Chapter one: Nuclear Radiation

1.1 Introduction:

Radiation is energy in the form of waves or streams of particles. There are many kinds of radiation all around us. When people hear the word radiation, they often think of atomic energy, nuclear power and radioactivity, but radiation has many other forms. Sound and visible light are familiar forms of radiation; other types include ultraviolet radiation (that produces a suntan), infrared radiation (a form of heat energy), and radio and television signals.

Uncontrolled use of man-made radiation carries a potential risk to the health and safety of workers and the public. This is where the Canadian Nuclear Safety Commission (CNSC) comes in. The CNSC regulates the use of nuclear energy and materials to protect the health, safety and security of Canadians and the environment from the effects of radiation [1].

The purpose of this document is to provide clear and simple information about radiation: what it is, where it comes from and how it is used. It also presents information on radiation health effects, radiation doses and how the CNSC ensures the safety of the Canadian nuclear sector through its comprehensive regulatory framework and vigilant oversight [1].

All life has evolved in an environment filled with radiation. The forces at work in radiation are revealed upon examining the structure of atoms. Atoms are a million times thinner than a single strand of human hair, and are composed of even smaller particles – some of which are electrically charged [1].

1.2 Types and Sources of Radiation:

Radiation is energy in the form of waves of particles. There are two forms of radiation – non-ionizing and ionizing [1].

1.2.1 Non-ionizing radiation

Non-ionizing radiation has less energy than ionizing radiation; it does not possess enough energy to produce ions. Examples of non-ionizing radiation are visible light, infrared, radio waves, microwaves, and sunlight. Global positioning systems, cellular telephones, television stations, FM and AM radio, baby monitors, cordless phones, garage-door openers, and ham radios use non-ionizing radiation. Other forms include the earth's magnetic field, as well as magnetic field exposure from proximity to transmission lines, household wiring and electric appliances. These are defined as extremely low-frequency (ELF) waves and are not considered to pose a health risk [2].

1.2.2 Ionizing radiation

Ionizing radiation is capable of knocking electrons out of their orbits around atoms, upsetting the electron/proton balance and giving the atom a positive charge. Electrically charged molecules and atoms are called ions. Ionizing radiation includes the radiation that comes from both natural and man-made radioactive materials. There are several types of ionizing radiation [2].

1.2.2.1 Alpha particle radiation (α)

Alpha radiation consists of alpha particles that are made up of two protons and two neutrons each and that carry a double positive charge. Due to their relatively large mass and charge, they have an extremely limited ability to penetrate matter. Alpha radiation can be stopped by a piece of paper or the dead outer layer of the skin. Consequently, alpha radiation from nuclear substances outside the body does not present a radiation hazard. However, when alpha-radiation-emitting nuclear substances are taken into the body (for example, by breathing them in or by ingesting them), the energy of the alpha radiation is completely absorbed into bodily tissues. For this reason, alpha radiation is only an internal hazard. An example of a nuclear substance that undergoes alpha decay is radon-222, which decays to polonium-218 [3].

1.2.2.2 Beta particle radiation (β):

Beta radiation consists of charged particles that are ejected from an atom's nucleus and that are physically identical to electrons. Beta particles generally have a negative charge, are very small and can penetrate more deeply than alpha particles. However, most beta radiation can be stopped by small amounts of shielding, such as sheets of plastic, glass or metal. When the source of radiation is outside the body, beta radiation with sufficient energy can penetrate the body's dead outer layer of skin and deposit its energy within active skin cells. However, beta radiation is very limited in its ability to penetrate to deeper tissues and organs in the body. Beta-radiation-emitting nuclear substances can also be hazardous if taken into the body. An example of a nuclear substance that undergoes beta emission is tritium (hydrogen-3), which decays to helium-3.6 December 2012 [3].

1.2.2.3 Photon radiation (gamma [γ] and X-ray).

Photon radiation is electromagnetic radiation. There are two types of photon radiation of interest for the purpose of this document: gamma (γ) and X-ray. Gamma radiation consists of photons that originate from within the nucleus, and X-ray radiation consists of photons that originate from outside the nucleus, and are typically lower in energy than gamma radiation.

Photon radiation can penetrate very deeply and sometimes can only be reduced in intensity by materials that are quite dense, such as lead or steel. In general, photon radiation can travel much greater distances than alpha or beta radiation, and it can penetrate bodily tissues and organs when the radiation source is outside the body. Photon radiation can also be hazardous if photon-emitting nuclear substances are taken into the body. An example of a nuclear substance that undergoes photon emission is cobalt-60, which decays to nickel-60 [3].

1.2.2.4 Neutron radiation (n):

Apart from cosmic radiation, spontaneous fission is the only natural source of neutrons (n). A common source of neutrons is the nuclear reactor, in which the splitting of a uranium or plutonium nucleus is accompanied by the emission of neutrons. The neutrons emitted from one fission event can strike the nucleus of an adjacent atom and cause another fission event, inducing a chain reaction.

The production of nuclear power is based upon this principle. All other sources of neutrons depend on reactions where a nucleus is bombarded with a certain type of radiation (such as photon radiation or alpha radiation), and where the resulting effect on the nucleus is the emission of a neutron. Neutrons are able to penetrate tissues and organs of the human body when the radiation source is outside the body. Neutrons can also be hazardous if neutron-emitting nuclear substances are deposited inside the body. Neutron radiation is best shielded or absorbed by materials that contain hydrogen atoms, such as paraffin wax and plastics. This is because neutrons and hydrogen atoms have similar atomic weights and readily undergo collisions

Between each other [3].

