CHAPTER 1

INTRODUCTION

CHAPTER OVERVIEW

This chapter provides an overview about the research done in this doctoral work, and also its layout into different chapters of this thesis. This chapter begins with a general introduction about the work area under focus. Ionizing radiation sources are used for various peaceful applications, which provide substantial benefits to the society. Various applications of ionizing radiation and the radiation hazards, along with the associated biological effects have been discussed in this chapter. Subsequent to this general introduction, this chapter provides the motivation behind the present research work. Moving further, the objectives of this research work are outlined in this chapter. Subsequently, an overview of the research methodology used for the present study and steps involved in the research work are provided in this chapter in the form of flow diagrams. And finally, the thesis structure and the chapter scheme are provided at the end of this chapter.

1.1. GENERAL

Radiation is a form of energy from some source, which travels in a medium or space. Heat, sunlight, microwaves, radio waves etc. are forms of radiation. Due to their multifarious applications, the ionizing radiation sources (radioactive sources and radiation generating equipment) have recently registered significant growth in their use in India, as well as all over the world. These sources are being used for various peaceful applications for the benefit of humankind, such as for power generation (nuclear power plant) and in medicine, industry, agriculture, research & calibration. Facilities using radiation sources are broadly classified either as a nuclear facility - using radiation sources for generation of nuclear power, or as a radiation facility (non-nuclear facility) - using radiation sources for the purposes other than nuclear power generation.

The type of radiation source used, and its activity, varies depending on the application requirements. Working with radiation sources holds risk for exposure to ionizing radiations, which may lead to adverse health effects to the concerned operating personnel (operators). Industrial radiography is one of the important industrial applications of radioactive sources. The risks associated with the operation of radiography equipment are presumed to be significantly high and various incidents/accidents have been reported in this practice [1].

In order to achieve the desired safety levels, and to continually enhance the safety of the operators, a prospective risk assessment for a given practice is required to be carried out. Any risk management in the facilities using radiation sources, would first require a proper risk assessment to be made. The risk assessment procedure can identify the weak areas, where appropriate available resources may be assigned to achieve the desired safety levels. The present study attempted to analyze and estimate the risks in both, the design and the operation, in industrial radiography practice in India. The present study also attempted to identify the areas which contribute significantly to the risks, for effective utilization of the resources for risk reduction in the practice.

1.2 IONIZING RADIATION AND ITS SOURCES

Radiations in the electromagnetic spectrum are categorized on the basis of their wavelengths and the energy they transfer. Radio waves, microwaves, visible light, ultraviolet, infrared, X-rays, gamma rays etc. are different types of radiations, categorized based on their wavelength. Figure 1.1 shows a typical representation of the electromagnetic spectrum. High wavelength, low energy waves like radio waves lie on the one end, and low wavelength and high energy waves like X-rays and gamma rays lie on another end of the electromagnetic spectrum. However, from the view point of safety and protection, radiation is broadly classified either as ionizing radiation, or as non-ionizing radiation.

Ionizing radiations are the radiations which have enough energy to knock out an electron(s) from the atoms, and thus produce ion(s) (charged entity) in matter. Thus, ionizing radiation is potent to cause damage to a living cell at its DNA level, thereby causing biological health effects in living beings.

