadequate generation capacity which, in turn, is limited by the insufficient supply of natural gas. Estimates by the GoG prepared in 2013, to sustain the country's current rate of economic growth, some 200 MW of additional generation capacity will be required per annum over the next 20 years (an additional 4,000 MW).

Ghana's electricity market has undergone significant restructuring and reforms, including the on-going unbundling of assets and the opportunity for increased private sector participation through IPPs. Tariff rates have increased significantly in the past years, making them more cost reflective. In an effort to keep pace with inflation, currency devaluations (Cedi to the US Dollar), and rising fuel costs, a quarterly adjustment mechanism has been put in place beginning January 1, 2014. There are wide opportunities for private investment in the energy sector in the form of IPPs and under Feed In Tariffs (FITs) for renewable energy projects. The GoG target of 5,000 MW by 2015/16 coupled with the estimated requirement of an additional 4,000 MW of capacity over the next 20 years, will require significant foreign investment, private capital, and technical expertise. The rapid demand for energy over the years necessitate the introduction of nuclear power into Ghana's energy mix as a base load.

1.2 Energy sector of Ghana

Until the discovery of oil and gas in the country, hydropower potential used to be the largest indigenous commercial energy resource. It has been estimated that the country has about 2,500 MW of hydropower potential, about 60 % of which was exploited by the end of 2013. The major exploited hydropower potentials are the 1,020 MW Akosombo Hydropower, 160 MW Kpong Hydropower plants on the Volta River and a third 400 MW Bui Hydropower plant on the Black Volta. Hydropower systems sometimes suffer from low capacity utilization due to perennial droughts. Extreme weather patterns will pose a lot of danger to the development and sustainability of mini and small hydropower facilities, as most of them could dry out completely in the dry seasons. Extreme weather patterns will pose a lot of danger to the development and sustainability of mini and small hydropower facilities, as most of them could dry out completely in the dry seasons [14].

Other extreme weather conditions which affect hydropower generation include observed rise in mean surface temperatures, which has led to increased evaporation of water from the 8,500 sq km surface area of the Volta Lake. This results in the loss of high volumes of water which could have been used for hydro generation. On the other hand, there have been severe rainstorms, especially in the catchment area of the Volta River. These rainstorms lead to excessive water inflows in the Volta Lake, which tend to threaten the safety of the dam. In November 2010, the Volta River Authority was forced to spill water from the dam when the water level in the reservoir reached a height of 277.1 ft (the maximum height is 278 ft).

The development of renewable energy sources like wind, solar and biomass-based electricity generation, which depend so much on weather patterns, could also be threatened by climate change and by extreme weather variability.

The country's domestic energy resources are crude oil, natural gas, hydropower, and other renewable energy sources like wind, solar and traditional biomass.

1.2.1 Electricity policy and decision making process

The main policies that govern the electricity sector are formulated by the Ministry of Energy. The Ministry is also responsible for the monitoring and evaluating of policies, programmes and projects in the electricity sector. The Energy Commission, a quasi-independent body established by the Energy Commission Act 1997 (Act 541), is the government's energy policy advisor and makes national energy policy recommendations to the Minister of Energy. The Commission advises the Minister of Energy on national energy policies for the efficient, economic and safe supply of electricity and natural gas, having due regard for the economy. In addition, the

Commission is to formulate national policies for the development and utilization of indigenous energy resources, in particular renewable energy: solar, wind and biomass.

The planning of the electricity sector system is the responsibility of the Energy Commission. The Commission has been given the mandate to prepare, review and periodically update indicative national energy plans, to ensure that all reasonable demands for energy are met. The Commission has undertaken the Strategic National Energy Plan (2006-2020) and Planning for Sustainable Energy Development – Ghana Country Study (2004-2030) studies, and is currently in the process to Updating the Strategic National Energy Plan. The Energy Commission and the Ghana Grid Company have also undertaken a Generation Master plan Study for Ghana.

Two power system planning studies have taken place in the recent past. The Energy Commission and other stakeholders under the IAEA National TC project GHA/0/008 undertook "Planning for Sustainable Energy Development – Ghana Country Study". The other study, "Generation Master-plan Study for Ghana", was undertaken by Tractebel Engineering on behalf of Energy Commission and GRIDCo Ltd. These two studies were based on Bui Hydropower plant coming online in 2013, the use of natural gas from Nigeria imported through the West African Gas Pipeline, and domestic Jubilee Fields for electricity generation [15]. Actual, proposed and generating master plan for sustainable energy was estimated and shown in fig 1.1 below;

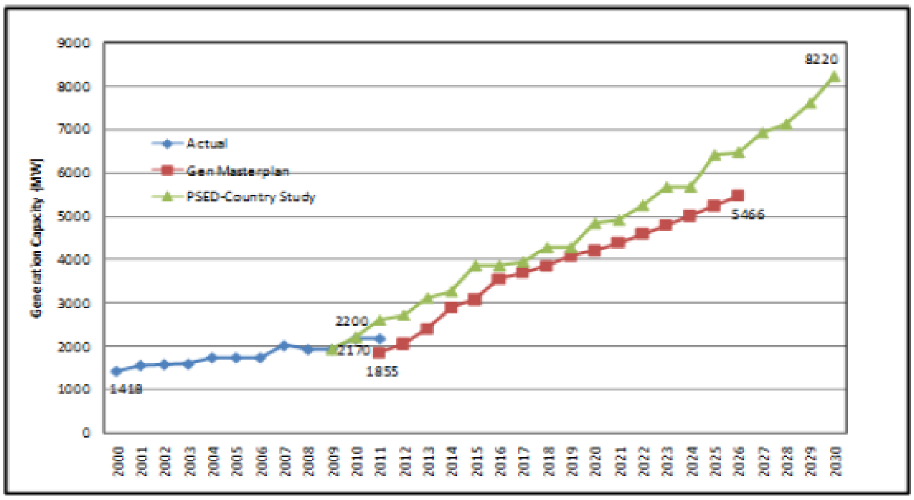

Fig. 1.1 – Actual and Projected Electricity Generation Capacity

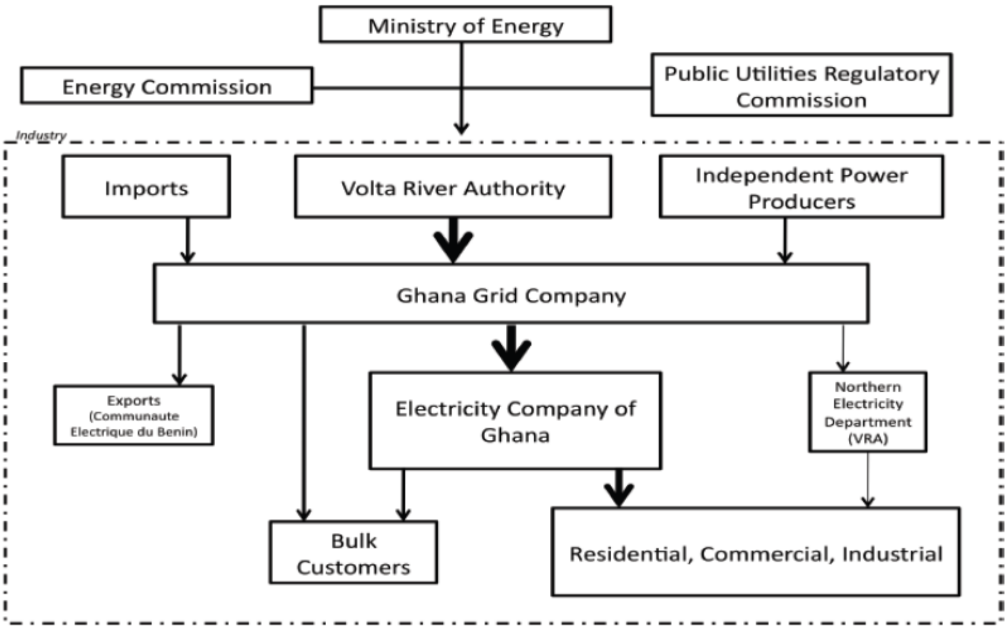

Fig. 1.2 – Structure of Ghana Electricity System

Figure 2.2 shows the hierarchical order of decision making and planning of the energy sector from the ministry of energy till final consumers.

1.3 Current organizational chart

The organizational structure envisaged for the implementation of the country's nuclear power programme and the relationships between the various stakeholders.

ORGANIZATIONS EXPECTED TO BE INVOLVED IN THE VARIOUS TASKS					
Energy Commission, Media, Ghana Institute of Engineers, Ghana Nuclear Association,	Ministry of Education, Ministry of Environment, Science and Technology, Universities, Polytechnics,	Energy Commission, GRIDCo, PURC, Utilities	Attorney General's Department, Legal Section of GAEC,	GAEC, EPA, Energy Commission, Geological Survey Dept, Ministry of Trade & Industry	NDPC, Ministry of Finance and Economic Planning, Energy Commission

Fig. 1.3 Working Groups to undertake various aspects of TCP GHA/0/011

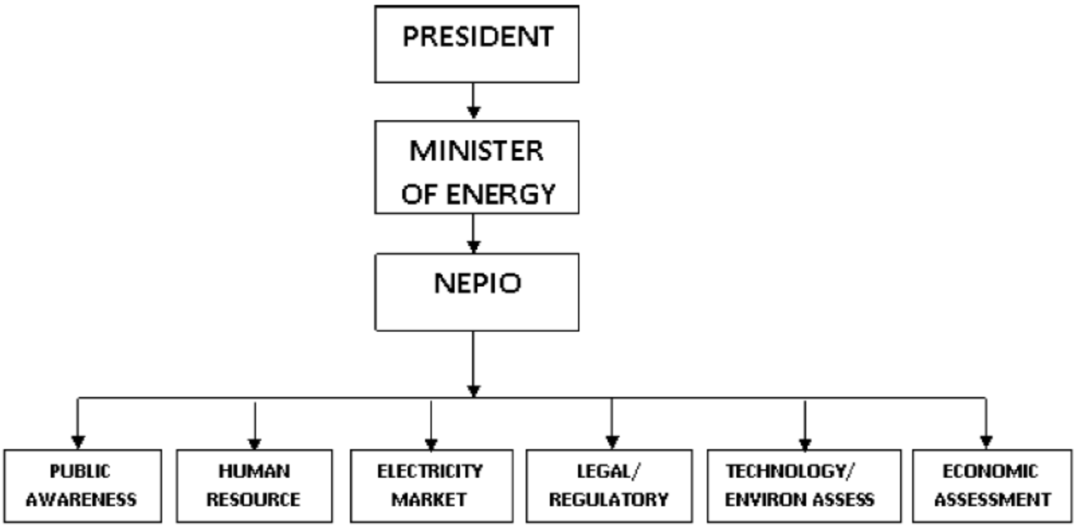

Fig. 1.4 Organizational chart of Ghana

The Ghana Atomic Energy Commission (GAEC) is expected to play a leadership role in the implementation of the country's nuclear power programme. The Commission has established four institutes and a school. And now, the Nuclear Power Institute has been established to initiate and monitor day to day progress of the procedures to obtain a nuclear power plant. The institutes are the Radiation Protection Institute (RPI), Biotechnology and Nuclear Agriculture Research Institute (BNARI), Radiological and Medical Research Institute (RAMSRI) and National Nuclear Research Institute (NNRI). They are intended to research into peaceful and safe applications of nuclear energy, science and technology, and biotechnology, in sectors such as agriculture, energy, environment, geology, health and industry. The Ghana Atomic Energy Commission, acting on behalf of the government, submitted a proposal to the International Atomic Energy Agency for support in undertaking a study to evaluate the role nuclear power will play in the country's future electricity generation.