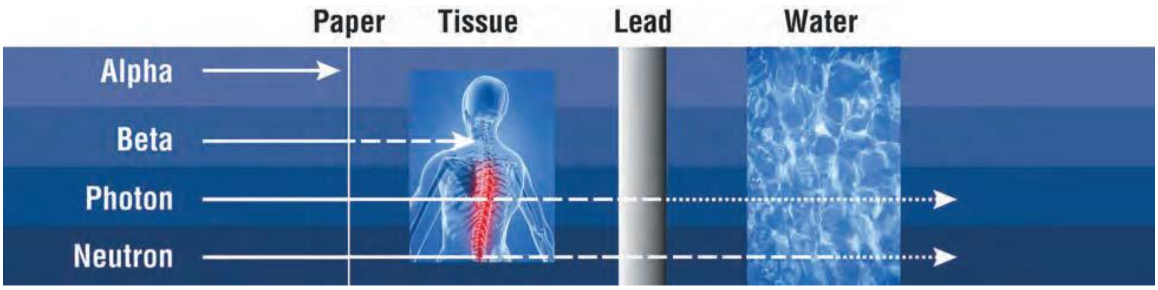


Figure 1.1: Penetration abilities of different types of ionizing radiation.

1.3 Natural sources of ionizing radiation:

Radiation has always been present and is all around us in many forms Life has evolved in a world with significant levels of ionizing radiation, and our bodies have adapted to it.

Many radioisotopes are naturally occurring, and originated during the formation of the solar system and through the interaction of cosmic rays with molecules in the atmosphere. Tritium is an example of a radioisotope formed by cosmic rays' interaction with atmospheric molecules. Some radioisotopes (such as uranium and thorium) that were formed when our solar system was created have half-lives of billions of years, and are still present in our environment. Background radiation is the ionizing radiation constantly present in the natural environment [3].

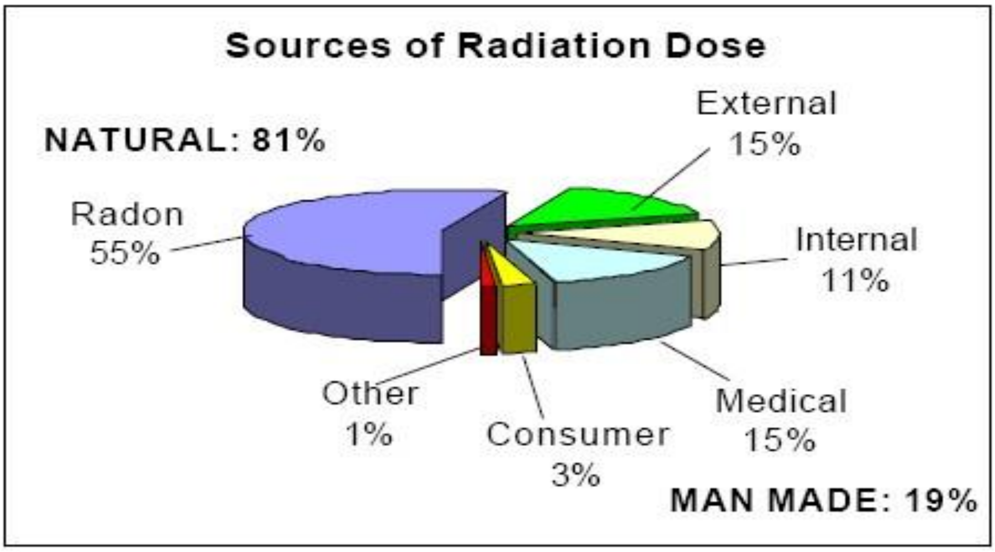
The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) identifies four major sources of public exposure to natural radiation:

• Cosmic radiation

• Terrestrial radiation

• Inhalation

• Ingestion



- **Figure 1.2** Natural sources (81%) include radon (55%), external (cosmic, terrestrial), and internal (K-40, C-14, etc.)
- Man-made sources (19%) include medical (diagnostic x-rays- 11%, nuclear medicine- 4%), consumer products, and other (fallout, power plants, air travel, occupational, etc.).

1.3.1 Exposure from cosmic radiation:

The earth's outer atmosphere is continually bombarded by cosmic radiation. Usually, cosmic radiation consists of fast moving particles that exist in space and originate from a variety of sources, including the sun and other celestial events in the universe. Cosmic rays are mostly protons but can be other particles or wave energy. Some ionizing radiation will penetrate the earth's atmosphere and become absorbed by humans which results in natural radiation exposure [4].

1.3.2 Exposure from terrestrial radiation:

The composition of the earth's crust is a major source of natural radiation. The main contributors are natural deposits of uranium, potassium and thorium which, in the process of natural decay, will release small amounts of ionizing radiation. Uranium and thorium are found essentially everywhere. Traces of these minerals are also found in building materials so exposure to natural radiation can occur from indoors as well as outdoors [4].

