Department of Mechanical and Aerospace Engineering

PUBLIC PERCEPTION TOWARDS NUCLEAR WASTE DISPOSAL: A CASE STUDY WITH KUDANKULAM NUCLEAR POWER PLANT

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Signed: NIKITHAA SURESH Date: 06.09.2013

ABSTRACT

Nuclear Power, in this current world, is one of the principle sources of energy world-wide. Electricity demand has to be met and nuclear power has the capacity needed for heat production in order to run the large turbines that generate electricity. Though this kind of power generation produces maximum power, it is a non-renewable source of energy and its effect on the environment is not predictable. Nuclear power relies directly on the usage of radioactive materials for the nuclear fission process. They leave highly radioactive material as residue and this poses a major threat to the environment. This paper, will aim at understanding the risks associated with nuclear waste and how perception of the society towards nuclear risk, known as "perceived risk", varies from the actual technical risks. The Kudankulam Nuclear Power Plant (KKNP), which is located in Tamil Nadu, India, is chosen as a case study for this project. The VVER (Version V-412) that is in use here is an advanced PWR, which incorporates all the features of a modern PWR as per the current Russian, Western and IAEA standards. Probabilistic Risk Assessment (PRA) techniques, such as Fault Trees, FMEA etc., are carried out in this study to analyse risks from a geological waste repository that is used for permanent disposal of waste. Also, a survey (using survey monkey) is taken to understand how safe the society thinks nuclear waste can be handled in India. Comparison of results from the base case model and the survey show that public awareness about the methods employed for ensuring safety with regards to waste disposal is very less. Though the issue is largely a huge one, the actual impact on the environment is very less, if the disposal is carefully handled.

DEDICATION:

This work is my dedication to Meenkulathi Bhagavathi Amman, whose grace and blessings made it possible for me to embark on this programme and to finish it successfully. It is also dedicated to my Father and Mother for giving me an opportunity to come abroad to start a new career path.

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Chapter 1: Introduction

It is a well- known fact that the Chernobyl power plant in Ukraine was considered to be one of the proudest technological achievements of The Soviet Union. The Chernobyl accident in 1986 created a revolution in the way nuclear power and safety was viewed. Nuclear Safety became the highest priority and ways to re-establish nuclear power proved to be difficult for quite some time. The scars of Hiroshima and Nagasaki blasts are still afresh in the minds of its people and this accident just added some more fuel to the fire. It is definitely not a surprise that there exist large anti-nuclear group all over the world. Greenpeace is one such global organisation that has been actively protesting against nuclear power. *"We have created a monster"*, they say.

Some experts have a difference in opinion about the "monster" that we have created. Even nuclear power has its own advantages. Without accidents, a nuclear power plant delivers a cleaner energy than fossil-fuels such as coal, gas or oil. The contribution to global warming is more from a fossil fuel. Also fossil fuels are being used up so quickly and it's only a matter of time before we run out of them. So will we not run out of Uranium? Considering the rate at which nuclear power plants are being built, yes, we will also run out of uranium eventually, but it will be at a considerably slower rate than fossil fuels because even a small chunk of Uranium can produce as much as energy as a 5000 tonnes of coal[1].

When it comes to the society, there is always an air of uneasiness with respect to nuclear power. This is true in most of the countries, especially in India. But the question here is, do they REALLY know the risks involved with nuclear power? This is an area that definitely needs to be addressed as it is very important for the growth of the nuclear industry. Great secrecy has always surrounded the production of nuclear power because of its close connection and a direct link with nuclear weapons.

1.1: Aim

- To understand the attitude of the public towards a nuclear waste disposal site
- To understand why and how scientific results vary greatly with perception.

1.2: Objective

1. Understanding a nuclear fuel cycle and the types of waste produced
2. Reviewing waste management techniques and PRA methods to assess waste
3. Building a base fault tree model of a geological waste repository for an Indian environment using Reliability Workbench v.11 to find out a probabilistic value for radioactive material to come into contact with the environment.
4. Undertaking a survey using Survey Monkey to understand perceived risks as seen by people.

1.3: Scope

The scope of this work entails assessing the impact of a public opinion on a powerful industry sector such as the Nuclear power industry. An attempt is made here to build a base case model using fault tree analysis for the KKNP site based on assumptions and historical data as no exact data is available for the site chosen. In addition to the quantification of the technical risk – the perceived risks are also quantified and a direct comparison between the two is made. It is essential to remember that this work is an attempt of an individual to understand the nuclear sector out of pure interest, with no prior experience in this field of expertise.

Chapter 2: Literature Review

The following review of literature aims to understand the nuclear fuel cycle and the efforts taken to reprocess the waste fuel. The review endeavours to understand the process of analysing risks associated with nuclear waste and what type of harmful effects it can have on the environment.

2.1: A Nuclear Fuel Cycle

In order to describe nuclear "waste", it is important to understand what goes in to a nuclear power plant and what comes out. As the name suggests, a nuclear fuel "cycle" is a sequence of technique through which the elements used for power production pass through[2]. It begins with Uranium Mining and Extraction and ends with the final disposal of waste materials.

There is some amount of waste produced in every stage of the fuel cycle and they can be classified according to origin or by the amount of radioactive content[3]. The types of waste will be dealt with in the sections to come.

A nuclear fuel cycle consists of the following steps[2];

Mining, Extraction and Milling of Uranium: Uranium is a slightly radioactive material that is commonly found in the earth's crust. Mining can be done in three different ways; underground mines, open pit mines and in-situ leaching where uranium is leached directly from the ore. In-situ leaching (ISL), also known as solution mining, involves recovering the minerals from the ore by dissolving and pumping the pregnant solution to the surface where the minerals can be recovered and leaving the ore as it is in the ground. No tailings or waste rock is generated in this process. However, the ore-body needs to be permeable to the liquids used, and properly located to avoid contaminating the groundwater. Milling is a chemical process where the mined uranium ore is crushed and treated to get the uranium separated. This uranium is then converted to a concentrated "yellow cake" of Uranium Oxide (U_3O_8). The extracted uranium is then converted to a gaseous form, Uranium Hexafluoride (UF_6) to enable uranium enrichment.

Uranium Enrichment: Natural Uranium has 2 isotopes, U- 238(99.3%) and U-235(0/7%). U-235 is responsible for the fission process but its available quantity is less when compared to U-238. Enrichment process is done to increase the concentration of U-235 isotope. It is normally enriched to contain about 5% of Uranium. Gaseous diffusion, gaseous centrifuge and laser separation are commonly employed techniques. But there are chances of mishandling the enriched uranium, which could potentially lead to a criticality accident.

Fuel Fabrication: This is last stage in the preparation of nuclear fuel prior to its use in a reactor. The fabrication process consists of three steps where uranium, after enrichment is converted into an oxide or metal by undergoing a series of chemical reactions. It is then loaded into metal tubes filled with gas and is sealed (metal claddings). The filled tubes are then assembled as clusters and prepared for insertion into the nuclear reactor.

Power reactor Operation: Nuclear Fission is the process by which the uranium atom splits to give off heat. This splitting causes a chain reaction to take place, which is called a nuclear reaction. Along with heat, other nuclear fission products are also released, most of which are radioactive. In addition to these, atoms heavier than uranium, such as Plutonium, Curium, and Americium are also produced.

Fuel Reprocessing: The spent fuel is reprocessed to recover unburnt fuel and plutonium from the waste. The remaining is considered as waste and is either stored or disposed. The plutonium recovered from the spent fuel can be used to fuel fast breeder reactors.

Waste Management: A variety of waste is produced in every stage of a nuclear fuel cycle. Some of the waste might be highly radioactive. Carefully managing waste in such a way that it does not compromise the health and safety of the workers and the general public is a very important aspect. This includes interim storage and disposal of waste into a suitable repository in the future.

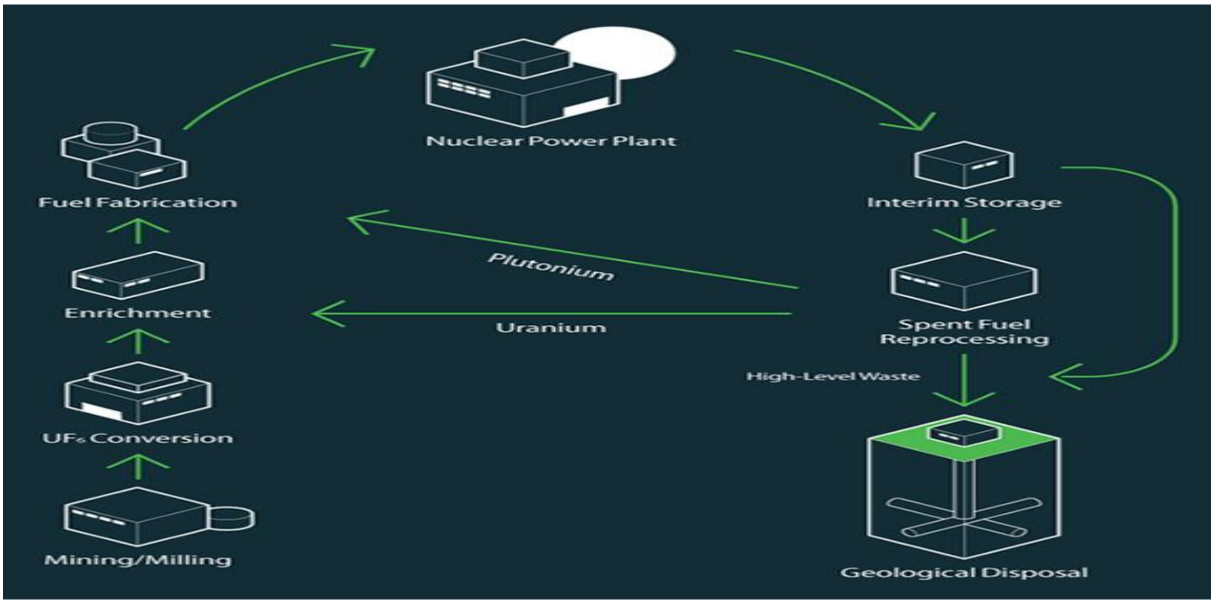


Figure 1: The Stages of a nuclear fuel cycle

2.2: Classification of Waste

Like mentioned before, waste can be classified either according to their origin or with the amount of radioactive content in it. By "origin", it means the waste that comes out from the different stages in the fuel cycle, either as leakages or residues.

When it comes to radioactive content, wastes can be classified into 3 types[3].

Low Level Waste (LLW): They contain very small concentrations of radionuclide, particularly those with shorter half-lives; those that take relatively less time to decay. Such low level wastes are not highly radioactive and they form the bulk of all the waste produced.

Intermediate Level Waste (ILW): These contain a higher concentration level of radionuclide. But the volume of these wastes is less compared to LLW.

High Level Waste (HLW): These contain the major part of radioactivity produced in the nuclear fuel cycle. They have high radioactive content and the heat given away from them during decay is very significant and harmful.