1.3.1 National Laws and Regulations

The Ghana Atomic Energy Commission and stakeholders, with assistance from the International Atomic Energy Agency, have drafted the Ghana Nuclear Energy Bill, 2009 to pave the way for peaceful uses of nuclear energy in Ghana. The Bill, which has been submitted to the Cabinet for consideration before being laid before Parliament, proposes the establishment of Ghana Nuclear Regulatory Authority. The Ghana Nuclear Energy Bill presented to parliament include the following; Introductory Provisions, The Ghana Nuclear Regulatory Authority, Regulatory Activities, Provisions for Reactors, Transportation of Nuclear Materials, Safeguards and Prohibitions, Provisions on Mining and Processing, Provisions on Nuclear Liability, Inspection and Enforcements, Offences, Penalties and Appeals, General Provisions. The bill was considered by cabinet and approved by parliament.

In 1993, the Provisional National Defence Council Law 308 established a twelve member Radiation Protection Board and issued concurrently a Legislative Instrument LI 1559, which prescribed the mandate and responsibilities of the Board as a licensing and regulatory Authority for the purpose of Radiation Protection and Waste Safety. Hence, to facilitate the mandate of the Board, the Ghana Atomic Energy Commission, in pursuit of Ghana Atomic Energy Commission Act, 2000: Act 588, established the Radiation Protection Institute (RPI) in February 2002. The organizational chart of the Radiation Protection institute is shown below,

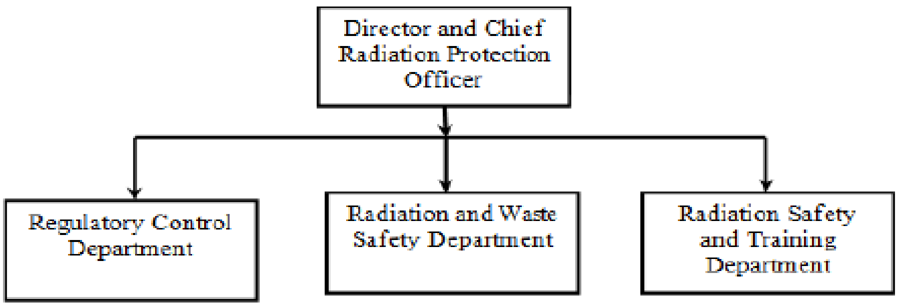

Fig. 1.5 – Structure of Radiation Protection Institute (under the Radiation Protection Board, now Ghana Nuclear Regulatory Authority)

The Radiation Protection Board issues licenses to persons who purchase, manufacture, acquire imports, sell or deal in, store, use, dispose of or export, any kind of irradiating device or radioactive material, or any other source of ionizing radiation. The Ghana Nuclear Power Programme Organization (GNPPO) is an organization mandated with the task of coordinating, overseeing and administering the phase-to-phase implementation of the Nuclear Power Programme in Ghana until the commissioning of Ghana's first nuclear power plant.

Ghana's Power Ministry and ROSATAM have signed an agreement for cooperation in peaceful use of the nuclear energy in the Republic of Ghana. The document of the agreement signed between Russia's ROSATOM and Ghana's Ministry for Energy and Petroleum establishes legal framework for cooperation in the field of peaceful application of atomic energy between the two countries. The two sides plan to jointly develop atomic energy infrastructure, and also, the plan is to construct reactors, including research reactor facilities in the Republic of Ghana. This is a framework agreement. Being signed, the document allows for development of the necessary contractual and legal framework for cooperation in the nuclear area between Russian Federation and Republic of Ghana. Within the agreement, the parties are intended to develop cooperation in design and construction of power and research nuclear reactors; exploration and production of uranium deposits; nuclear fuel cycle services; production of radioisotopes and their application in industry, medicine and agriculture; education, training and retraining of experts for the nuclear energy industry.

1.4 Nuclear power development strategy

The country was awarded a national TCP GHA/0/011: "Evaluating the role of nuclear power in Ghana's future electricity generation mix". The successful implementation of the IAEA TCP GHA/0/011: "Evaluating the role of nuclear power in Ghana's future electricity generation mix" is expected to present the framework for developing the country's nuclear power development strategy. A Nuclear Energy Programme Implementation Organization has been established to manage the activities of seven working groups. The seven working groups will address issues with regards to the following:

1 Siting Grid Infrastructure Assessment

This working group is expected to undertake a series of studies to develop a strategy for the determination of potential sites, evaluation of these sites for characterization, and final determination. It will also assess the national grid and its interconnection with the West African Power Pool, and develop a strategy for nuclear power operation suitable for the national grid or in the context of the West African Power Pool. A preliminary potential site mapping has been undertaken as part of the implementation of IAEA national TCP GHA/0/011: “Evaluating the role of nuclear power in Ghana’s future electricity generation mix”. The working group dealing with siting issues is expected to undertake further assessment of the sites that have been mapped out for characterization, to determine such factors as source of cooling water, transport and grid infrastructure, for the ranking of the nuclear power plant site.

2 Techno-economic Assessment, Financing and Procurement

This working group is expected to review future electricity generation expansion plans to determine the role of nuclear power and undertake a comprehensive techno-economic assessment of these plans. The group is also expected to develop a strategy for funding the nuclear power programme, long-term spent fuel handling and final disposal, waste management and decommissioning of the nuclear power plant. The government is funding all activities related to the implementation of the nuclear power programme. The Techno-economic Assessment, Financing and Procurement working groups are expected to develop a strategy for funding the nuclear power project.

3 Legal and Regulatory Issues

This working group will address all legal and regulatory issues pertaining to the country’s nuclear power programme. A Nuclear Bill has been drafted, which proposed the establishment of a Nuclear Regulatory Authority to be in charge of licensing nuclear power plants and all nuclear related facilities and in charge of undertaking nuclear regulatory activities. The Bill has been submitted to Cabinet, it was approved and the Nuclear Regulatory Authority was established.

4 Technology Assessment

This group is expected to undertake the assessment of specific technologies suitable to be adopted for the country's nuclear power project for electricity supply and for a policy for nuclear fuel acquisition. It is also expected to develop a strategy for management of the various levels of nuclear waste.

5 Human Resource Development

This working group is expected to undertake assessment of human resource requirements at all stages of the nuclear power programme, and to develop a strategy for human resource development.

6 Nuclear Power Project Management

This working group is expected to develop the nuclear power project framework, activities and time scales. It is also expected to develop best strategy or type of contract for securing a nuclear power plant e.g. turnkey, split package or multi packages.

7 Stakeholder Involvement

This working group is expected to develop a comprehensive Communication Strategy for public awareness campaigns and for ensuring the involvement of all stakeholders.

1.4.1 Developing a National Position towards a Nuclear Power Plant

A national position is the outcome of a process that establishes the governmental strategy and commitment to develop, implement and maintain a safe, secure and sustainable nuclear power programme [10]. This process results in a national decision that clearly communicates the Country's national policy, as well as its commitments in accordance with all international obligations, norms and standards.

Conditions required for national position in phase one (1)

In line with the IAEA milestone approach for the development of nuclear infrastructure, a newcomer country can be considered to have satisfied national position requirements when the following are met.

When a long-term commitment and the importance of nuclear safety, security and non-proliferation have been duly recognised. This condition is demonstrated with a clear statement by government of its intent to develop a nuclear power programme with a strong commitment to safety, security and non-proliferation [11].

A nuclear energy programme implementation organisation is established and staffed: with a clear mandate to see to the development of the programme; be recognised by all relevant ministries as having that role; report to a senior minister or directly to the head of government; have the required funding, resources and expertise, and involve all relevant stakeholders, including the country's major utilities, the regulatory body for security and radiation safety, relevant government agencies, decision makers.

A national nuclear energy strategy has been defined. This defines and justifies the national strategy for the role of nuclear power in a country's energy mix. Among others, this may include: an analysis of energy demand and energy alternatives; an evaluation of the impacts of nuclear power on the national economy, e.g. GDP and employment; a preliminary technology assessment to identify technologies that are consistent with national expectations consideration of siting possibilities and grid capacity; consideration of financing options, ownership options and operator responsibilities; consideration of long-term costs and obligations relating to spent fuel, radioactive waste and decommissioning, and considerations of the human resource needs and external support needs of the regulatory body and owner/operator [12].

Status of Ghana in phase 1

1. The Ghana Nuclear Power Programme Organisation, chaired by the Deputy Minister of Power, has been established.

2. Ghana Nuclear Regulatory Authority has been established.

3. The Strategic National Energy Plan (SNEP), prepared by Energy Commission (EC) in 2006. This involved projected total national energy demand up to year 2020. An update of the SNEP is currently in progress.

4. Sustainable Energy Development Plan (SEDP) - Ghana Country Study prepared by GAEC and the EC was completed in 2010. This covered a period of 2004 to 2030. An update of the SEDP is currently in progress.

5. Generation Master Plan Study for Ghana prepared by GRIDCo for 2011/2026.

In January 2017, the IAEA carried out a phase 1 integrated nuclear infrastructure review INIR missions in Ghana. Out of the mission’s analysis, 12 recommendations, 8 suggestions and 3 good practices were captured by the mission. This promises the progress of the nuclear power program of Ghana.

2 Ensuring safety in the operation of nuclear power plants

Safe development of a state's nuclear program involves nuclear safety. The ability to sustain a nuclear chain reaction is essential in a nuclear facility development. This chapter describes the use of control and protecting systems to maintain criticality during operation of a nuclear reactor. The use of asymptotic period method to analyze reactivity was studied. Critical concentration of Boric acid required to sustain criticality of the VVER reactor was as well analyzed in this chapter. All analyses were carried out using the DYNCO simulator.