1.3.3 Exposure through inhalation:

Most of the variation in exposure to natural radiation results from inhalation of radioactive gases that are produced by radioactive minerals found in soil and bedrock. Radon is an odorless and colorless radioactive gas that is produced by the decay of uranium. Theron is a radioactive gas produced by the decay of thorium. Radon and thorn levels vary considerably by location depending on the composition of soil and bedrock. Once released into the air, these gases will normally dilute to harmless levels in the atmosphere but sometimes they become trapped and accumulate inside buildings and are inhaled by occupants. Radon gas poses a health risk not only to uranium miners, but also to homeowners if it is left to collect in the home. On average, it is the largest source of natural radiation exposure [5].

1.3.4 Exposure through ingestion:

Trace amounts of radioactive minerals are naturally found in the contents of food and drinking water. For instance, vegetables are typically cultivated in soil and ground water which contains radioactive minerals. Once ingested, these minerals result in internal exposure to natural radiation. Naturally occurring radioactive isotopes, such as potassium-40 and carbon-14, have the same chemical and biological properties as their non-radioactive isotopes. These radioactive and non-radioactive elements are used in building and maintaining our bodies. Natural radioisotopes continually expose us to radiation and are commonly found in many foods, such as Brazil nuts [6].

1.4 Artificial (man-made) sources of ionizing radiation:

People are also exposed to man-made radiation from medical treatments and activities involving radioactive material. Radioisotopes are produced as a by-product of the operation of nuclear reactors, and by radioisotope generators like cyclotrons. Many man-made radioisotopes are used in the fields of nuclear medicine, biochemistry, the manufacturing industry and agriculture. The following are the most common sources [7].

1.4.1 Medical sources:

Radiation has many uses in medicine. The best-known application is in X-ray Machines, which use radiation to find broken bones or to diagnose diseases. Another example is nuclear medicine, which uses radioactive isotopes to diagnose and treat diseases such as cancer. A gamma camera (see Figure 2) is one piece of medical equipment commonly used in diagnosis [8].

Figure1.3: A gamma camera used in nuclear medicine, for diagnosing illnesses

1.4.2 Industrial sources:

Radiation has various industrial uses, which range from nuclear gauges (see Figure 3) used in the building of roads to density gauges that measure the flow of material through pipes in factories. Radioactive materials are also used in smoke detectors and some glow-in-the dark exit signs, as well as to estimate reserves in oil fields. Other applications include sterilization, which is performed using large, heavily shielded irradiators. Industrial activities are licensed by the CNSC [9].

Figure1.4: A portable nuclear gauge

1.5 Nuclear fuel cycle:

Nuclear power plants (NPPs) use uranium to produce a chain reaction that produces steam, which in turn drives turbines to produce electricity. As part of their normal activities, NPPs release small quantities of radioactive material in a controlled manner to the surrounding environment. These releases are regulated to ensure doses to the public are well below regulatory limits. Uranium mines, fuel fabrication plants and radioactive waste facilities are also licensed so the radioactivity they release (that can contribute to public dose) can be controlled by the CNSC [10].

Figure 5.1: Mc Clean Lake Uranium Mine (Saskatchewan):

1.6 Health Effects of Radiation Exposure:

The word “safe” means different things to different people. For many, the idea of being safe is the absence of risk or harm. However, the reality is that almost everything we do presents a certain level of risk. For example, speed limits on roads are set to maximize safety. Nevertheless, accidents occur even when drivers obey the speed limit. Despite this risk, we still drive.

Similar informed decisions are made when radiation is used. Radiation exposure carries a health risk. Understanding the risks helps the CNSC and other regulatory bodies establish dose limits and regulations that keep exposure at an acceptable or tolerable risk level, where it is unlikely to cause harm. One significant advantage of radiation is that more is known about its associated health risks than about any other chemical or otherwise toxic agent. Since the early 20th century, radiation effects have been studied in depth, in both the laboratory and among human populations [11].

Chapter Two: Effect of Nuclear Radiation to Human and Environment

2.1 Introduction:

All life has evolved in an environment filled with radiation. The forces at work in radiation are revealed upon examining the structure of atoms. Atoms are a million times thinner than a single strand of human hair, and are composed of even smaller particles – some of which are electrically charged.

2.2 Effects of Ionizing Radiation:

Ionizing radiation has sufficient energy to knock bound elections out of an atom or molecule. Includes alpha/beta particles and gamma/x-rays. Can form highly reactive free radicals with unpaired electrons

For example, H2O → [H2O.] + e-

Rapidly dividing cells in the human body are particularly susceptible to damage by free radicals. Radiation can be used to treat certain cancers and Graves' disease of the thyroid However, ionizing radiation can also damage healthy cells Biological damage determined by radiation dose, type of radiation, rate of delivery, and type of tissue [12].

2.3 Radiation Units:

Activity- disintegration rate of radioactive substance Becquerel- SI unit (Bq) = 1 disintegration per second (dps). Curie (Ci) = 3.7 x 1010 Bq = # dps from 1g Ra Absorbed dose- energy imparted by radiation onto an absorbing material. Gray- SI unit (Gy) = 1 joule per kilogram. 1 Gy = 100 rads. Dose Equivalent (DE)- dose in terms of biological effect. DE = Absorbed dose X Quality factor (Q). Q = 1 for beta particles and gamma/x-rays. Q = 10 for alpha particles. Sievert- SI unit (Sv). 1 Sv = 100 rem [13].

