NUCLEAR ENERGY

RISKS AND DECISIONS

OPRE 6335 - SYSM 6304

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Table of Contents

ABSTRACT

The increasing energy demand of the world is satisfied with the usage of multiple energy sources which will be divided into renewable and non-renewable. One such major renewable energy source is the operation of nuclear power plants. Typically, a nuclear power plant uses radioactive fuel to generate energy with the help of the fission reaction on the radioactive element's atoms. The establishment and the construction of a nuclear power plant involves a lot of different sectors of work. The different categories of work that needs to be taken care of is going to be segmented into

- GEOPOLITICAL
- PRIVACY AND SECURITY
- FINANCIAL WORK
- ENGINEERING
- SUPPLY CHAIN AND LOGISTICS

These segmented divisions should be completed individually and connected with each other during all the stages of operation for the nuclear power plant to function with full efficiency.

The establishment of the plant goes through various stages of planning, but it is important to know that the risk and decision analysis techniques for the nuclear power plant takes a dominant hand over the planning stage. Every decision made during the analysis is always linked to a common timeline. This reference timeline of the nuclear power plant goes into the past and the future as well. This multi-directional research approach will give way to better information on the research and analysis of risks involved in the process of running a nuclear power plant. This report will give information about the various risks involved in the different segmented sections of work and a detailed explanation about how the risks occur. A few of these risks will eventually fade away but most of them are included to give awareness only.

1) Geopolitical Risks of Nuclear Energy (Sanyukta Suryavanshi srs210007)

Nuclear Energy is criticak issue in global affairs. Nuclear energy is a geopolitically sensitive topic in countries in Asia, Africa, and even Europe. In order to understand the geopolitical risks of nuclear energy, three major risks in this area are discussed.

These include Risk of

1. Anti-Nuclear Sentiment : In today's world when energy transition is given utmost importance, the world looks at nuclear energy for its energy security. However, anti nuclear movements and a general sentiment of fear towards nuclear energy is deterrent to the objective to enhance nuclear in the world energy mix.
2. Nuclear Weapon Proliferation Risk: Another issue which needs to be tackled before proliferating nuclear energy is the use of nuclear fuel as weapons of mass destruction. For this there are already global organizations like IAEA which mandates the non-proliferation treaty and promote atom for peace agenda. This potential risk is explored
3. Supply of Uranium: If the nuclear power plants are to be established around the globe including third world countries then the supply chain of uranium is also to be assessed. The supply is however dominated presently by Russia and it is crucial to look at the other players to understand ways to mitigate the supply diversification and shortage.

Anti-Nuclear Sentiment

Anti-Nuclear Movements is a social movement that opposed the production of nuclear weapons and using nuclear fuel to generate electricity. This movement around the world have pioneered:

1. Nuclear test ban treaty in 1963 which prohibited the testing of nuclear weapons under water, in the atmosphere, or in outer space. This treaty was signed by United States, Soviet Union, and United Kingdom.
2. Environmental impact assessment of nuclear power plants. The issue of environmental impact spurred because of concerns of thermal pollution due to discharge of hot water from nuclear power plants. Even though the intensity of pollution was minimal regulations were strengthened and led to technological improvements.
3. The Fukushima incident caused public anxiety. This led to a wave of protest in Japan. This pushed TEPCO to release disaster report and unravel the series of incidents that occurred and bring them to public light.
4. Fukushima effect led to major phaseout of Nuclear Power Plants in Germany. Germany's engineering giant Siemens also announced withdrawal from nuclear power projects.

The lessons learned from Chernobyl and Fukushima have imposed five basic requirements on the nuclear power: safety, economy, non-proliferation, management of spent fuel and management of radioactive waste.

In one such incident the geopolitical issue between two countries was hanging in a delicate balance. This incident brought into light that such potential issues can cause delays in the project, a sentiment of distrust and a possible loss in revenue.

Astravets' Nuclear Power Plant – Delicate Geopolitics

During the nuclear disaster of Chernobyl, Belarus was hit more than 70%. Belarus launched its nuclear power plant project in Astravet at the beginning of 2020.

Its neighboring country of Lithuania post the Chernobyl disaster, shutdown its nuclear power plant in Ignalia in 1963. The reactor of the plant was RBMK nuclear reactor, same as Chernobyl and to mitigate the risk of an accident decommissioned the power plant. The Baltic countries were dependent on this plant for its supply of electricity and now import electricity from Russia, Belarus, Poland and Scandanavia.

Belarus government believed that the Nuclear power plant at Astravets would reduce its dependency and lead to reduction in import of natural gas. The power plant will also produce a surplus of electricity which can be traded to the Baltic countries.

This power plant faced a major opposition from Lithuania. Astravets NPP constructed by Rosatom just 15km from Lithuanian border and 50km from Vilnius.

By The New York Times

Figure 1: Map showing proximity of Astravets location to Lithuania.

This nuclear power plant was funded by Russia and constructed by Rosatom. This is one of the reasons of opposition for the power plant.

Feasibility study conducted in 1993 for sites in Belarus declared the Astravet site unsuitable for construction of a nuclear citing risk of earthquakes. In 2013, IAEA recommended not to construct the NPP. Belarus ignored project safety concerns from Lithuania, European Union and its own population and commissioned the project.

Lithuanian Govt. Arguments

The Lithuanian government argued that Astarvets plant was constructed on an unsuitable site for nuclear power plant. This violated a key nuclear safety requirement that a nuclear power plant is not to be constructed 100 km from major cities. This was a major requirement as per IAEA post Fukushima disaster. Considering the risk of earthquake at the Astravet site and its proximity to Lithuania, the power plant was looked on as a threat. It was also argued that the power plant is constructed without transparent public participation.

Major accidents have occurred at the Astravet nuclear site during the construction phase. A total of 6 accidents took place in a matter of just 6 months. In one accidents the nuclear reactor fell from a height of 4.5 m and believed it to be damaged. Another nuclear reactor collided railway infrastructure and was still installed at reactor 1.

The Belarus government committed to perform a risk and safety assessments called the stress test for the European Union in 2011 and but did not submit it until 2017. Lithiuania argues that timeliness is crucial in such matter and mere submission of a report cannot be considered as a progress.

Based on the regulations of Western Europe Nuclear regulators Association, all newly built nuclear power plant much consider heavy airplane crash in their designs. This requirement is implemented post Fukushima disaster. The Belarus nuclear power plant did not conduct such evaluation inspite of Lithuanian govt's insistence.

There were also claimed about the project being controlled by Russia. This project is geopolitically driven to export electricity to Baltic countries.

However, after the Lithuanian governments strong opposition Poland and the Baltic countries refused to buy electricity from Belarus.

Actions by European Union

In 2018, the EU reviewed the project and addressed the safety recommendations following a stress test. A peer review was recommend. The EU nuclear safety regulators visited the Astravets site in February of 2021 for a second review The European Nuclear Safety Regulators Group (ENSREG) approved the preliminary report on the peer review of the power plant. This lead to a end of the first phase of nuclear peer review. Post this the ENSREG will continue to engage with Belarus to ensure that the safety recommendations are followed meticulously.

The committee also declared that its approval cannot be used to obtain certifications for the nuclear powerplant. The auditing and certification are a responsibility of Belarus government and must be executed to obtain commercial licensing of the plant.

Reactor Technology

The reactors installed at the Astravet power plant at VVER 1200, a flagship Rosatom's reactor. This reactor is said to be safer and more advanced and capable of boosting economic growth than its predecessor VVER 1000. This reactor was approved by IAEA for its safety commitments.

Rosatom's VVER reactors are operational at various parts in the world are are believed to have longer track record of safety. This concludes that awareness of the reactor technology is very important in order to make arguments in favor of nuclear power plants.

Nuclear Proliferation Risk

The history of nuclear technology development was focused on creation of nuclear weapons of mass destruction during the Cold war. The modern nuclear energy is a mature technology for domestic production of electricity.

For peaceful use of atomic energy, the international atomic energy agency (IAEA) was founded in 1957. The agency was created as an independent inter-governmental organization within United Nations.

The role of the agency is to mandate the Treaty of Nuclear Proliferation of nuclear weapons on each participating state. The NPT came into force in 1970s as an agreement between five nuclear weapon states of United States, Russia, United Kingdom, France, and China.

The functions of the agency include:

- Formation and application of a system of guarantees that civilian nuclear programs and developments will not be used for military purposes.
- Development, establishment, and adaptation of health and safety standards.
- Encouraging research and development on the peaceful uses of atomic energy.
- Encouraging the exchange of scientific advances and methods.

In the 1980s, the IAEA believed that any nuclear non-proliferation treaty ratification would be based on diversion of nuclear materials from the nuclear materials under the safeguard of IAEA. It was also believed that such activities would not go undetected by the national securities.

North Korea in late 1985, established a research facility, a gas cooled, and graphite moderated, natural uranium powered experimental power reactor. IAEA inspected the facility and in 1992 the inspectors' found discrepancies in running logs of the plant. This led to conclusion that North Korea has been using the facility to produce weapon grade plutonium. This breach of NPT was controlled by bilateral negotiations between North Korea and USA. The agreement post, this was to cease the facility and eventually dismantle it. IAEA was said to monitor the facilities till the dismantling, but North Korea did not cooperate, though no operations were carried out.