The value of effective multiplication factor allows to estimate with what intensity the processes of increase and decrease of power occur in the reactor. The time-dependent behavior of a reactor is very sensitive to small deviations of the multiplication about one. Reactivity is a ratio of the values of excessive multiplication factor to the effective one.

$$\rho = \frac{k-1}{k} \qquad 2.1$$

The greater the reactivity by the module, positive or negative, the higher the rate of decrease or increase of power, respectively. In order to provide a possibility to increase reactor power, compensate for neutron absorption by fission products and to operate for a long time, a reactor must have excess reactivity ($\rho > 0$). Reactivity margin of a reactor is its maximum value which can be released in the present state of the reactor with the full extraction of reactivity control elements from the core. When all control elements are completely immersed in the reactor, its reactivity must have a negative value sufficient to bring the reactor to a subcritical state from any state. In nuclear reactors, control of a chain reaction is usually carried out by injecting materials absorbing neutrons into the reactor core. Rods of neutron-absorbing material are installed in nuclear reactors to provide precise, adjustable control of reactivity. In exception of control rod, other factors affect reactivity, such as change of coolant density, temperature, etc. Knowledge and consideration of these phenomena are important aspects of safety in the design and operation of nuclear reactors.

2.1 Description of the DYNCO Simulator

The software SSL DYNCO LAB SYSTEM is used to research the neutron-physical and thermo-hydraulic features of the reactor facilities. The simulator is oriented to carry out practical training in the frames of educational programs of universities in the field of reactor physics and nuclear technology of NPP. The Complex promotes students' knowledge in the field of reactor physics and provides a deeper understanding of the processes occurring in the reactor and the factors influencing the dynamics of the reactor facility.

SSL DYNCO LAB SYSTEM allows to maximize the simulation processes in the core and calculate them with high accuracy while providing real-time simulation on PC. Change of the neutron cross sections follows CPS rod position. Calculating the neutron cross sections it should be checked if CPS is available in this FA layer.

Library of the neutron cross-sections comprises two sets of the constants, for CPS rods inside the assembly and outside it. In the case of the differential characteristics evaluation with a middle position of CPS rod in the computational cell a special method of interpolation is used. The model of the reactor core calculates 3D distribution of the residual energy emission that is added to the neutron power. To run the reactor core model in SSL DYNCO LAB SYSTEM the group library of macro cross-sections is pre-computed by using the transport program.

The library of the constants for different temperatures from cold to hot core and different fuel burnup, from the beginning to the end of the campaign is computed for all types of assemblies. Computed library of the constants for every type of reactor in the mode of steady re-loadings is included into delivery. For precise definition of macro cross-sections, which are within the previously computed cross-sections range, a special interpolation block of DYNCO code is used. It allows to describe with the required accuracy the various states of the core [39].

2.2 Determination of the Critical Position of the Group of Absorbing Rods Using the DYNCO Simulator

Control rods are an important safety system of nuclear reactors. Their prompt action and prompt response of the reactor is indispensable. Control rods are used for maintaining the desired state of fission reactions within a nuclear reactor, i.e. subcritical state, critical state, power changes. They constitute a key component of an emergency shutdown system. Control rods are rods, plates, or tubes containing a neutron absorbing materials with high absorption cross-section for thermal neutron such as boron, hafnium, cadmium, samarium, xenon etc., used to control the power of a nuclear reactor. By absorbing neutrons, a control rod prevents the neutrons from causing further fissions.

Control rods usually constitute cluster control rod assemblies (PWR) and are inserted into guide thimbles within a nuclear fuel assembly. The absorbing material such as pellets of Boron Carbide is protected by the cladding usually made of stainless steel. They are grouped into groups and the movement occurs usually by the groups. Typical total number of clusters is 70. This number is limited especially by number of penetrations of the reactor pressure vessel head.

In PWRs they are inserted from above, with the control rod drive mechanisms being mounted on the reactor pressure vessel head. Due to the necessity of a steam dryer above the core of a boiling water reactor, this design requires insertion of the control rods from underneath the core. Control Rods are used during reactor start-up, Control of the reactor and power manoeuvring, Axial offset control, Reactor shutdown and Emergency shutdown.

A thermal power of the reactor is determined by a number of fission reactions per time unit and by remaining decay heat (~tens of MW). During the normal operation of the reactor, the thermal power from fission dominates. The number of fission reactions is determined by the neutron flux in the reactor. A position of control rods directly affects a criticality of the reactor. When the reactor is critical, control rods are on a critical position, the power of the reactor and the neutron flux is stable at a given power level. When the reactor is subcritical, control rods are below a critical position, the power of the reactor and the neutron flux is exponentially decreasing. When the reactor is supercritical control rods are above a critical position, the power of the reactor and the neutron flux is exponentially increasing. It should be noted this behaviour describes "zero power criticality" i.e. a reactor without reactivity feedbacks, 10E-8% – 1% of rated power.

The method of the inverse multiplication is based on suggestion that reactivity of the subcritical reactor with a neutron source is inversely proportional to the detector count rate located in or near the reactor. Assuming that the detector counting rate is proportional to the reactor power, it may be written the following:

$$W = -\frac{Ql}{\rho} \qquad 2.2$$

Where; W – Power of reactor, Q – power of neutron source, *l* - time of neutrons generation and ρ – reactivity of reactor.

Such simplest relationship is realized at reactivity changes when:

- No changes of efficiency of the detector;

- No changes of effective power of the neutron source;

- The proportion of neutrons from the source, recorded by the detector, is small compared with the proportion of neutrons from fission.

The last item determines the type of the inverse multiplication curve, concave or convex. For safe use the inverse multiplication curve should be of a concave or a linear form.

In this analysis method of the inverse multiplication was applied to the task of monitoring the reactivity of the subcritical reactor with a source at the withdrawal of the control rods to achieve the critical state. The effective neutron multiplication factor is changed from the initial (unknown) value to $0 \leq k_{eff} < 1$ to 1. With withdrawing of a selected group of rods from the core, the neutron flux and, consequently, the reactor power increases. Therefore, in the withdrawing process of the control rods to construct dependence of the inverse multiplication $OY = \frac{W_o}{W_h}$, it is possible to predict the reactivity of the reactor in relative units.

Simulation Procedure

1. The initial reactor power was equal W_0 (100 Watts). Thus, $OУ_0 = W_0/Wi = 100/100 = 1$. The value $OУ_0 = 1$ was denoted on the graph by the position of the 10th group of control and protection rods, with which the reactor was displayed in a critical condition.

2. The 10th group of the control rods were selected in the input parameter tab: GPS 15(gr. 10(1)) GPS 16(gr. 10(2)), 19 GPS 30(gr. 10(3)), GSP 32(gr. 10(4)), 46 GPS(gr. 10(5)) of GPS and 47(gr. 10(6)) and on a speed button 2 was selected throughout the experiment and then clicked "OK".

3. The group of control rods were change from its original position (0 cm) at 50 pressed the button "apply to all" and "OK".

4. In the main window "Dynamic mode" the button "Start calculation" was clicked and the program begun to simulate the process of power change due to the rise of control rods.

After the completion of the transition process (in about 2 min) the capacity the capacity reached its stationary value. The "Pause" or stop button was clicked to stop the simulation and the steady-state values of reactor power (Wi) and the time of its establishment after the start of the transition process was recorded.

5. The calculated value OY = W0/Wi was entered in the table and plotted on the graph by the position of the 10th group of CPS. Through these two points draw and extrapolate it to the intersection with the abscissa axis. This is the first extrapolated value of the critical situation of the group of rods (Hext).

6. According to the rules of the nuclear safety importance of the next step of lifting the rod should not exceed ¼ of the distance to extrapolated value, so the calculation of the next step for OP was done by the formula:

$$h_{i+1} = h_i + 0.25\,(H_{extr\,i} - h_i) \tag{2.3}$$

$$\Delta \mathrm{H} \approx 0.25(\mathrm{Hext} - \mathrm{Hi}) \tag{2.4}$$

$$H_{extr\,i} = \frac{H_{i-1} * IM - H_i * IM_{i-1}}{IM_i - IM_{i-1}} \tag{2.5}$$

Where; h_i – Previous height of CPS system, h_{i+1} - Current height to be determined, $H_{extr\,i}$ – extrapolated height

7. Steps 3-6 were repeated with each recording and calculating the H_{extr} and the H_i until OY reached a value less than 0.005. The results obtained are shown in table A in the Appendix.

The change in the thermal power of reactor with variation of CPS height is shown in figure 2.1 below. Fig 2.2 below shows the graph of inverse multiplication against rod position.