2.4 Physiological Effects of Acute Radiation Exposure:

No observable effect (< .25 Gy) - .25 Gy is nearly 70 times average annual radiation exposure. White blood cell count drops (.25 to 1 Gy)

Mild radiation sickness (1 to 2 Gy absorbed dose)

- Nausea and vomiting within 24 to 48 hours
- Headache
- Fatigue
- Weakness

Moderate radiation sickness (2 to 3.5 Gy) Nausea and vomiting within 12 to 24 hours

- Fever
- Hair loss
- Vomiting blood, bloody stool
- Poor wound healing
- Any of the mild radiation sickness symptoms
- Can be fatal to sensitive individuals

Severe radiation sickness (3.5 to 5.5 Gy) Nausea and vomiting less than 1 hour after exposure.

- Diarrhea
- High fever
- Any symptoms of a lower dose exposure
- About 50% fatality

Very severe radiation sickness (5.5 to 8 Gy)

- Nausea and vomiting less than 30 minutes after exposure
- Dizziness
- Disorientation
- Low blood pressure
- Any symptoms of a lower dose exposure
- > 50% fatality

Longer term or chronic radiation effects include genetic mutations, tumors/cancer, birth defects, cataracts, etc. [14].

2.5 Effect of Smoking on Radiation Dose:

Average annual whole body radiate dose is about 360 mrem. If you smoke, add about 280 mrem (source does not specify # packs per day smoked) Tobacco contains Pb-210, which decays to Po-210. Pb-210 deposits in bones. Po-210 in liver, spleen, and kidneys [15].

2.6 Long Term Effects of Low Radiation Doses:

Long term effects of low doses of radiation still unknown. Two radiation dose-response models. Linear non-threshold. More conservative model used by EPA and other federal agencies

Radiation harmful at all doses, even low ones. Threshold. Assumes cellular repair at low doses. Assumes low doses are safe.

2.7 Safety in nuclear reactor:

2.7.1 Introduction:

The basic principle of nuclear safety, defense-in-depth, continues to be employed also in advanced reactors. However, it was recognized that future and advanced reactors pose several questions and challenges to the implementation of defense-in-depth. In the past, this has been achieved primarily through deterministic implementation of provisions and multiple physical barriers against the release of fission products, and by measures to prevent accidents and mitigate their consequences The emphasis put on prevention and/or mitigation differs among the various advanced concepts. The approach to the safety of future reactors will need to be derived from a more advanced interpretation of defense-in-depth fully integrated with PSA insights. How the best integration of the deterministic and probabilistic concepts will be achieved is still a major open question?

The advanced reactor concepts discussed in the workshop were mostly limited to Advanced Light Water Reactors (ALWRs), High-Temperature Gas-Cooled Reactors (HTGR) and Liquid-Metal Cooled Reactors (LMR). The concepts discussed can be divided roughly into two categories: mature ones, (more or less) ready for market, such as Framatome-ANP's SWR-1000 or Westinghouse AP-600, and preliminary ones, such as IRIS (an ALWR), and most LMRs and HTGRs. A common feature to all advanced reactor types is that they promise safety enhancement over the current generation of plants; likewise, the safety significance and provisions to be made against external hazards are common questions that pertain to all future designs.

Mature ALWR concepts are characterized by increased simplicity and streamlining in their safety system design, significant amount of passive (system) features, and explicit consideration of severe accidents as a part of their design basis. Regarding severe accidents, the ambitions of their technical and regulatory treatment varies between Europe and United States. European vendors and

Regulators specifically require qualification of the dependability of their severe accident capabilities (which does not mean that all related technical issues would already have been categorically resolved;

Design features are selected also on the basis of PSA insights to effectively eliminate severe accident sequences that would be overly complex to manage) while in the US, PSAs are relied upon more

Extensively to identify severe accident vulnerabilities and appropriate measures to reduce the risk from severe accidents.

As to LMRs, considerable experience base from operating sodium-cooled reactors exists, and convergence seems to be occurring in treatment of certain major issues such as Core Disruptive Accidents and sodium related issues. As far as lead/bismuth cooled reactors are concerned, significant remaining questions relate (among others) to materials and thermal-hydraulics issues (integrity, corrosion, thermal loads and heat transfer, irradiation effects, etc.). It should be noted, though, that11 considerable operating experience (about 80 reactor-years) has been gained with Russian submarines

Using the same type of coolant. Several research institutions in OECD Member countries are building research facilities to intensify experimental and analytical HLM investigations [16].

2.8 Literature Review:

2.8.1 Reactor Characteristics Important in Control System Design:

An important problem in reactor control system design is the requirement that the instrumentation and control equipment be capable of operating over an unusually wide range, Ranges of 10 to 11 decades are not uncommon. Figure 1 shows typical reactor startup. and operating ranges. Appropriate instrumentation is indicated'. It is necessary to use several different types of detecting equipment to provide, valid information throughout the entire startup. From shutdown or source level to about three decades above, proportional counters are used, Over the next to three decades, fission chambers are employed. By moving these chambers away from the reactor core the effective range can be extended to provide information up to full power. Compensated ionization chambers, if properly adjusted, can be used from about six decades below up to full power. Uncompensated chambers provide information from three decades below up to and somewhat above the full Power rating of the reactor. These detectors are usually employed in the safety system. For safe operation of a nuclear reactor a knowledge of the rate of change of power level as well as the power level itself is required. Since in most cases the nuclear instruments sense the neutron population within the reactor, rate of change of neutron population can be derived. The rate of change of neutron population is usually described in terms of the reactor period. Reactor period is defined as the time required for the neutron flux to change by a factor of e. Figure 1 indicates that period information is usually available from six decades below up to full power, Instrumentation exists which will provide period information from the low level counting channels. Period information is used for control purposes during startup. It is fed to the safety system both during startup and operational fixed power. The safety system thus protects against short reactor periods in addition to excessively high power levels.

