



RISK ASSESSMENT FOR THE PRESSURIZED WATER REACTORS NUCLEAR POWER PLANT

By

Melouk Mohsen Abass

A Thesis Submitted to the
Faculty of Engineering at Cairo University
In Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
in
Risk Engineering

FACULTY OF ENGINEERING CAIRO UNIVERSITY
GIZA, EGYPT
2018



RISK ASSESSMENT FOR THE PRESSURIZED WATER REACTORS NUCLEAR POWER PLANT

By

Melouk Mohsen Abass

A Thesis Submitted to the
Faculty of Engineering at Cairo University
In Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
in
Risk Engineering

FACULTY OF ENGINEERING CAIRO UNIVERSITY
GIZA, EGYPT
2018

**RISK ASSESSMENT FOR THE PRESSURIZED WATER
REACTORS NUCLEAR POWER PLANT**

By
Melouk Mohsen Abass

A Thesis Submitted to the
Faculty of Engineering at Cairo University
In Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
in
Risk Engineering

Under the Supervision of

Prof Dr. Iman El Mahallawi

.....

Mining and Metallurgical Department,
Cairo University, Faculty of
Engineering

Prof Dr. Abd El Aziz Fahmy Waheewd

.....

Egyptian Atomic Energy Authority

FACULTY OF ENGINEERING CAIRO UNIVERSITY
GIZA, EGYPT
2018

RISK ASSESSMENT FOR THE PRESSURIZED WATER REACTORS NUCLEAR POWER PLANT

By
Melouk Mohsen Abass

A Thesis Submitted to the
Faculty of Engineering at Cairo University
In Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
in
Risk Engineering

Approved by the
Examining Committee

Prof Dr. Iman El Mahallawi , Thesis Main Advisor
Mining and Metallurgical Department, Cairo University, Faculty of Engineering

Prof Dr. Abd El Aziz Fahmy Waheewd, Advisor
Egyptian Atomic Energy Authority (EAEA)

Prof Dr. Nabil Mahmoud Abdel Moneim, Internal Examiner
Chemical Engineering at Faculty of Engineering, Cairo University, Faculty of Engineering

Prof Dr. Karim Eddin Abdel Aziz Aldahm, External Examiner
Nuclear and Radiological Regulatory Authority

FACULTY OF ENGINEERING CAIRO UNIVERSITY
GIZA, EGYPT
2018

Engineer's Name: Melouk Mohsen Abass Shahata
Date of Birth: 31/10/1990
Nationality: Egyptian
Email: meloukmohsen@yahoo.com
Phone: +2-01278169017 /01002205285
Address: Cairo, Egypt
Registration Date: 2014
Awarding Date: 2018
Degree: Master of Science
Department: Risk Engineering
Supervisors:



Prof Dr. Iman El Mahallawi
Prof Dr. Abd El Aziz Fahmy Waheewd

Examiners:

Prof Dr. Iman El Mahallawi , Thesis Main Advisor
Mining and Metallurgical Department, Cairo University, Faculty of Engineering
Prof Dr. Abd El Aziz Fahmy Waheewd, Advisor
Egyptian Atomic Energy Authority (EAEA)
Prof Dr. Nabil Mahmoud Abdel Moneim, Internal Examiner
Chemical Engineering at Faculty of Engineering, Cairo University, Faculty of Engineering
Prof Dr. Karim Eddin Abdel Aziz Aldahm, External Examiner
Nuclear and Radiological Regulatory Authority

Title of Thesis:

RISK ASSESSMENT FOR THE PRESSURIZED WATER REACTORS NUCLEAR POWER PLANT

Key Words: Nuclear PWR, Accidents, Safety, Risk, Control

Summary:

Nuclear power generating plants are one of the most important sources for electricity generation. Nowadays Egypt starts its first nuclear project. One of the main disadvantages of using nuclear energy is the nuclear energy accidents which can spread radiations over a wide area, these radiations harm the cell of the body which can make human death and genetic problems can occur too. So this work tries to decrease the probability and the severity of nuclear accidents by studying the parts of the pressurized water reactor nuclear plant and the sources of hazards in it then find the reason for these hazards and its effect and apply the required control on it to decrease the probabilities and the severities of this hazard on the plant and finally draw the risk matrix for the plant. Also some safety considerations must be applied on the plant to ensure its reliable and safe operation. Finally, nuclear energy is a double edged weapon so it must be handled in careful way.