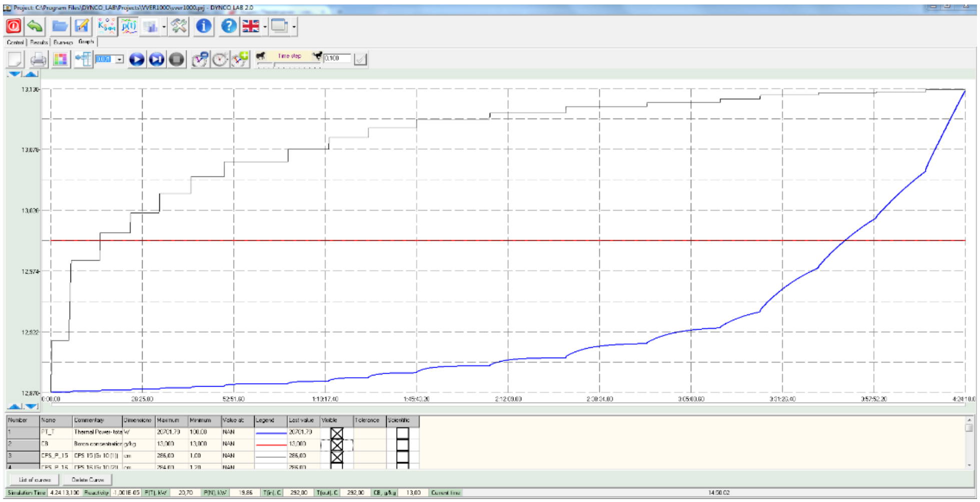

Figure 2.1 Change of reactor power with variation of CPS position

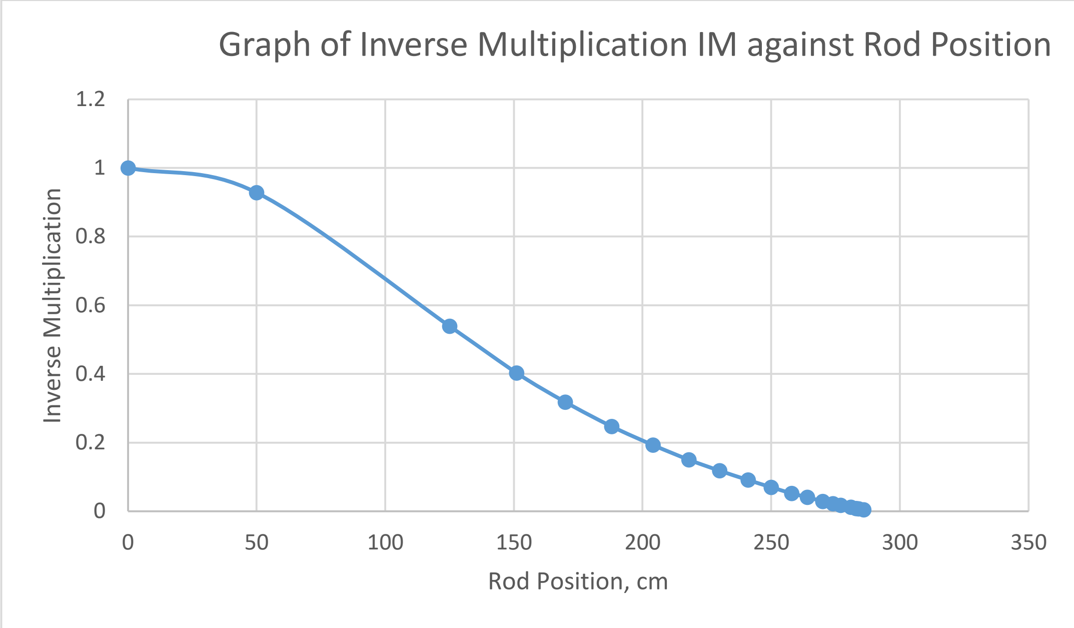

Fig 2.2 Graph of inverse multiplication against rod position

The following observation and deductions where made from the results of the experiment, the changes of the locations (positions) of the group (10) of control rod resulted in the increase of the set power hence results in decrease in the inverse multiplication. The increase in power occurred within 3mins after which it becomes stable and hence the inverse multiplication calculated. The preceding heights of the group of control rods were calculated with the formula 2.1, 2.2 and 2.3. The results are found in table of values in Appendix A.

2.3 Analysing the Critical Concentration of Boric Acid in VVER-1000

Isotope ^{10}B has many applications. Its (n, alpha) reaction cross-section for thermal neutrons is about 3840 barns (for 0.025 eV neutron) and therefore it is very good neutron absorber. In nuclear power mostly natural boron is used, but it is not an exception the use of enriched boron (by the isotope ^{10}B). Boron as the neutron absorber has following applications:

- Chemical shim; by chemical shim, we mean that boric acid is dissolved in the coolant/moderator. Chemical shim is used to long term reactivity control.
- Control rods; many control rods use isotope ^{10}B as a neutron absorbing material.
- Safety systems; the one of three primary objectives of nuclear reactor safety systems is to shut down the reactor and maintain it in a shutdown condition. Therefore, all safety systems which must ensure sub criticality of the reactor after the transient use high concentrations of boric acid.
- Burnable absorbers; Isotope ^{10}B is widely used as the integral burnable absorber. When compared to gadolinium absorber, another commonly used burnable material, ^{10}B has an order of magnitude smaller cross-sections. Therefore, ^{10}B compensate reactivity longer, but not so heavily.
- Converter in neutron detectors; Neutrons are not directly ionizing and they have usually to be converted into charged particles before they can be detected. Most common isotope for the neutron converter material is ^{10}B.

Most of (n, alpha) reactions of thermal neutrons are ^{10}B (n, alpha) ^{7}Li reactions accompanied by 0.48 MeV gamma emission. Boric acid is dissolved in the coolant or moderator. Boric acid (H_3BO_3), is a white powder that is soluble in water. In pressurized water reactors, chemical shim (boric acid) is used to compensate an excess of reactivity of reactor core along the fuel burnup, long term reactivity control. At the beginning of specific fuel cycle concentration of boric acid is highest. At the end of this cycle concentration of boric acid is almost zero and a reactor must be refuelled.

In certain cases, also fine power changes can be controlled by chemical shim. If it is desired to increase power, then the boric acid concentration must be diluted, removing ^{10}B from the reactor core and decreasing its poisoning effect. When compared with burnable absorbers, long term reactivity control or with control rods rapid reactivity control the boric acid avoids the unevenness of neutron-flux density in the reactor core, because it is dissolved homogeneously in the coolant in entire reactor core. On the other hand, high concentrations of boric acid may lead to positive moderator temperature coefficient and that is undesirable. In this case, more burnable absorbers must be used. Moreover, this method is slow in controlling reactivity. Normally, it takes several minutes to change the concentration (dilute or borate) of the boric acid in the primary loop. For rapid changes of reactivity control rods must be used.

The following steps outline the simulation procedure:

1. The initial reactor power was equal W_0 (100 Watts). Thus, $OУ_0 = W_0/Wi$ = 100/100 = 1. The value $OУ_0 = 1$ was denoted on the graph with which the reactor was displayed in a critical condition.

2. The boric acid concentration was decreased by 0.1 g/kg with operational speed of 0.001 g/kg·sec (at this point set the simulation step of 1 sec). After the transition process is completed, the value was recorded in the log and the new value of the established power W1.

3. Extrapolated critical concentration of boric acid was obtained analytically. With this, equation of a straight line passing through two points and find the point of intersection with the abscissa axis. All data on reactor state and boric absorber concentration are registered in the log.

4. The next values of the boric absorber concentration were calculated by the formula:

$$C_{i+1} = C_i - 0.25 * (C_i - C_{extri}) \qquad (2.5)$$

$$C_{extr\ i} = \frac{C_{i-1} * IM - C_i * IM_{i-1}}{IM_i - IM_{i-1}} \qquad (2.6)$$

Where, C_{i+1} – Current concentration of Boric acid, C_i – Previous concentration $C_{extr\ i}$ – Extrapolated concentration.

The whole procedure is repeated until there was indications that the critical concentration was reached. The inverse multiplication was always calculated in relation to "zero" power of the reactor, and the extrapolation was performed between two adjacent points. Concentration of boric acid was determined with accuracy up to the third decimal.

5. The actual shape of the inverse multiplication curve depends on many factors. In principle, it can have both concave and convex form. The latter, however, is highly undesirable, rather, is prohibited, as an extrapolation underestimates the critical state, what is very dangerous.

6. In the simulation mode "Static calculation" perform calculation k_{eff} for C_{init} and C_{crit} and register in the log. According to these values to calculate the change in reactivity with change of boric acid concentration from C_{init} to C_{crit}.

From the results obtained, and the graph of IM against concentration of Boric acid, it was realised that the decrease in the concentrations of boric acid resulted in the increase of the set power hence results in decrease in the inverse multiplication. The increase in power occurred in each within 3mins after which the power becomes stable and hence the inverse multiplication calculated. The preceding concentrations were calculated with the formula 2.5 and 2.6. The results are recorded in table A.2 and shown in the Appendix. Figure 2.3 below shows the variation of inverse multiplication against the concentration of Boric acid. The critical concentration was reached at point where the graph cuts the x-axis.

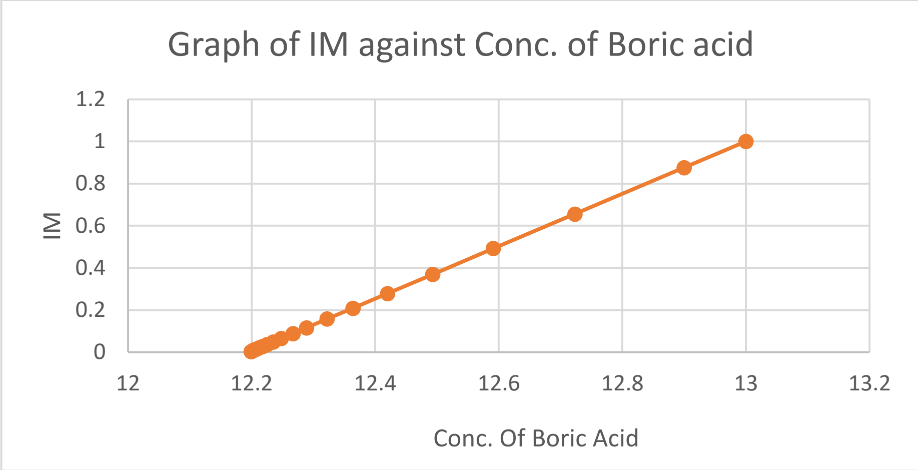

Fig 2.3 Graph of inverse multiplication against Concentration of Boric Acid.

2.4 Construction of Relative Integral and Differential Characteristics of Absorbing Rods Group

Relative Integral Characteristics

Graduation is a measurement of the effectiveness of the regulator, depending on its position, i.e. definition (in absolute or relative units) changes in reactivity when moving the rod per unit length or changes in the total reactivity as a function of the rod position in the core. The effect of an individual control rod and groups of such rods on reactivity can be determined in two ways: the integral and differential rod worth. The integral rod worth is the total reactivity change due to movement of the control rod to the reactor core. But, the differential rod worth is the reactivity change per unit movement of the control rod into the core. Depending on the conditions and requirements the different ways may be used for graduating: over the period of runaway, the method of compensation, in the subcritical state, the jump in power, etc. An integral characteristic is a graphical dependence of the total reactivity of the submerged part of the absorber on its position of the core height. It is convenient to construct an integrated characteristic in relative units normalized to the overall efficiency of the rod. Integral characteristics is used in the calculation of the critical position of control rods to determine the reactivity margin, evaluation of reactivity changes when moving the rod, determine the level of sub criticality of the reactor, the construction of differential characteristics, etc. In this laboratory task method of graduation in the subcritical reactor based on the inverse multiplication is applied. In view of the fact that this method is time consuming to complete the transition process for moving the rods, laboratory work is done in simulation mode "Static".

The method of the inverse multiplication is based on suggestion that reactivity of the subcritical reactor with a neutron source is inversely proportional to the detector count rate located in or near the reactor.