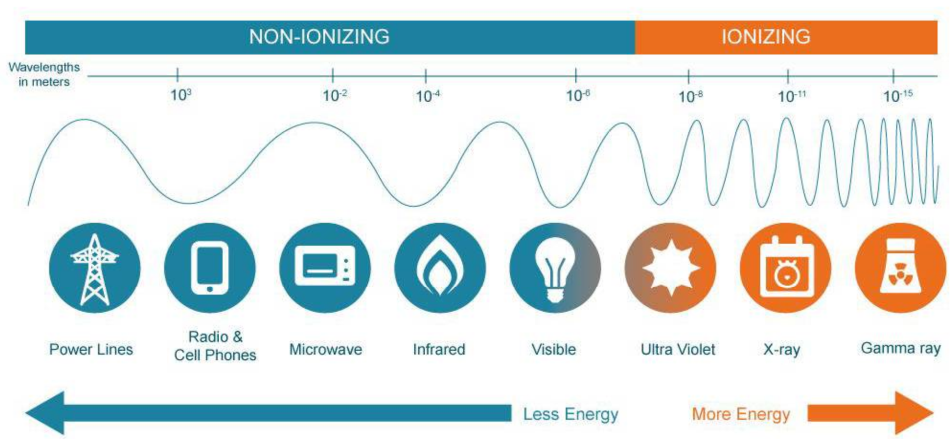

Figure 1.1. Electromagnetic spectrum showing ionizing and non-ionizing radiation

There are various types of ionizing radiations, like the alpha particles, beta particles, gamma rays, X-rays, neutrons etc. Ionizing radiations are produced by unstable atoms when they lose their excess energy to become stable. An ionizing radiation may be emitted from either a naturally occurring radioactive source or by a man-made source. Man-made sources can be either, the radioisotopes produced by neutron bombardment on stable isotopes, accelerating charged particles or the X-ray generating equipment.

Every living being receives radiation exposure from the naturally occurring radioactivity in the environment, like from, uranium and thorium in the soil, radon inside buildings, radioactivity in the food, cosmic radiation etc. This type of radiation is called natural background radiation, and the amount of which varies from place to place. Other sources of radiation exposure to humans are man-made activities like medical exposure, from nuclear power plants, industrial applications etc.

1.3 APPLICATIONS OF IONIZING RADIATIONS

Since the discovery of X-rays by Wilhelm Conrad Roentgen in 1895, ionizing radiations are being used for various medical, military, industrial and research applications. And as mentioned above, broadly speaking, the applications of ionizing radiations are classified as either nuclear or non-nuclear. Nuclear reactor facility utilizes fuels based on uranium or thorium for power generation. The non-nuclear facility utilizes radioisotopes and radiation generating equipment for medicine, industrial, agriculture and research purpose.

