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Study of Radioactive Waste Management of Nuclear Power Plant: Prospect of Rooppur Nuclear Power Plant

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Abstract- The nuclear power plant is required to supply a substantial amount of electricity for a densely populated country like Bangladesh. The government of Bangladesh has attached to a commitment to implement the Rooppur Nuclear Power Plant, and so Bangladesh will be the 33rd nuclear power-producing country after the successful construction of this plant. Bangladesh has planned to construct two power units (Rooppur-1 & Rooppur-2) with a capacity of 1200 MW, each of and is expected to go into operation in 2023. Russian Rosatom State Atomic Energy Corporation is constructing this nuclear power plant, which is the generation-3+ VVER-1200 model. But the main concern is how a third world country like Bangladesh can handle the tons of radioactive waste of RNNP. Radioactive waste i.e., a variety of solids, liquids, and gases which are produced during the generation of nuclear energy in a nuclear reactor. Depending on activity content, solid and liquid waste are disposed of in near-surface or deep geological facilities, and gaseous waste is dissolved by following some filtering process. If not properly disposed of or recycled, irradiation from radioactive waste will cause major problems for the environment. Various stages should be required for the removal of a tremendous amount of radioactive waste in a cost-effective way. This paper mainly delineates the proximate of radioactive waste management of RNNP and gives an account of (1) Radioactivity and radiation level, (2) Classification, (3) Treatment of solid, liquid and gaseous radioactive waste, (4) Reprocessing and packaging, (5) Storage and (6) Disposal.

Keywords: radioactive waste, waste management, LLW, ILW, HLW, process, storage, disposal.

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I. Introduction

The created radioactive by-product while producing nuclear power is called radioactive waste. The importance of researching radioactive waste has a significant research area all over the world. But the waste management of radioactive waste is a cause of public concern. Safe and economic radioactive waste management is the first and foremost requirement to implement a nuclear power plant. Spent fuel referees to as high-level waste, and no country yet has a complete long-term solution for storing this waste. The amount of high-level waste is currently increasing by around 12,000 metric tons each year in the world. According to IAEA, a nuclear power plant of 1000 megawatts produce approximately 27 tons of high-level waste each year. And the two power units of RNPP generating 2.4 GWe is expected to go into operation in 2023 and 2024. So, according to the expectation, RNPP will produce about 50-60 tons of high-level waste every year. High-level waste requires both cooling and shielding during handling and transport. Remaining low-level waste contains a small amount of short-lived radioactivity that requires no special shielding. Most countries in the world are efficient at handling and managing low-level waste. But radioactive waste from nuclear reactors can be hazardous for the environment, and inhaling ionizing radiation at high dose levels can increase the risk of cancer. Hence, therefore, radioactive waste needs proper management from production to disposal. Russia has ensured that they will take back the high-level wastes of the Rooppur nuclear power plant. But today or tomorrow, Bangladesh has to be self-standing in the management of all kinds of radioactive waste arising during the operation of this nuclear power plant.

II. Radiation

When the emission or transmission of energy comes in the form of a wave from a source and travels through space is called radiation, and that is part of our everyday environment. Alpha, beta, and gamma radiation are three primary types of radiation that have different penetrating power in the matter. Alpha radiation passes through 5 cm air only and is a few cms of air can absorb it, beta radiation passes through air and paper and a thin sheet of paper can absorb it and gamma radiation passes through most things except thick lead and concrete and very thick wall of concrete can absorb it. Alpha radiation has maximum ionizing power, but beta radiation ionizing power is less than alpha radiation ionizing power, whereas gamma radiation has minimum ionizing power among them.