Waste Disposal is a broad topic and a huge issue in hand that is faced by almost all the countries that do work on nuclear power. Depending on whether the spent fuel is reprocessed or not, there are three main commonly identified fuel cycle types[5].

1. Once-through fuel cycle: As the name suggests, the fuel passes through the cycle only once and the spent fuel is considered as a waste. It is kept in storage till it can be disposed in a suitable geological site/ repository. Though this method is currently employed by certain countries and is very much in practice, it has certain disadvantages; the most important of them all being the disposal of long-lived Transuranium Isotopes (TRU), fission products (FP) and Plutonium.

2. Thermal reactor fuel cycle: The spent fuel is reprocessed and the remaining uranium and generated plutonium are separated from the fission products. The fission products are stored in liquid form for a few years before they are sent for vitrification, where they are stored in engineered storage facilities. The vitrified waste is a HLW and it has to be disposed off along with the TRUs.

3. Fast Breeder reactor cycle: This uses the spent fuel not only from the core but also from the surrounding blanket region to reprocess. The uranium-plutonium product separated from it can again be used in the reactor.

The choice of a specific fuel cycle depends on various inter-related factors. Environmental considerations, policies and politics, price of uranium in the market, availability of uranium, and cost of electricity production from uranium are some of the factors that play an important role in deciding the right choice of fuel cycle. The choice of the fuel cycle will also influence the type of waste that is being produced. Earlier, these factors were predictable to an extent. But in this present world, energy demand is rocketing to such a height that it is becoming highly impossible to forecast the future of the energy industry.

2.3: Spent Fuel Storage

Spent Fuel is the fuel that no longer has the ability to undergo nuclear activity. The storage method adopted for spent fuel and other radioactive materials in the nuclear site ensures minimal exposure to on-site operators as well as the public. Initially, this spent fuel is stored in pools in the reactor site. The storage of spent fuel requires a lot of facilities like 1: shielding to handle the fuel, 2: cooling to maintain fuel temperature, 3: criticality safety control, 4: controlling water chemistry, 5: decontamination[5]. Of these, maintaining fuel temperature and cooling it is the most important of them all.

There are two commonly accepted types of fuel storage; Pool storage method and the Dry Storage method. The two methods are briefly discussed below;

Pool Storage: Storing spent fuel assemblies under at least 20 feet of water. It provides adequate shielding from the radiation. The assemblies are moved into the water pools from the reactor along the bottom of water canals, so that the spent fuel is always shielded to protect workers. About one-fourth to one-third of the total fuel load from the pools is spent and removed from the reactor every 12 to 18 months and replaced with fresh fuel[6].

Dry Storage: For increasing spent fuel storage capacity, utilities began looking at options such as dry cask storage as the need for alternative storage began to grow when pools at many nuclear reactors began to fill up. Spent fuel that has already been cooled in the pool for at least one year, is stored in a container called a cask. The cask contains an inert gas that surrounds the fuel. The casks are typically cylinders made up of steel that are either welded or bolted closed. The steel cylinder provides a leak-tight confinement of the spent fuel. To provide radiation shielding to workers and the public, each cylinder is surrounded by additional steel, concrete, or other material. Some of the cask designs can also be used for safe transportation[6].

There are specific features that characterize the safety of each type of spent fuel storage. The following factors define the main safety requirements [7]:

- Minimizing the danger of hermetic sealing damage (leading to release of radioactivity by the fuel)
- Minimizing the release of radioactivity and its migration to the environment in case of fuel-element cladding damage
- Minimizing the mechanical damage of spent nuclear fuel elements as a result of external impacts (earthquakes, fires, explosions, projectiles, fall of flying objects).

The continuous production of spent fuel and the delay in developing the required re-processing capacity has led to increasing the pool storage capacity by expanding the existing pool capacity, building new facilities and re-racking. So this provides room for accidents and disturbances to happen. These include loss of power, component failures, fuel handling mishaps and leakage of pool water.

Radioactive contamination of pool water is one of the issues associated with wet storage of spent fuel. If defective fuel rods are not identified and isolated before they are placed inside the pool then this will lead to water contamination. For occupational safety, the contamination must be maintained at $30MBq/m^3$. If the heat of the fuel increases so much that the fuel cladding loses its integrity or if there is a massive impact on the stored fuel then this might lead to a significant release of radioactive material to the environment, along with some gaseous material.

Maintaining the level of pool water is by far the most important condition that has to be satisfied for storing spent fuel under water. Pool water helps maintain the fuel temperature and loss of water will trigger the increase of temperature due to decay heat. The pool water can either be lost due to leakage or due to the failure of the system itself, thereby leading to evaporation and overheating of the pool. When it comes to increasing the capacity of a storage facility or re-racking the fuel assemblies, the extra heat load might raise the temperature of the water to an unacceptable level.

Even though such bizarre accidents can be restrained from happening by taking the right action at the right time, the probability of risk leading to a contamination or leakage still exists and so it will always remain as an area of concern.

2.4: Radioactive Waste Management

Any kind of waste that cannot be recycled or destroyed can be dealt with in two ways. It can either be stored for a long period of time or it can be disposed. With respect to radioactive waste, both these kinds are employed. It is necessary to understand the difference between "storage" and "disposal" to avoid confusions, especially when it comes to talking about radioactive waste. When we say that the waste is "stored", it means that the waste is placed under a supervised facility, away from human contact, but in recoverable conditions when required. But in the case of "disposal", the waste cannot be recovered. The quantity of waste produced greatly depends upon the reactor type and its construction, operating conditions, site conditions and by the way the fuel is treated[2].

Waste from fuel reprocessing is responsible for generating almost all the high level radioactive waste. After removing uranium and plutonium through fuel reprocessing, the residual waste contains about 99% of the total fission product activity which is highly volatile[2]. This waste has to be isolated from the biosphere mainly because of its high toxic content. Wastes such as STRONTIUM-90 and CAESIUM-137 require longer periods of isolation as they have half lives for about 30 years. Studies have been made on ways to manage such kind of wastes. Perhaps, the most practical strategy would be to convert all the long-lived nuclides to short-lived ones through processes such as "nuclear incineration"[3]. What is achieved out of this method is the reduction in the volume of waste. Though this method reduces the amount of long lived nuclides, it also increases the quantity of short-lived nuclides and this only causes an increase in the total amount of waste. What should not be forgotten is that, incineration *does not reduce the radioactivity* of the waste.

Wastes such as the high level and the medium level ones can be immobilized for the purpose of long-term storage and can be later disposed in geological repositories that are very deep. This type is generally not considered as the best option mainly because it places a huge burden on the future generations. A site once used for disposal/storage of radioactive content can *never* be used again. Apart from this, there are also accidental risks associated with the storage sites. Medium Level Liquid Waste (MLLW) is subjected to a flocculation treatment and the supernatant (the liquid lying above a solid residue) is discharged as a low level liquid waste into natural water bodies such as oceans or streams and the sludge from the treatment is embedded in cement and stored as solid waste[5]. Gaseous radionuclide particles such as KRYOTPN-85, IODIONE-129, HYDROGEN-3, CARBON-14 and other aerosols are subjected to chemical scrubbing and physical filtration with the help of high-efficient particulate air filters (HEPA). Of all the wastes that have to be managed, HLW requires greater attention than the rest of them because it is highly radioactive. It produces significant amount of heat and this condition persists for a long time, maybe even for a few hundred years. The highly radioactive wastes are mainly from the contaminated swarf or metal cladding that is removed from irradiated fuel before reprocessing. A number of very exotic suggestions such as firing waste into space and burial in polar ice caps were made[2]. But these are not practical solutions at all. Polar ice caps are already weak and melting and burying toxic in ice caps might only lead to unimaginable catastrophic events. Disposing them in deep repositories is the most sorted out solution for this, and is even currently employed.

Effort is taken in this literature survey to understand the working of such a repository. A repository aims at preventing any radioactivity from causing harm or damage to mankind. Selection of the right rock environment and massive engineering techniques help make this kind of safety possible. Multiple layers of barriers are always preferred to keep the toxicity of the waste material intact. The rocks used can generally be classified as either dry or wet. Dry rock like salt or anhydrite does not contain a groundwater flow mechanism so this might prevent the degradation of the engineered barriers and also prevent the transportation of the radionuclide to the surface of the repository. Wet rocks contain mobile groundwater but it will not pose as a problem provided the level of flow is low. The favourable low flow condition is ensured by the geography of the chosen site. Absence of oxygen in such deep sites is necessary as the presence of dissolved oxygen could lead to corrosion of the barriers or the dissolution of nuclide. Other than providing a physical protection, the rock has other important barrier roles to play. Sorption of nuclides on the rock will greatly reduce the transportation of any released radionuclides from the repository.

The performance of any repository is assessed based on the time-scale of the hazardous waste, which is usually a few hundred years. Taking a granite host rock in Northern Switzerland as an example, the depth at which a repository construction can take place would be at 1200 meters. The expected water flow rate at this depth for this site is less than 1 litre per year. The groundwater is chemically near neutral and the ambient rock temperature is about 60° C. The Swiss Disposal concept includes the following details:

- A Glass Matrix that restricts release of radioactive material
- A Steel Canister, covering the glass matrix; that prevents penetration of water into the glass matrix
- Bentonite clay that holds the canister. It restricts water penetration and delays the release of material
- The host rock, where the above arrangement is buried. It’s placed in the Repository zone which has limited water supply and holds favourable chemical conditions
- A sedimentary overburden, above the host rock, that provides additional retardation of transportation of radioactive material to the surface and long-term stability

The most likely failure for a repository like this is the gradual degradation of the engineered barriers due to the inflow of groundwater. Studies suggest that by the time the radioactive material escapes all these barriers, its radioactivity content would have reduced so much that it cannot possibly cause any harm to the environment. Most radioactive nuclides will decay completely within the engineered barriers. It will even take very long lived radionuclides a thousand years or even more to reach the surface.

So, if a repository is really a safe option, then why is this frenzy about nuclear power being dangerous? Why do people not accept that long term disposal of nuclear wastes can be safe?

2.5: How safe is safe enough?

A very common question that is asked when it comes to risk analysis of nuclear power is, *"how safe is safe enough?"* From what is recorded and noted, no matter how hard scientists try to prove that nuclear power is safe, there is always someone somewhere to prove it otherwise. Disposing nuclear waste in a geological site is by far the most "feared" risk of them all. Public support is very essential for such big industries to survive. This diverse group receives all of its information from the media and it is not in their nature to give a balanced presentation[8]. Starr (1969) in his research noted that "*individuals seem to accept a much higher risk if it is voluntary, e.g. sky-diving, than if it is imposed, such as, by electric power"*. He concluded with a *LAW OF ACCEPTABLE RISK*, which states that, "*Risk Acceptability is proportional to the cube of the benefits".* While nuclear power has the least risk, it also has the least perceived benefits[8]. So it's only natural that people prefer other methods of electricity production where the benefits are more. When it comes to taking surveys, as studied by Covello (1981), people tend to respond with the first things that strike their mind when they read a question. It is possible to get answers from them even when they have very little knowledge about the topic under discussion[8].