Iraq and Iran had accepted the NPT safeguards at its declared facilities. However, in a clandestine manner Iraq and Iran constructed uranium enrichment facilities. IAEA failed to note that the uranium for these enrichment facilities was not diverted from domestic uranium fuel. They had accumulated 550 tonnes of uranium oxide. UN Security council ordered IAEA to destroy all of Iraq's nuclear facilities which was done by 1998.

The shifting nuclear dominance from USA to Russia and China, is the primary reason of fear for nuclear proliferation in third world country, than a threat. Russia is a major exported of nuclear technology like VVER nuclear reactors for domestic electricity production. Additionally, Russia has lucrative credit system for development of nuclear power plants. This suite is followed by China as well.

Yet a multitude of preventive measures are exercised and under progress to prevent proliferation of nuclear weapons.

Nuclear Proliferation Preventive Measures

The ratifications of NPT exposed the fact that Uranium is ubiquitous and can be extracted indigenously. But IAEA has claimed that the uranium that is used as fuel cannot be used in nuclear weapons. The safeguard also added additional clause for special inspection which allows IAEA to conduct inspection on suspected illicit facilities.

Other measures could be to implement safeguard regimes that ensures continuous material protection, control, and accounting through advanced information, monitoring and containment technology.

Providing economic or political incentives from the UN and IAEA, to motivate compliance to the NPT safeguards.

Also, research is ongoing to develop high burn-up nuclear fuel. This ensures minimized wastage, meaning lesser resource to produce plutonium.

Geopolitical Risk of Uranium Supply

Uranium is the primary fuel for nuclear power plants. Uranium ore is mined either underground or in a open cut manner. The mined ore is then milled to obtain uranium oxide (U_3O_8) concentrate, which is then traded worldwide. The world consumes 55,000 to 65,000 tonnes of uranium oxide annually. The uranium supply is concentrated in the countries like Australia, Kazakhstan, Canada, Namibia, Russia etc. In the year 2021, Kazakhstan was the world's largest producer of uranium and supplied 45% of uranium oxide. This is followed by Namibia (12%), Canada (10%) and Australia.

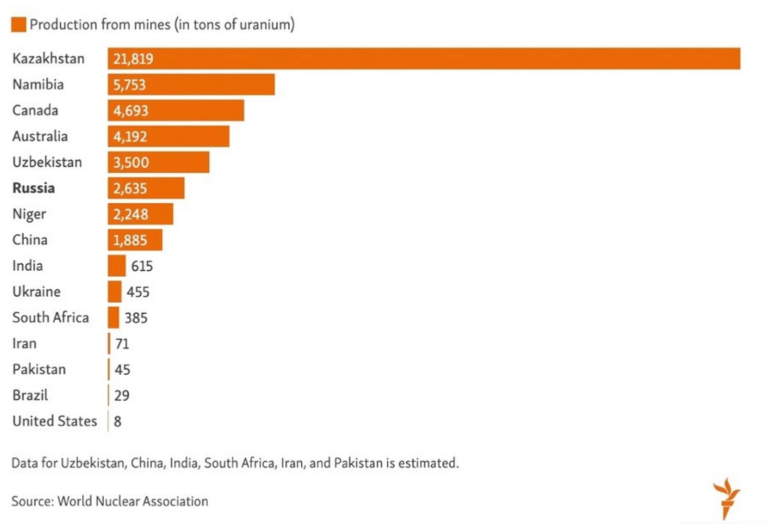

Figure 2: Uranium Producing countries in 2021

However, raw uranium cannot be used as nuclear fuel. Instead, raw uranium undergoes the process of gasification and enrichment to obtain nuclear fuel. Around the globe there are only 4 countries that have conversion facilities. These nations are Russia, China, Canada and France. As of 2021, Russia is dominant player providing 40% of converted uranium to the world. As of 2018 Russia has the largest uranium enrichment capacity followed by China.

However, by the year 2030, it is expected that Russia’s capacity may drop to 36%.

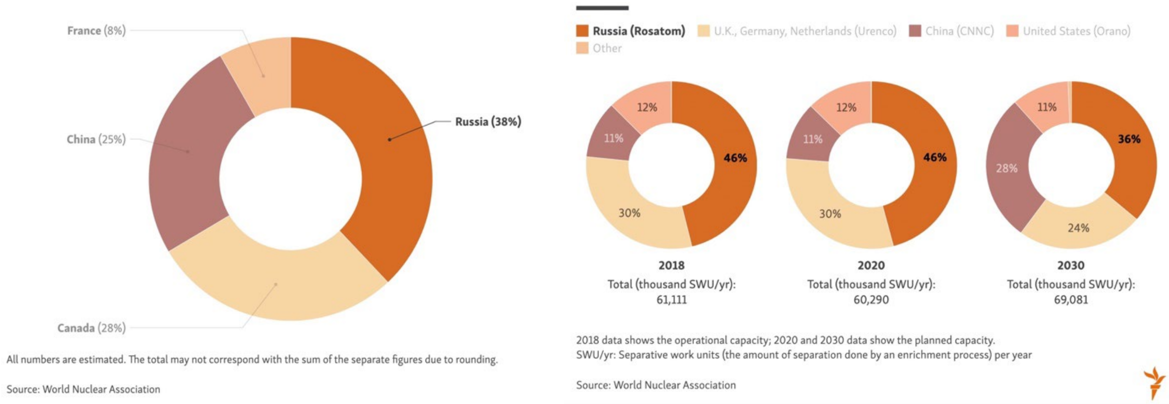

Figure 3: Uranium Gasification and Enrichment Facilities

Russia is a significant supplier of uranium to European union and United States and supplies 20% and 15% of its requirements.

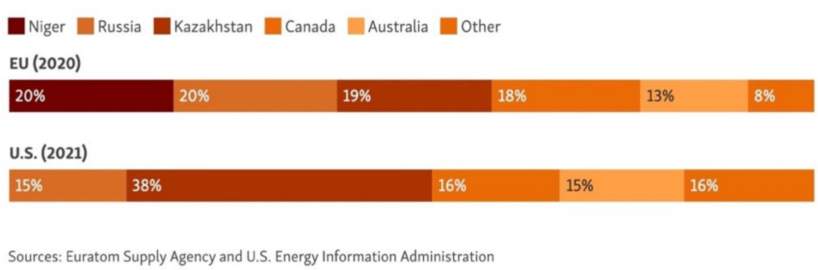

Figure 4. Uranium Supply from Russia to EU and USA.

Supply chain of uranium has never been a critical issue. However, in the current light of Russian war against Ukraine, it is important to understand the supply actors. As Russia is an important supply actor the war has affected the spot price and future prices which have been stable since 2018. A sudden spike can be seen on March 31st, 2022, post which the prices of uranium are maintained at an inflated rate. Additionally, European Union and USA are discussing a ban on Russian commodities. It takes years of planning and authorizations from IAEA to establish facilities and produce enriched uranium. Hence for the EU and USA to diversify their Uranium supply requires investments not only monetary but also time. Hence Uranium supply is at potential risk at the face of the present geopolitical turmoil.

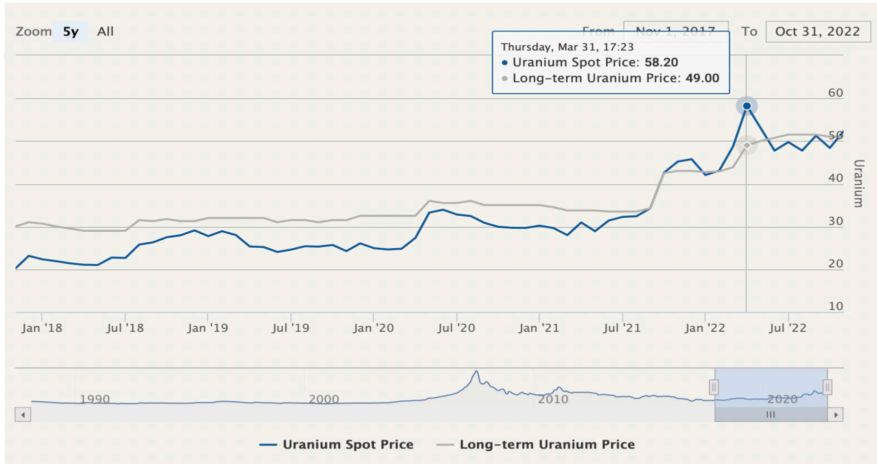

Figure 5: Spot and Futures Prices of Uranium till Oct 31st 2022.

2) Security and Privacy Risks of Nuclear Energy by Mahesh [mkr200000]

Introduction and the organization of the chapter

As of May 2022, there were 439 nuclear reactors in 30 countries for power generation. Also, many countries use nuclear materials for military and scientific experiments. Thus, the security of these nuclear power plants, nuclear material, and sensitive information are three main challenges that all nations face.

International Atomic Energy Agency (IAEA) [1] defines the nuclear security as “The prevention and detection of any response to, theft, sabotage, unauthorized access, illegal transfer or other malicious acts involving nuclear material, other radioactive substances or their associated facilities”. IAEA emphasizes improved protection as an essential component of security by considering the amount of nuclear and other radioactive materials in transit and in storage. Furthermore, it also describes that physical protection requires a mix of hardware (security devices), procedures (organization of guards and performance of their duties), and facility design including layout.