Disclaimer

I hereby declare that this thesis is my own original work and that no part of it has been submitted for a degree qualification at any other university or institute.

I further declare that I have appropriately acknowledged all sources used and have cited them in references sections.

Name: Melouk Mohsen Abass

Date: 21-11-2018

Signature:

Acknowledgment

I would like to express my deep appreciation to all those who helped in preparing this thesis and in particular to

- Prof /Dr. **Iman El Mahallawi**
- Prof/ Dr. **Foaud Khalaf**
- Prof./ Dr. **Abd El Aziz Fahmy Waheewd**
- Prof / Dr. **Nabil Mahmoud Abdel Moneim**
- Prof / Dr. **Karim Eddin Abdel Aziz Aldahm**

I would also like to express my deep gratitude to my mother and sister.

Table of Contents

Disclaimer	I
Acknowledgment	II
Nomenclature.....	VII
Abstract.....	IX
Chapter 1 : Introduction	1
1.1 Significance of work.....	3
1.2 Objectives	3
Chapter 2 : Literature Review	4
2.1- Nuclear energy's contribution to global electricity supply:	4
2.2- Electricity generation form power plants.....	5
2.3- Nuclear energy:.....	6
2.4- Advantages and disadvantages of nuclear energy:	7
2.5- Parts of nuclear power plant:	8
2.6- Types of nuclear reactors:.....	9
2.7- The pressurized water reactor core:	13
2.8- World statistics:	14
2.9- Safety codes and regulations.....	16
2.10- Review of previous accidents	19
2.10.1- Nuclear and radiation accidents and incidents	19
2.10.2- Description by levels of INES:	21
2.10.3- Accident I: Three Mile-Island (1979)	23
2.10.4- Accident II: The Chernobyl accident (1986)	25
2.10.5- Accident III: The Fukushima Daiichi nuclear disaster	27
(2011)	27
2.10.6- Problem definition and objective of work.....	31
Chapter 3 : Risk Assessment or Management Methodology	33
3.1 System identification	34
3.2 Hazard identification.....	34
3.3 Risk assessment	34

3.4	Risk management and control.....	36
3.5	Record and review of findings.....	37
Chapter 4 : Results and Discussion		38
4.1	Plant flow sheet:.....	38
4.2	The risk assessment tables:	41
4.3	Representation of results:.....	75
4.4	Risk matrix:.....	78
Conclusions and Recommendations		79
	Safety measures to avoid nuclear accidents.....	79
	Reasons for nuclear accidents	79
	References.....	80

List of Tables

Table 1:Reactor type Vs Number of reactors and Total net electrical capacity[13]	15
Table 2: Famous Nuclear Accidents [18]	19
Table 3: The probability description	35
Table 4: The Severity description.....	36
Table 5:The reactor hazards	42
Table 6:The control rod hazards	47
Table 7:The reactor core hazards.....	47
Table 8: The coolant pump hazards.....	49
Table 9:The pressurizer hazards	49
Table 10:The radiation hazards	51
Table 11:The steam hazards	53
Table 12:The generator hazards	54
Table 13:The heat exchanger hazards	54
Table 14:The reactor coolant system (RCS) hazards	55
Table 15:The steam generator hazards	58
Table 16:The piping and valves hazards	60
Table 17:The BTRS (The boron thermal regeneration system) hazards	60
Table 18:The solids hazards	62
Table 19:The RHRS (residual heat removal system) hazards	62
Table 20:SGBPS (The steam generator blowdown processing system) hazards	63
Table 21:Safety injection system (SIS) hazards	65
Table 22:The containment building hazards	66
Table 23:The natural hazards	69
Table 24:The containment spray system hazards	70
Table 25:The control room hazards.....	71
Table 26:The power hazards.....	72
Table 27:The reactor protection system (RPS) hazards	72
Table 28:The Process monitoring and controlling hazards	73
Table 29:Human error hazards	74
Table 30:Recording system (videos and IT system) hazards	74
Table 31: Source of hazards vs Number of hazards , Cumulative frequency and CF %	75