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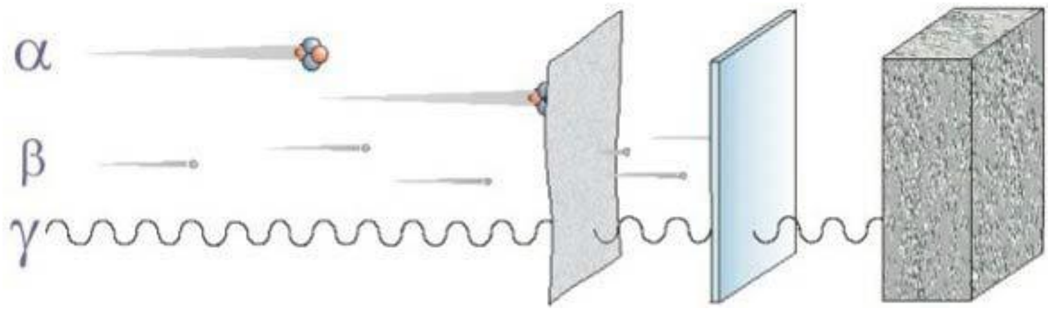

Fig. 1: Alpha, beta, and gamma have specific penetrating power in matter.

III. Radioactivity and Radiation Levels of RNNP Site

Typical radionuclide levels ^{238}U, ^{232}Th, and ^{40}K in the earthbound of the nuclear power plant site remain global midpoints, and ^{137}Cs of dirt and water tainting levels are below the detection level. The Bangladesh Atomic Energy Commission (BAEC) has implemented a robust radiation monitoring system at the RNPP site. The world average (1-4) radioactivity levels of ^{40}K, ^{232}Th, and ^{238}U are recorded as 400, 30 and 35 Bq.kg–1 on a complete basis, while the standard NPP values at Rooppur recorded as 379.6, 26.6 and 17.9 Bq.kg–1 on a stand-alone basis are in world esteem. Average annual viable estimates are 0.96 mSv.y-1 (96 mrem. y–1) considering indoor and outdoor inhabitance factors respectively 0.8 and 0.2. In 2015, J. Ferdous researched soil radioactivity at the proposed RNPP site and had an average of 30.85 Bqkg-1Ra-236, 40.88 Bqkg-1Th-232, and 390.10 Bqkg-1 K-40. A comparison of the number of radioactive particles of RNPP with other locations of the world is given below.

Table-1: Comparison of RNPP with other locations of the world.

Location	Activity in Bqkg-1		
	Ra-236	Th-232	K-40
Dhaka, Bangladesh	37.8	58.2	790.8
Chittagong, Bangladesh	34.6	60	438
Jessore, Bangladesh	48	53	481
Nine Southern Districts, Bangladesh	42	81	833
Eastern Sichuan Province, China	26	49	440
Peshwar, Pakistan	65	84	646
Nigeria	8.3	34.3	684
Louisiana, USA	43-95	50-190	43-729
Worldwide average	40(15-50)	40(7-50)	580(100-700)
RNPP Site	29.55	42.07	393.60

IV. Classification of Radioactive Waste

There are six categories of radioactive waste according to the International Atomic Energy Agency (IAEA) they are as follows:

- ➔ Exempt waste (EU).
- ➔ Very short-lived waste (VSLW).
- ➔ Very low-level waste (VLLW).
- ➔ Low-level waste (LLW).
- ➔ Intermediate-level waste (ILW).
- ➔ High-level waste (HLW).

- Exempt waste

Exempt waste is a kind of waste that contains radioactive materials at a certain level, which no longer requires further any treatment to control. It consists of small concentrations of radionuclides that once regulatory authority cleans this, it won't be regarded as baneful for the environment.

- Very short-lived waste

This type of waste has very short half-life radionuclide that can be stored for some time up to a few years until its radioactive content diminished by radioactive decay (radioactive decay is the process by which an unstable atomic nucleus loses energy by electromagnetic radiation) and so it is baneful for certain period. This waste is stored for a certain period so that the activity falls to the level of exempt waste. Very short-lived waste is usually using for medical and research purposes.

- Very low-level waste

The radioactivity of very low-level waste is close to natural radioactivity, and its activity is less than 100 kBq/kg. It is compatible with the regulation in near-surface landfill type facilities with limited regulatory control. This type of radioactivity falls to natural radioactivity after a few decades, and disposing of this waste is not a serious issue. It consists of rubble and scrap metals produced during the operation of nuclear power sites.