About 50 new nuclear power plants are under construction all over the world and the process control systems in nuclear power plants have been transitioned from analog systems to highly digitized systems. Furthermore, the evolution of digital systems from specialized hardware and software to more standardized hardware and software in Supervisory Control and Data Acquisition (SCADA) systems brings new risks and vulnerabilities [2], especially cyber-threats are increasing.

Finally, World Nuclear Association (by March 2022) states that, to date, cyber-attacks on information and control systems have not compromised safety. However, it brings the world’s attention to the fact that the first time an operating nuclear plant was attacked by an armed group during Russia’s military operations in Ukraine.

So, we wish to focus our attention on the security risks including the privacy of sensitive data of nuclear energy in three main streams as Risks of Cyber Security, Risks of Physical Protection, and Risks due to Negligence (overthrow of Procedures). Also, it is worthwhile noticing, at the beginning of the discussion, that three aspects above are very much inter-related and we wish to us on Risks of Cyber Security mainly as it is increase with development of the science and technology.

Risks of Cyber Security

Cyber security risks are critical, and the number of cyber-threats is increasing with the development of technology and various other reasons. As mentioned above, one of the main reasons is that the development in the software in Supervisory Control and Data Acquisition (SCADA) systems that brings the operation in a Nuclear Power Plan to an autonomous process.

For comprehensive understanding of the risks of cyber security and data privacy of Nuclear Power Plant (NPP), we need a view of the architecture of it. In general, the Industrial Control Systems (ICSs) are the most critical components of any infrastructure [3]. See figure1.

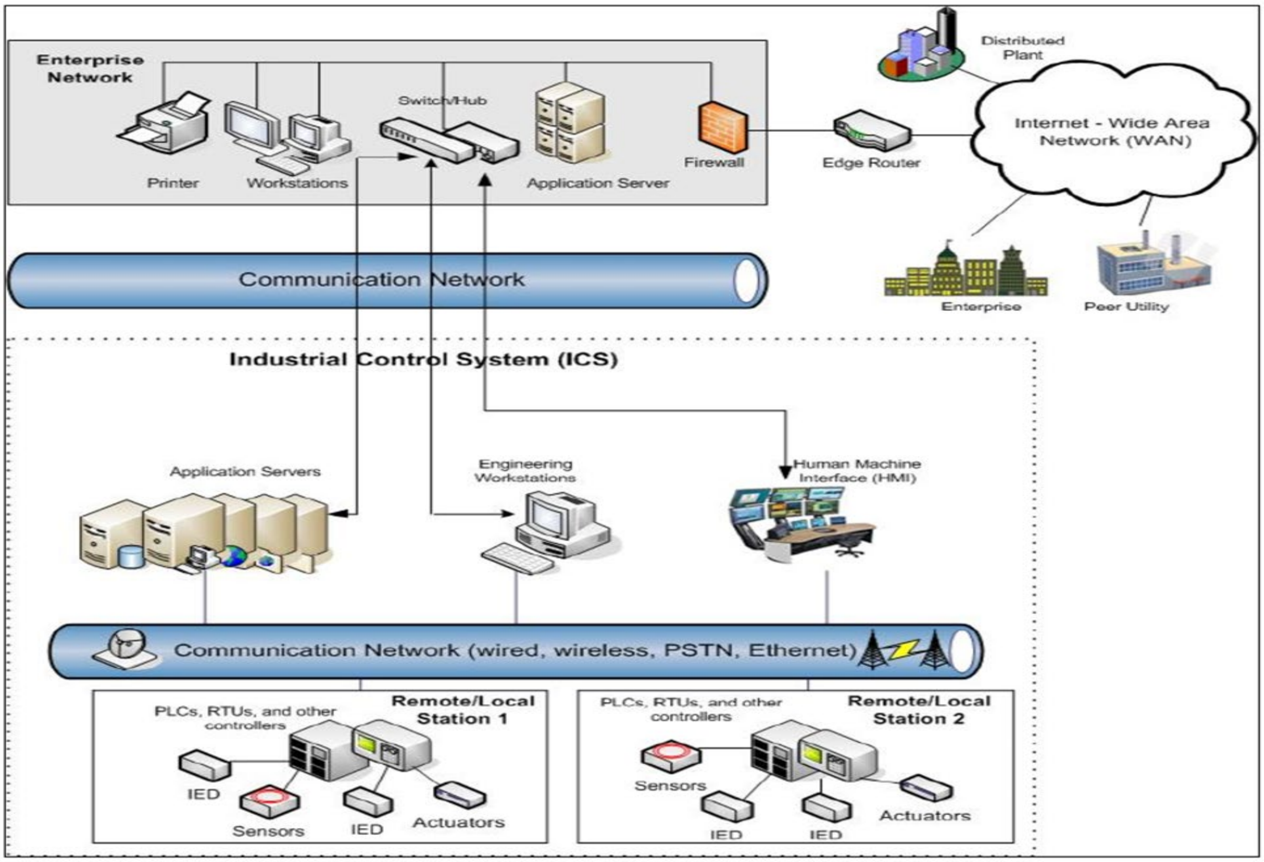

Figure 1: Schematic view of the architecture of a NNP [3]

ICSs are found in two main types, namely, Distributed Control systems (CDS) that are used within small or single NNPs and Supervisory Control and Data Acquisition (SCADA) systems that are used in large NNPs [3]. Also, some ICS can include SCADA system as a part of it and other components are a central repository, monitoring station, sensors, and field devices [3]. Simply, the SCADA system issues commands or instructions to field device. The monitoring station includes several human machine interfaces that are used by remote operators. In short, these various components of the NNPs are connected via wireless or with wired communication network to exchange information, control purposes, etc. [3]. Figure 1 shows these different communication networks. In fact, these communication networks are the reason as to why the ICSs are vulnerable to cyber-threats. Identifying this risk, a defense mechanism is developed. This mechanism is called the protection by Firewalls or often called being “air-gapped” which creates a barrier for outside user to reach the NNPs via network connection to the NNPs and isolates the NNPs from outside internet connections [4].

However, as mentioned above, there are communication networks within the NNPs and that carries cyber security risks along with it. These cyber risks scenarios are divided into three categories as follows [3].

1. **Cyber Attacks**: These are highly sophisticated attacks aimed at corrupting nuclear command and control systems and remove radioactive materials. Since cyber-attacks are sophisticated, it is hard to execute them. However, with proper identification of the specific vulnerabilities in ICSs and support from an insider, it could be possible to launch a cyber-attack [3].
2. **Cyber Sabotage**: These attacks aim to affect the operations of the NNP and damage the equipment in various forms. It could come as a virus or malware into the system. Cyber Sabotages are more frequent than Cyber Attacks as they do not require such sophistication. However, because NNPs are "air-gapped," it requires a connection to the inner communication network of a NNPs. There are numerous ways this can happen and many examples in history. One of the most famous series of cyber sabotage cases occurred at Iran's nuclear power plant. Stuxnet was the most sophisticated cyber sabotage that altered the frequency of the centrifuges and caused damage to SCADA systems in Iran's NNP from 2010 to 2014 [3,5].
3. **Cyber Espionage**: These attacks aim to collect confidential information from an NNP and use them for malicious purposes. Out of three scenarios, cyber espionage is the most frequent type of attacks since these are not sophisticated attacks as the two types. Also, with the development of computer science and technology, there are many tools available freely. What is required is to infect or remotely install a targeted personal computer to penetrate the trusted network of an NNP. This brings our attention to another matter that compromises the security of a NNP which is a threat from insiders and negligence. There are numerous examples of cyber espionage that can be found in [3].

The literature shows that there are many incidents where the security and privacy of data of NNPs were compromised, see [7]. All these incidents have one thing in common. The NNPs were "air-gapped" yet the virus or malware was entered to the facility and penetrated the trust network within the NNP via personal devices such as USB flash drives or computers proving that being air-gapped alone is not effective and enough. Also, for maintenance purposes or other supply chain management purposes administrative network and devices have access to different personnel from outside the NNPs that allows attackers to get access in directly.

Risks of Physical Protection

Physical protection is an important aspect of the security of nuclear and radioactive material. Nuclear materials are available in several countries including Kazakhstan and Australia [6]. But most of the Nuclear Power Plants are located far from these places. Thus, the nuclear material must be transported from mining to NNPs. Also, during transportation, the nuclear materials must be stored in between for many reasons including inefficiencies of coordination. Finally, nuclear materials must be stored securely at the storage in NNPs. In this process, security of the nuclear material and the nuclear power plant itself are at risks due to theft of radioactive materials and nuclear materials, terrorist attacks, and military actions [7,8,9]. Also, according to IAEA reports, there are about 610 thefts of radioactive materials that were recorded out of which 310 (57%) were stolen during transportation [9]. Also, various type of terrorist attacks to nuclear power plants or during the transportation are another threat. In 1979, environmental terrorists damaged to a French nuclear plant, and in 1982, five rockets were fired into the French Creys-Malville nuclear facility. From 1969 to 1975, there were 14 actual and attempted bombing incidents of U.S. nuclear facilities and 240 bomb threats [8]. Due to the recent war between Russia and Ukraine, during Russia's military actions, one of the largest NNP in Ukraine was attacked though the NNP was not damaged heavily [10]. This clearly addresses that the consideration of risks due to military actions are indispensable.