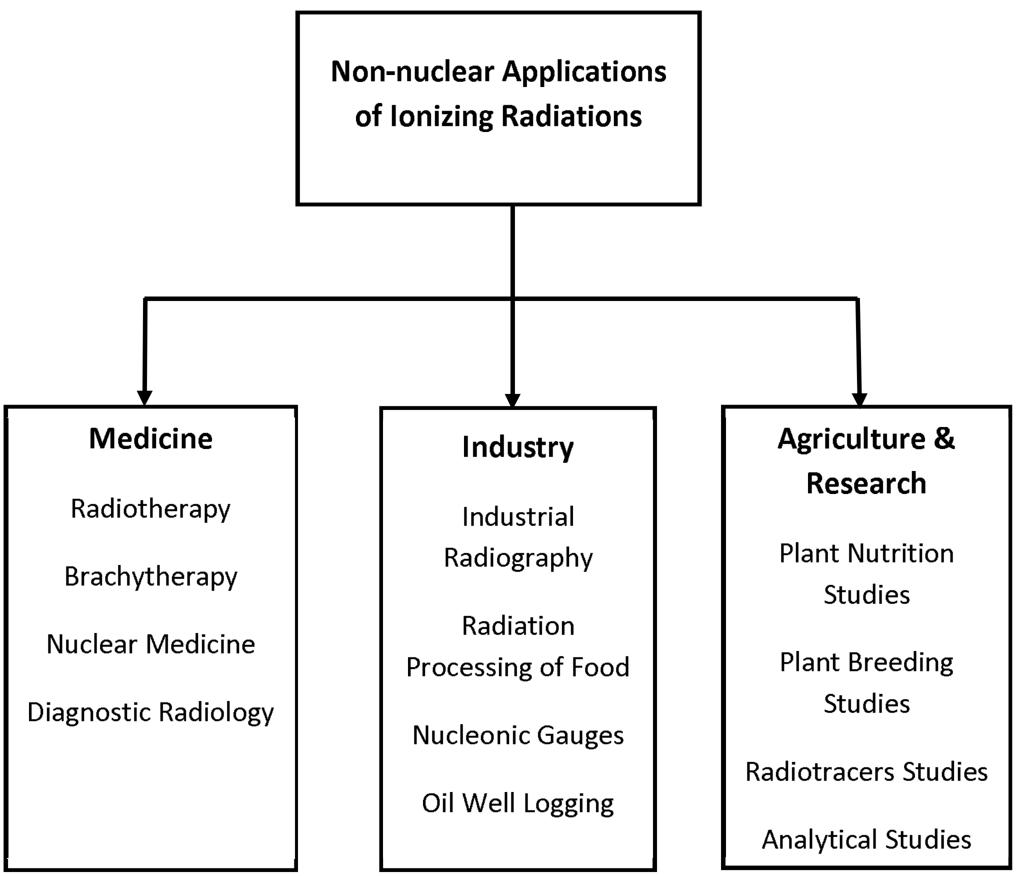

Figure 1.2. Non-nuclear applications of ionizing radiations

Figure 1.2 shows non-nuclear applications of ionizing radiation. Sources used in these applications vary depending on the requirements of the application, viz, the type of radiation, energy and radiation intensity. Some of the applications require sealed radioactive sources, while some require unsealed sources. Activity of these sources also varies from kilo-Becquerel (kBq) to Peta-Becquerel (PBq) range. Some of the practices utilize specialized radiation generating equipment, instead of radioisotopes.

1.3.1 Industrial Radiography Practice

Industrial radiography is one of the important and indispensable applications of ionizing radiations, where radiation sources are used to find out any defects in the weld joints or castings. Manufacturing defects in industrial equipments like pressure vessels, boilers, steam generators etc. may cause severe accidents during their operations. To detect these defects, Non-Destructive Testing (NDT) of these industrial equipments ('jobs') are required to be carried out using various methods like industrial radiography, ultrasound, magnetic particle testing etc.

Radiography of industrial jobs is performed in the same manner like the X-ray scan of human body parts. However, high density of steel requires use of high energy sources like Co-60, Ir-192 or Se-75. These radioactive sources are housed inside a radiography device, which provides shielding against ionizing radiation when not in use. These devices are called Industrial Gamma Radiography Exposure Device (IGRED) or simply "radiography camera".

Figure 1.3 shows the radiography setup for imaging of a weld joint of a pipe using gamma-ray source and figure 1.4 shows processed radiographic image of the pipe.