2.8.2 Kinetic Behavior of Reactors:

The response of a reactor to a change in excess reactivity is an important factor in the successful performance of a control system. This response is strongly dependent both upon the operating power Level' and the amount of excess reactivity present. If the excess reactivity of the reactor is such that it is delayed critical, that is the contribution of delayed neutrons is necessary to produce criticality, its behavior depends. Almost entirely on the delayed neutrons. In a thermal reactor usingUranium235 the average generation time for neutrons is then about 0.1 seconds and the response of the reactor to changes in excess reactivity is relatively sluggish. However, should the excess reactivity in the reactor exceed the delay fraction A, the generation time is determined by prompt neutrons and is of the 'order of microseconds. for instance, for the swimming-pool-type research reactor the.

generation time under these circumstances would be about 5*10 -5 seconds. On fast reactors these times maybe: of the order of 5*10 -5 seconds. These short generation times produce correspondingly more

rapid changes in. power level in response to a change in reactivity.

It is seen that those reactors in which excess reactivity's are maintained at less than their delay fractions, will be relatively easier to control. Once beyond the delay fraction the control requirements become quite severe because of the fast response required of the control system. Reactors designed so that delayed neutrons do not contribute to critical it may place severe requirements on a control system.

2.8.3 Reactor Protection:

Emergency shutdown of a reactor maybe accomplished by rapid insertion of neutron absorbing materials into the core, by rapid removal of fuel or by a rapid change of the neutron leakage from the core.

Most research reactors and manpower reactors employ absorbing rods containing cadmium or boron. Some of these rods are used to make small slow changes in reactivity for control. The others are inserted or dropped into the reactor when an emergency condition arises. The process of dropping or rapidly inserting safety rods into a reactor is often referred to as scramming the reactor.

In addition to changes reactivity made externally, internal changes in core composition or structure may occur. For example, a change in power level may cause a change in neutron absorption or leakage thus changing the excess reactivity. Such changes may be caused by changes in temperature or pressure which produce Corresponding. Changes in core density or structure. If an increase in temperature decreases reactivity, the reactor is said to have a negative temperature coefficient of reactivity. Conversely if an increase in temperature produces an increase in reactivity, the coefficient is said to be positive. Clearly, a negative temperature Coefficient, of reactivity which remains negative over the entire range of operating temperatures provides a degree of self-protection. The size and time of lag of the coefficient and thus the degree of protection depends on the reactor type. For instance, a homogeneous reactor has a much larger negative temperature coefficient than the Swimming—pool-type reactor.

2.9 The IAEA Safety Standards:

2.9.1 Background:

Radioactivity is a natural phenomenon and natural sources of radiation are features of the environment. Radiation and radioactive substances have many beneficial applications, ranging from power generation to uses in medicine, industry and agriculture. The radiation risks to workers and the public and to the environment that may arise from these applications have to be assessed and, if necessary, controlled.

Activities such as the medical uses of radiation, the operation of nuclear installations, the production, transport and use of radioactive material, and the management of radioactive waste must therefore be subject to standards of safety. Regulating safety is a national responsibility. However, radiation risks may transcend national borders, and international cooperation serves to promote and enhance safety globally by exchanging experience and by improving capabilities to control hazards, to prevent accidents, to respond to emergencies and to mitigate any harmful consequences. States have an obligation of diligence and duty of care, and are expected to fulfil their national and international undertakings and obligations. International safety standards provide support for States in meeting their obligations under general principles of international law, such as those relating to environmental protection. International safety standards also promote and assure confidence in safety and facilitate international commerce and trade. A global nuclear safety regime is in place and is being continuously improved. IAEA safety standards, which support the implementation of binding international instruments and national safety infrastructures, are a cornerstone of this global regime. The IAEA safety standards constitute a useful tool for contracting parties to assess their performance under these international conventions (16).

2.9.2 Safety Fundamentals:

Safety Fundamentals present the fundamental safety objective and principles of protection and safety, and provide the basis for the safety requirements.