Cohen B.L (1998) used nuclear energy to show that "*public perception can be completely out of touch with the results of scientific risk analysis"*[9]. Refusal of the media to communicate direct results to the public, especially results pertaining to probabilities is the underlying problem. Media has complete control over public perception and the messages they transmit are not influenced by scientific analysis. The only two popular public concerns with regards to generation of electricity from nuclear power are the release of radio-active materials due to a bad reactor accident and the proper disposal of radioactive waste. The second issue remains to be (and will remain to be) an unsolved problem. Our interests lie with public perception of radioactive waste management.

Seeing this from a scientific analysis point of view, the solution to proper disposal is, as discussed before, burying in a geological repository site. It is not within the scope of a PRA (Probabilistic Risk Assessment) to develop an accurate model for a geological repository because far-future geological events and climatic changes are impossible to predict. But by determining the rate at which an average rock under a given depth will be dissolved by water, it is possible to build a PRA. The result is a total of 0.02 deaths over a million of years, from one reactor-year of electricity generation. When similar kind of studies were conducted for generation of electricity from coal, the numbers were a thousand times more.

What is the difference between the way a scientist and public person address the same issue? A public person (politician/ media)

- Does not attend scientific meetings where such kind of issues are debated
- Provides/ gains information through press-talks and talks non-scientific audiences
- Do not provide papers with results to prove their point that another peer person can criticize

Clearly, media is the only direct link between the commons and the intellectuals. The public gets all of its information from the media and it is a well known fact that the results from a PRA have never once been published or even mentioned in any of the news paper articles or TV programmes. They conveniently choose to thrash nuclear power but without any underlying facts. Any technology will have its own risks and those risks can be made more dangerous by assuming further failures. Because of this kind of negligence, the importance and the role nuclear activity plays in medicine, agriculture, engineering etc is unknown to the public. This battle between public perception of risk and the actual scientific risks has been going on since the early 70's. Environmental groups found it easier to target the safety aspect of nuclear power and question it in order to gain media's attraction. Now, why did the media support this and publicize them? Just for the same reason as the environmental groups, "attract audience". Scaring people with "mystery" and "suspicion" is by far the easiest way to increase sales/ growth. Many call it marketing strategy.

Deeper review shows that, though the scientists are the ones with the facts, only the "other side" has a strong hold on the public and so no matter with how many facts they come up with, they will always fail to reach the public. The scientists have no time for political battles and even if they did, they are not well educated in these lines to face one. Both sides come from very different backgrounds and each one is a winner in their own field. While one was absorbed in laboratory work, the other was busy establishing political relationships. In a political campaign, it is necessary to demonstrate "selectivity" and they choose to select and present in such a way that makes nuclear industry look bad. Their influence is so strong, that there is absolutely no room for nuclear scientists to reach out and prove their point.

From the above review, it is very clear that public perception of a nuclear hazard is completely different from calculated risks. This difference is tested in this project by taking KKNP located in India as the case study. An attempt is made to quantify the technical risks using fault trees where as the perceived risks are quantified with the help of a survey that is structured with the idea of targeting audience who have a very general outline and perception about the nuclear industry. A comparison is made between the two and the results are discussed.

Chapter 3: Site Description

The following sections will concentrate on describing the geographical location of the Kudankulam power plant, the PWR in use in the site and a multiple barrier repository system concept. To understand the working of a PWR in general, please refer to Appendix A.

3.1: Site Selection

The Nuclear Power Corporation of India Limited (NPCIL), in collaboration with Atom Stroy Export, built this nuclear power plant in Kudankulam. The site is located along the cost of Gulf of Mannar, 25km north-east of Kanyakumari. The Site Selection Committee of the Department of Atomic Energy decided to go ahead with this location after considering several aspects including the guidelines set by the International Atomic Energy Agency (IAEA). Some of them include assessment of seismicity, location of faults, geology, foundation conditions, meteorology, potential of flooding (from tsunami, storm surge, etc. at coastal sites and from rain, upstream dam break, etc. at inland sites), proximity to airports, military installations, facilities storing explosive and toxic substances, etc. The site is located in low seismic area, zone-II as per the Indian Standards of Classification. It has no active faults in the vicinity and provides preferable foundation conditions, ambient for building structures. The site is free from severe cyclonic activities and has low potential of Tsunami effects[10]. Nuclear Power Corporation of India Limited has acquired the land within the 2 km radius from the main plant. About 40% of 2 km radius areas acquired lie in the Gulf of Mannar. The balance portion is mostly barren lands and without any habitation. The radiological impact on the site is said to be lower than the stipulated regulatory requirements. The environmental clearances have been obtained from State and Central Government statutory authorities. The activity will not in any way affect the marine life nor curtail the fishing activities of the fishermen living nearby. Nuclear reactors provide clean power and there is no release of gases like sulphur dioxide, carbon monoxide and carbon dioxide. This will also not affect the Vivekananda Rock Memorial (a sacred monument), located nearby. The requirements of fresh water are very small and will be drawn from the Pechiparai Reservoir. The fresh water requirements will thus not affect the drinking water and agricultural needs of the local population [10].

Figure 2 : A one sided picture of the site [1]

3.2: Nuclear Reactor in use

The type of reactor in use here is an advanced 1000 MWe design of VVER reactors. VVER stands for “Vada Vada Energy Reactor” which means it is a water-cooled, water moderated energy reactor. These reactors fall under the category of pressurized water reactors; light water reactors. Uranium, enriched to about 4% is used to fuel the reactor. The KK-VVER has a 3 year fuel cycle. Approximately 55 fuel assemblies are required for the purpose of refuelling annually (filling one-third of the core). Four circulating loops and a pressurizing system are connected to the reactor [10]. Each loop contains a horizontal steam generator, a main circulating pump and passive part of emergency core cooling system (accumulators). Interconnecting pipes are used to connect the loops with the reactor pressure vessel assembly. The reactor plant also consists of a reactor protection and regulation system, engineered safety features, auxiliary system, fuel handling and storage system, etc.

Some of the main design features of a VVER are as follows;

- Reactor core has hexahedral assemblies
- Horizontal steam generators
- Ability to arrange the spent fuel pool inside the containment
- No openings in the reactor bottom
- Fuel rod claddings of zirconium-niobium alloy
- Carbon alloy steel reactor vessel

The reactor vessel is designed to contain the fuel assemblies of the core and the vessel internals. The reactor is placed in a concrete pit inside the containment. Heat generated in the reactor core is transferred by the Reactor Coolant System (RCS) to the steam generators. The steam generators produce the required steam to run the turbine generators. The coolant used in the coolant system is borated demineralised water and this also acts a neutron moderator, reflector and as a solvent for neutron absorption. The pressure boundary of the coolant system acts a barrier against the release of radioactive material to the environment [12].

The reactor core can hold one hundred and sixty-three fuel assemblies in a hexahedral lattice pattern with the help of stainless steel supporting structures. There are 331 locations in each fuel assembly out of which 18 are for the control rods, one for instrumentation tubes and the rest 311 contain enriched uranium di-oxide pellets placed inside tubes made of Zr-Nb.

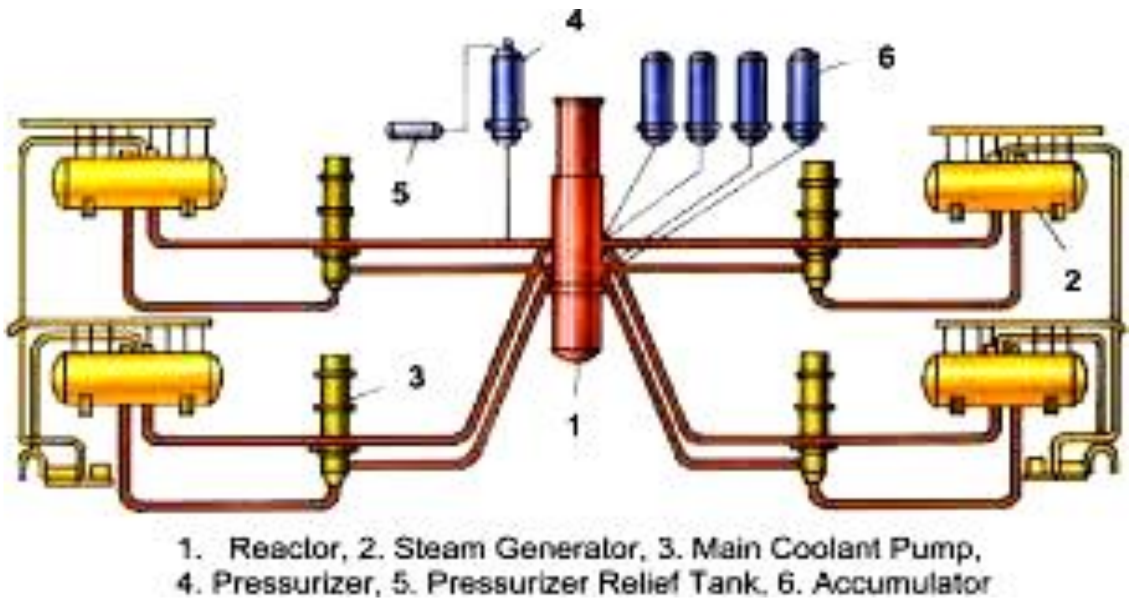


Figure 3 : VVER reactor design [10]

3.3: Risk Analysis Techniques

The following section will describe the risk analysis techniques researched and employed in this study in order to undertake an analysis to understand the risks associated from a nuclear waste disposal repository.

3.3.1: Fault tree Analysis[13]

Fault tree analysis uses simple logical relationships like AND, OR, XOR, etc., to relate events that interact to produce other undesirable events. This allows us to build a methodical structure that represents the system as a whole. In order to construct a fault tree, it is mandatory to understand the functioning of the system under analysis. A flow diagram or a functional logic diagram can be used for this purpose. Another method used frequently to understand failure modes is Failure Modes and Effects Analysis (FMEA). An introduction to FMEA will be dealt with in the following chapters.

The *top event* in a fault tree is the system failure event that is to be studied. In other words, the top event is the “undesirable event”. Logical event connections are then used to link and relate subordinate failure events that might lead to the occurrence of the top event. The subordinate events are once again broken down to their logical connections and by this way, a fault tree is created. When a contributing event cannot be broken down further into other sub events, then the corresponding branch is terminated with a “basic event”. This basic event is responsible for the top event to occur.

When constructing a fault tree, the first step to it is selecting the top failure event. The events following it will be considered according to the effect they place on the top event. The next step is to find contributing events that will lead to the occurrence of the top event. There are at least four possibilities that exist (these are applicable to any kind of fault tree construction).