Figure 1.3 Industrial radiography setup

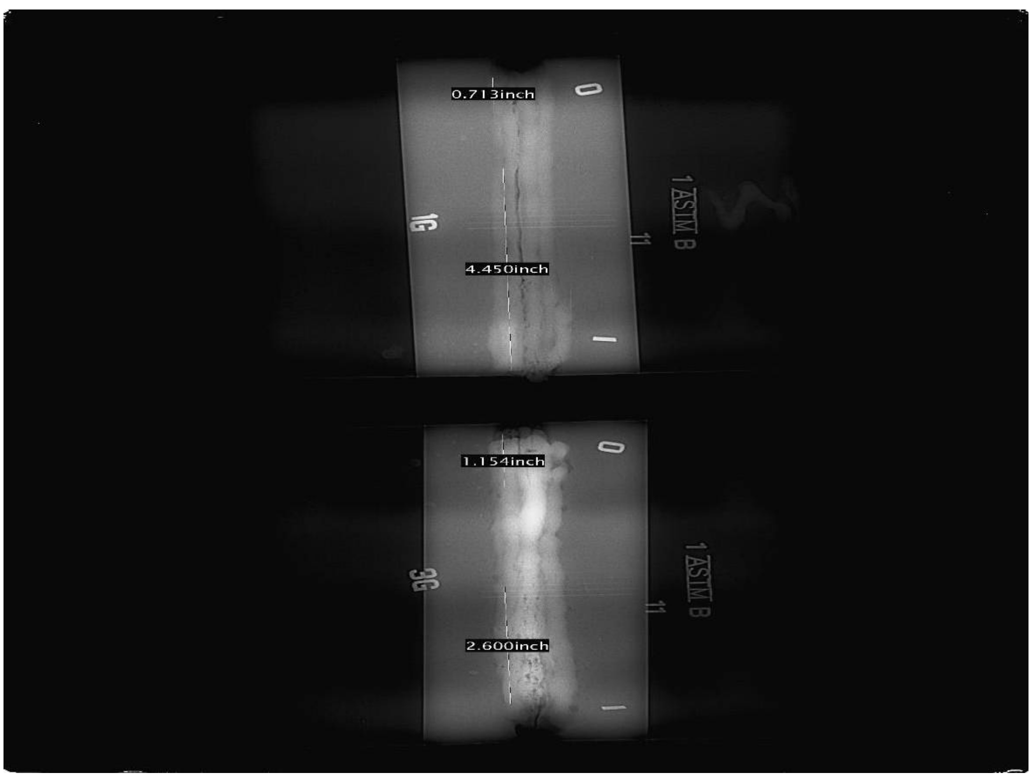

Figure 1.4 Radiographic image of welding in a pipe

1.4 HEALTH HAZARD ASSOCIATED WITH THE IONIZING RADIATION

Working with radiation sources is always associated with possible health hazards. When ionizing radiation interacts with living cells, it causes ionization and/or excitation of the atoms, resulting in damage to the DNA of the living cells. This damage may be done either by the direct action of the ionizing radiation on to the DNA, or by the indirect action arising due to the free radicals produced by radiolysis of water molecules present in the body. The manifestation of biological effects in the human body, due to 'radiation damage', depends on various factors like radiation quality, dose, radiation energy, the sensitivity of the affected organ, linear energy transfer of the radiation, etc.

Biological effects due to ionizing radiation are divided into two categories, namely stochastic effects and deterministic effects. Stochastic effects are the effects the occurrence of which are probabilistic in nature, although the probability increases with the radiation dose. Cancer and genetic effects produced by ionizing radiation are the examples of stochastic effects. Deterministic effects are the effects, which are certain to occur due to a standard dose of radiation. The severity of deterministic effects varies with radiation dose. Radiation-induced skin erythema, sterility, cataract are the examples of deterministic effects. All the radiation-induced deterministic effects can be completely avoided, if the doses received are limited to values below the threshold limits for the specified effect.

1.5 MOTIVATION FOR THE RESEARCH

Radiography of industrial vessels like pressure vessels, boilers etc., is an essential requirement to reduce the probability of accidents (e.g. explosion, fire due to leakage etc.) occurring in them due to manufacturing defects or due to aging-related defects in these 'jobs'. These defects may lead to accidents either during the commissioning or during their continuous operation, and may endanger the lives of people involved. Industrial radiography is a very effective and well-accepted technique to detect these defects.

Industrial radiography is carried out using appropriate radioactive sources. These sources may pose serious health hazards if not handled carefully. The overall safety records of these radioactive sources for their various applications have been good in India. However, accidents involving them have resulted in occasional dangerous exposures to individuals. While in the case of medical applications, in addition to the operator a patient is also at risk of getting exposed to radiation whereas in the case of industrial applications it is the operating personnel who is at this risk.