- Low-level waste

Low-level waste contains mostly limited amounts of long-lived radionuclides that have high radioactivity. It requires appeasement for a few hundred years and can be deposited near the surface level. So, there is no requirement of any further shielding during transport or handling. This type of waste can be disposed of at varying depths from the surface down to (25-30) meters.

- Intermediate-level waste

Though intermediate-level waste, contains high amounts of radionuclide compare to low-level waste it requires no cooling but shielding. Usually, it is solidified in bitumen before storage. It contains long-lived radionuclides that it's not that much easy to deposit near surface level like 30-meter depth. So, it requires disposal at greater depth up to a hundred meters.

- High-level waste

The high-level waste consists of 3% of the volume, which is produced from reprocessing of spent fuel of the world's radioactive waste. High-level radioactive waste is the highly radioactive material produced as a byproduct of the reactions that occur inside nuclear reactors. This waste requires both cooling and shielding. It is the most detrimental among all the waste because these materials are highly radioactive. Reprocessing or recycling spent nuclear fuel is not a proper solution because it still causes a quantity of waste. So, dispose of this type of material in the deep inside geologically is the right and safest solution.

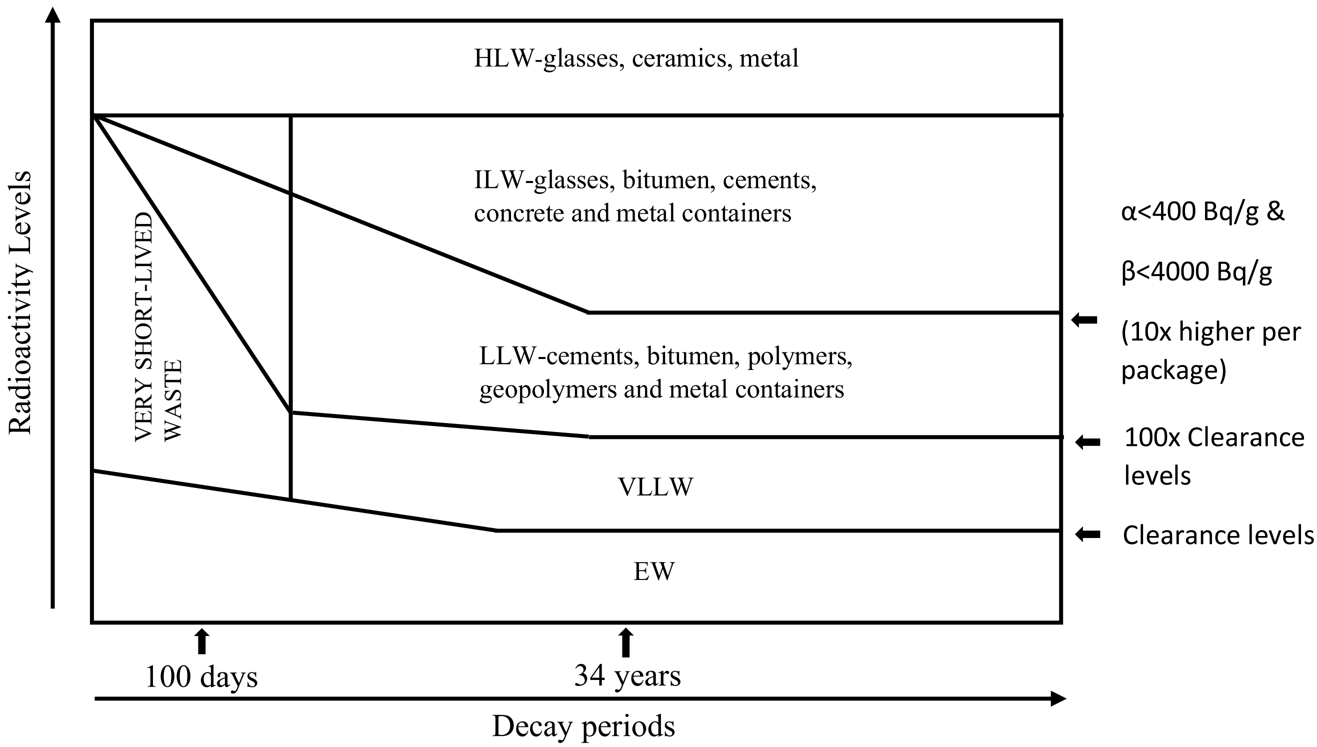

Fig. 2: Schematic of IAEA radioactive waste classification.