2.9.3 Safety Requirements:

An integrated and consistent set of Safety Requirements establishes the requirements that must be met to ensure the protection of people and the environment, both now and in the future. The requirements are governed by the objective and principles of the Safety Fundamentals. If the requirements are not met, measures must be taken to reach or restore the required level of safety. The format and style of the requirements facilitate their use for the establishment, in a harmonized manner, of a national regulatory framework. Requirements, including numbered 'overarching' requirements, are expressed as 'shall' statements. Many requirements are not addressed to a specific party, the implication being that the appropriate parties are responsible for fulfilling the [16]

Table 2.1 safety Fundamentals

SAFETY FUNDAMENTALS
Fundamental Safety Principles

General Safety Requirements

Part 1	Governmental, Legal and Regulatory Framework for Safety
Part 2	Leadership and Management for Safety
Part 3	Radiation Protection and the Safety of Radiation Sources
Part 4	Safety Assessment for Facilities and Activities
Part 5	Predisposal Management of Radioactive Waste
Part 6	Decommissioning and Termination of Activities
Part 7	Emergency Preparedness and Response

Specific Safety Requirements

1	Site Evaluation for Nuclear Installations
2 2.1 2.2	Safety of Nuclear Power Plants Design and Construction Commissioning and Operation
3	Safety of Research Reactors
4	Safety of Nuclear Fuel Cycle Facilities
5	Safety of Radioactive Waste Disposal Facilities
6	Safe Transport of Radioactive Material

Collection of Safety Guides

2.10 Control and safety of nuclear reactors:

to reduce to negligible number, the probability of a serious episode in the core, in the control systems and in the operation of the reactors. Safety and control systems of nuclear reactors are developed with every technological resource available at the time they are conceived and obey strict manufacturing and certification norms established by international agencies. Even in older reactors, these devices are almost "fail-safe". For instance, Angra I reactor in Álvaro Alberto Nuclear Complex, built with technology from the 1970's, had a turbulent beginning with problems that interrupted the generation of energy on several occasions; yet, none of these were related to the core – the most critical, and therefore most protected region of the reactor. In addition to being technologically advanced, the safety devices for reactor cores comprise redundant systems, that is, they include more than one protection circuit for the same component of the reactor. Should one circuit fail, another comes immediately into action, reducing the probability that a nuclear malfunction progresses over time. A quick overview of the history of nuclear energy shows that the most significant accidents with nuclear reactors were due to operational failure, to misguided or mistaken interventions in the reactor's test procedures. That is what happened at Three Mile Island, in the US in 1979, and at Chernobyl, in Russia in 1986. In the former, operators mistakenly turned off a protection system of the reactor, which led to the excursion of the core's temperature. In the latter, specific safety devices were turned off during the profiling of an accident and the operators were unable to identify the proper time to intervene in the system [17].

2.11 Reactor Characteristics Important in Control System Design:

An important problem in reactor control system design is the requirement that the instrumentation and control equipment be capable of operating over an unusually wide range, Ranges of 10 to 11 decades are not uncommon. Figure

1 shows typical reactor startup. And operating ranges. Appropriate instrumentation is indicated'. It is necessary to use several different types of detecting equipment to provide, valid information throughout the entire startup. From shutdown or source level to about three decades above, proportional counters are used, over the next to three decades, fission chambers are employed. By moving these chambers away from the reactor core the effective range can be extended to provide information up to full power. Compensated ionization chambers, if properly adjusted, can be used from about six decades below up to full power. Uncompensated chambers provide information from three decades below up to and somewhat above the full power rating of the reactor. These detectors are usually employed in the safety system.

For safe operation of a nuclear reactor a knowledge of the rate of change of power level as well as the power level itself is required. Since in most cases the nuclear instruments sense the neutron population within the reactor, rate of change of neutron population can be derived. The rate of change of neutron population is usually described in terms of the reactor period. Reactor period is defined as the time required for the neutron flux to change by a factor of e. Figure 1 indicates that period information is usually available from six decades below up to full power, Instrumentation exists which will provide period information from the low level counting channels. Period information is used for control purposes during startup. It is fed to the safety system both during startup and operation at fixed power. The safety system thus protects against short reactor periods in addition to excessively high power levels [18].

2.12 Safety Systems:

Two safety systems which have been widely used are the "auctioneering" type and the coincident" type. The MTR—ORNL safety system is an auctioneering type. This system employs several complete channels that monitor the neutron or power level as well as the reactor period during all phases of reactor operation. These channels feed information to a common bus, known as the Sigma bus, which in turn monitors the mechanisms which hold the safety rods. Coupling between the electronic instrumentation and the safety rods is accomplished by specially designed electromagnets. When the period or neutron level reach certain pre-selected values the Sigma bus acts to decrease the current in the electromagnets thus releasing the safety rods which then fall into the reactor.

Since all channels are connected to the Sigma bus, any single channel is capable of dropping all rods into the core 0 on most installations employing the MTR-ORNL type safety system, the rods fall under the, influence of gravity. Because of its extremely short response time and its auctioneering arrangement (the control of the safety rods goes to the highest. bidder) it provides a maxi mum of protection. This system was developed primarily for research reactors whose operational and experimental characteristics are frequently changed. Although any malfunction or false signal, in any single channel of the system will shut down the reactor, this is usually more of an inconvenience than a disadvantage on a research reactor.

Power reactors cannot usually withstand physically or tolerate operationally unnecessary shutdowns. The coincident, type safety system 3 is designed to reduce such shutdowns to a minimum. In this system, which also uses a multiplicity of channels, two or more channels must agree that an emergency condition exists before a reactor scram is initiated. This system, although it provides for continuity of reactor operation does not generally offer the same degree or reliability of protection as the auctioneering type there are two reasons for this:

(1) The requirement that two or more channels concur usually introduces delays in the initiation of safety action, and (2)additional equipment is required which increases the probability of component failure. Siddall has shown, however, that if properly selected and arranged in a suitable complex, the addition of components can enhance rather than diminish the reliability of a system [20].