An integral characteristic is a graphical dependence of the total reactivity of the submerged part of the absorber on its position of the core height.

$$\rho(h) = \int_0^H \frac{d\rho}{dh} dh \tag{2.7}$$

Assuming that the detector counting rate is proportional to the reactor power, it may be written the following:

$$W \approx -\frac{Ql}{\rho} \tag{2.8}$$

where: W – power of reactor; Q – power of the neutron source*;* l – time of the neutrons generation*;* ρ – reactivity of reactor

Change in reactivity corresponding to displacement of the rod (with respect to the initial value) may be written as:

$$\Delta\rho_i = \rho_i - \rho_o = \frac{Ql(W_0 - W_i)}{W_0 W_i} \tag{2.9}$$

At step by step withdrawing of the calibrated rod set of values and Δhi with an accuracy up to an unknown constant . This allows to construct dependence of the relative efficiency of the absorber normalized to the overall efficiency on its position in the core as;

$$\rho_i(h) = \frac{W_{100}(W_0 - W_i)}{W_i(W_0 - W_{100})} \tag{2.10}$$

The steps below shows the simulation procedure;

1. When launching the variant of task, the “zero” state of reactor is being loaded. The reactor is at very small power level which was caused by the neutron source. In this state feedbacks can be ignored. It is necessary to pass into mode "Static calculation".

2. During the performance power of the reactor does not change. Changing the position of the rods leads to a change of variable “External Source”. Initial value of “External Source” is (Ql). Graduated rods (or group) is removed from the core with the step specified in the exemplary form of the laboratory log. After each step a static calculation is performed and the values (Ql)i are recorded.

3. After filling the table the values of (ρi (h)) are calculated and plotted.

From the results and the graph below, it was observed that the reactivity increases with increase in the withdrawal of the control rod.

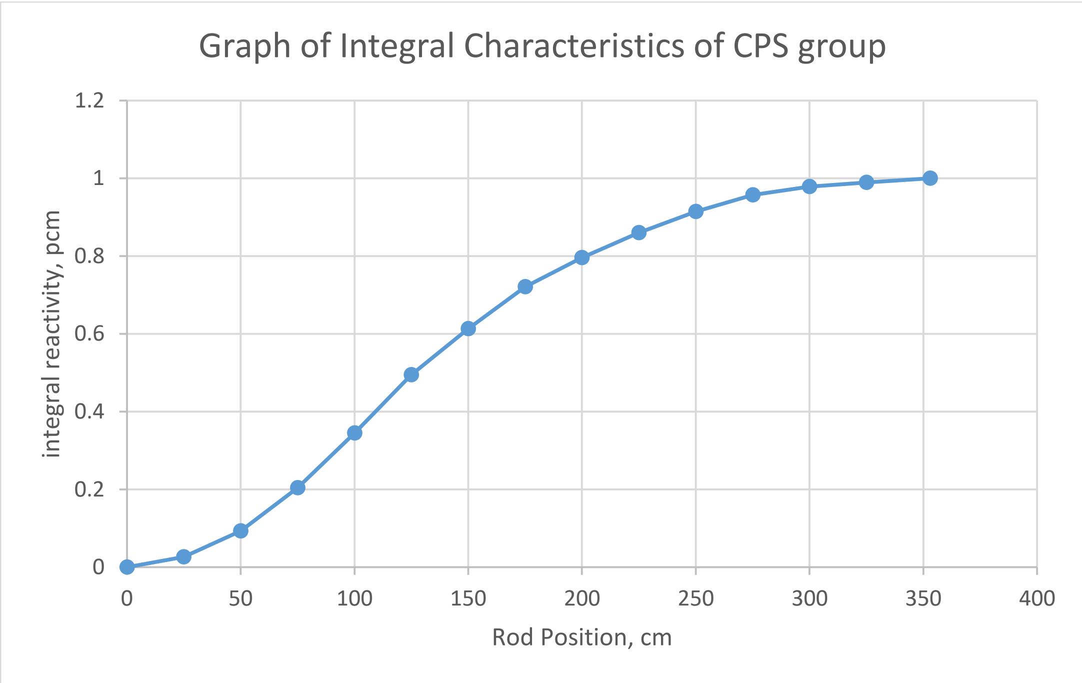

Fig 2.4 showing the graph of integral reactivity against rod position.

Differential Characteristics of Absorbing rod Group

Differential characteristic is a graphical dependence of effectiveness of the absorber 1 mm displacement on the rod position along the core height.

$$f(h) = \frac{d\rho}{dh} = \frac{\Delta\rho}{\Delta h} \tag{2.11}$$

In the process of constructing a differential curve for each position of the rod a pair of values is calculated.

$$f_i = \frac{(\rho_{i+1} - \rho_i)}{(h_{i+1} - h_i)} \tag{2.12}$$

Position of control rods is calculated as

$$Z_i = \frac{(h_i + h_{i+1})}{2} \tag{2.13}$$

Graph 2.5 below shows the variation of differential reactivity against rod position.

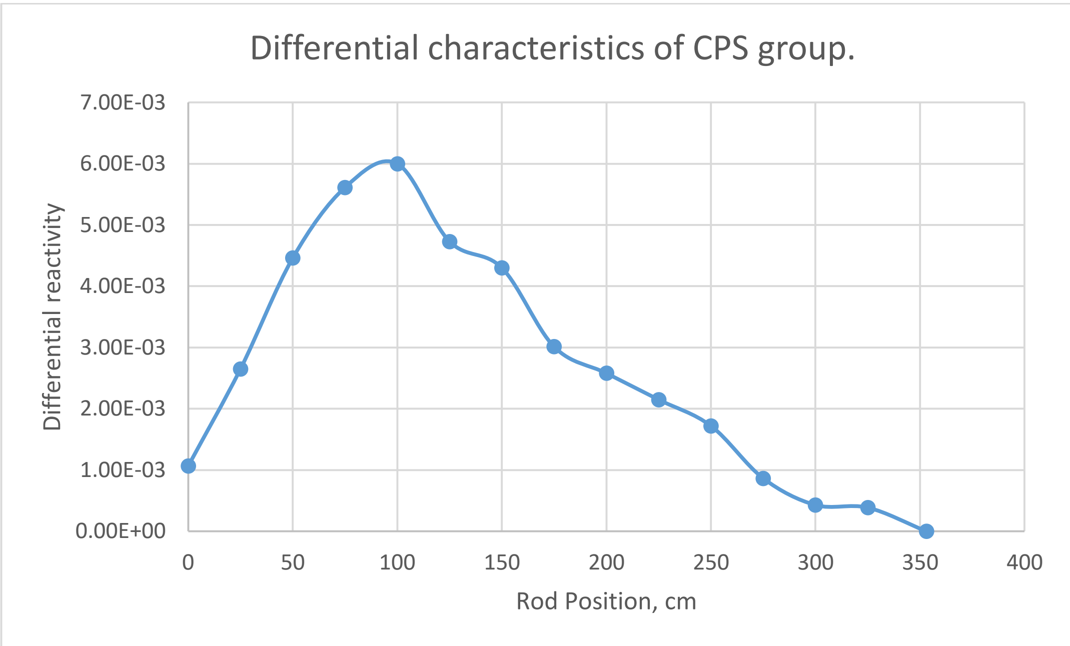

Fig 2.5 showing the graph of differential reactivity against rod position

2.5 Measurement of Reactivity by the Asymptotic Period Method

Practical application of the asymptotic period method of reactivity measurement was conducted on the VVER reactor using DYNCO-Lab simulator. The studies were carried out at “zero” state of reactor. The boric acid concentration was decreased up to a value with operational speed of 0.001 g/kg·sec. Transient changes in reactor power at time intervals of 10s was then observed and recorded. A graph of ln(t) against time was then constructed and the period of reactor determined from the slope. Below is the procedure of the analysis;

i. The DYNCO-Lab simulator was launched with the variant of task and the "zero" state of reactor is being loaded. The calculations were performed relative to this "zero" state. As the rule reactor is at very small power level caused by the neutron source.

ii. The boric acid concentration was decreased up to value (C_{crit} + ΔC)g/kg with operational speed of 0.001 g/kg·sec (at this point simulation step was set at 1 sec). The critical concentration of boron absorber C_{crit} was previously defined in the task VVER-02 up to the third decimal place. The recommended value is ΔC = 0.020 g/kg. After the transition process was completed, values of $C_{subcritic}$ and the established power $W_{subcrit}$ were recorded.

iii. After measurement of $W_{subcrit}$ with operational speed of 0.001 g/kg·sec decrease the boric acid concentration up to value (C_{crit} - ΔC) g/kg. Wait until the end of the transition process and the stabilization of power due to feedback. Record in the log the values of , C_{crit}, $C_{supercrit}$ and power W_{crit} .

iv. By the dependence of W(t) with interval Δt = 10s, power was determined and recorded.

v. Construct a semi-logarithmic dependence and determine the period of the reactor by this dependence. In the case of the asymptotic period equation, the equation is of a straight line, where 1/T is the tangent of the slope to the time axis.

Solution of reactor kinetics equation at Keff>1 may be represented as the sum of seven exponentials, with six exponentials have negative indexes, and one a positive:

$$n(t) = \sum_{j=0}^{6} A_j \bullet e^{wjt} \quad (2.14)$$

So some time later after introducing reactivity in the critical reactor, increase in reactor power may be described by a single exponential with index

$$w_o = \frac{1}{T} \tag{2.15}$$

Where T – reactor period, i.e. the time during which the reactor power changed by e = 2.7 times.

The reactivity of the reactor and the period are interconnected by the inverse hours formula

$$\rho = \frac{l}{T} + \sum_{i=1}^{6} \frac{\beta_{ieff}}{1+\lambda_i \cdot T} \approx \sum_{i=1}^{6} \frac{\beta_{ieff}}{1+\lambda_i \cdot T} \tag{2.16}$$

Where

l - time of the neutrons generation, *sec*;

β_{ieff} - effective part of the delayed neutrons of *i-th* group;

λ_i - decay constant of nuclear precursors of delayed neutrons of *i-th* group, *sec-1*;

T – Reactor period, sec

The first term on the right side may be ignored because its contribution is less than 1% at T > 10 sec.

Thus, with the known parameters of delayed neutrons the problem of determining the reactivity is reduced to measuring the asymptotic period of reactor. Graph 2.6 below showing a plot of In y(t) against time.