Risks due to Negligence (Overthrow of Procedures)

Indeed, one of the root causes of many risks is negligence and it is complimented by overoptimism. There are many examples, including many cyber security risks discussed above, to prove that the risks due to negligence and overthrow of procedures must be addressed and mitigated. To be specific, Kudankulam Nuclear Power Plant in Tamil Nadu, India, experienced a cyber-attack and the authorities had noticed this incident on September 4, 2019. The investigation found that the cause was malware-infected personal computer was connected to the plant's administrative network [11]. In this case, it was clear that the person who connected the personal computer clearly violated protocols connecting personal computer to the administrative network. Also, Fukushima Daiichi disaster was foreseeable as there were several reports indicating the risks. However, TEPCO has built the NNP neglecting those reports findings. Furthermore, even the Chernobyl disaster clearly indicates the risks of negligence.

In short, understanding the risks, their nature, and their roots should be a focus to mitigate them. We have described Risks of Cyber Security, Risks of Physical Protection, and Risks due to Negligence (overthrow of Procedures) with some key features mentioned above. Also, Risks of Physical Protection and Risks due to Negligence (overthrow of Procedures) are understood and studied well in the literature. For solution to mitigate risks, there are guidelines and protocols that should be practiced published by International Atomic Energy Agency. However, Risks of Cyber Securities are changing with time. For example, the recent developments of artificial intelligence increase the threats of cyber security of nuclear energy. We suggest that the risk due to AI in nuclear energy should be well studied.

3) Financial Risks of Nuclear Power Plants: By Kunal Shah (KAS200001)

Overview:

This section of the report aims to provide a measured recounting of all known nuances and known financial risks associated with the creation, management, and decommissioning of Nuclear Power Plants (NPP). The Figure Below shows the typical life cycle of a Nuclear Power Plant.

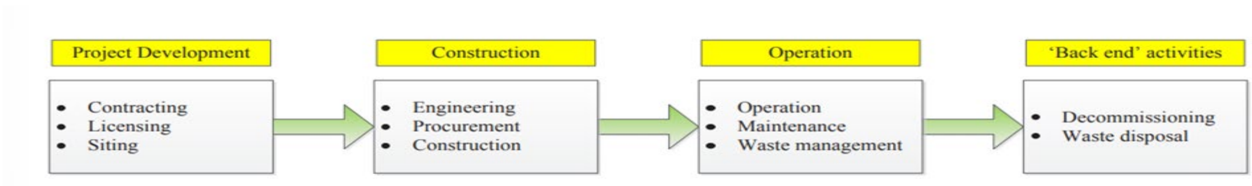

Figure 1: Life Cycle of a Nuclear Power Plant (Managing the Financial Risk Associated with the Financing of New Nuclear Power Plant Projects, 2017)

The financial risks of building an NPP are allocated amongst multiple stakeholders as you will see in Figure 2., These stakeholders must come to an agreement on multiple points of contention to find an equitable contract (i.e., Fuel Supply Agreement, Equity Agreement, EPC Contracts, Electricity Off-Take Agreement, Loan & Security Agreements) that allows for this venture to be profitable at its eventual financial closing. The stakeholders themselves can be a varied set of entities ranging from commercial energy companies to governments of countries and states, construction companies, financial institutions, and even retail investors.

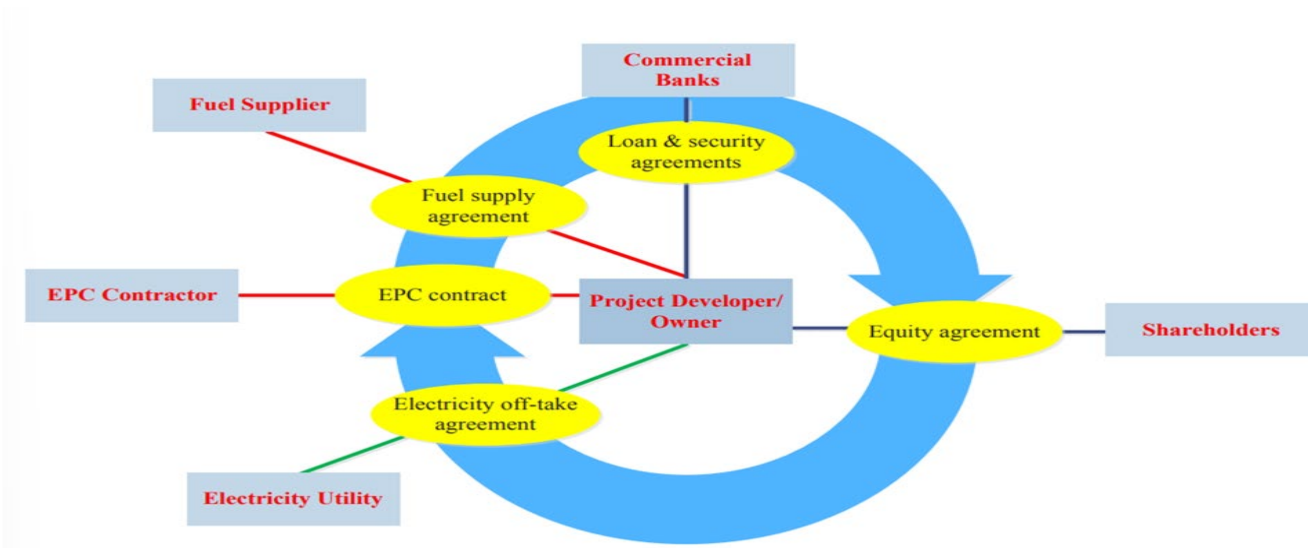

Figure 2 Chart to show allocation of Financial Risk amongst varied stakeholders (Managing the Financial Risk Associated with the Financing of New Nuclear Power Plant Projects, 2017)

Revenue of the project across usable life is largely determined by the terms of the utility (electricity) off-take agreement, contrariwise the Engineering, Procurement, and Construction (EPC) contracts will largely determine the costs of the project. The combination of these factors will inform the Project owner of the expected residual income available to the lenders as a form of repayment on the principal and its subsequent interest payments as well as to shareholders.

Determining the Financial Viability of a Nuclear Power Plant:

Nuclear power production projects are capital-intensive investments with a unique cost structure. The permitting and licensing procedures for such projects are prolonged and costly, and construction can reasonably take up to seven years. The contractual situation for these projects is complicated and can lead to delays and numerous cost variations. Additionally, these projects require large upfront capital investment. These factors make the cost of capital a key factor in the overall economic calculation of the feasibility of a nuclear power project. The cost of capital is defined by the interest the lenders demand and is calculated using the weighted average cost of capital (WACC), this reflects the combination of both debt and equity financing utilized to raise capital for the project.

Nuclear power plants (NPPs) are known to be capital-intensive investments with a unique economic structure and cost structure. These characteristics make NPPs risky for investors and lenders and require careful consideration of the potential risks and consequences. One key factor in the financial risks of NPPs is the permitting and licensing process. This process is exhaustive, lengthy, and expensive, and can result in significant delays and added costs (OECD Nuclear Energy Agency, 2018). In addition, the construction of NPPs often takes many years, with several interconnected series of production and testing (OECD Nuclear Energy Agency, 2018). This long construction period, along with the possibility for construction delays and cost variance, adds to the list of financial risks of NPPs.

In addition to the specific risks associated with NPPs, all risks can ultimately be deemed to be a financial risk. When seeking to raise capital from likely investors and lenders, project developers need to be able to establish the volatility of both risk measures and returns to the key risks of the project (completion delays, performance shortfalls, etc.) (OECD Nuclear Energy Agency, 2018).

Despite the financial risks associated with NPPs, they are still often pursued for political and policy reasons, such as a desire for energy independence or the advancement of a national nuclear industry (OECD Nuclear Energy Agency, 2018). However, it is important for project developers and investors to understand the cost implications and sensitivity to the cost of capital at the outset of any project.

The cost of capital utilized in an NPP is a key factor in the overall project economics. In general, NPP projects are funded through a blend of both equity and debt, and the different amounts and costs of these sources must be considered when estimating the total cost of capital for the project (OECD Nuclear Energy Agency, 2018). This is done using the weight average cost of capital (WACC), which reflects the relative riskiness of the different sources of finance (Principles of Corporate Finance, 2014).

The WACC not only plays a role in determining the overall cost of capital for an NPP project, but it is also important for project financiers in determining the returns they require to invest in the project (OECD Nuclear Energy Agency, 2018). This highlights the importance of understanding and considering the WACC when evaluating the financial risks of NPPs. The WACC is a measure of the average cost of all the capital that a company has raised to finance its operations. In the context of the cost analysis of a nuclear power plant, the WACC is a key metric that is used to determine the overall cost of building, operating, and decommissioning the plant. The WACC is calculated by considering the cost of equity, the cost of debt, and any other sources of capital that the company has raised, and then weighing these costs based on their relative importance to the company's overall capital structure. The WACC is an important input to the cost analysis of a nuclear power plant, as it provides a benchmark for the cost of capital that the company can use to compare the potential returns from the NPP to the cost of financing the project. The following equation tries to capture the above discussed factors.

$$\mathrm{WACC} = (k_E \times C_E) + (k_D \times C_D) \times (1 - t) \tag{1}$$

where

C_D is the cost of debt
C_E is the cost of equity
K is equity + debt
k_D debt divided by K
k_E is equity divided by K

and t is the corporate tax rate.