Although many safety systems fall into one of the two categories discussed above it is generally true that both the characteristics of the individual reactor and its operational requirements strongly influence the choice of an appropriate safety system. Thus some modification of one of the above systems may be used or some entirely different scheme may be employed.

No matter what type of safety system is chosen, the response time of the system is of primary importance. 5 A quantitative value of time response may be difficult to establish. The response time must generally be evaluated separately for each type of reactor accident considered. Response time may be defined as the total elapsed time from the existence of an emergency condition to the time the reactor power level (or period) is brought to a prescribed value, Response time defined in this way is critically dependent on the type of accident, the type of reactor, and the design of the safety system itself. For example, if an amount of reactivity equal to A is suddenly i±iserted into the reactor, making it prompt critical, a meaningful definition of response time is the elapsed time from the insertion of the positive reactivity to the time that the reactor power level ceases to increase. In other cases we may wish to define the response time as that time required by the safety system to reduce the power to a prescribed value. Under either of the definitions above, the response time depends on the -time constants of the instrumentation, the release time of the electromagnets, or similar devices, the effectiveness of the safety rods, Orr, their equivalent, and the inherent characteristics of the reactor.

The time response required of a safety system must be determined during the initial design stages of the reactor and its control system. Establishing the requirements of a system requires detailed examination of reactor response. For instance, if we postulate the sudden insertion of 2 of positive reactivity, it night be expected that 2.62 of negative "reactivity would have to be inserted rapidly to stop the power excursion. Actually, if approximately l' is inserted quickly, the reactor power will level off momentarily hile waiting for the delayed neutrons. This delay gives additional time for the remaining necessary negative reativity to be inserted, Figure 3 clearly demonstrates this point).

2.13 startup consideration:

starting the reactor from shutdown level and raising it to full power covers a wide range of operation. During startup safety rods are withdrawn, introducing positive reactivity. If this reactivity is introduced rapidly, the reactor gets on a short period and rises to a high power level in a short interval of time, If this period is short compared to the response time of the safety system, the reactor nay be damaged or destroyed before the safety system has time to take corrective action. To avoid this situation, withdrawal rates are restricted such that if an accident occurs in which all of the safety rods are withdrawn simultaneously at the maximum possible speed, the resulting period and power excursion fall we'l within the capabilities of the safety system. Newson's criterion ,2 has been used on several reactors in establishing the rate of insertion of reactivity consistent with the response time of the safety system. This criterion was established for a heterogeneous-light-water-moderated research reactor. This or similar criteria should be involved for other-reactor types [21].

Chapter Three: Safety of Nuclear Power Plants

3.1 Introduction:

Basic Safety Problem and Safety Philisophy („Defense-in-Depth"), Design Principles, Accident Management, Trends.

3.2 Safety Features of Nuclear Power Plants

3.2.1 The major engineering safety features to cope with LOCA:

1. The Emergency Core Cooling System (ECCS) designed to supply water to the reactor core in the event of a Loss of Coolant Accident (LOCA).
2. The containment vessel designed to provide a barrier to the escape to the environment of possible radioactivity - released from the core/primary circuit.
3. The clean-up system designed to remove part of the radioactivity and the heat that may be present in the containment.
4. Hydrogen control to prevent formation of an explosive mixtures in the containment.

3.2.2 The ECSS of a pressurized water reactor consists of:

1. High Pressure Injection System (HPIS)
2. Accumulator Injection System (AIS)
3. Low Pressure Injection System (LPIS)

Note: HPIS and LPIS are active systems while AIS is a passive system.

3.3 Physical Barriers of a Light Water Reactor:

- **Fuel matrix** (made of ceramic material, which has a lower heat flux conductivity compared to metallic uranium, but a higher melting point).

- **Fuel rod** (made of zircaloy used for reasons of the neutron flux) keeps mechanically together the fuel pellets and retains fission products.
- **Envelop of primary loop** (in case of PWR: reactor pressure vessel and pipes to and within the steam generator; in case of BWR also the water-steam-circuit including the turbine housing), made of high quality steal.
- **Containment** designed against accidental pressures and for reactor protection against external loads; adequate sub-systems for complete isolation against the environment.

3.4. Design Basis Accidents (DBA):

- Selection of (representative, covering) accidents, which are expected to occur during the lifetime of a nuclear power plant or which cannot be excluded following human discretion (i.e. frequency > 10^{-6} per year).
- Design of the plant in such a manner, that the occurrence of such an accident does not lead to unacceptable consequences in the environment.
- For the verification, both an accident initiating event and the unavailability of an independent safety system needed to handle accidents are assumed (redundancy criterion; there is no need to assume additional system failures).

3.5 Design Base Accidents (DBA) or "Postulated Initiating Events" (PIE):

- IAEA requirement to take events into account when designing the plant that have a probability of accuring more than once every 10,000 years. PIEs will cause no or minor radioactive release.

- Countries are expected to incorporate IAEA require.

3.6. Beyond Design Basis Accidents (BDBA):

- Accidents are beyond design basis, if they can be characterized by multiple failures of systems needed to handle accidents or if they are instantiated by very rare events. The occurrence of such accidents is understood, based on the experience, as very unlikely (frequency < 10^{-6} per year).
- In contrast to DBA, it cannot be excluded that radioactive substances in a harmful amount are released to the environment; no dose limits for persons around the site are defined.