V. Basic Steps in Radioactive Waste Management

Bangladesh Atomic Energy Commission (BAEC) has established the Central Radioactive Waste Processing and Storage Facility (CWPS) on the campus of AERE, Savar under the Government Annual Development Project, and the IAEA Technical Co-operation Project. The function of this facility is to handle the low and intermediate level of radioactive waste except for high-level radioactive waste during the production of electricity in the nuclear power plant. Bangladesh and Russia together came to a decision that Russia will take back the high-level radioactive waste. So, various stages should be required to perform the function of this facility. They can be categorized into the following steps:

a) Characterization

The characterization of radioactive waste is the first and foremost thing because it is necessary to determine whether it is in physical or chemical states. It is an essential parameter to enable dissociation of radioactive waste for demobilization, recycle, and transfer or disposal. Low-level waste can be disposed of near-surface level, but high-level waste will require the deep geological facility.

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b) Reduction

Generation-3+ VVER-1200 model is modern technology, which would be helpful to reduce the amount of radioactive waste just because of its easy maintenance.

c) Reprocessing and packaging

During the production of electricity, radioactive waste emerges in the form of liquid, solid, and gaseous. By super compacting, low-level solid waste and intermediate-level solid waste can turn into much smaller volumes, but the main issue is liquid waste can't be disposed of. Filtration and ion exchange are vital to remove radioactive material from liquid and then transform it into solid. Typical immobilization methods include solidification of low and intermediate-level radioactive waste in cement or polymer and vitrification of high-level liquid waste in a glass matrix. After applying this method, low-level waste and intermediate-level waste can be packaged in the steel containers.

d) Storage

It is a vital part of the processing of waste management to avoid further any chance of radiation, which can devastate the environment. Radioactive isotopes disintegrate from few minutes to hundreds of years depends entirely on its half-life. As an example, strontium-90 and cesium-137 have half-lives of 30 years, whereas plutonium-239 has a half-life of 24,000years. Most nuclear-spent fuel, which has not been reprocessed, is safely stored in a specially designed pool at the reactor site. After some years it can be stored in some steel containers.

e) Disposal

It is the most challenging task of waste management yet all over the world. A deep and stable geologic location is the appropriate selection to store radioactive waste for the long-term. In this method, at first, the appropriate geologic place needs to be selected appropriately and excavate to form long tunnels under the surface using traditional mining technology. Then radioactive wastes need to be placed there safely far from the human population. But the technique is still under observation. If any geological changing occurs like an earthquake, then it would be a massive disaster because the stored nuclear waste has the potential to leak into the environment. Recently Germany is working on this, and they are expecting to place radioactive waste in a long tunnel from 2027. According to this plan, the path of the concrete tunnel will be closed completely by cement barrage so that radioactive isotopes can disintegrate. Another kind of geologic disposal is storing radioactive waste under the deep ocean. But this method is even riskier because it would be difficult to monitor for leakage of radioactive waste and the management of the whole procedure. Disposal of radioactive waste is still under investigation, and it won't be a simple task for a third world country like Bangladesh.

The waste management of RNPP can be sorted out according to these steps:

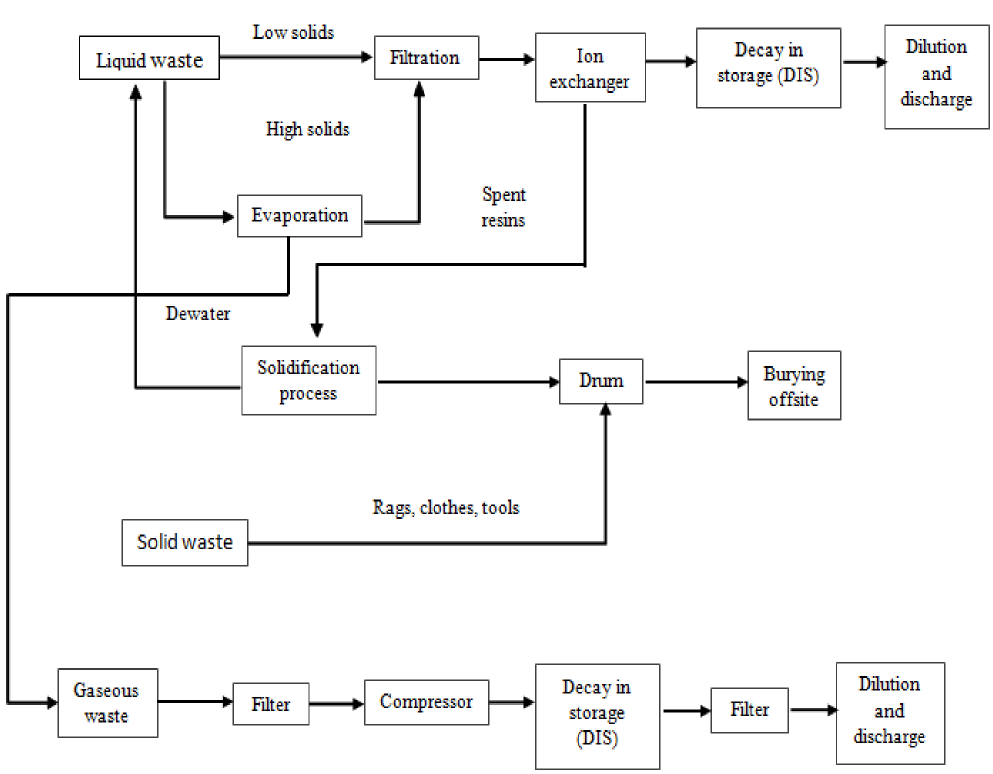

Fig. 3: Block diagram of radioactive waste handling system.

VI. Treatment of Liquid Radioactive Waste

Different radioactive waste streams arise (usually contains soluble and insoluble radioactive components) during the generation of electricity in a nuclear power plant. This steam is different, depend on the amount of liquid waste generated and the activity content as well. The main sources of liquid radioactive waste are water from the fuel storage pools and the primary coolant in water-cooled reactors. According to the reactor type, the formation of the liquid radioactive waste varies, which contains boric acid or organic substance that need individual disposition. The essential treatment and conditioning of liquid radioactive waste are ion sorption, chemical precipitation, evaporation, cementation, membrane process, polymerization, bituminization.

The schematic representation of liquid radioactive waste management operations is given below:

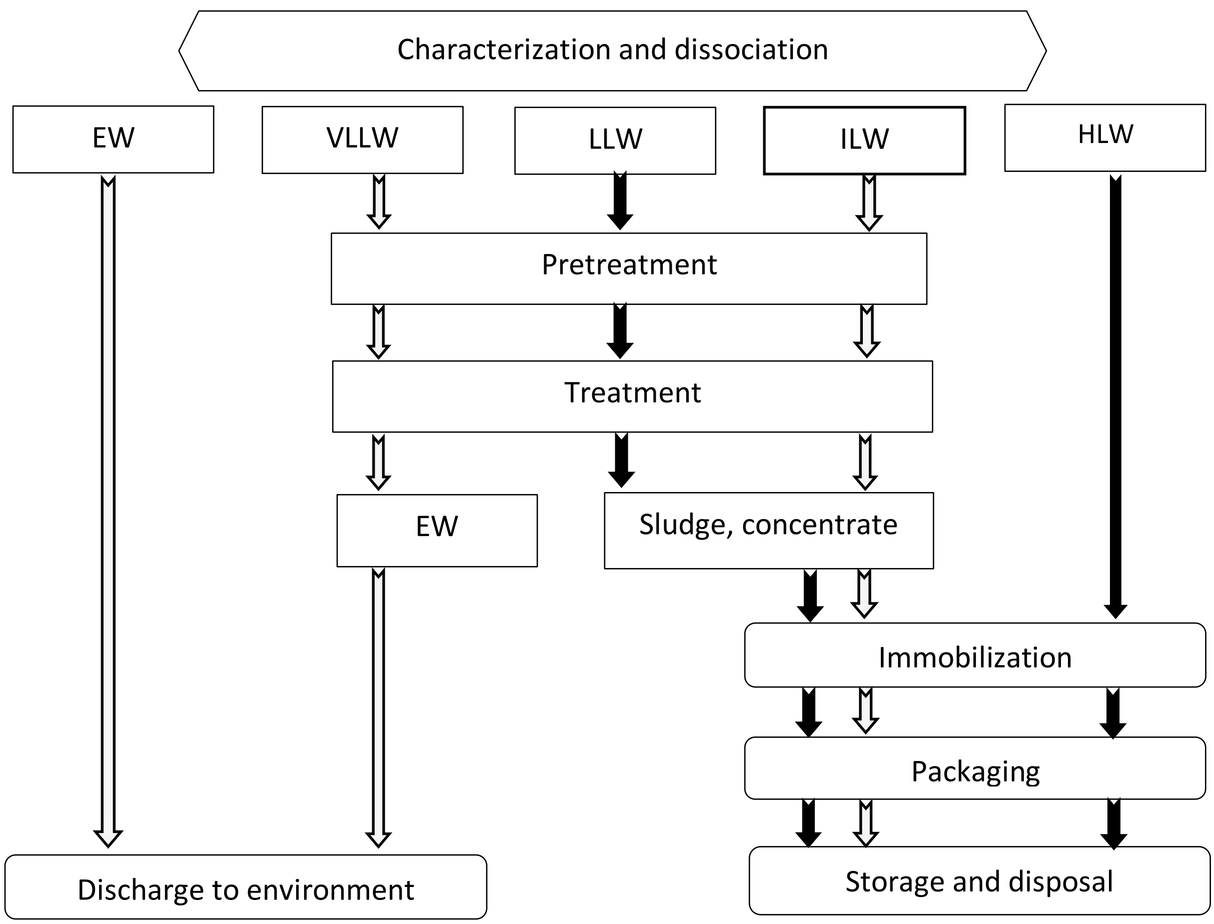

Fig. 4: Schematic representation of liquid radioactive waste management operations.

- Chemical precipitation process

One of the primary methods of radioactive waste management is to dispel radioactive materials from liquid waste. Chemical treatment or precipitation is one of the removal processes by which the majority of liquid waste could be reprocessed and dismiss to the surrounding without any risk. This method is mainly used in the VVER-1200 model nuclear power plant, which is based on the coagulation-flocculation segregation principle. It is generally used to treat high volume, low-level liquid waste streams. Most radionuclides can be precipitated by calcium or iron phosphate, barium sulfate, sodium sulfate, copper sulfate, cobalt sulfide, calcium carbonate, sodium borohydride, etc. Those precipitated chemicals treat the low-levels liquid waste (37-3.7 x 10^6 Bq/L) containing activity Strontium-90 and cesium-137 as the prime radionuclides. The resulting sludge from a combination of clarification and flocculation is concentrated by transfusion, filtration, and separating substances of

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different densities by centrifuge. Mainly a chemical precipitation process comprises four stages:

- ➔ Addition of reagents, adjustment of pH to form the precipitate.
- ➔ Coagulation-flocculation
- ➔ Alluviation
- ➔ Solid-liquid segregation.