- Failure of the device to receive an input signal
- Failure of the device itself to operate
- Human error
- Failure due to external events

Each branch from the first level of contributing events must then be examined for further breakdown. If a given event cannot be broken down further, then it is treated as a basic event and is graphically represented with a circle. The final level of the fault tree will only consist of independent basic events.

Some of the commonly used symbols to represent logical relationships between events are as follows;

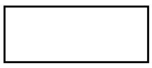
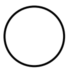
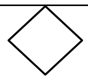
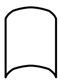
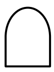
Symbol	Name	Description
	Rectangle	Fault event (resulting from the logical combinations of other events)
	Circle	Independent primary fault event
	Diamond	Underdeveloped fault event
	OR gate	Output occurs if one or more of the input event occurs
	AND gate	Output occurs only if all the input events occur
	Triangle	Transferring the tree construction to another sheet

Table 1: Commonly used fault tree symbols

After constructing, the fault tree can be evaluated by following a set of Boolean Algebraic equations depending on the type of gates used in the tree. Table 2 shows the gates that are commonly used in fault trees and their Boolean logic. For each gate, the input variables are the independent variables and the output is the dependent variable. Solving the Boolean equations will help us to individually express all the events in terms of minimal cut sets. A minimal cut set expresses the top event as a collection of multiple scenarios that will cause the top event to occur. Using Boolean functions to analyse fault trees is called qualitative analysis.

Type	Boolean Expression
OR	A+B
AND	A.B

Table 2: Gates and their Boolean expressions

Another approach to evaluating a fault tree is by the quantitative approach where the probability of occurrence of the top event is calculated. There are two methods for this approach. If there is data available about the minimal cut sets, then the probability of the top event occurring will just be the probability of the union of the minimal cut sets. If the cut sets are not known and if the fault tree is not complex, then the probability can be found by manual calculation. In this case, the probabilities can be found by applying the following equations;

$$P(A_1 + A_{2\ldots\ldots} + A_n) \approx \sum_{i=1}^{n} P(A_n) \qquad P(A_1 A_{2\ldots\ldots} A_n = P(A_1)P(A_2)\ldots P(A_n)$$

To illustrate the use of fault tree, let's build one for the failure of a stereo system. The stereo music system consists of the following separate units: Speakers (L and R), Amplifier, Radio Tuner, and CD player. The top event "No sound from system", is our concern for this system. There are two possible reasons for the system to not produce sound. The speakers may not be working or they may not be getting a signal from the amplifier. Similarly, the amplifier may not be working or it might not be getting a signal either from the tuner or the CD player.
For convenience we introduce a number of symbols to represent the different events.

T: the top event, "No sound from system"

G1: "No signal to speakers"

G2: "No sound from speakers"

G3: "No signal to amplifier"

} Intermediate/Subordinate events

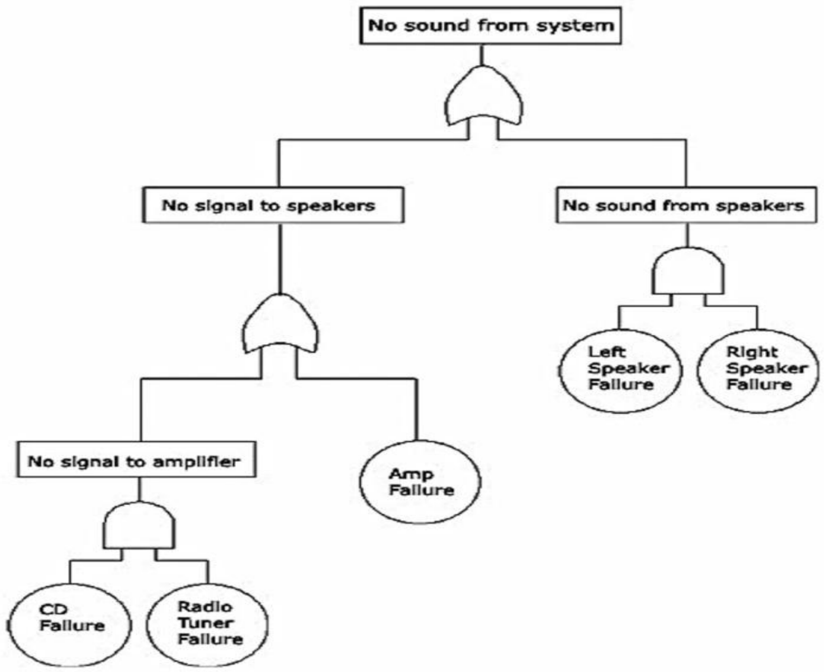


Figure 4 : A simple fault tree

C: "CD failure"

R: "Radio Tuner failure"

A: "Amplifier failure"

LS: "Left Speaker failure"

RS: "Right Speaker failure"

} Basic events

Using the respective Boolean expressions for the gates, we see that

T=G1+G2

Where G1=G3+A, G3=C.R, and G2=LS.RS

By substituting we arrive at,

T=G1+G2
=G3+A+G2
= C.R+A+LS.RS

This gives the Boolean expression and the minimal cut sets that will together result in no sound coming from the sound system. This method will later be used to build an elaborate fault tree to understand the ways in which nuclear waste can reach the environment.

3.3.2: Failure Modes and Effects Analysis (FMEA)

This tool helps to systematically identify all modes contributing to failure and analyse their resulting effect on the system. Nuclear power applications frequently use this when a detailed analysis that involves fault trees and event trees is not needed. In FMEA, the failure or malfunction of each component of the system is considered along with the mode of failure. These effects are then traced through the system to analyse the ultimate effect on the system[13]. FMEA includes reviewing the following [14];

- Steps in the process
- Failure modes (What could go wrong?)
- Failure causes (Why would the failure happen?)
- Failure effects (Consequence of each failure)

For each failure mode, a numeric value, known as the Risk Priority Number (RPN) is assigned for likelihood of occurrence, likelihood of detection, and severity. Assigning RPNs helps to prioritize areas to focus on and can also help in assessing opportunities for improvement. For every failure mode identified, it is necessary to answer the following questions and assign a score from 1 to 10, with 1 being the least and 10 the highest.

Likelihood of occurrence: How likely is it that this failure mode will occur?
(1 - Very unlikely to occur; 10 - very likely to occur)
Likelihood of detection: If this failure mode occurs, how likely is it for the failure to be detected?
(1 -very likely to be detected; 10 -very unlikely to be detected)
Severity: If this failure mode occurs, how likely is it that harm will occur?
(1-very unlikely that harm will occur; 10-very likely that severe harm will occur)
The below table can be used to tabulate the values and calculate the RPN value.
RPN value = Likelihood of occurrence * Likelihood of detection * Severity

FMEA is one of the several variations of an inductive approach. FMEA considers only one failure at a time. It does not consider multiple failures or common cause failures and this poses as a main disadvantage in this method. Nevertheless, it is a simple application and can provide an orderly examination of the hazardous conditions in a system. The use of this tool for this study will be demonstrated in the following sections.

Steps in the process	Failure mode	Failure causes	Failure effects	Likelihood of occurrence (1-10)	Likelihood of detection (1-10)	Severity (1-10)	Risk Profile Number (RPN)	Actions to reduce occurrence
1								
2								
3								

Table 3: Calculation of RPN; FMEA Matrix [14]

Chapter 4: Analysis and Results

This section will introduce the fault tree built to analyze the probability of failure of a nuclear waste repository site. Also, a bigger fault tree is built to show all the possible ways nuclear waste can come in contact with the environment.

4.1: The Big Picture

It is worthy to note that there is so far no repository site identified or located in India for permanent disposal of waste. Nuclear waste generated in India is too small to deserve a separate geological repository. India's existing nuclear waste site is located at Tarapur where high-level radioactive waste is first converted into inert and stable materials which are kept inside stainless steel canisters sealed with lead covers. Almost 75 per cent of this solid storage surveillance facility is still vacant. But the country will eventually need a geological repository, considering its ambitious expansion and to generate 63000 MW of electricity with the help of nuclear power by 2032[15]. Also, absence of a repository is one of the crucial arguments used by anti-nuclear groups to oppose against nuclear power amongst other reasons such as security and the nuclear liability act.

Even though there are many currently running projects in India, Kudankulam Nuclear power plant is chosen as the case study because this site is known for its many controversies and oppositions it has been getting since 2011. The plant is relatively new and its units became functional only in July 2013. The following are a few of the many reasons for opposing a nuclear power plant in this area.

- People claim they were made false promises such as 10,000 jobs, water from Pechiparai dam in Kanyakumari district, and fantastic development of the region.
- The Environmental Impact Assessment (EIA), Site Evaluation Study and Safety Analysis Report were not shared with the people, or the people's representatives or the press. No public hearing or democratic decision-making or public approval is known for this project.
- The Tamil Nadu Government establishes clearly that the "area between 2 to 5 km radius around the plant site, [would be] called the sterilization zone." This means that people in this area could be displaced. But the KNPP authorities promised orally that nobody from the neighbouring villages would be displaced. This causes suspicion and fear of displacement in the future.
- The population living within the 30 km radius of the KNPP far exceeds the AERB (Atomic Energy Regulatory Board) stipulations. It is quite impossible to evacuate this many people quickly and efficiently in case of a nuclear disaster at Kudankulam.

- The coolant water and low-grade waste from the KNPP will be dumped into the sea which will have a severe impact on fish production and catch. This will undermine the fishing industry, push the fisher folk into deeper poverty and affect the food security of the entire Southern Tamil Nadu and Southern Kerala.

- Even when the KNPP projects functions normally without any incidents and accidents, they would be emitting Iodine 131, 132, 133 isotopes, Caesium 134, 136, 137 isotopes, Strontium, Tritium, Tellurium and other such radioactive particles into the ecosystem. Also, the question of “where will the waste go” remains a mystery.

- The quality of construction and the pipe work and the overall integrity of the KNPP structures have been called into question by the workers and contractors who work in Kudankulam. There have been international concerns about the design, structure and workings of the Russian-made VVER reactors.

- Many political leaders and bureaucrats try to reassure us that there would be no natural disasters in the Kudankulam area. But it impossible to give such an assurance. In-fact, the 2004 December tsunami did flood the KNPP installations.

- Finally, the Indian government’s mindless insistence on nuclear power, utmost secrecy in all of its nuclear agreements and activities, and its sheer unwillingness to listen to the people’s concerns and fears makes the society very doubtful about the real benefactors of this energy sector.

Concentrating on the environmental aspect, the release of radioactive waste material into the ecosystem will be the area of concern for this study. There are different pathways in which nuclear waste can come into contact with the system. Four pathways have been identified and a fault tree is built to show the connection.