3.7. Safety Concept - Basic provisions:

3.7.1 Design Basis Accidents:

- Categories:

1. $\leq 10^{-1} \ldots > 10^{-2}$
2. $\leq 10^{-2} \ldots > 10^{-4}$
3. $\leq 10^{-4} \ldots > 10^{-6}$

- No ineligible release of radioactivity and radiation of persons, limits – depending on frequency of DBA – fixed by radiation protection ordinance Frequency to be determined by multiplication of frequency of initiating event and single failure probability (0.1, 0.01 if proven by experience).

3.7.2 Beyond Design Basis Accidents:

- Initiating events and additional failures beyond design

- Release of dangerous amounts of rad. substances cannot be excluded

3.8 Concept of defense in depth:

3.8.1 Protection Goals:

- control of reactivity
- cooling of core material and rad. waste
- confinement of rad. substances
- limitation of radiation expose

3.8.2 Accident Analysis:

- deterministic analysis to demonstrate compliance with protective goals
- probabilistic analysis (PSA) to demonstrate that protective measures are sufficient and balanced.

3.8.3 Target values for existing NPPs:

- total core damage frequency (CDF) less than 10^{-4}/a
- adequate precautions against accidents for CDF between 10^{-4} and 10^{-5}/a
- frequency of large release of rad. substances significantly less than CDF
- Guidelines for PSA - requirements to be established.
- proof of sufficient protection against natural events for hazards $\geq 10^{-4}$/a,e.g. earthquakes.
- protection against aircraft crash for military and commercial planes in operation when applying for a construction license.

3.9 Design and Construction of Nuclear Installations:

- The design of nuclear power plants allows with standing a set of events and resulting loads in an acceptable way.

- Classification of different events based on their frequency of occurrence; events covering all incidents used as design base (e.g. guillotine break of the main cooling pipe); fulfilling deterministically safety and protection goals (e.g. 3×100% or 4×50% redundant design of vital safety systems).
- Accident scenarios with an extreme low probability of occurrence are investigated within a probabilistic risk analysis (PRA).
- Design limits are not fixed but flexible based on experience gained and on development of state of science / technology and related safety requirements.
- Experience from operation and incidents within the design base, data collected and evaluated in order to avoid repetition of unwanted events (e.g. OECD/NEA – IAEA IRS).
- Standardization as natural development, implementation with delay.

3.10. Future Requirements Commonly shared principles for all types of NPPs and for all countries:

"to prevent with high confidence accidents in nuclear plants; to ensure that, for all accidents taken into account in the design of the plant, even those of very low probability, radiological consequences, if any, would be minor; and to ensure that the likelihood of severe accidents with serious radiological consequences is extremely small."

3.11 EPR safety objectives, motivated by the continuous search for a higher safety level, involve reinforced application of the defense-in-depth concept:

- by improving the preventive measures in order to further reduce the probability of core melt.

- by simultaneously incorporating, right from the design stage, measures for limiting the consequences of a severe accident.

Chapter Four: Conclusion and Recommendation

4.1Conclusion:

Out of experience with reactors now in operation, a philosophy of control and safety is developing for these particular reactor types. At present, these control: systems have many features in common. Extensions of present systems will probably be applied to reactors of many types for research and for power. Fundamental principles of reactor control, which will serve as the foundation for control and safety criteria, must be carefully developed in the design and specification of reactor control systems of the future.

The International Nuclear Safety Advisory Group (INSAG) is an advisory group to the Director General of the International Atomic Energy Agency, whose main functions are:

(1) To provide a forum for the exchange of information on generic nuclear safety issues of international significance;

(2) To identify important current nuclear safety issues and to draw conclusions on the basis of the results of nuclear safety activities within the IAEA and of other information;

(3) To give advice on nuclear safety issues in which an exchange of information and/or additional efforts may be required;

(4) To formulate, where possible, commonly shared safety concepts.

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4.2 Recommendation:

The Nuclear Regulatory Commission (NRC) is currently working closely with France and Finland to ensure that the insights from the construction of a new reactor in Finland are integrated into future U.S. regulatory activities. In addition to this effort, the NRC and the Energy Department should jointly commission a detailed study on lessons learned from recent worldwide efforts to build new nuclear reactors, incorporate the commission's recommendations, and hold forums to discuss these issues with nuclear industry officials and other stakeholders. The NRC should vigilantly and proactively enforce its current regulations and encourage a strong safety culture to reduce the risk of significant operating events that can lead to extensive plant shutdowns. The Energy Department, in collaboration with the NRC, should also create a new research and development program in nuclear engineering to provide the advanced tools needed to analyze the safety of reactor designs, fuels, siting options, etc. This would allow the NRC to independently analyze new reactor designs with the expectation that such an approach can lead to transparently safer and less costly projects. The Energy Department should fund projects that find creative solutions via regional partnerships to the nuclear waste created from reactor operation; these grants should include representatives from the countries under discussion. The United States should provide adequate funding to the IAEA to carry out necessary nonproliferation work on a growing industry. Importantly, the nuclear industry should strive to reduce the proliferation potential of its reactors and fuel-cycle facilities and regularly revisit this risk.

If Sudan wants to use these methods to obtain nuclear energy, it must comply with these recommendations and seek to train qualified cadres to comply with these recommendations and laws, especially that Sudan has many deposits of uranium, which is used as a fuel in nuclear.

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