Following are some of the facts about industrial radiography practice in India, which necessitated and motivated the present research work:

a) Out of the total unusual occurrences/accidents reported in all of the industrial applications of radiation, industrial radiography practice alone contributes about 54% of the total accidents, whereas, from a device point of view the industrial radiography devices contribute only about 21% of the total devices used in industrial applications in India.

b) Out of the total reported excessive exposure (of radiation dose) cases in India, industrial radiography contributes about 20 % of them, which is the second highest contribution after that from medical diagnostic radiography (X-ray), and highest among all the industrial applications.

The safety records and past experience of industrial radiography practice give clear indication that this practice requires a significant improvement to reduce the incidents/accidents and the associated risk of excessive exposure from ionizing radiation to the occupational worker and public.

1.6 RESEARCH OBJECTIVES AND SCOPE

The principal objectives of this present doctoral study is to perform safety analysis of the existing industrial radiography practice in India and to do the risk assessment to identify the weak areas in this practice, which require urgent and long-term improvement to achieve the desired level of radiation safety. This research work also includes doing the risk analysis and risk assessment in both, the design of the radiography devices as well as the operational aspects of industrial radiography operations in India.

The main objectives of this research study are, thus, as listed below;

I. To analyze operations in selected scenarios of the industrial radiography practice for assessment of probabilities of radiation exposures, which exceed the prescribed dose limits and may lead to deterministic health effect to the operating radiography personnel.
II. To assess the probability of occurrence of such selected operational events (or sequence of events) in industrial radiography practice which will lead to potential exposures to operating radiography personnel.
III. To identify the weak areas in the operation of radiography devices, so as to make recommendations for enhancement in the operational safety.
IV. To calculate the ‘risk priority’ numbers for failures of different components of industrial radiography exposure device, and to appropriately rank these failures based on their criticality.
V. To make recommendations for interventions in the design and operational procedure of radiography equipment to reduce the accident probability and radiation hazards in the industrial radiography practice in India.
VI. To verify the feasibility of using selected methods of risk assessment i.e. PSA and FMEA, for the industrial radiography practice.

The radiography operations are carried out by either using a radioactive source or a radiation generating equipment (X-ray machine). Most of the radiography work is, however, carried out by using the device, IGRED (containing radioactive sources), because of its advantages of portable size and non-requirement of electric power to operate it. The scope of the present study is, hence, limited to the industrial radiography practice using radioactive sources only.

It is pertinent to note that as the present research work has been carried out in the Indian scenario, the assessment results may vary from those of other places/other countries due to variations in the operational conditions and human actions during the radiography practice.

1.7 AN OVERVIEW OF THE RESEARCH MODEL

Two of the most important accident initiators in any industry are the ‘human error’ and the ‘equipment failure’. Therefore, inbuilt safety and operational safety are the two components considered for any “Safety” as shown in the figure 1.5. To achieve the total safety in any practice, both of these components are required be addressed;

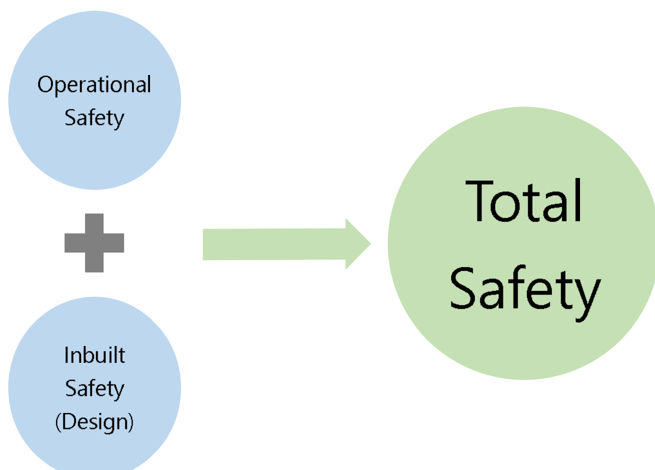

Figure 1.5: Safety Components

The present research work has been carried out for risk assessment in the industrial radiography practice by analyzing both these aspects i.e. design of the equipment and the operational aspects.