The top event as seen in the fault tree is the “release of radioactive material into the environment, which as described before is the “undesirable event”. The next level of sub-ordinate events gives the four possible pathways that have been identified that could lead to the occurrence of the top event. An OR gate is used here to show that the occurrence of even one of the events will lead to the release of radioactive material. The four pathways are as follows;

1. Failure of High-level waste tanks

2. Failure during glasification process

3. Failure during interim storage

4. Failure during long-term disposal of waste

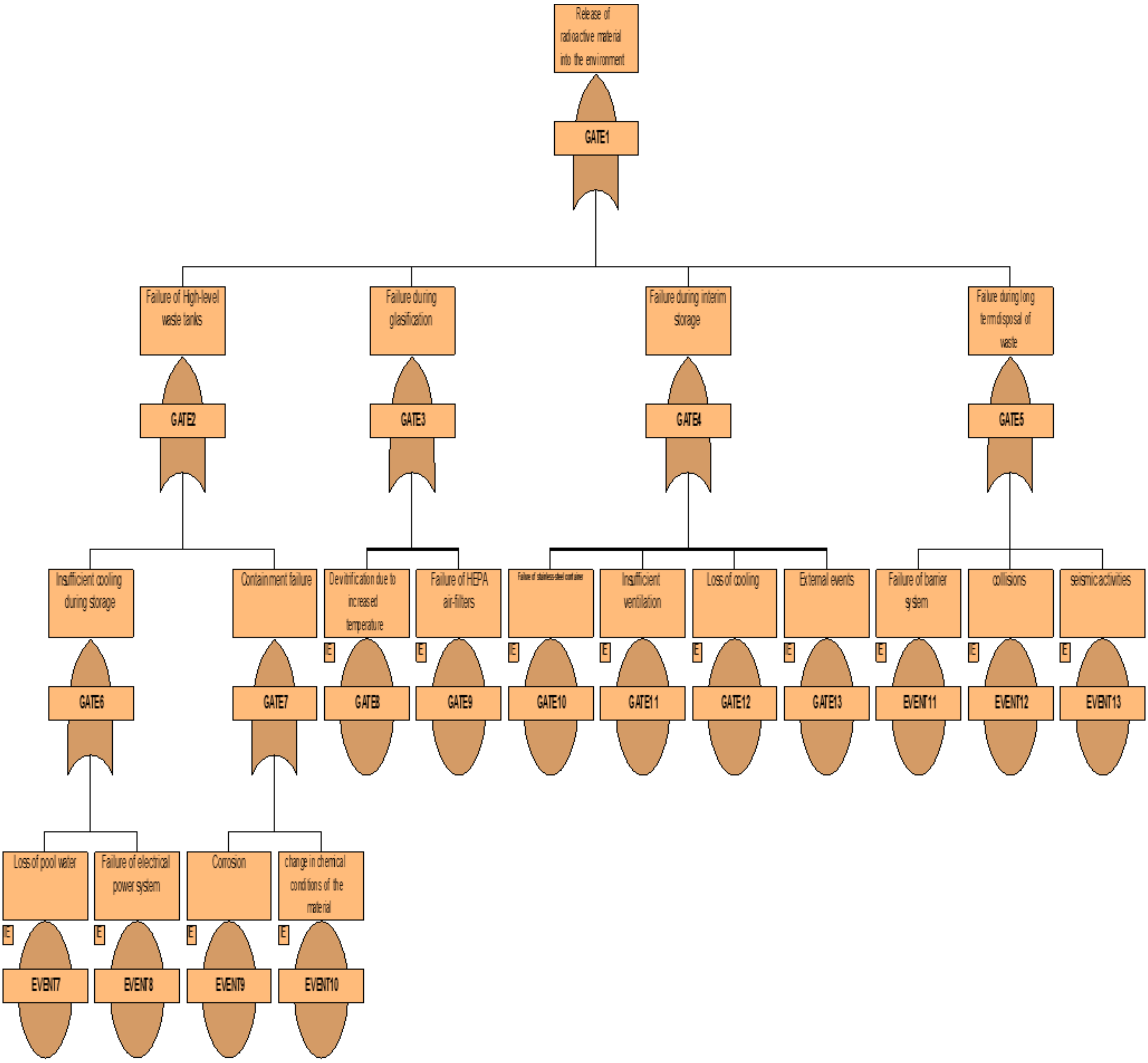


Figure 5 : Fault tree showing different pathways leading to radioactive release

Failure of High-level waste tanks: As mentioned in the previous section, spent fuel is reprocessed and stored in engineered tanks for years before it is sent for the vitrification process. There are two possible ways for the waste tanks to fail that might cause a release of the material; 1. Insufficient cooling during storage 2. Containment failure. OR gate is once again used in the fault tree to indicate the relationship. Cooling is very important during storage and loss in the level of pool water has the potential to cause major problems which will ultimately lead to the top event. Cooling can also be lost if the electrical system fails to operate. In the fault tree, the relationship is again denoted with an OR gate for the subordinate event to occur. "Loss of pool water" and "Failure of electrical system" are shown with a circle representing basic events.

Containment failures can occur due to corrosion. The containers are made of steel and increased oxygen content may corrode the steel making the container weak. There are possibilities of leakage to occur. Also change in the chemical conditions of the nuclear material in storage could alter the strength of the containment. "Failure due to corrosion" and "change in chemical conditions" are the two basic events that will lead to a containment failure. The relationship between the two levels is denoted with an OR gate.

Failure during Glasification: It is the process of turning radioactive waste into glass. In a hardened state, the radioactive material is encased, to prevent it from leaking. Waste, stored in tanks, is combined with molten glass. The glass is then sealed in steel containers. The waste should remain stable as the radioactivity dissipates. Failure during glasification process can happen because of two reasons; Temperature increase can lead to a devitrification process that might lead to leakage of radioactive waste. Failure of air filters will cause an increase in temperature, which again will lead to devitrification and finally leakage. The relationship is shown with an OR gate.

Failure during interim storage: There are four pathways that can lead to a failure during interim storage. If the steel containers are of poor quality and are not strong enough to hold the waste, it will become a pathway for leakage of radioactive waste into the environment. Reduced ventilation and loss of cooling will lead to increase in temperature of the waste, which might alter the strength and durability of the steel container. In the fault tree, these basic events are once again connected with an OR gate to show their relationship with the upper node.

Failure during long- term disposal of waste: This path is discussed in detail in the next section.

4.2: Failure during long-term disposal of waste

In the previous section, we discussed and built a fault tree for the different possible ways for a nuclear waste to come into contact with the environment. This section will concentrate solely on the last part of the previously built fault tree, “failure during long-term disposal of waste” and expanding it further by building another fault tree for it and performing the necessary analysis to find the probability of a possible release of nuclear waste from a waste repository. Long term disposal is the final stage for any nuclear waste and it is at this point that the public start to panic and oppose to the idea of permanently disposing it in the deep pits. As mentioned before, the anti-nuclear groups use the uncertainty in the safety of long term disposal as a reason to lobby against nuclear power.

So let us consider a nuclear waste repository site with the following barrier system characters;

- A Glass Matrix that restricts release of radioactive material
- A Steel Canister, covering the glass matrix; that prevents penetration of water into the glass matrix
- Bentonite clay that holds the canister. It restricts water penetration, delays the release of material

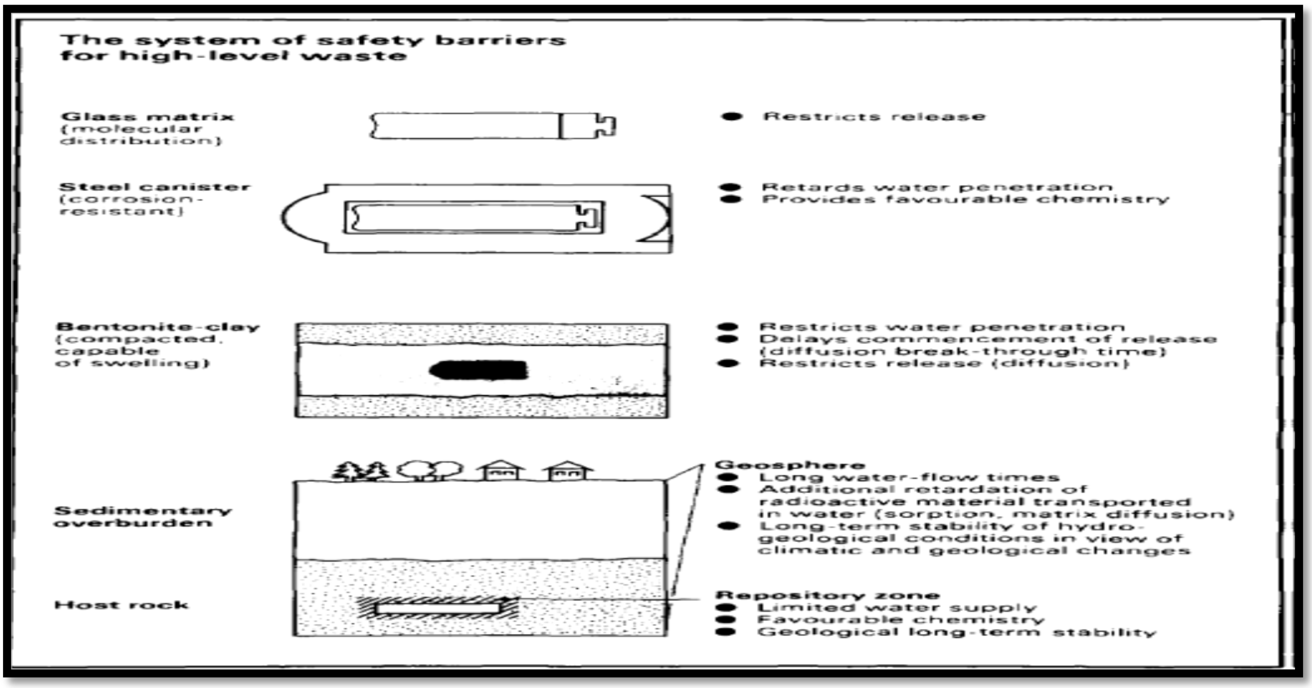


Figure 6 : An example model of geological repository [3]

So let us discuss the probability of failure for a geological repository over a period of 1000 years. The fault tree for the same is given below.