Figure 3: WACC Formula (Managing the Financial Risk Associated with the Financing of New Nuclear Power Plant Projects, 2017)

Interest during construction (IDC) is a key metric when deciding whether to build a new nuclear power plant because it is a measure of the cost of financing the project. Interest is the cost that a company incurs when it borrows money to fund the construction of an NPP, and the IDC is the amount of interest that the company will pay over the course of the construction period. The interest during construction is an important factor in the decision to build a new nuclear power plant because it can have a significant impact on the overall cost of the project and the potential returns on the investment. A high interest during construction can increase the overall cost of the project and reduce the potential returns, which can make the project less financially viable. On the other hand, a low interest during construction can lower the total cost of the project and expand the potential returns, which can make the project more financially viable.

There are several factors that can affect interest during construction of an NPP. The IDC is the cost that a company incurs when it borrows money to fund the construction of a nuclear power plant, and the interest rate is determined by a variety of factors. Some of the factors that can affect the interest during construction include the creditworthiness of the company, the terms of the loan, the state of the economy, and the overall level of interest rates in the market. Additionally, the interest during construction can be affected by the specific terms of the loan, such as the length of the loan and the repayment schedule. These factors can all affect the interest during construction of an NPP and can impact the total cost of the project and the potential returns on the investment as shown in the following figure.

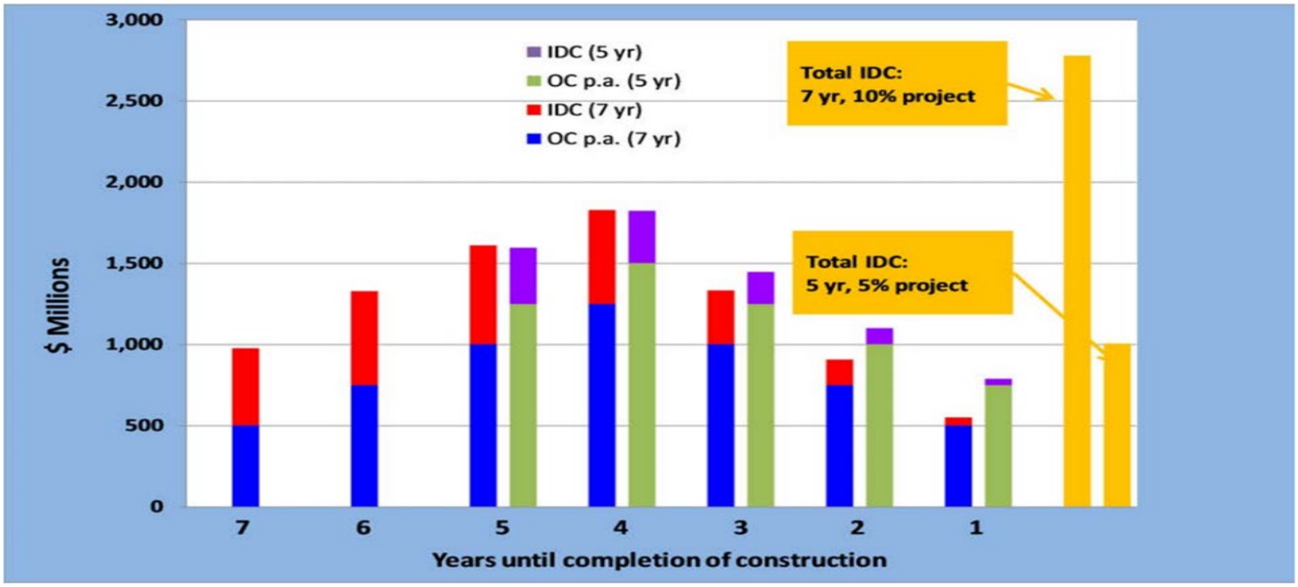

Figure 4: Chart to showcase compounding effect on Interest during Construction (IDC) (Managing the Financial Risk Associated with the Financing of New Nuclear Power Plant Projects, 2017)

Typology of Financial Risks in an NPP across its Life span:

There are several different financial risks that can be associated with building, operating, and decommissioning nuclear power plants. These risks can occur at different points of the lifespan of an NPP, these consist of the construction, operation, and decommissioning stages.

During the construction phase of an NPP, there can be financial risks associated with the cost of building the plant. This can include the cost of materials, labor, and any other expenses that are incurred during the construction process. Additionally, there can be financial risks associated with potential delays in construction, which can raise the total cost of the project and diminish the potential ROI.

During the operation stage of a nuclear power plant, there can be financial risks associated with the cost of operating the plant. This can include the cost of fuel, the cost of maintenance and repairs, and the cost of complying with government regulations. Additionally, there can be financial risks associated with changes in market conditions, such as changes in the price of electricity, which can affect the plant's financial viability.

During the decommissioning stage of a nuclear power plant, there can be financial risks associated with the cost of decommissioning the plant once it achieves the end of its functional life. This can include the cost of removing and disposing of the plant's radioactive materials, as well as the cost of cleaning up and restoring the site. Additionally, there can be financial risks associated with potential liabilities and legal expenses that may arise during the decommissioning process.

Overall, the financial risks associated with building, operating, and decommissioning nuclear power plants can include the cost of construction, the cost of fuel and operating expenses, the potential for cost overruns and delays, and the cost of decommissioning the plant. These risks can affect the financial viability of a nuclear power plant and can impact the potential returns on the investment.

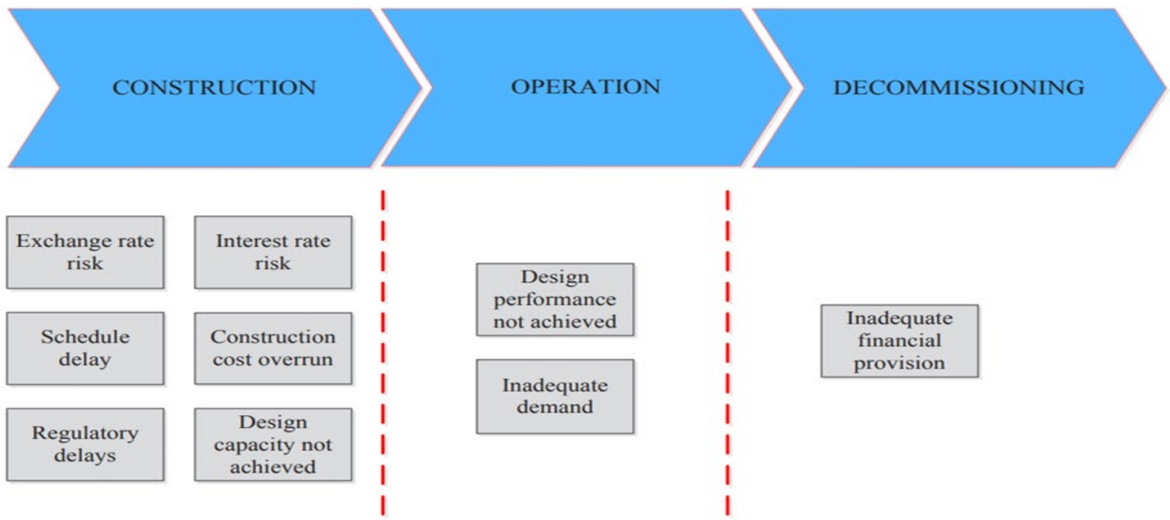

Figure 5: Types of Risk across the 3 general phases of the NPP life Cycle (Managing the Financial Risk Associated with the Financing of New Nuclear Power Plant Projects, 2017)

Controllable v. Uncontrollable Risks in an NPP:

Controllable financial risks in the building of nuclear power plants are risks that can be managed or mitigated through careful planning and decision-making. Examples of controllable financial risks in the building of nuclear power plants could include the cost of construction, the cost of fuel and operating expenses, and the potential for cost overruns and delays. These risks can be managed by carefully estimating the cost of the project, securing adequate funding, and implementing effective project management practices to minimize delays and cost overruns.

Uncontrollable financial risks in the building of nuclear power plants are risks that are outside of the control of the company building the plant and cannot be managed or mitigated. Examples of uncontrollable financial risks in the building of nuclear power plants could include changes in government regulations or policies, changes in market conditions, or the potential for accidents or incidents at the plant. These risks cannot be controlled by the company building the plant and can have a substantial bearing on the economic viability of the project.

A more comprehensive list of these controllable and uncontrollable risks can be found in the graphic below.