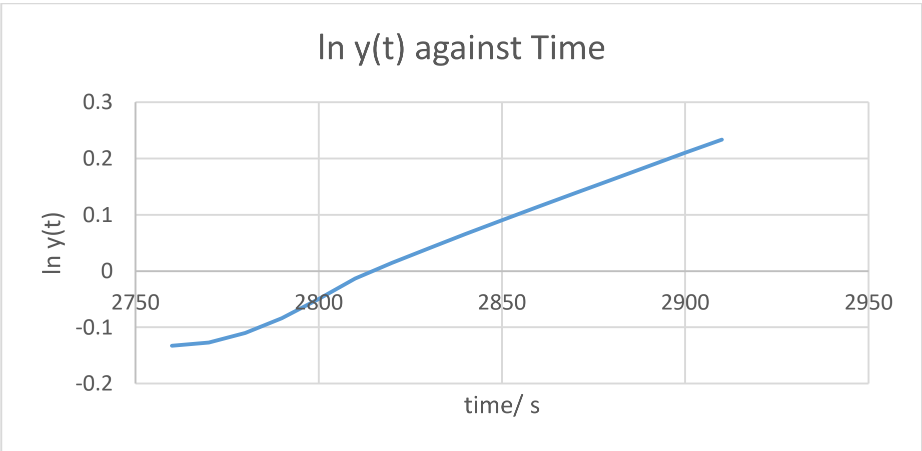

Fig 2.6 Graph of In y(t) and time/s

2.6 International Obligations for Licencing Nuclear Installations

Regulatory body need to access requirements for applicant for a nuclear installation before granting licence. The regulatory body should review, assess and inspect the information on the nuclear installation provided by the applicant or licensee, in particular, documents that form part of the preliminary safety analysis report.

Safety analyses of anticipated operational occurrences and postulated initiating events, which may be caused by external hazards, internal hazards and internal events. External hazards include tsunamis, flooding, seismic events, volcanic eruptions, aircraft crashes, tornadoes, cyclones, hurricanes, external fires, explosions of gases or liquids. Internal hazards consist of fire, spillages of corrosive material, internal flooding and that of internal events are mechanical failures, electrical failures and human error.

Description, identification, categorization and classification of structures, systems and components important to safety. Operational limits and conditions, and permitted operational states must be defined by the regulatory body. A list of barriers with their relative contributions to confinement of radioactive material and related limits, that is means by which defence in depth are met should be made known and clear by the regulatory authority. Analytical methods and computer codes used in the safety analyses and the verification and validation of such codes is to be made known to the applicant. Radioactive discharges and radioactive releases into the environment, and radiation exposure of workers and the public during normal operation and under accident conditions must be monitored and the necessary action taken by the regulatory authority when the need arises. The regulatory body is responsible for verification and validation of the safety analyses and evidence of their robustness that is sensitivity studies, research, testing, operating experience in nuclear installations.

The applicant or licensee has the following obligations:

The applicant or licensee should prepare and submit a comprehensive application to the regulatory body that demonstrates that priority is given to safety; that is, that the level of safety is as high as reasonably achievable and that safety will be maintained at the site for the entire lifetime of the nuclear installation. The applicant or licensee must meet its responsibility for safety at the nuclear installation until the installation is released from regulatory control by the regulatory body. The applicant or licensee should have the capability within its own organization (either on-site or within the organization as a whole) to understand the design basis and safety analyses for the nuclear installation, and the limits and conditions under which it must be operated. The applicant or licensee should exercise control over the work of contractors, understand the safety significance of this work and take responsibility for its implementation [31].

Also the applicant or licensee should submit a procedure or description to the regulatory body of the process for dealing with modifications, which may be subject to approval by the regulatory body, depending on national legislation, regulations and practices. Alternatively, requirements dealing with modifications may be established directly in the regulations, and the regulatory body may then carry out inspections to verify that the licensee meets such requirements. The applicant or licensee should have a design capability and a formal and effective external relationship with the original design organization or an acceptable alternative. The applicant or licensee should assess safety in a systematic manner and on a regular basis. The applicant or licensee should ensure physical protection and security at the nuclear installation.

Furthermore, the applicant or licensee should demonstrate in its application for a licence that it has and will continue to maintain: Adequate financial resources that is depending on national legislation and regulation, for regulatory fees and liability insurance, and for funding of the construction, operation and decommissioning stages and of maintenance. Adequate human resources to safely construct, maintain, operate and decommission the nuclear installation, and to ensure that regulatory requirements and safety standards are met and will continue to be met.

4 Financial management, resource efficiency and resource conservation

4.1 Financial Management

Financial Management refers to planning, organizing, directing and controlling the financial activities such as procurement and utilization of funds of an organization. It is the application of general management principles to financial resources of an organization. Scholars in the field of financial management have different definitions of financial management;

S.C. Kuchal says "Financial Management deals with procurement of funds and their effective utilization in the business".

Howard and Upton: Financial management "as an application of general managerial principles to the area of financial decision-making.

Weston and Brigham: Financial management "is an area of financial decision-making, harmonizing individual motives and enterprise goals".

Joshep and Massie: Financial management "is the operational activity of a business that is responsible for obtaining and effectively utilizing the funds necessary for efficient operations.

Financial Management is simply concerned with the effective funds management in the business.

Nuclear power plants play an important role in providing secure, economic and low-carbon electricity supplies in many countries. There is increasing recognition that an expansion of nuclear power could play a valuable role in reducing future carbon dioxide emissions. Organisation for Economic Co-operation and Development (OECD) studies comparing the costs of electricity generation from different sources indicate that nuclear power is competitive on a levelised cost per kWh basis (particularly when the costs of carbon-dioxide emissions are taken into account). Volatility in fossil fuel prices has also increased the attractiveness of nuclear energy's more stable generating costs [34].

Despite the numerous advantages of nuclear power plants, NPPs are more capital-intensive than other large-scale power generation plants, because they are more complex and take longer to construct. Once in operation, the higher capital costs are offset by lower and more stable fuel costs, but the need to finance high up-front construction costs presents a challenge to those wishing to invest in new nuclear capacity, particularly in areas with competitive electricity markets. An approximate breakdown of levelised electricity generating costs for nuclear, coal and natural gas fired generating plants is shown in table 4.1 and table 4.2 below.

Table 4.1 - 5% discount rate (%)

	Nuclear	Coal	Natural Gas
Investment costs	50	35	14
O and M costs	30	20	9
Fuel cost	20	45	77

Table 4.2 - 10% discount rate (%)

	Nuclear	Coal	Natural Gas
Investment costs	70	50	20
O and M costs	20	15	7
Fuel cost	10	35	73

Source: [33]

The higher capital costs of an NPP mean that its overall economics are more dependent on the cost of capital, or discount rate, which applies to the investment in its construction. Since there is always a link between risk and return, the cost of capital depends on potential investors' assessment of the risk factors involved. This will vary depending on who the investors are, the legal and regulatory framework in which the plant would be built, as well as national energy policy and the political background.

4.2 Resource Efficiency and Conservation

The reliability of a country's electric grid depends on nuclear energy. The loss of nuclear energy plants would have major impacts on electricity prices, grid reliability and access to dependable energy. Nuclear power is the most efficient and reliable source of large-scale and constant electricity. Nuclear energy plants maintain a national average reliability between 85 and 90 percent, with many power plants routinely operating at 93 to 95 percent capacity over extended periods. No other electricity generating plant can be compared to the level of reliability provided by nuclear power plant, which brings tremendous benefits to consumers and businesses. Nuclear energy's closest competitors in this regard are clean energy sources geothermal and biomass, extremely small producers of electricity that operated at 67 percent capacity in 2012. High reliability and dependability mean that electricity is available on the grid whenever needed, all the time. This is particularly important during periods of extreme heat or cold [34].

Nuclear energy remains the world leader in reliable, dependable electricity production in part because nuclear plants require refuelling only every 18-24 months. They are not subject to interruptions in fuel supplies caused by weather, transportation or curtailments. Another prove of efficiency and resource conservation of a nuclear power plant is the energy generated by a pellet of uranium fuel. That is the reliability of the energy-intensive nature of uranium fuel. A single uranium pellet, slightly larger than a pencil eraser, contains the same energy as a ton of coal, three barrels of oil or 17,000 cubic feet of natural gas. Each uranium fuel pellet provides heat for up to five years to make steam for power generation, making uranium an important part of base load fuel diversity that ensures grid stability. Nuclear plants are built to run all the time and provide full power when it is most needed.

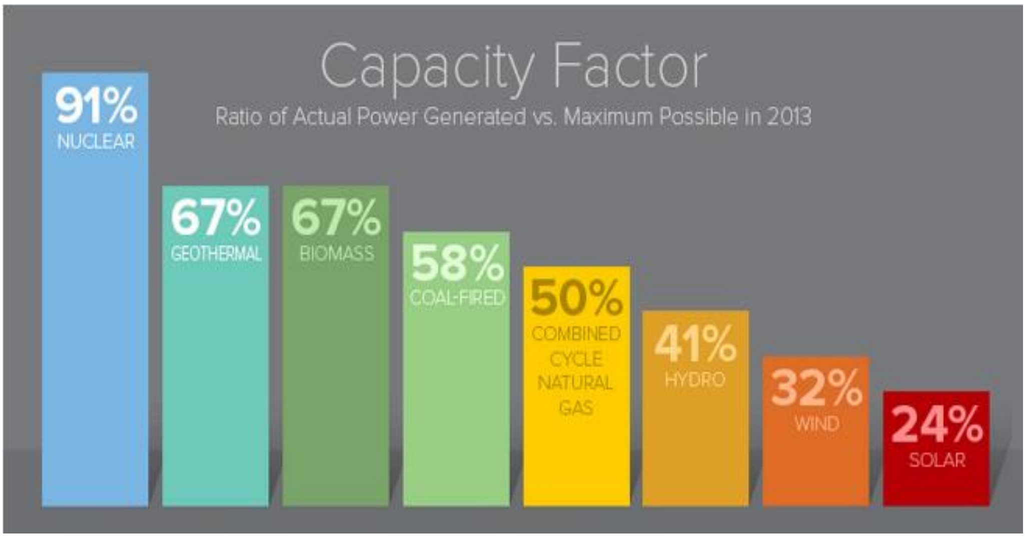

Fig 4.1 Ratio of actual Generated power verses Maximum Possible

A third of a reactor’s fuel is replaced every 18-24 months during short, scheduled refuelling periods. This means nuclear energy plants can supply large amounts of predictable, reliable electricity through virtually every period of extreme heat and cold.

Nuclear energy is the world's largest source of emission-free energy. Nuclear power plants produce no controlled air pollutants, such as sulphur and particulates, or greenhouse gases. The use of nuclear energy in place of other energy sources helps to keep the air clean, preserve the Earth's climate, avoid ground level ozone formation and prevent acid rain.

Application of nuclear fuel recycling technologies proves resource conservation in the nuclear industry. A spent nuclear fuel that was once used at a nuclear power station contains 96% of unburnt uranium (about 1% of uranium 235 and about 95% of uranium 238), and about 1% of plutonium produced by uranium 238 that absorbed neutrons. They can be used again as fuels, if they are reprocessed.