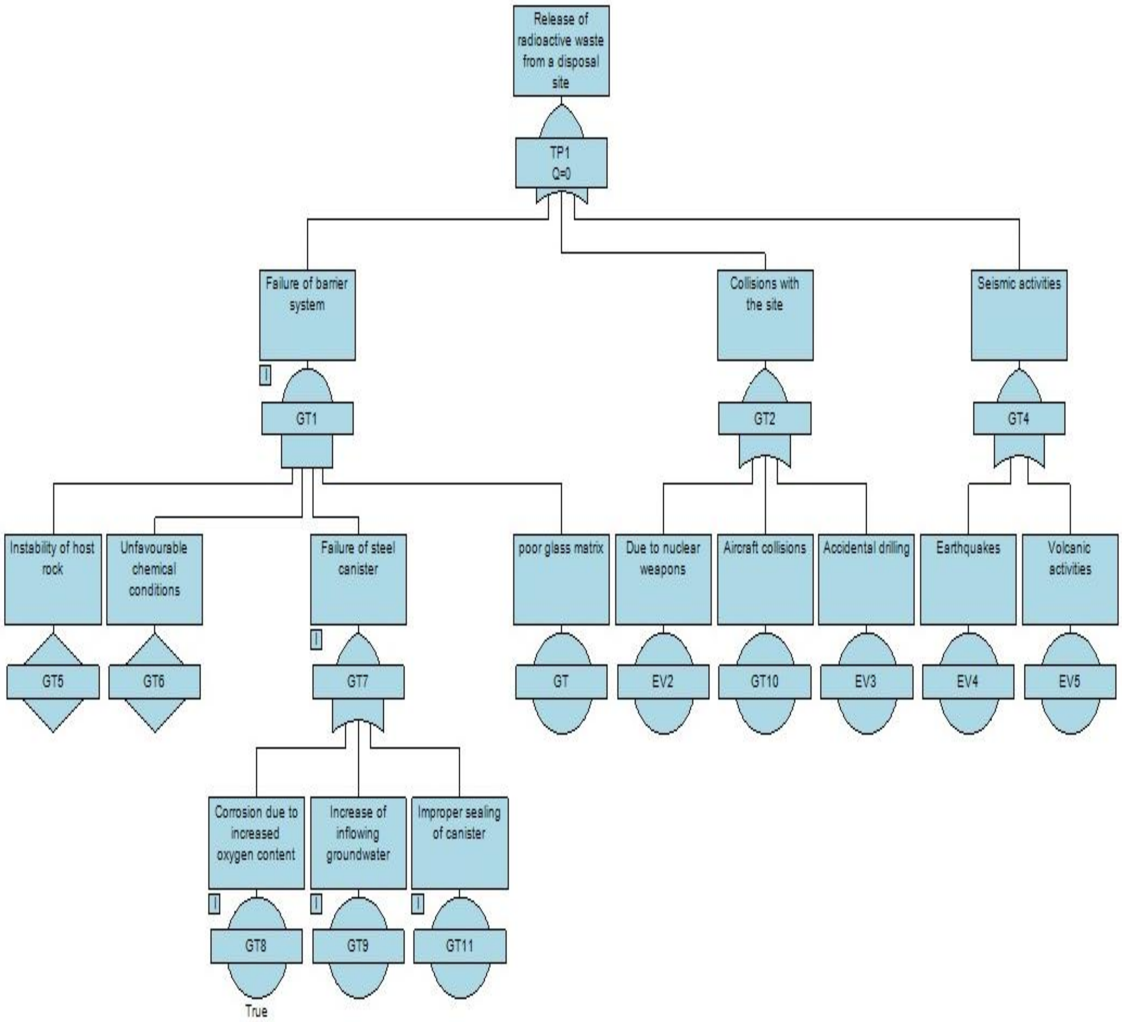


Figure 7: Fault tree model for failure during long-term disposal

The top event, as seen in the above figure, is the “release of radioactive material from a disposal site” and there are three possible pathways of which one is an engineered effect. The first level of sub-ordinate events (Failure of barrier system, Collisions with the site, Seismic activities) are all related with an OR gate to the top event. Any kind of collision that can have a huge impact on the repository site is an undesirable event and three paths have been identified for this; 1. Activities caused by nuclear weapons; war etc 2. Aircraft collisions and 3. Accidental drilling in the disposal site. Of the three, accidental drilling has a higher probability of occurrence than the other two events. The probability calculations for each of the events will be shown in the following sections. External events such as volcanic activities or earthquakes depend on the geography of the location. Probability estimation of such kind of seismic activities cannot be predicted correctly. Timescale for such predictions is very hard to set.

Let's consider the failure of the barrier system. The waste from the nuclear power plant is permanently disposed in a repository which is a multiple barrier system consisting of a combination of both natural and engineered barrier. After the waste package is placed and the tunnel is filled, the engineered barrier will begin to degrade. Gradual degradation of the barriers caused by the increased level of inflowing groundwater is by far, the most likely failure mechanism. The Bentonite buffer will begin to swell and adsorb the water that reinvaded into the zones of the host rock. But because of the low hydraulic conductivity of the backfill, this resaturation process will take a long time to completely have some effect on the barrier system. Corrosion will occur when this wetting comes in contact with the steel canister. The rate of corrosion is affected by the build of oxyhydroxides. Once the canister is corroded, the fluid will come into contact with the glass matrix. Once the fluid is out of the matrix, it is transported to the surface of the environment and thus comes in contact with the environment. But the rate at which the transportation occurs depends entirely on the rate of diffusion of the Bentonite pores, the magnitude of different retardation process that will occur and on the level of water flow into the host rock.

Following the laws Boolean expression, the below equations are obtained for each of the levels.

Top event: TP1 = GT1 + GT2 + GT4

Where GT1 = (GT5)* (GT6) * (GT7)

GT7= GT8 + GT9 +GT11

GT2= EV2 +GT10 + EV3

GT4= EV4 + EV5

Substituting in the expression for top event, we get;

TP1 = ((GT5)* (GT6) *(GT8 + GT9 +GT11)) + (EV2 +GT10 + EV3) + (EV4 + EV5)

The FMEA method that is employed to predict the unknown probabilities is shown in Appendix B. Substituting the probabilities of each failure event in the above equation, the probability for the top event to occur is ***2.4963×10^{-10}***.

4.3 Public Perception towards Nuclear waste and Disposal

A survey, using SURVEY MONKEY is taken to understand public perception towards nuclear waste and disposal. This section will explain the questions along with their choices asked in the survey and the reason for choosing the given set of questions. The results obtained from this survey will be dealt with in the next section.

Description of Survey (for the public):

"Nuclear waste disposal is an unresolved issue in most of the countries that utilize nuclear energy to produce electricity. This survey is to understand public perception towards nuclear waste and disposal.

As a participant, you are expected to only read the below questions carefully and answer them to your level best. This survey is solely for research purpose and will remain confidential. It is completely voluntary and should you wish to quit the survey, you are free to do so any time.

Thank you for your time!"

Survey Questions:

1. *The most practical way to produce electricity to meet demands is with a. Fossil fuel b. Nuclear c. Renewable*

Reason: Power production by means of coal is hugely relied upon in India. As recently as August 26th 2013, there have been talks on installing 28 more power projects in India. Nuclear power is the next power generation technique used to generate power. Renewables are greatly in use in the country but ways to use this power is still a question. Answer to this question will help to form an opinion about how many people think nuclear power can be used as a solution to the power crisis in the country. This will help ascertain how many prefer nuclear over the other two forms of power generation.

2. *Exposure to harmful radioactive material can cause more harm to the human health than drinking alcohol or smoking.*
    a. *Strongly agree b. Agree c. Neutral d. Disagree e. Strongly Disagree*

Reason: It is a common belief that radioactive material will cause more harm than drinking alcohol or smoking. While it might be true, most people do not realise that more than half of the Indian population is exposed to smoking and drinking alcohol, while exposure to radioactive material is only confined to a certain location. Besides, the population is exposed to so many other harmful materials and chemicals that it is difficult to solely pin down the harm caused on radioactive materials. For e.g. there are chemical substances that enter into the human body through the food and other substance that is consumed. Answer to this question will help determine if the public perceive radioactive material to cause more harm than regular drinking alcohol and smoking.

3. *Disposal of nuclear waste in a geological site is the safest solution to mankind and the environment.*
    a. *Strongly agree b. Agree c. Neutral d. Disagree e. Strongly Disagree*

Reason: A solution has to be reached sooner or later with regards to nuclear waste disposal and disposing in a geological site is one possible practical solution. There have been other options like transporting the waste into outer space, using the ice caps as a disposing site and so on. Though they sound as a viable option, they are impractical. This question is asked to analyse how many people understand and agree along with other scientists to use a geological site to dispose nuclear waste. When a participant chooses option C. Neutral, then it is to understand that the person either has no knowledge about the topic under discussion or is neutral towards the entire nuclear proceeding that is taking place in the country.

4. *If nuclear waste is buried in solid rock, below the Earth's surface, it will be isolated from the living environment for 10,000 years.*
    a. *Strongly agree b. Agree c. Neutral d. Disagree e. Strongly Disagree*

Reason: From the previous fault tree results and from prior research, it is understood that when the barrier system fails to function efficiently, it takes a long time for the waste to seep through the system to reach the environment; say 10,000 years. By the time this reaches the environment, most of the radioactive material would have lost its radioactivity. There is also a linkage between questions 3 and 4. Those who agree with question 3 should normally agree with question 4. If this is not the case, then it can be concluded that public awareness is less.

5. *Are you aware of the way nuclear waste is reprocessed and prepared for storage? a. Yes b. No*
6. *Are you aware of the risk assessment techniques employed to ensure environmental safety? a. Yes b. No*
7. *The results published by the media about nuclear power and its development are always true and exact.*
    a. *Strongly agree b. Agree c. Neutral d. Disagree e. Strongly Disagree*
8. *How do you educate yourself about the nuclear industry and its developments*
    a. *Media b. Personal research c. None of the above*

Reason: The above questions are asked to understand if the public is actually aware of the techniques that are employed in a nuclear industry or if it is just blind faith in the media. It is well known that the media plays a very important role in the growth of an industry. The news is catered according to what news will attract the public. If a certain publisher chooses to support the anti-nuclear campaign, then the news released will portray nuclear power and its relation to terrorism or other similar activities. Before a person chooses to protest against something, some knowledge has to be gained about the sector, not just from the media, but from other academic publications and journals that state numbers facts and views of other scientists working in the field; in short, personal research is important.

9. *What type of person would you categorize yourself as?*
    a. *Pro-nuclear b. Neutral c. Anti-nuclear*

Reason: Categorizing one into the above three options will help classify how much the public accepts nuclear power. Those who perceive nuclear power to be a risk and a potential threat to the environment will not support this technology and will naturally fall under the anti-nuclear category.

It is important to understand that no technology can survive without the support of the public. It is necessary to recognize what they think about a certain technology and show or prove to them the good uses of it. A survey is just one way of "asking people". The ability to investigate respondents is a task by itself. It helps to collect a wide range of data (attitudes, opinions, beliefs, values, behaviour, factual). Addressing the concerns of the public is mandatory and survey will help to understand what they need/think.

Chapter 5 Discussion and Conclusions

From the technical risk analysis that was conducted using fault trees, it is seen that the probability for the radioactive material to reach through the various paths designed is approximately 2.4963×10^{-10}; which means that it has no immediate impact on the environment even if the barrier system fails to work. With respect to the Indian scenario, there are still no concrete talks about a permanent disposal, so this analysis is based on assumptions and other historical data. When actual data is produced, this risk analysis technique can then be employed to calculate risks. Also, the nature of the geological structure will not remain constant throughout. Changes in the geological background might affect the working of the barrier. Hence, continuous monitoring and update of the numbers is essential. Nevertheless, geological disposal is a safe and viable option and the engineered barrier system will prevent the radioactive materials from reaching the environment. Safe disposal is definitely feasible with the current technology.