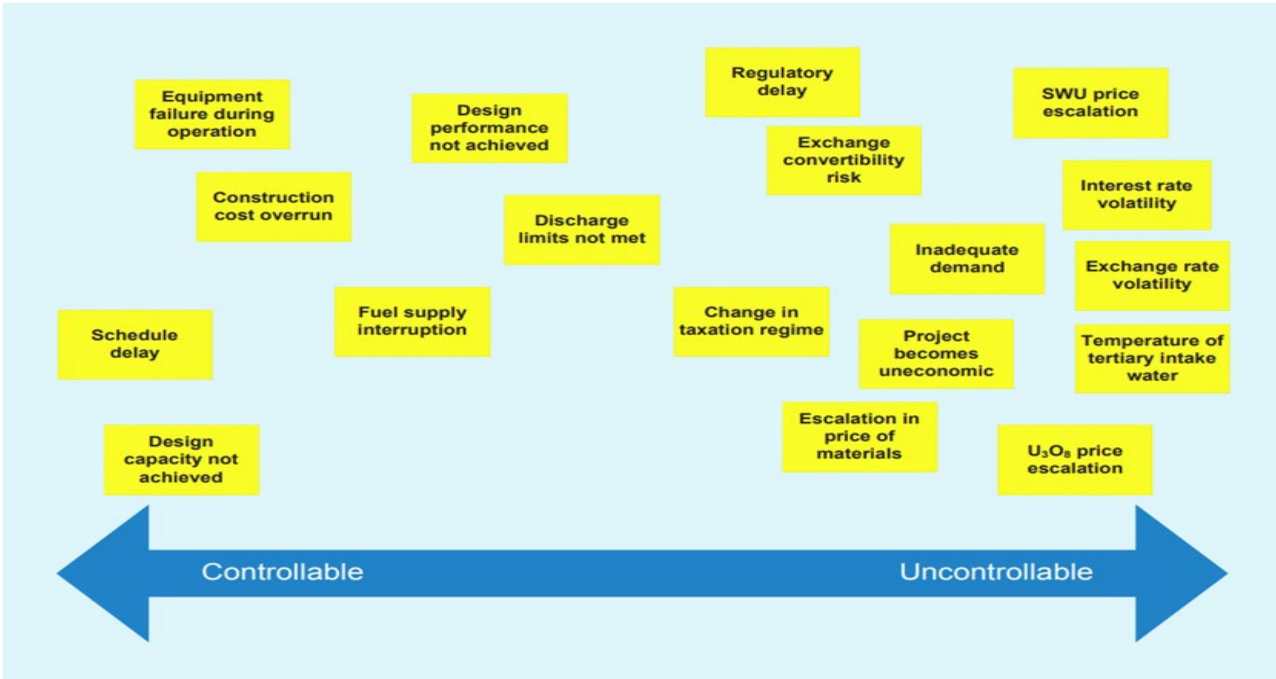

Figure 6: Typology of Controllable and Uncontrollable risks (Managing the Financial Risk Associated with the Financing of New Nuclear Power Plant Projects, 2017)

Risk Mitigation Tools:

This section will introduce some basic financial products and best practices a project developer can leverage to reduce their exposure to unmitigated financial risks in the construction of an NPP. It is to be noted however that these risk mitigation tools in no sense eliminate the concept of the risk, they merely reduce exposure to tolerable levels that would then allow for the project developer to pursue this venture with an acceptable risk to reward ratio. The table below will capture some of the risk mitigation methodologies a project developer could adopt.

Tools:

- Financial Products (Forward contracts, futures contracts, swaps and options, and Insurance)
- Escalation Formulas (Ramalingam, 2016)
- Procurement Strategies
- Commercial and Contractual arrangements

Reduced Risk exposure towards:

- Δ in (Commodity prices, Interest rates, FX rates, credit standing)
- Change in political, regulatory, or legal frameworks.
- Delay in investment timelines
- Shortage of capital

Figure 7: List of Risk Mitigation Methodologies

Escalation formulas are mathematical equations that are used to factor-in the impact of inflation on the costs of a project. In the case of building an NPP, an escalation formula could be used to approximate the future costs of raw material, labor force, and other operating expenses over the duration of the project. This information can then be used to weigh the probable financial risks linked with the project and to develop tactics for mitigating those risks.

Procurement is the process of obtaining goods and services, and efficient procurement strategies can help to decrease financial risks in the developing of a nuclear power plant in numerous ways. For example, by carefully choosing contractors and discussing advantageous terms, a company can lower the risk of cost overruns or delays due to unforeseen variations in the market price of materials or labor. Procurement strategies can also ameliorate the risk ratio of project delays by ensuring that materials and equipment are supplied on time and in acceptable condition. Additionally, effective procurement strategies can help to reduce the risk of technical and or safety problems by safeguarding that all materials and equipment meet the requisite specifications and standards.

Commercial and contractual arrangements are the deals and terms that govern the relationship between all the parties engaged in the project. These provisions can affect the financial risks associated with the project in multiple regards. For example, well-designed contracts can aid in safeguarding the company's interests by plainly specifying the rights and responsibilities of all parties, and by providing processes for resolving disputes and managing risks. These agreements can further impact the financial risks by clearly stipulating the terms of payment, including the timing and amount of any progress payments or incentives. In addition to listed impacts of these contracts, they can define the allocation of risks amongst all concerned entities, such as by demanding the suppliers carry the cost of any delays or shortcomings in the materials or equipment.

Financial products like forward contracts (Ramalingam, S. 2016), futures contracts, swaps, and options, and insurance, can be utilized to handle the risks associated with building a nuclear power plant. Forward contracts and futures contracts are agreements to buy or sell a particular asset at a preset price on a specified future date. These contracts can be used to manage the risk of price fluctuations in the materials or labor needed for the project, by locking in a fixed price for these items.

Swaps are contracts between two entities to trade one set of cash flows for another. These contracts can be employed to handle the risks linked with fluctuations in interest and or exchange rates, which can impact on the costs of a project. Options give the buyer the right, but not the obligation, to buy or sell an asset at a specified price on or before a certain date. These contracts can be used to manage the risk of price fluctuations in materials or labor, by allowing the buyer to protect against unexpected increases in the price of these items.

Insurance can also be used to manage the risks associated with building a nuclear power plant. For example, a company can purchase insurance to protect against the risks of accidents, natural disasters, or other unforeseen events that could impact the project. This can help to reduce the financial risks associated with the project, by shifting some of the costs and risks to the insurance company.

Scoping the domain of future Research in this domain:

There is additional scope for research and study in the domain of financial risks associated with the building of an NPP. Here the report attempts to enlist such fields of importance and emphasize the potential impact that a keener understanding in said fields would bring to the discipline of financial risk analysis in complex systems.

In view of Risk Allocation further study can be done to assess the impact of overall risk with different ownership structures and how the risk allocation would subsequently change if for example the ownership structure was state owned vs. public private partnership. Further work can also be done to assess the impact oof credit enhancement and commercial contracting on the overall risk allocation amongst all parties involved.

Looking at it from a financing perspective a comparison of the following models and the delta in the risks associated with the must be studied, these models namely are, Sovereign, Corporate, and Project based Model. An enhanced study into hurdle rates and their impact on the investor’s decision to invest must be analyzed.

4) Engineering Risks by Karthik Shrinivas [kxs210096]

The Nuclear power plant uses a planning committee that will be established very early in the timeline of a nuclear power plant. Typically, the complete timeline of any nuclear power plant will range between 35 to 50 years. The timeline will further be divided into 3 stages; Pre operating, Operating and post Operating. Hence, the planning committee established will work on designing an engineering structure for the power plant that takes up different responsibilities during these varied phases.

Pre operating

Before the establishment of the engineering structure of the plant the siting of nuclear power plant involves three major considerations

- Effects of External Events – The events around the power plant that occur naturally and made by humans will affect the structure of the plant in both direct and indirect ways. Naturally occurring external events are Earthquakes, Surface faulting, Meteorological events, Flooding, shoreline erosion, aircraft crash and chemical explosions

The man-made external events are often related to the Minning activities, storage of resources are flammable, drilling the surface with explosives and subsurface extraction.

- Effects of the structure installation- The nuclear power plant once established on site will affect the environment and population around it since it is linked up to heavy risks and vulnerability. Hence the analysis should be done in the pre operation stages using multiple simulation techniques that gives out the result of analysis based on the sample run of the nuclear power plant. A few evident factors that are influenced by the installation is Land-Water usage, radioactivity dispersion to the environment, Loss of ultimate heat sink and population distribution.
- Factors affecting emergency methods- The planning committee should work on multiple emergency situations and methods to make sure the plant will be well equipped to tackle future emergency situations. Establishing a quality control system ensures that the plant is ready to tackle the emergency before the operating stages

All the pre-operating decisions made by the committee will be following the safety guidelines published by the International Atomic Energy Agency. Once the decisions are approved from the pre operating stage then the nuclear power plant will be established for the operation phase. The average time taken for the research and pre-establishment activities is 8 years.

Financial decisions and business actions will also be taken during the pre-operating stages of a nuclear power plant

Operational

The Nuclear power plant consists of multiple different engineering elements in its entire structure, but the major segmentation will be based on three factors,

1. Power plant

2. Fuel
3. Nuclear reactor

The basic operation of a nuclear reactor involves the process of fission reaction of the radioactive fuel’s atoms. The Nuclear power plant will be the home for the nuclear reactor which is responsible for the process of energy generation.