The design of the existing industrial gamma radiography exposure devices has been analyzed in depth in the present work, to identify all possible failures in safe operations along with their causes and consequences. For this, the risk assessment for the design of radiography devices has been carried out using the Failure Modes & Effects Analysis (FMEA). Figure 1.6 shows the flow diagram summarizing the research work and the process flow for design analysis of the industrial gamma radiography exposure devices and the associated risk assessment.

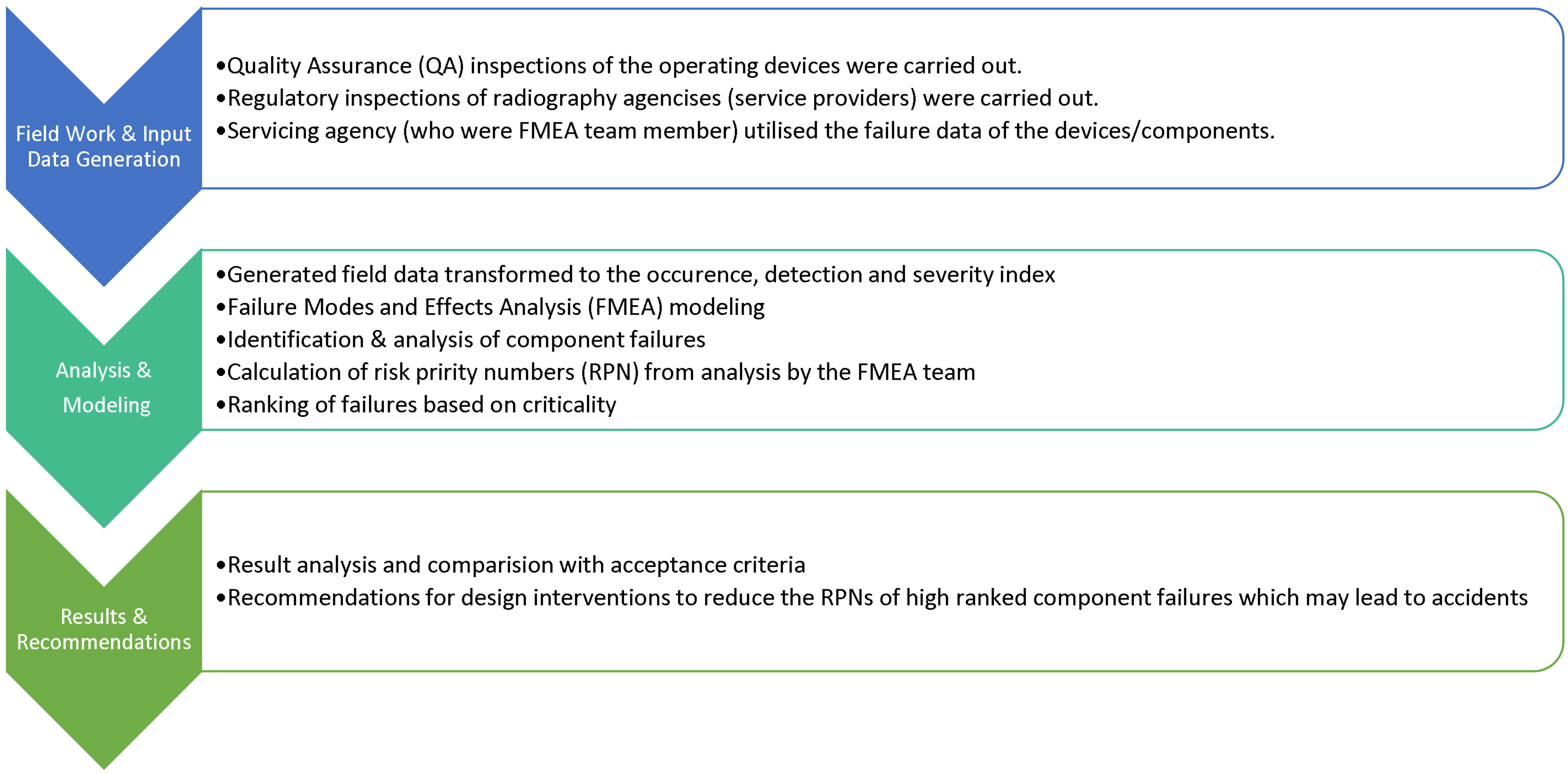

Figure 1.6. The process flow of research work for design analysis and risk assessment for industrial radiography exposure devices.