Waste is a product of all industries and nuclear power is responsible for some types of waste which are particularly unattractive. But, such wastes are produced only in low quantities when compared to the end product value which is electricity. Hence repositories involving high-level barrier system design can be used to provide a high degree of safety. The only issue now is to convince the public that such kind of technology is safe to use. Nuclear power is a much need amenity for the power sector in India and considering the regular power-cuts for almost 15 hours a day, the country can very well use the power generated from a nuclear source, apart from the electricity generated from hydro, fossil fuel and renewable. Giving up this additional source of power is harmful for the country. When it was necessary to ascertain the radiation levels in the surrounding areas, it was found to be minimal when compared to the upper limits as prescribed by the Atomic Energy Regulatory Board (AERB). The Nuclear Power Corporation has taken steps to create awareness and spread confidence among the civilians by issuing booklets and publicising through radio, but the task goes in vain. People are still not satisfied with the effort that is taken by the government to show that nuclear power is safe.

Let's analyse the responses collected from the survey. The survey was distributed through online social networking site; Facebook and the targeted number for this survey was 50. The number of people who answered the survey was 59. The participant was not required to disclose any personal details, such as name, phone number or email address. Since the account created in survey monkey was a basic one, it did not include options to download the results and so the print-screen option has been used instead.

Looking into Questions 1 and 2, we see that 55.9 % think renewables is the most practical way of producing electricity. But the problem is, they cannot give a stable output and as of Aug 29th 2013, the population is once again experiencing power cuts because of the lack of power supply from the wind energy sector. So, power generation through renewables cannot be completely relied upon. More stable source of power is required for maximum production. Out of the 59 who answered, only 13 believe nuclear to be a practical solution to the power crisis that India is facing, which is an indicator to the level of confidence the public has on nuclear power. The reason behind this can be seen in question 2; where 66.1 % strongly feels that exposure to radioactive material will cause more harm than drinking alcohol or smoking. They perceive it to be harmful by just reading the question. What they do not realise is that exposure to radioactive material is confined to a very close proximity, whereas drinking alcohol and smoking is a day to day activity of the population. Even passive smoking has its own effect on the human body and it has been medically recorded and proven. Clearly, public perception matters and questions 1 and 2 are a direct link to what they think.

1. The most practical way to produce electricity to meet demands is with — Create Chart — Download

	Response Percent	Response Count
Fossil Fuel	16.9%	10
Nuclear	27.1%	16
Renewables	55.9%	33
answered question		59
skipped question		0

2. Exposure to harmful radioactive material can cause more harm to the human health than drinking alcohol or smoking. — Create Chart — Download

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Rating Average	Rating Count
Scale	66.1% (39)	23.7% (14)	1.7% (1)	6.8% (4)	1.7% (1)	4.46	59
answered question							59
skipped question							0

Let's look into questions 3 and 4. When asked if disposal of nuclear waste in a geological site is the safest solution, it can be seen that the answers are almost equally divided. 30.5 % of the respondents agree to the question, while there a 28.8 % neutral to the question. It can be concluded that the reason for them to agree to it, is perhaps because of the great reduction in the amount of radioactivity. Only 26 out of the 59 believe it be a safe solution, whereas 16 out of the 59 think it is not a safe solution. If the survey were to be conducted for a longer period, covering more number of people, then it acceptable to assume that this trend might have continued. In question 4, we can again see that the majority chose between "agree" and "neutral". Generally when a respondent chooses the "neutral" option, it can be assumed that they either do not have prior knowledge about the topic under discussion or they do not want to take sides; as in, remain neutral. But having a majority of the respondents falling under this category is not good too. It means that the government has failed to reach out to the majority of the population and convince them to support nuclear power. Also, 17 out of the 59 who took the survey do not agree to question 4. This can be because of 2 reasons, lack of knowledge or fear. There might be some who think that the ground cannot hold so much of waste for such a long period of time, which is not true. This might be because of the lack of knowledge in this field or because of the blind belief in what the media gives to the society. Either way, there is still a lot of work that has to be done in order to gain trust.

3. Disposal of nuclear waste in a geological site is the safest solution to mankind and the environment. Create Chart Download

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Rating Average	Rating Count
Scale	13.6% (8)	**30.5% (18)**	28.8% (17)	13.6% (8)	13.6% (8)	3.17	59
					answered question		**59**
					skipped question		**0**

4. If nuclear waste is buried in solid rock, below the Earth's surface, it will be isolated from the living environment for 10,000 years. Create Chart Download

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Rating Average	Rating Count
Scale	10.2% (6)	**30.5% (18)**	**30.5% (18)**	18.6% (11)	10.2% (6)	3.12	59
					answered question		**59**
					skipped question		**0**

In questions 5 and 6 , it can bee seen that the majority of the people who answered the survey do not know about the technical processes undertaken to assure safety. Now, is the public at fault for not knowing about it or is it the goverments fault for not keeping the records open to the public? There have been concerns raised by the anti-nuclear groups stating that the goverment is reluctant on revealing the findings of the environmental impact assessments . this makes it easier for them to create fear among the people. On the other hand, there are journal papers and other case studies that are available and open for public use. Only those who interested will take the pain of downloading the documents and reading them. The rest will only believe what they hear. Going against a technology with no prior knowledge about it or self research to ascertain the details is a total act of injustice . Once an image is formed with the public, it is very hard to change it and nuclear power is a clear example for it. The goverment needs to act mor vigilantly because they can expect protests much worse when it comes to choosing a proper disposal site.

5. Are you aware of the way nuclear waste is reprocessed and prepared for storage? Create Chart Download

	Response Percent	Response Count
Yes	28.8%	17
No	71.2%	42
	answered question	59
	skipped question	0

6. Are you aware of the risk assessment techniques employed to ensure environmental safety? Create Chart Download

	Response Percent	Response Count
Yes	47.5%	28
No	52.5%	31
	answered question	59
	skipped question	0

In question 7, we see that 27 of them have a neutral opinion about the media publications on this topic and 25 out of 59 believe that the media publications are not always true. In question 8, it can be seen that 26 out of 59 educate themselves through the media. It is now confusing to analyse what they exactly understand from the media when most of them believe that media does not give true facts. It can also be assumed that its not just the media who play a role in casting a dim light on nuclear power. Politicians and policy makers also have a huge role to play in this matter and it is very difficult for scientists to get past them to convince the public. Also there is a 10% who do not use the media or personal research option to educate themselves about nuclear power. It can be assumed that they are either with or against nuclear power based on what they hear from their surroundings through conversations with others. They form easy targets to talk to and manipulate their thoughts about nuclear. Spreading the news about nuclear through pamphlets or public talks will help them to form an opinion by themselves and help boost confidence level.

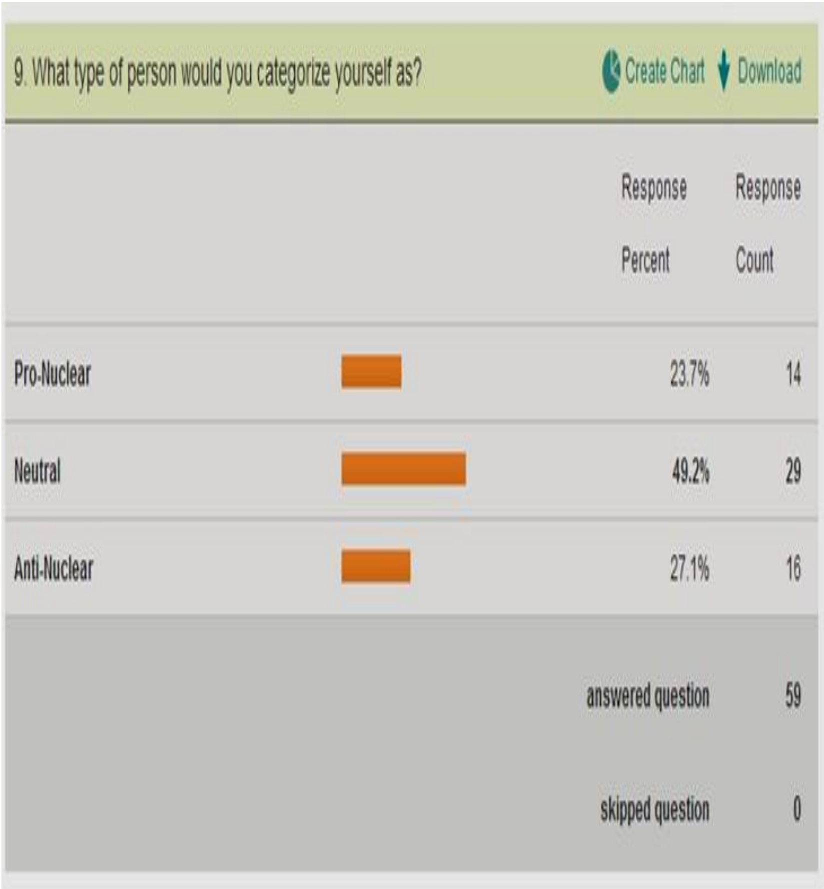
7. The results published by the media about nuclear power and its developments are always true and exact. Create Chart Download

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Rating Average	Rating Count
Scale	5.1% (3)	6.8% (4)	**45.8% (27)**	35.6% (21)	6.8% (4)	2.68	59
						answered question	**59**
						skipped question	**0**

8. How do you educate yourself about the nuclear industry and its developments Create Chart Download

	Response Percent	Response Count
Media	44.1%	26
Personal research	**45.8%**	**27**
None of the above	10.2%	6
answered question		**59**
skipped question		**0**

The final question shows us that 49.2 % are neutral towards nuclear power whereas there is a 27.1 % against nuclear. so it can be concluded that the majority either do not know which side to take or are anti-nuclear, which is not a good thing. The various nuclear accidents across different parts of the world have left the people to believe that nuclear power is dangerous. Radiation exposure following the nuclear accident at Fukushima-Daiichi did not cause any immediate health effects. It is unlikely to be able to attribute any health effects in the future among the general public and the vast majority of workers. The only form of health effects from the Fukushima accident are stemming from the stresses of evacuation and unwarranted fear of radiation.


9. What type of person would you categorize yourself as? Create Chart Download

	Response Percent	Response Count
Pro-Nuclear	23.7%	14
Neutral	49.2%	29
Anti-Nuclear	27.1%	16
	answered question	59
	skipped question	0

So what can we conclude from this study?

i) It has been shown that operating nuclear power plants does not cause cancer to the residents of nearby communities from normal operations;

ii) Over the past 40 years nuclear power has in fact saved almost 2 million lives through a real reduction in pollution by not burning fossil fuels and its resultant health impacts;

iii) Radiation has not harmed any of the people of Japan and is unlikely to do so in the future, even after the biggest nuclear accident.