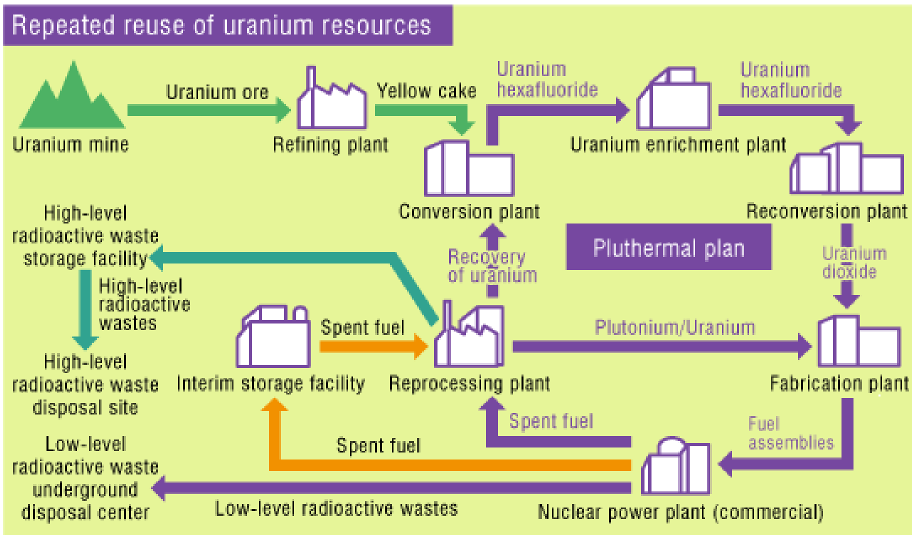

Fig. 4.2 – Nuclear fuel cycle.

4.2.1 Energy Return on Investment

The role of abundant, cheap and high quality energy sources in the development of modern civilizations is widely recognized. The energy returned on energy invested (EROEI) and similar concepts like energy payback time, energy money returned on invested provide a measure of the energetic efficiency of technologies and fuels. Energy Return on Energy Investment can be defined as the “ratio of how much energy is gained from an energy production process compared to how much of that energy (or its equivalent from some other source) is required to extract, grow, etc., a new unit of the energy in question”.

A typical example of its application is the ratio of the energy contained in a given quantity of nuclear fuel relative to the energy required to grow, harvest and process that quantity of fuel. An EROEI above the physical threshold of 1, meaning that more energy is being produced than is being consumed, is a desirable attribute of any energy chain — the greater the value, the better. On the other hand, an EROEI value of less than 1 would challenge the viability of an energy chain. Published estimates of the ratio of EROEI for conventional oil and gas indicate that when the quality of reserves is taken into account, there has been a substantial decline over time: the EROEI was over 100 in 1930, dropping to 30 in 1970 and to some 11–18 in 2005.

This resulted in the rapid increment in the extraction costs over the recent past years especially in the oil industry. EROEI values for coal shows coal have so far remained relatively stable since coal reserves are further from being depleted.

Considering the relative abundance of uranium fuel sources and the small role played by the nuclear fuel in electricity generating costs, the EROEI of nuclear energy exhibits relative stability and it is likely continue to do so over the long term. The EROEI is also an indicator for comparing power supply technologies as it describes the overall life cycle efficiency, i.e. the ratio of electrical energy produced by a given power source to the amount of energy needed to build, fuel, maintain and decommission that power plant. A study was carried out on buffered and unbuffered generation sources.

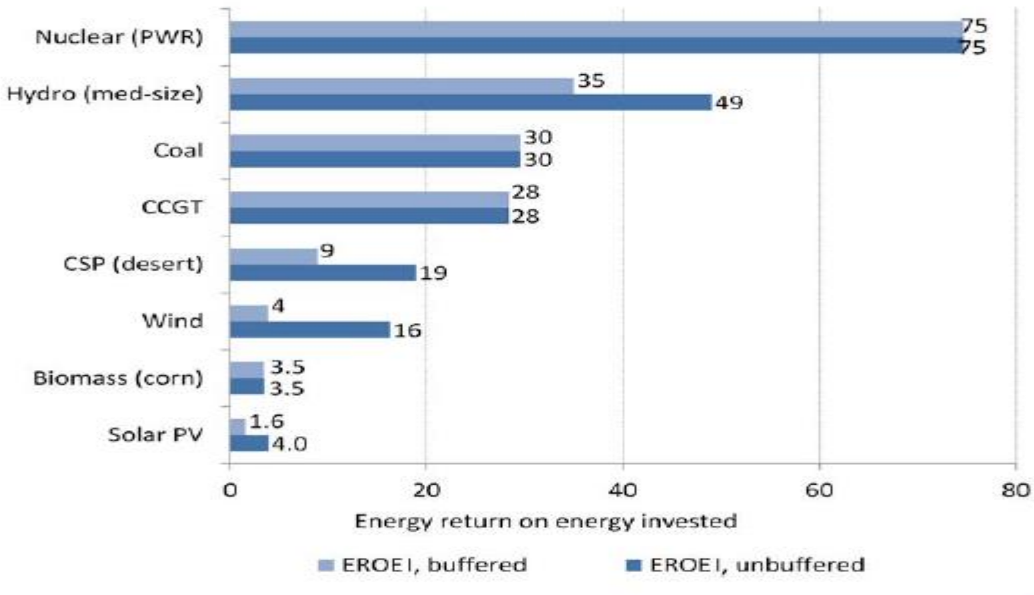

Fig 4.3 EROEI for some selected technologies.

'Unbuffered' refers to raw generation without storage. Some energy generation techniques need buffering (wind energy, photovoltaic (PV), concentrating solar power (CSP)) using technological solutions such as storage systems and overcapacities, which are included in the system borders, replacing the flexible usage of mined fuel with fuel based technologies. Fuelled energy sources already store energy in the fuel, so no additional buffering is necessary. Buffered sources include pumped hydro storage where it is needed to buffer the difference in peaks between production and consumption. Investing energy to build and operate nuclear, hydro, coal and natural gas power systems is one order of magnitude more effective than PV and wind power over their respective operational lifetimes.

According to the EROEI indicators, nuclear power and run-of-river hydro offer the best returns. Indeed, the EROEI for nuclear power has been rising rapidly as the industry switches from the gas diffusion enrichment of uranium to centrifuge enrichment, estimated to be 35 times more energy efficient. Since the electricity used for uranium enrichment is added to the invested energy, it reduces the EROEI remarkably. For comparison, an NPP using 100% gas diffusion would have an EROEI of 31 whereas with 100% centrifuge enrichment, the EROEI would be of the order of 106, according to analysis. The switch from diffusion to centrifuge increases the overall energy efficiency of nuclear power by a factor of 3.4.

The analysis of the EROEI highlights some of the merits of nuclear power and gives support to its potential role in a future sustainable energy mix for at least two reasons: (1) the EROEI of major fossil fuels has been decreasing over time, suggesting that technological advances are falling short of offsetting depletion effects, and (2) most renewable energy sources exhibit relatively low EROEI values pertaining to low capacity factors and aspects such as the employment of oil, natural gas and coal in the production, transport and implementation of wind turbines and PV panels

4.2.2 Competitiveness of Nuclear Power Based on SWOT Analysis

SWOT analysis is a process of making decisions. It is used to analyse Strength, Weakness, Opportunity and Threat. The SWOT analysis can help enterprises to find their positions in the competitive environment. The efficiency and competitiveness of Nuclear Power was analysed comparing to other sources of energy production.

Strength of nuclear power enterprise

Considering the economic point of view, nuclear power has the ability to compete with thermal power in the long term completely. Nuclear power has a considerable competitive edge, especially in the sphere with the fast development of nuclear power. Therefore, under the circumstance of the thermal power in a high cost, nuclear power will become a very important part of the energy structure. In the severe situation of energy shortage, many countries start to develop new energies to relief the contradiction between energy supply and demand. From the global scale, nuclear power has accounted for 16% in power supply. Due to certain limitations, some kinds of sustainable and clean energy cannot give full play to their function, like solar energy, wind energy. With the development of new generation nuclear technology, nuclear energy will embody the importance in all the energies significantly in the future.

Weakness of nuclear power enterprise

The low utilization ratio of nuclear fuel is a major problem in the process of nuclear power development. The nuclear waste disposal is a serious problem. With a large number of nuclear power put into production and use, the rapid growth of the number of nuclear waste will become the constraints of nuclear power development. The issue of radiation and nuclear safety is a major problem in the nuclear industry. Protection of nuclear materials from access of terrorist post a major problem in the nuclear power industry.

Opportunities

On the basis of low carbon economy and new energy in global, nuclear power is paid more attention. Among these non-fossil energies, nuclear power has a very clear advantage. Nuclear Power has a lower generating cost compared to other sources of electricity generating plants. For example, after years of development, the generating cost of nuclear power in China is estimated at about thirty fens per kilowatt hour, which is much lower than wind power, solar power or other new energies. The generating cost's advantage of nuclear power in the price will lead to the decline of the on-grid, which greatly enhance the competitiveness in new energy. From the price point of view, nuclear power has the best conditions to develop on scales compared to other sources of energy. Wind power and solar power have the characteristics of intermittent and randomness. And these characteristics will bring a lot of technical problems on network operations. The synchronizing and closing of nuclear power almost has no influence on network as stable as thermal power. Moreover, the annual utilization hours of nuclear power are far larger than wind power and solar power. Therefore, nuclear power is an inevitable choice of the energy structure optimization in the future.

Threat

Problem of nuclear safety is bound to face in the process of development of nuclear power. The leakage problems of Japan's nuclear power plants after earthquake attracted concerns and attentions to the security of nuclear power facilities in the world. Japan's nuclear accidents have an impact on decision making of different countries on nuclear power development. That is a particular attention is given to safety requirements. Also the construction of nuclear power plant takes a long time; from decision making to construction and commissioning. This is due to the complicated procedure made by the international atomic energy commission [36].

4.2.3 Economics of Nuclear Power

Nuclear power plants are one of the most economical forms of energy production. Including capital and non-fuel operating costs, the cost of operating a nuclear power plant is roughly equivalent to fossil fuels. As of 2012, the average cost of power generation by nuclear plants was 2.40 cents per kilowatt-hour, for coal-fired plants 3.27 cents, for oil 22.48 cents, and for gas 3.40 cents. Costs for solar and wind are still well beyond that considered to be competitive to the public.

The cost of regulation and industry oversight of nuclear power generation is substantially more than that of other power generation sources; however, improvements in reliability and operational and maintenance efficiency have contributed to reducing those costs.