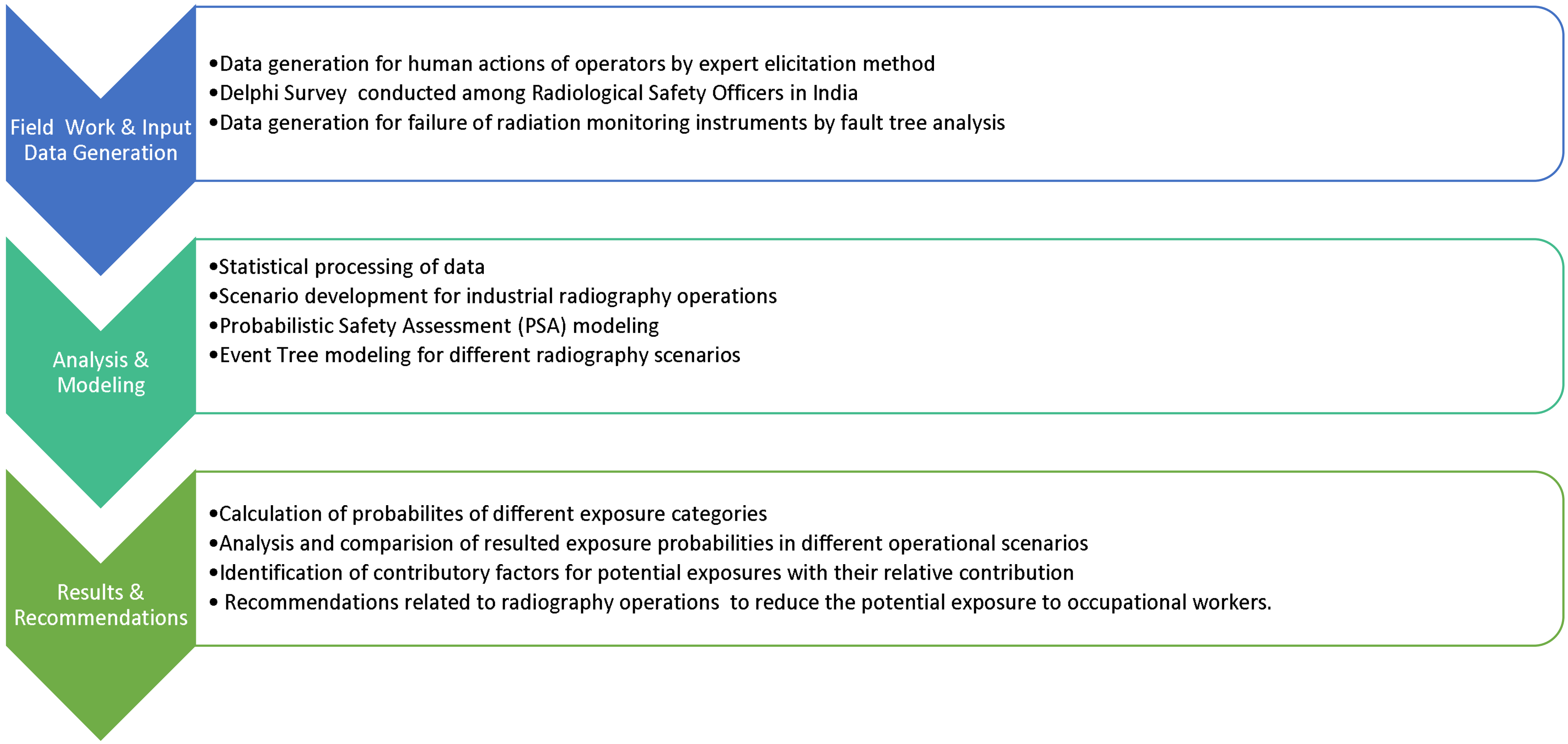

Figure 1.7. The process flow of research work for operational analysis and risk assessment in industrial radiography practice.

Standard operating procedures (SOPs), as with any industrial process or practice, are recommended for the industrial radiography practice too, which are to be followed by the operators for safe operation of the radiography devices. However, due to overconfidence and/or ignorance, some of the steps of SOP may not be followed, ill followed or missed by the operator, thus, leading to potential exposures to ionizing radiation. Depending on the accidental scenario, sometimes the exposure received may be high enough to cause radiation injury, and in extreme cases, lead to permanent amputation of the organ. All the aspects related to radiation safety during operation of IGRED have been analyzed in this research work.

Industrial radiography operations are carried out, both, in the open field and the enclosed installations scenarios. Risk assessment has been carried out in both of these practical scenarios using the Probabilistic Safety Analysis (PSA) methodology. The process flow for the operational analysis and the risk assessment is provided in figure 1.7.

1.8 CHAPTERS SCHEME

The content of this thesis is structured into chapters as follows:

CHAPTER 1 provides a general introduction to the research topic, the objectives and the scope of the present research work. This chapter also describes the properties of ionizing radiations and the associated health hazards. Various applications of radioactive sources have also been described in this chapter. This chapter outlines in brief the methodology used, including the research model used for the analysis and risk assessment.

CHAPTER 2 reviews the existing literature related to safety analysis and risk assessment for practices using radiation sources, especially about the non-nuclear radiation facilities. This chapter also reviews other research studies published in the field of industrial radiography. Based on the literature review, 'gap' areas have been identified in this chapter. The chapter also outlines the international guidelines and recommendations for carrying out risk assessment for non-nuclear radiation applications.