1. **Risks Related to the Nuclear Plant.**

The basic nuclear plant consists of a Containment Structure and a pressure vessel that helps in the process of Nuclear Fission reaction that gives out a lot of energy and radiation. The Plant will also have a cooling system along with the major part that will work based on the nuclear reactor type of the plant. Hence the risks associated with the structural part of the plants are:

- Pressure Error – The Nuclear power plant will have the containment structure as the external layer that will house all the other engineering structure within itself. This last layer will also be the one that will be in contact with the external environment. The pressure difference between the external atmosphere and the plant should always be balanced. Sometimes, due to the varied functions that happen inside the plant, this pressure balance will not be maintained. This imbalance will start affecting the strength of the containment vessel.
- Combustible gas inside the containment structure- Leakage of the explosive gases from the pipeline and damaged storage units inside the plant will make the plant vulnerable to explosions and the leakage will further affect the external environment around the plant.
- Minute Cracks and damages on the pressure vessel- The pressure vessel handles the enormous pressure and heat activity that will be generated during the operation of a power plant. The low Maintenace of the pressure vessel and irregular quality control will lead to the damage of pressure vessel.
- Rusting of pressure vessel – A few pressure vessels will be open the external environment or at least to the constant exposure of oxygen in the nuclear power plant reaction
- External Accidents- The nuclear power plant is always exposed and vulnerable to multiple attacks and natural accidents that come from its environment. Aircraft crashes and pre planned attacks on the nuclear power plant will be the direct external influences and natural calamities will be the examples for naturally occurring ones. The other accidents and incidents include the ones caused by the employees and untrained manual workers.

Risks related to the coolant system.

Any coolant that runs through the nuclear reactor to transfer or take away the heat from the power plant will be used as a cooling system. The cooling system will further change depending on the nuclear reactor that is used in the power plant. The requirement of the cooling system is essential in all the power plants as it uses the process of fission that gives out a larger amount of heat and energy when the atoms are breaking apart. The basic components of the cooling systems are:

Coolant, Coolant pumps and Steam Generator and piping.

The coolant pump pushes the coolant throughout the nuclear reactor that will go into another unit after collecting the heat from the reactor. The other unit will have a cooling system that takes away the temperature of the heated coolant.

- The risks associated with the cooling system thus involve the major issues with the components and coolant itself.
- Radioactive Risks of coolant- The coolant, mostly the water coolant, will take the radioactive nature of the fuel due to the dispersion of radiation through the air medium. This radioactive coolant will be reused multiple times but its disposal after complete usage will affect the environment. Leakage of this radioactive coolant is also a potential hazard if the risk is not handled or cared about in the right way.
- Overheating risks- The coolant that runs along or around the nuclear reactor is always exposed to maximum heat and temperatures. This sometimes will change the integrity of the coolant material that will affect the functioning of the coolant system. This overheating of coolant will thus indirectly affect the efficiency of the nuclear reactor and sometimes tend to damage the nuclear reactor as well.
- Pipe cavitation- The entire coolant system connected to the plant has a lot of pipe connections that help in the movement of the coolant. The movement or the push of the coolant into the pipes by the pumps should always be having high pressure. High pressure movement of the coolant helps the heat exchange process to happen faster. But the high-pressured molecules of the coolant will move through the pipes along with random spontaneous contact with the pipes. The accumulation of these spontaneous contact of the molecules will eventually damage the structure of the pipe and this leads to the cavitation of the pressure pipes of any cooling system.
- Rusting of Turbine blades- The cooling system will always be located near to a major water source in most of the common nuclear power plants. This is because the cooling system requires a constant supply of water. The turbine used in any cooling system is always exposed and in constant touch with the water and oxygen environment. The metal turbine plates often go into the rusting process, and this will slowly damage the strength of the turbine. The rust particles will not only affect the efficiency of the system, but also the purity of the coolant that runs through the nuclear reactor.

Fuel Management Risks

The fuel used in most of the nuclear reactor will be a radioactive element that will go through the process of fission. During the fission reaction the atoms of the fuel will be broken that will give out enormous amounts of energy along with neutrons.

Radioactive fuel is an important engineering element of a nuclear power plant that comes with few risks like,

- Uncontrolled Fission – The process of fission involves breaking atoms that gives rise to energy and other atomic particles like neutrons. The fission process should be linked up and should happen continuously. The neutrons aid the process of fission to be continuous until the operation of nuclear plant gets shut down. The control rods in the nuclear reactor are used to absorb the neutrons to stop this continuous fission process. The control rods will sometimes get super used, and they will not be able to control the reaction of the fuel and this in turn becomes a major hazard.
- Used Rod Disposal- The rods that are completely used will not be able to absorb extra neutrons in the process and it must be removed and disposed. The used control rods will be radioactive and cannot be disposed of in the open environment. Hence the risks are greater when we take care of the disposal process of these used control rods. The recent development of strategies includes disposal of these used rods by packing them with a lot of metal structures around them.
- Illegal risks- The fuel being a radioactive element is placed in a very higher cost range. These fuels will be first purchased from different countries in the form of impure ore and then will be purified into enriched fuel. The supply chain around the fuel is expensive as it involves a lot of international transactions between nations. These expensive elements around the fuel will open the opportunity for illegal trade and movements in the black market.

Nuclear reactor

The core element of any nuclear plant will be its reactor where the exact fission reaction occurs. All the nuclear reactors will be related and linked up to other essential elements to decide the type of reactor that the plant is going to use. Major segmentation on the type of reactors happens in terms of the coolant system that the reactor will be using. A few major types are divided based on the risks and the coolant that they use.

- Pressurized water reactor
- Boiling water reactor
- Light water Graphite Reactor
- Gas cooled reactor
- Fast Neutron Reactor

The water reactors use water as the coolant that goes into the reactor to take away the heat generated by the nuclear power plant. The coolant will be pushed throughout the plant using high pressure pumps. The latter two will be using gas and plutonium as fuel.

All these different reactors will have their own highlighted risks among their different varied risks that they have.

Pressurized Water reactor's major risks will be associated with the high-pressure movement of the coolant through its system. The pump and the turbine system are prone to rusting processes which will eventually damage and reduce the efficiency of the reactor. The high-pressure coolant movement through the pipes will cause pipe cavitation in this type of reactor.

Boiling Water Reactor are built in a very large space because of their structures demanding greater sizes compared to the PWR. The risks of this nuclear reactor are often financial risks as it involves high level budget planning to establish the entire plant. The boiling water inside the pressure vessel of the reactor will sometimes be having contaminations and sludges will be deposited in the form of salt on the inner layer of the reactor. This deposition of sludges and contamination will damage and reduce the strength of the pressure vessel.

Light water reactors share similar risks of the pressure water reactor, but it leans more towards the rusting process of its components inside the reactors. The light water reactor's coolant will also have the risk of radioactive coolant running through the nuclear power plant

Gas cooled reactor and the fast neutron reactor will have risks related to uncontrolled fission reaction and over radiation risks. The fast neutron reactor will use plutonium to conduct the fast fission reaction rather than conducting the slow fission of the uranium fuel. Due to the fast reaction, the neutrons will not be absorbed by the control rod in the right way which will lead to uncontrolled reactions inside the nuclear reactor.

Post operational

After the operation of a successful nuclear power plant, the plant will be decommissioned in a way where it will not be affecting the environment. The decommissioning process itself will take around 10 to 15 years. A few major post operational risks involved are often related to the following activities,

- Removing the fuel and other fuel related elements from the reactor
- Storage of used radioactive elements of the power plant
- Decontamination of structures and work units
- Security and protection of the storage units and the remaining plant structures.

5) Transportation Risks by Nilesh Dhanawat [nxd200007]

PACKAGE DESIGN: BASIC PRINCIPLES

The objective for the safe transport of radioactive materials as per the regulations is to protect the environment, property, and people. The requirements to achieve this protection are:

1. Radioactive contents get contaminated;

2. External radiation levels are controlled;

3. Criticality is prevented;

4. Damages due to heat need to be prevented.

Concept of the package

Built-in safety in the design of the package is a Regulations cornerstone. The contents and the packaging are the two parts of the package system. To make sure that the total safety of the package is not compromised, the reliance on both parts is inversely proportional as having less reliance on one part means more for the other. Highly stringent demands are placed on the containment system of the packaging of radioactive materials when the quantity being transported as either a gas, liquid, or powder is significant. It can be argued that part of the containment itself is backed up by the containment features of the packaging if the state of the radioactive material being transported is a metal or ceramic or other solids.

GRADED APPROACH

Packages and conveyances have content limits for which the graded approach is used to satisfy the requirements and depending on how hazardous the radioactive contents are, package designs have their own performance standards.

There are five different primary types of packages that have been effective since 2001. These are:

1. excepted packages

2. industrial packages

3. Type A packages

4. Type B packages

5. Type C packages

Excepted packages

Very small quantities of materials are contained in Expected Packages. Most number of designs are available for these packages and they contain a lot of requirements. Only by meeting the requirements can the packages be identified and transported safely.

Industrial packages

The materials transported using Industrial Packages have very low radioactivity per unit mass and some non-radioactive objects known as low-specific activity (LSA) materials and surface contaminated objects (SCOs). The non-radioactive objects may qualify as SCOs. As both categories have very low levels of risk, they do not require very strong packaging that needs to withstand transport accidents.

Type A packages

For an economical and safe transport of small quantities of radioactive material, Type A packages are used. The integrity of these packages is expected to be retained such as being struck by a sharp object, dropped during handling, exposed to rain, or heavy cargo being stacked on top.

Such packages have a limit on the maximum number of radionuclides that can be loaded as specified by the Regulations. In spite of accidents occurring, contamination and external radiation are low due to the limits ensured on the packages.