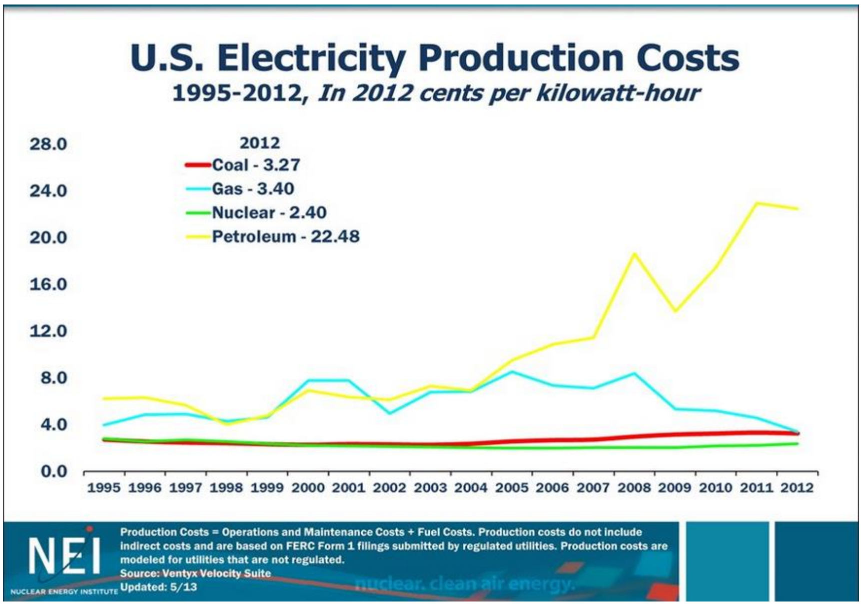

Fig. 4.4 Graph showing cost per kilowatt for different power plants
Source [40]

4.2.4 Fuel Comparison of Coal, Mineral Oil and Nuclear fuel

With a complete combustion or fission, approx. 8 kWh of heat can be generated from 1 kg of coal, approx. 12 kWh from 1 kg of mineral oil and around 24,000,000 kWh from 1 kg of uranium-235. Related to one kilogram, uranium-235 contains two to three million times the energy equivalent of oil or coal. The illustration shows how much coal, oil or natural uranium is required for a certain quantity of electricity. Thus, 1 kg natural uranium - following a corresponding enrichment and used for power generation in light water reactors - corresponds to nearly 10,000 kg of mineral oil or 14,000 kg of coal and enables the generation of 45,000 kWh of electricity.

From the outset the basic attraction of nuclear energy has been its low fuel costs compared with coal, oil and gas fired plants. Uranium, however, has to be processed, enriched and fabricated into fuel elements, and about half of the cost is due to enrichment and fabrication. Allowances must also be made for the management of radioactive spent fuel and the ultimate disposal of this spent fuel or the wastes separated from it.

4.2.5 Nuclear fuel supply

The high capital costs of NPP construction, and thus the long pay-back period, mean that the availability at reasonable prices of nuclear fuel (comprising principally uranium, enrichment and fabrication) is of concern to investors. Given the long operating lifetimes of most NPPs, with new plants designed to operate for at least 60 years, this concern extends over an extended timescale compared to other energy resources. Any significant expansion of nuclear power would need to be matched by an increase in uranium production and by a matching expansion of fuel cycle facilities.

In the case of transport of nuclear fuel from Russia to Ghana, special attention is paid to the route of transport until final delivery to plant site in Ghana. An algorithm of the route of transport of nuclear fuel from Russia to Ghana is shown in figure 4.3 below.

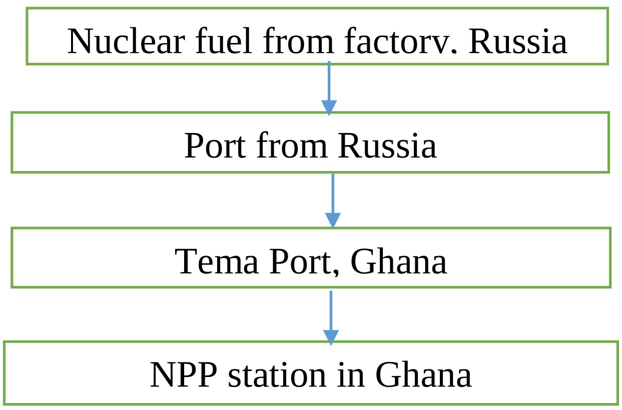

Fig 4.5 – Algorithm of Transport of NF from Russia to Ghana

The International Atomic Energy Agency (IAEA) Regulations for the Safe Transport of Radioactive Material set the basis for nuclear fuel cycle material transport. The basic concept is that safety is vested principally in the package that has to provide shielding to protect people, property and the environment against the effects of radiation, to prevent chain reactions and also to provide protection against dispersion of the contents. The containment used for the transport of nuclear fuels is mainly transported by a specialized vehicle to the port and transported to the destination by ship. The transport of nuclear fuels from Russia to Ghana is therefore not comfortable to be transported by air but rather ship [23].

4.3 Planning And Management of Scientific and Technical Project

4.3.1 Hierarchical structure of the project works

As a part of the planning of a research project, it is necessary to draw a working calendar graphic. This was used to monitor and guide the progress of work carried out.

The Gantt chart was used to map the distribution of the work carried out. Gantt chart is a type of bar charts which is used to illustrate the planned schedule of project, in which the works can be shown the extensive length of time, characterized by the dates of beginning and end of the implementation of these works.

The graph is constructed and shown in figure 4.4 below by month and seven-day working periods during run-time of project. The difference in the length of the distribution of each working period largely depends on the task needed for a particular work. The task performed are written and shown in appendix B.

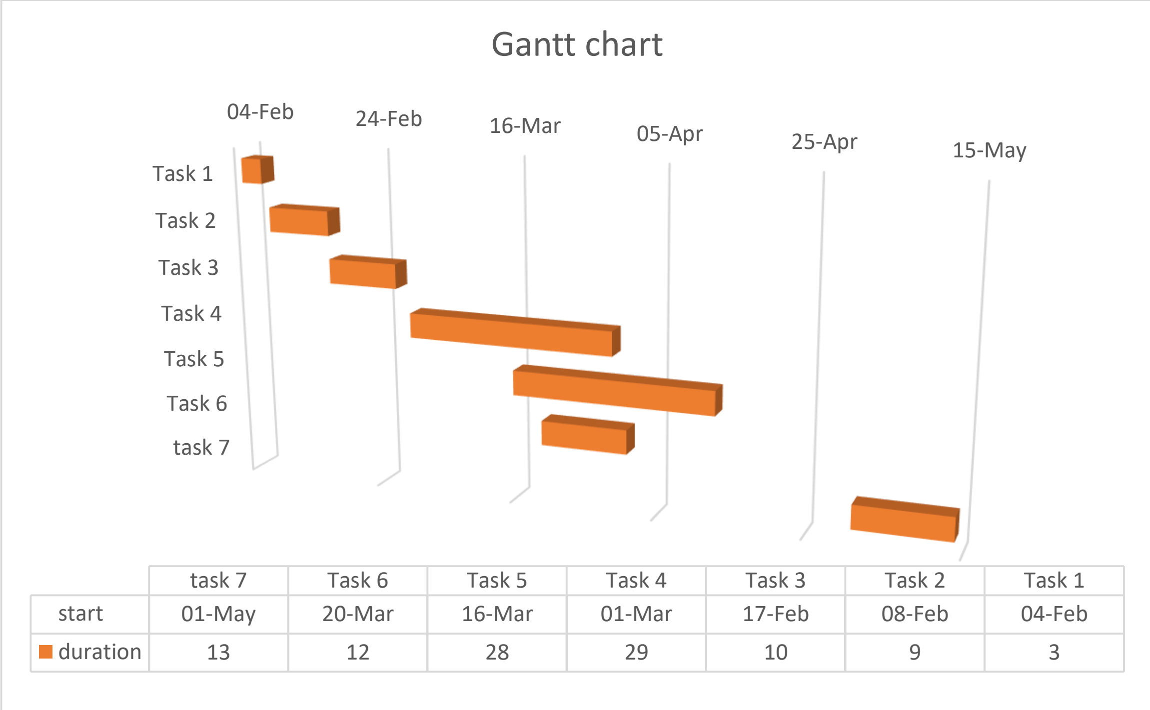

Figure 4.6 Gantt chart showing the tasks and their respective working periods.

4.3.2 Budget of scientific research

The scientific work was carried out under a budget allocated to two supervisors and one engineer of the university. Supervisor 1 and the engineer from the institute of Physics and Technology and supervisor 2 from the financial management department. The two supervisors are allocated 300 Rub per hour and the engineer has 100 Rub per hour.

The total cost incurred during the cost of the project was then calculated and shown below:

According to the Salary System for Employees, the wage of people, who are working in university can be determined by:

Salary of supervisor 1 per month: 24,000 rubles;

Per day: 1200 rub

Salary of supervisor 2 per month): 24,000 rubles

Per day: 1200 rub

Engineer: 2000 rubles

Per day: 100 rubles.

Number of days spent to carry out the research;

Total: 104 days. Total working days with scientific supervisors is 73.

Supervisor 1: 73 days;

Wage: 20×1200 = 24000 rub

Supervisor 2: 26 days.

Wage: 20×1200 = 24000 rub

Engineer: 20×100 = 2000 rub

Table 4.3 – Raw materials, components and semi-finished products

Title	Mark, size	Quantity	Price per each, rub	The su ruble
Computer	HP	1	25 00	25 000
Notebook	Note 3	5	30	150
Pen	Stabilo	5	15	75
Printing		5	500	2500
Total of materials				27725
Transportation and procurement expenses (3.5%)				890.6
Total items $C_{м}$				28615.6

Table 4.4 Estimation of overall expenses.

S.No	Type of expenses	Budget Rubles	Citation
1	Labor wages	50,000	3.1
2	Raw materials and resources	28615.6	-
3	Social insurance	10,736	3.2
4	Over head	13,349	3.3
5	Total	102700.6	

Conclusion

The dissertation was done in a period three months and two weeks totally with the participation of master's student and the support of two supervisors. In which, the researcher, i.e. the student, who carried out this thesis spending all the three months and two weeks for working on, the supervisor 1 is 20 days in a month and supervisor 2 is 20 days as well. The amount of money had been spent for doing this dissertation is 175,000 ruble totally. Particularly, 24,000 ruble is the salary per month for each supervisor and 2000 ruble per month for the engineer. In addition, there are some money also paid for some necessary equipment, which had been used for doing this research, such as computer, notebooks, pen, printing, specific textbook. Totally, it costs 28,615.6 ruble for all.