List of Figures

Figure 1: Nuclear power plant distribution all over the world [2].....	4
Figure 2: different sources to generate electricity [3].....	5
Figure 3: pressurized water nuclear reactor power plant to generate electricity [3]	5
Figure 4: Fission of a Uranium – 235 atom[4]	6
Figure 5: Nuclear power plant parts [7].....	8
Figure 6: Pressurized water reactor (PWR)[8]	9
Figure 7: Boiling water reactor (BWR)[9]	10
Figure 8: Pressurized heavy water reactor (PHWR)[10]	11
Figure 9: Advanced gas-cooled reactor (AGR)[11]	11
Figure 10: Light water graphite-moderated reactor [12]	12
Figure 11: floating nuclear power plant [13].....	12
Figure 12: The nuclear reactor core and fuel assembly	14
Figure 13: Number of reactors VS Reactor Type	15
Figure 14: Total Net Electrical Capacity VS Type of Reactor	16
Figure 15: International nuclear event scale levels description [17]	23
Figure 16: Tsunami Affected Area	27
Figure 17: Nuclear contamination in atmosphere.....	29
Figure 18: Nuclear contamination in ocean.....	29
Figure 19: Risk Assessment Form[24]	37
Figure 20: Nuclear power plant flow sheet	39
Figure 21: Number of hazards vs Source of hazards	76
Figure 22: Number of hazards vs CF %	77
Figure 23: Risk Matrix for the plant	78

Nomenclature

BTRS: BORON THERMAL REGENERATION SYSTEM
BRS: BORON RECYCLE SYSTEM
CRDM: CONTROL ROD DRIVE MECHANISM.
CVCS: CHEMICAL AND VOLUME CONTROL SYSTEM
CR: CONTROL ROD
CCW: COMPONENT COOLING WATER
CSS: CONTAINMENT SPRAY SYSTEM
CSST: CONTAINMENT SPRAY STORAGE TANK
DRPI: DIGITAL ROD POSITION INDICATION SYSTEM
EFWS: EMERGENCY FEEDWATER SYSTEM
FMEA: FAILURE MODE EFFECT ANALYSIS
HX: HEAT EXCHANGER
HHSI: HIGH HEAD SAFETY INJECTION
HDS: HYDROGEN DETECTION SYSTEM
NSSS: NUCLEAR STEAM SUPPLY SYSTEM
RCCA: ROD CLUSTER CONTROL ASSEMBLY
RCS: REACTOR COOLANT SYSTEM
RCP: REACTOR COOLANT PUMP
RCS : REACTOR COOLANT SYSTEM
RFCC: REACTOR CONTAINMENT FAN COOLER SYSTEM
RHRS: RESSIDUAL HEAT REMOVAL SYSTEM
RMW: REACTOR MAKEUP WATER
RWST: REFUELING WATER STORAGE TANK
P: PROBABILITY
S: SEVERITY
R.R: RISK RANKING
SAT: SPRAY ADDITIVE TANK
SGBPS: STEAM GENERATOR BLOW DOWN PROCESSING SYSTEM
SIS: SAFETY INJECTION SYSTEM
TTFM: TRANSIENT TIME FLOW METER
VCT: VOLUME CONTROL TANK
WPS(L):WASTE PROCESSING SYSTEM(LIQUID)
WPS(G):WASTE PROCESSING SYSTEM(GAS)

Scientific units:

Bq: Becquerel, SI unit for radioactivity
MBq: Megabecquerel (1×10^6 Becquerel)
PBq: Petabecquerel (1×10^{15} Becquerel)
Sv: Sievert, SI unit for dose equivalent
mSv: Millisievert (1×10^{-3} Sievert)
μSv: Microsievert (1×10^{-6} Sievert)

Acronyms:

BEIR: National Academy of Sciences Advisory Committee on the Biological Effects of Ionizing Radiation
CTBT: Comprehensive Test Ban Treaty
ECRR: European Committee on Radiation Risks
GRS: Gesellschaft für Anlagen- und Reaktorsicherheit
(German Society for Reactor Safety)
GS: Gesellschaft für Strahlenschutz
(German Society for Radiation Protection)
IAEA : International Atomic Energy Agency
INES: International Nuclear Event Scale
IRSN: Institut de Radioprotection et de Sécurité Nucléaire
(French Institute for Radiation Protection and Nuclear Safety)
JAEA: Japan Atomic Energy Agency
MAFF: Japanese Ministry of Agriculture, Forestry and Fisheries
MEXT: Japanese Ministry of Education, Culture, Sports, Science and Technology
NILU: Norsk institutt for luftforskning
(Norwegian Institute for Air Research)
TEPCO: Tokyo Electric Power Company
WHO: World Health Organization
ZAMG: Zentralanstalt für Meteorologie und Geodynamik
(Austrian Central Institute for Meteorology and Geodynamics)
NRC: The U.S Nuclear Regulatory commission.

Abstract

Nuclear Energy is one of the most important sources of energy. It is a double-edged weapon, so it must be handled in a careful way. Nuclear power generating plants are one of the major electricity producers. Nuclear energy supplies about 12% of the world electricity. Many countries use nuclear energy to generate one – quarter to one third of their electricity. The nuclear plants produce electricity by boiling water into steam like plants that burn oil or natural gas. The difference is that the nuclear plants use uranium fuel. The steam produced turns turbines to produce electricity.

Egypt started one of its most important projects, which is Dabaa nuclear power plant for electricity generation. Nuclear energy has many advantages, but similarly have some disadvantages. One of its disadvantages is the nuclear power plants accidents, which can spread radiation over a wide area; these radiations harm the body cells, which causes human sickness or even death, illness and genetic problems can occur too.

A nuclear and radiation accident is defined by the International Atomic Energy Agency (IAEA) as “an event that has led to significant consequences to people, the environment or the facility.” Some measures to reduce the risk of accidents or to minimize the amount of radioactivity released to the environment have been adopted. Despite the use of such measures, human error remains, and "there have been many accidents with varying impacts as well near misses and incidents".

Our thesis main aim is to achieve to a safe plant so we try to decrease the severity and the probability of the hazards that may occur like natural hazards like earthquakes, tornados..., etc. such as what happened in Fukushima accident or hazards that occur as a result of lack in personal experience (human technical error, like Chernobyl accident or any other hazards).

The plan of this work starts with identifying the different types of nuclear reactors, focusing on pressurized water type. Hence, analyzing the different parts and procedures in nuclear power plant for electricity generation. Finally, the hazards associated with the process, their risk assessment, and mitigation with control methods will be presented.

The aim is to have all activities of the process in the safe zone (green zone in risk matrix).

Chapter 1 : Introduction

Nuclear power generating plants are one of the most debatable electricity producers. Nuclear energy supplies about 12% of the world electricity. Many countries use nuclear energy to generate one – quarter to one third of their electricity. The nuclear plants produce electricity by boiling water into steam like plants that burn oil or natural gas. The difference is that the nuclear plants use uranium fuel. The steam produced turns turbines to produce electricity.

The nuclear reactor main components are:

a) Fuel:

The most used fuels are uranium or thorium. Uranium is the preferable one because of its high melting point.

b) Moderator:

Moderators reduce the speed of the neutrons to convert it from fast neutron to thermal neutrons. Moderators adsorb energy of the neutrons but do not absorb the neutrons. Graphite, Heavy water and Beryllium are the main materials used as moderators.

c) Control Rod:

The control rods are to absorb neutrons to slow down chain reactions or stop it. Control rods are made of steel tubes containing material like cadmium or boron.

d) Shielding:

Shielding is used to prevent radiation from spreading outside of the reactor. Lead blocks and concrete are used for shielding. They are several meters thick for complete shielding.

e) Coolant:

Coolant absorbs heat produced in the reactor and transfers it to heat exchanger to produce steam. The common coolant material is water, carbon dioxide gas or liquid sodium.

f) Turbine:

Steam produced in heat- exchanger passes to turbine. The force of steam and it is converted to mechanical energy.