CHAPTER 3 describes in detail the industrial radiography practice in India. Historical background and current status of this practice carried out in India has been discussed. The chapter also provides a brief note on the unusual incidents/accidents in industrial radiography.

CHAPTER 4 provides a detailed analysis of the design of industrial gamma radiography exposure devices. Data generation for failure assessment and its utilization for the present study have been discussed in this chapter. This chapter describes the research work carried out for the design based risk assessment of radiography devices using FMEA methodology. Based on the results of the present research work, recommendations have been provided for risk management in industrial radiography practice.

CHAPTER 5 describes the operational and safety aspects of the industrial radiography practice. The reliability assessment for the radiation monitoring instruments has been carried out in this chapter. Failure rate and unavailability of these instruments for their intended function have been calculated. Different practical scenarios of radiography operations have been discussed and analyzed for this work. This chapter describes the standard operating procedures (SOP) for radiography operations under these scenarios. The framework of SOP which has been utilized for risk assessment has been analyzed and discussed there.

CHAPTER 6 describes the research work carried out for the operational risk assessment in industrial radiography practice in India. Data generation methodology and data analysis related to radiography operations have been provided there. Operational risk assessment has been carried out using risk assessment methodology. Probabilities of potential exposure and contributing factors for potential exposure to operating personnel in industrial radiography practice have been identified from those results, and recommendations have been made to enhance the radiation safety in the practice.

CHAPTER 7 provides a summary of the research work carried out for design and operational analysis, and risk assessment in industrial radiography practice in India. The result based conclusions have been discussed in that chapter. That Chapter also provides suggestions for future work for the risk assessment and management in applications of radiation sources.

References and Appendix have been consolidated and have been provided at the end for cross reference purpose.