Considering these kinds of results, why aren't we seeing this reported in the main stream media? With this kind of story there should be universal praise of nuclear power and strong support for its expansion. Frankly, if it were any technology other than nuclear that was reported to have saved millions of lives we likely would have seen it in the headlines of media report. So why is the world not blown away by this fantastic evidence of the benefits to our lives of nuclear power?

The reality is that some people will never change their view of nuclear power and will oppose it no matter what evidence is brought before them. Nuclear power is a positive hope for the future. But overcoming fear is no easy task. Fear is a powerful emotion. It will take hard work, commitment – and most of all - time. But if all goes well then there is a bright future ahead. The time has come to get the message out and show how much nuclear power contributes to society, and how necessary it is in a high energy resource intensive world. We have both the pro and the anti nuclear sides debating about facts, but the most important thing is how the facts feel. Perception of risk is not a purely rational, fact-based process. It is found that risk perception is an affective combination of facts and fears, intellect and instinct, reason and gut reaction. Research into how people perceive and respond to risk has identified several psychological characteristics that make nuclear radiation particularly frightening:

• It is undetectable by our senses, which makes us feel powerless to protect ourselves, and lack of control makes any risk scarier.

• Radiation causes cancer, a particularly painful outcome, and the more pain and suffering something causes the more afraid of it we are likely to be.

• Radiation from nuclear power is human-made, and human-made risks evoke more fear than natural threats.

• Nuclear power plants can have accidents and people are intrinsically more afraid of risks associated with a single large-scale "catastrophic" event than they are of risks that cause greater harm spread over space and time.

• Many people don't trust the nuclear industry or government nuclear regulators and the less we trust, the more we fear.

Whether this is rational or irrational, right or wrong, is irrelevant. It is, inescapably, how it is. Our response to risk can pose a danger all by itself. Our fear of nuclear power has led to energy economics that favour coal and oil for electricity, at great cost to human and environmental health. Particulate pollution from fossil fuels kills tens of thousands of people every year, and CO_2 emissions fuel a potentially calamitous shift in global climate.

No amount of education or good communication can get around this. Subjective risk perception is hard-wired into our architecture and chemistry. What governments can do is to learn what psychological research has established: our perceptions, as real as they are and as much as they must be respected in a democracy, can create their own perils.

With that understanding, government risk assessment can account not only for the facts, but also for how the public feel about them and how it behaves. That way, conflict over nuclear power and other risk issues can be reduced and wiser and more productive policies for public and environmental health can be fostered.

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Appendix A: Pressurised Water Reactor

A nuclear reactor produces and controls the release of energy from splitting the atoms of certain elements. In a nuclear power reactor, the energy released is used as heat to make steam to generate electricity. In a research reactor the main purpose is to utilise the actual neutrons produced in the core. In most naval reactors, steam drives a turbine directly for propulsion.

The principles for using nuclear power to produce electricity are the same for most types of reactor. The energy released from continuous fission of the atoms of the fuel is harnessed as heat in either a gas or water, and is used to produce steam. The steam is used to drive the turbines which produce electricity (as in most fossil fuel plants). The pressurised water reactor (PWR) has water at over 300°C under pressure in its primary cooling/heat transfer circuit, and generates steam in a secondary circuit. The less numerous boiling water reactors (BWR) make steam in the primary circuit above the reactor core, at similar temperatures and pressure. Both types use water as both coolant and moderator, to slow neutrons. Since water normally boils at 100°C, they have robust steel pressure vessels or tubes to enable the higher operating temperature. (Another type uses heavy water, with deuterium atoms, as moderator. Hence the term 'light water' is used to differentiate.)

Components of a nuclear reactor:

There are several components common to most types of reactors:

<u>Fuel</u>**:** Uranium is the basic fuel. Usually pellets of uranium oxide (UO_2) are arranged in tubes to form fuel rods. The rods are arranged into fuel assemblies in the reactor core. In a new reactor with new fuel a neutron source is needed to get the reaction going. Usually this is beryllium mixed with polonium, radium or other alpha-emitter. Alpha particles from the decay cause a release of neutrons from the beryllium as it turns to carbon-12. Restarting a reactor with some used fuel may not require this, as there may be enough neutrons to achieve criticality when control rods are removed.

<u>Moderator</u> **:** Material in the core which slows down the neutrons released from fission so that they cause more fission. It is usually water, but may be heavy water or graphite.

Control rods**:** These are made with neutron-absorbing material such as cadmium, hafnium or boron, and are inserted or withdrawn from the core to control the rate of reaction, or to halt it. In some PWR reactors, special control rods are used to enable the core to sustain a low level of power efficiently. In fission, most of the neutrons are released promptly, but some are delayed. These are crucial in enabling a chain reacting system (or reactor) to be controllable and to be able to be held precisely critical.

Coolant**:** A fluid circulating through the core so as to transfer the heat from it. In light water reactors the water moderator functions also as primary coolant. Except in BWRs, there is secondary coolant circuit where the water becomes steam.

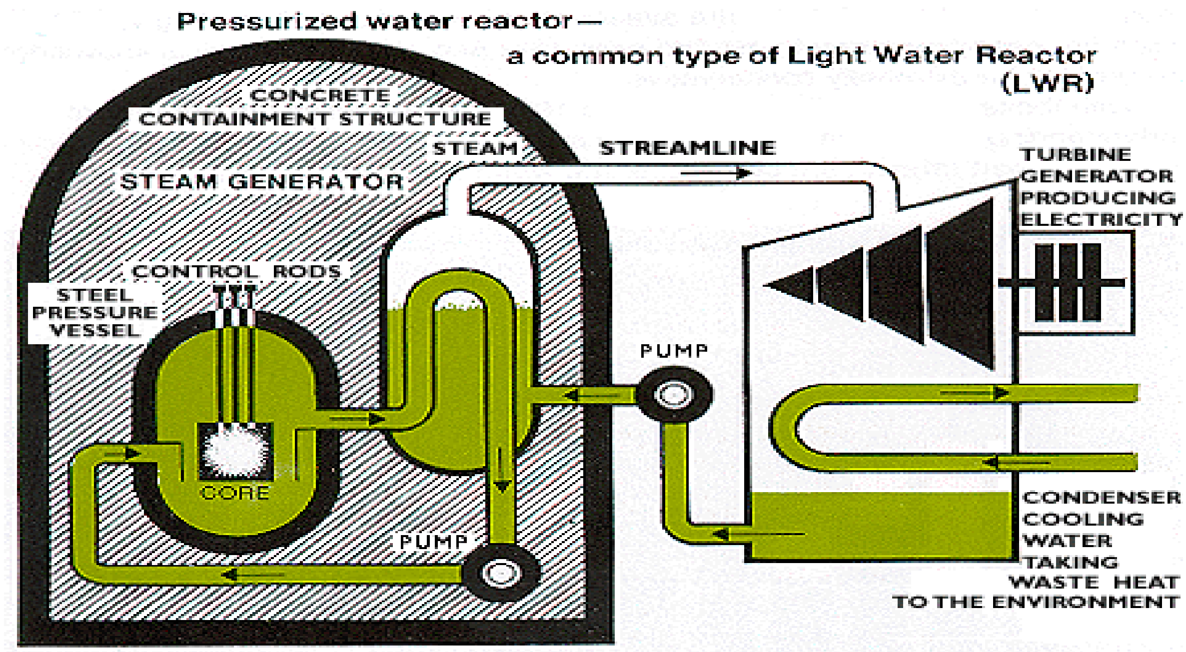
Pressure vessel or pressure tubes**:** Usually it is a robust steel vessel containing the reactor core and moderator/coolant, but it may be a series of tubes holding the fuel and conveying the coolant through the surrounding moderator.

Steam generator**:** It is a part of the cooling system where the high-pressure primary coolant bringing heat from the reactor is used to make steam for the turbine, in a secondary circuit. Reactors may have up to four 'loops', each with a steam generator. These are large heat exchangers for transferring heat from one fluid to another – here from high-pressure primary circuit in PWR to secondary circuit where water turns to steam. Each structure weighs up to 800 tonnes and contains from 300 to 16,000 tubes about 2 cm diameters for the primary coolant, which is radioactive due to nitrogen-16 (N-16, formed by neutron bombardment of oxygen, with half-life of 7 seconds). The secondary water must flow through the support structures for the tubes. The whole thing needs to be designed so that the tubes don't vibrate and fret, operated so that deposits do not build up to impede the flow, and maintained chemically to avoid corrosion. Tubes which fail and leak are plugged, and surplus capacity is designed to allow for this. Leaks can be detected by monitoring N-16 levels in the steam as it leaves the steam generator.

Containment **:** The structure around the reactor and associated steam generators which is designed to protect it from outside intrusion and to protect those outside from the effects of radiation in case of any serious malfunction inside. It is typically a metre-thick concrete and steel structure.

Pressurised Water Reactor (PWR)

This is the most common type, with over 230 in use for power generation and several hundred more employed for naval propulsion. The design of PWRs originated as a submarine power plant. PWRs use ordinary water as both coolant and moderator. The design is distinguished by having a primary cooling circuit which flows through the core of the reactor under very high pressure, and a secondary circuit in which steam is generated to drive the turbine. In Russia these are known as VVER types - water-moderated and -cooled. A PWR has fuel assemblies of 200-300 rods each, arranged vertically in the core, and a large reactor would have about 150-250 fuel assemblies with 80-100 tonnes of uranium. Water in the reactor core reaches about 325°C , hence it must be kept under about 150 times atmospheric pressure to prevent it boiling. Pressure is maintained by steam in a pressuriser. In the primary cooling circuit the water is also the moderator, and if any of it turned to steam the fission reaction would slow down. This negative feedback effect is one of the safety features of the type. The secondary shutdown system involves adding boron to the primary circuit. The secondary circuit is under less pressure and the water here boils in the heat exchangers which are thus steam generators. The steam drives the turbine to produce electricity, and is then condensed and returned to the heat exchangers in contact with the primary circuit.



Appendix B: FMEA Calculation

The following FMEA calculation is done to determine failure rates for those events whose probabilities were not known. In practices, such calculations are done in groups but because this is an individual presentation, the below calculations are made by just one person.

For a period of one year;

Steps in the process	Failure mode	Failure causes	Failure effects	Likelihood of occurrence (1-10)	Likelihood of detection (1-10)	Severity (1-10)	Risk Profile Number (RPN)	Actions to reduce occurrence
1 Unfavourable chemical conditions	Will lead to the failure of the barrier system	Changes in the chemical conditions of the radioactive material stored	Will result in the release of radioactive material into the environment	3	2	8	48	Ensure favourable chemical conditions of the material
2 Increased Oxygen content	Will cause corrosion of steel container	Increase in oxygen level in the repository site	Corrosion of steel, thereby leading to leakage of stored radioactive waste	3	2	8	48	Provide corrosion resistant steel container.

3 inflowing ground water increase	Will transport radioactive waste to the surface	Changes in geographical structure, leading to cracks	Will lead to exposure of radioactive material	3	2	8	48	Careful location of site