Type B packages

Radioactive materials in huge quantities are transported using Type B packages. To keep the risks low, withstanding accidents is necessary for these packages. The competent authorities of each country where the packages are designed must approve each design. Severe accident conditions such as fire, crush, immersion, penetration, and impact are tests that all Type B packages must withstand. The package designs have a certificate of approval which specifies the content limits for transport by surface modes such as sea, inland waterway, rail, and road. A limit on the content quantity for transport via aircraft was imposed in the 1996 Edition of the Regulations. Also, according to the 1996 Edition, to carry low dispersal material (LDM) in Type B packages a stringent set of specifications must be met. The International Civil Aviation Organisation (ICAO), on the use of some Type B packages, implemented this restriction on packages traveling by air.

Type C packages

In the 1996 Edition of the Regulations, for large quantities of radioactive material, for transport by air, Type C packages and their requirements were introduced. The severity of air accidents, although rare, are more severe than surface mode transport accidents, especially on impacts, this led to the introduction of Type C packages. Type C packages have more rigorous tests than that of Type B packages. Also, the competent authorities of each country where the packages are designed must approve each design.

PACKAGE PERFORMANCE TESTS

The test requirements are summarised in the following paragraphs. In this section, some of the aspects might not be reported. The Type C packages introduced in the 1996 Edition have their performance tests described in better detail as they have not been well reported elsewhere at present.

Tests to endure normal conditions of transport

The following tests to withstand minor incidents and accidents must be passed by packages that are designed without any significant increase in external radiation hazard or loss of contents:

1. the penetration test
2. the compression test
3. the free drop test (from a height of 1.2 m) and
4. the water spray test

Tests to endure accident conditions of transport

Surface modes

The following tests must be undergone by packages designed to withstand accidents, after which the retainment of shielding properties and the radioactive contents is within defined limits:

1. Dropped from a height of 9 meters with an impact speed of 13.3 meters/second to suffer maximum damage onto an effectively unyielding target;
2. Dropped on a metal steel bar with a diameter of 15 cm from a height of 1 meter;
3. Engulfed in 800°C for a thermal test of 30 minutes; and
4. Immersion into 15 meters depth in water (irradiated fuel flasks immersed for 200 meters).

Air mode

The cumulative test sequences are required to be fulfilled as the packages are made to handle aircraft accidents. Following this, the retainment of shielding properties and radioactive contents is defined within the limits.

Sequence 1 (carried out on the same specimen in the given order) in which the specimen is:

1.Dropped from a height of 9 meters with an impact speed of 13.3 meters/second to suffer maximum damage onto an effectively unyielding target;

2. In the worst orientation, placing it on the same unyielding target while being subjected to dynamic crush, and from a height of 900 cm, dropping a 500-kilogram plate onto it;

3. Dropping it onto a conical probe from a height of 3 meters to subject it to a puncture/tearing test; and

4. For a period of one hour, engulfed at 800°C for a thermal test.

There is a possibility for long-duration fires (one hour) occurring followed by the low-speed impact which resulted in crushing and puncturing/tearing.

Sequence 2 (Compared to sequence 1 this may be carried out on a separate specimen) in which the specimen is:

1. To suffer maximum damage by being subjected to an impact onto an essentially unyielding target at a speed of 90 meters/second.

It is better to use a different sample for the test as there are no long-duration fires after a high-speed impact. Dispersion of fuel that was on board takes place so as to not form pools creating long-duration fires.

Additionally, these packages must not be shown to rupture when immersed in 200-meter-deep water and get the same shielding criteria and containment as those above when burial takes place. The assumptions made for withstanding the burial are that it is buried in dry soil at 38 °C in a steady state condition. As the packages involved in high-speed crashes may be covered by debris or buried in soil, the burial test was introduced. There may be an increase in internal pressure and package temperature if the package is buried and can generate heat.

From:	To:	Material	Notes
Mining	Milling	Ore	Rare: usually on the same site
Milling	Conversion	Uranium oxide concentrate ('yellowcake')	Usually 200-litre drums holding 400 kg, in standard six-metre transport containers
Conversion	Enrichment	Natural uranium hexafluoride (UF_6)	Special UF_6 containers, Type 48Y
Enrichment	Fuel fabrication	Enriched UF_6	Special UF_6 containers, Type 30B
Fuel fabrication	Power generation	Fresh (unused) fuel	Type A casks unless MOX fuel (Type B)
Power generation	Used fuel storage	Used fuel	After onsite storage, large Type B casks
Used fuel storage	Disposal*	Used fuel	Large Type B casks
Used fuel storage	Reprocessing	Used fuel	Large Type B casks
Reprocessing	Conversion	Uranium oxide	Called reprocessed uranium (RepU)
Reprocessing	Fuel fabrication	Plutonium oxide	
Reprocessing	Disposal*	Fission products	Vitrified (incorporated into glass)
All facilities	Storage/disposal	Waste materials	Sometimes on the same site

*Not yet taking place

Figure 1: Stages of Nuclear Transport [5]

TRANSPORT ACCIDENT RISK

The safety record for the transport of radioactive materials over the last 40 years may be excellent, but we cannot disregard the accidents and incidents which may lead to the release of significant quantities of radioactive materials. The probability or frequency of accidents leading to the release of radioactive materials and resulting radiological consequences such as contamination of the environment or radiant exposure of people lead to the determination of risks. The transportation of vitrified high-level waste spent fuel and large amounts of Plutonium in various forms are of special concern. Huge quantities of radioactive material are contained in vitrified waste and spent fuel, whereas in the case of Plutonium shipments if it becomes airborne as particulate matter and is in a respirable particle size range there is higher radiotoxicity.

Probabilistic risk assessment is a technique used to analyze the statistical nature of such accident events. On an annual basis, or per distance travelled, the risks can be quantified. Such assessments call for a lot of information:

• Depending on the severity of accidents, the probability or frequency of the accidents is important;

•Determining the release fractions based on the radioactive contents and behaviour of the package;

•Dispersion modelling;

•Consequence modelling and radiation exposure.

In a number of countries, many institutions have performed or are performing such kinds of studies. Comprehensive studies for the transportation of waste to operating or final waste repositories have been made, for instance, by IPSN and GRS [1,2]. The risks during the transport of return shipments of bituminized waste and high-level vitrified waste from reprocessing German spent fuel in France have been quantified in a common study funded by the European Union of both institutions [3].

The risks for transportation of radioactive materials being low is the conclusion reached via the mentioned and other studies. Over the past 40 years, the findings are in accordance with the worldwide safety record which is observed in this domain. The accident risk of spent fuel transport in the three countries France, Germany, and the UK has given an estimate here for an illustration concerning: In the context of the Konrad Transport Study the statistics for train accidents over a ten-year period of the German railways were analysed by GRS [1]. According to a study cited by US NRC [4], the severity comparable to the IAEA test conditions is in about one in a hundred railway accidents which could result in thermal impact or mechanical impact to the spent fuel package.

There are about 1000 transports of spent fuel annually originating in the three countries: Germany has 80, France has about 200, and the UK has about 700 (Magnox and AGR spent fuel). Assuming an average transport distance by rail of 700 km leads to an expected frequency of 0.7 million per year. On the assumption that the continuous transport operations are maintained at the present level, this value is comparable to a statistical average of one severe accident happening in 14000 years. A significant release of radioactive material is not expected as the safety margins for the casks of spent fuel are higher than the regulatory requirements.

Transportation Risk Classification

Public Health England separates radiation transport occasions into one of the five following classifications:

1. **A Transport Accident (TA) -** is characterized as any occasion that happens during the carriage of a radioactive material transfer and that delays or interrupts either the transfer or the actual vehicle, from having the option to finish its excursion.
2. **A Transport Incident (TI) -** is characterized as any occasion, other than an accident, that brings harm or loss of the consignment or unexpected exposure to humans or the environment.
3. **A Handling Accident (HA) -** is characterized as any occasion which may lead to a mishap during the loading, shipping, storing, or unloading of radioactive material leading to harm.
4. **A Handling Incident (HI) -** is considered as any handling event, other than an accident, that might happen during the loading, unloading, storing, or shipping of radioactive materials.
5. **Contamination (C) -** can be classified as an occasion where on the outer layer of the package, radioactive contamination is found, or conveyance is more than the regulatory limit for radioactive material.

Dangers of Nuclear Waste Disposal

Nuclear wastes are generally stored in steel containers which are then placed inside cylinders made of steel. These protective layers prevent radiation from leaking and harming the waste's environment or surroundings. There are multiple risks associated with the disposal of nuclear waste.

1. **Long Half-life**: These wastes have a very long half-life, which means that they will remain radioactive, therefore hazardous, for thousands of years.
2. **Storage:** There are multiple methods discussed for the storage of nuclear wastes. The most used method for disposal of nuclear waste is "ocean disposal". This practice is no longer feasible.
3. **Effects on Nature:** Although these wastes are well-sealed, there is always a risk of some accidents happening which can exposures leading to extreme damage to plant and animal life on a genetic level.
4. **Scavenging:** There is a market for such goods in some countries. Hence, some people do not mind exposing themselves to radiation to make money.

6) Conclusion

The research and planning required to establish a Nuclear Power plant should thus involve and give importance to the risks around these discussed factors to successfully run the power plant. This report successfully identifies all the major divisions of work around the nuclear power plant and the risks involved in every individual section. The report does not include any solutions for the risks, but it gives information about the risks so that we can reduce them and be aware of the future risks involved.

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