Table-2: Typical chemical reagents used in precipitation processes-

Radionuclide	Process agent	pH	Decontamination factor
Pu, Am	Hydroxides	7-12	>10^3
	Oxalates	1	>10^3
Cr	Ferrous hydroxide	≥8.5	>10^2
Mn	Manganese hydroxide	≥8.5	>10^2
	Manganese dioxide	≥8.5	>10^2
Co, Fe	Ferrous or ferric hydroxides	≥8.5	>10^2
Sr	Calcium or iron phosphate	>11	>10^2
	Calcium carbonate	10.5	>10^2
	Barium sulphate	≥8.5	>10^2
Zr, Nb, Ce	Hydroxides	>8.5	10^2-10^3
Sb	Ferrous hydroxides	5-8.5	5-10
	Titanium hydroxide	5-8.5	10-10^2
	Diuranate	8.5-10.5	20-30
Ru	Copper + ferrous hydroxide	8.5	10-25
	Cobalt sulfide	1-8.5	30-150
	Sodium borohydride	8.5	50
Cs	Ferrocyanide	6-10	>10^2
	Zeolite	7-11	10
	Tetraphenylborate	1-13	10^2-10^3
	Phosphotungstic acid	1	>10^2

- Ion exchange process

Ion exchange is standardized and has a widespread application in the treatment methods for the management of liquid radioactive waste at nuclear power plants. It is so efficient at transferring the radioactive content of a large volume of liquid into a small volume of solid. Vermiculite is the natural minerals that are widely used for decontamination of cesium-137 in effluents in spent fuel storage pool water. Ion exchangers carry exchangeable ions which can be interchanged by an equal number of positive or negative ions when the ion exchanger is in contact with a liquid that contains ions and conducts electricity easily. The positively charged functional groups involve anions, and similarly, when they negatively charged, they involve cations. According to the following equation:

$$R - H + Cs+ \leftrightarrow R - Cs + H+$$

Where R is the insoluble matrix of the ion exchange resin, hydrogen releases its hydrogen ion into the solution and takes cesium ion from this solution. Here electroneutrality is maintained because every Cs+ dispelled from solution is replaced by an H+.

To remove radioactive metals from liquid radioisotopes are concentrated onto the $Fe(OH)3$. The resulting sludge should be placed in a metal drum before being mixed with cement to form a solid waste. Ion exchange properties of zeolite are the possible solution for low-level and intermediate-level liquid waste treatment. The ion exchange with the sodium ions of zeolite can dispel the cationic radioisotopes.

Table-3: pK values for the most common functional groups of organic ion exchangers

Cation Exchangers		Anion Exchangers	
Functional group	pK	Functional group	pK
-SO3H (strong acidic)	1-2	≡N+ (strong basic)	1-2
–PO3H2	2-5	=N	4-6
–COOH	4-6	=NH	6-8
–OH (weak acidic)	9-10	–NH2 (weak basic)	8-10

- Evaporation process

When liquid radioactive waste has a high concentration of radionuclides as well as high decontamination factor (e.g. 10^4-10^6), it is convenient to concentrate the liquid waste by using vaporization. This process is widely using in the nuclear power plant, which is entirely based on the thermosiphon system to minimize maintenance problems. Two-stage evaporation is inevitable to perform this process, one stage is decontamination, and the other is concentration. The first stage can be applied when the required decontamination factor is lower. While evaporating distilled water (high purity), non-volatile components such as radionuclides and salts remain. The presence of stabilized components such as ruthenium, iodine, high concentration of HNO_3 reduces the high decontamination factor clearly. Though evaporation is a common practice all over the world; it has some disadvantageous too. The large size of apparatus, high maintenance costs, requires exposure of enormous surfaces of liquid, temperature enhanced rapidly are the main disadvantages of evaporation.

- Cementation process

This method has been practiced for immobilization of low-level radioactive waste concentrates on the nuclear power plant for more than 40 years. The cementation process has some advantages due to the availability of cement, inexpensive raw material, low volume reduction, operational simplicity, thermal stability, provide better radiation resistance, and based on traditional technology. Cementation is one of the conventional processes of converting liquid radioactive waste into a solid for long term storage or disposal. Some common types of cement such as pozzolanic cement, high alumina cement, ordinary Portland cement, blast furnace slag cement is used in power plants all over the world. The application of some cement is listed below for further study.

Table-4: Application of cement types

Cement type	Application
Ordinary Portland cement	very high chloride and sulfate resistant, organic ion exchange materials, inorganic ion exchange materials and secondary process waste (dry and wet)
Pozzolanic cement	hydraulic structures-dams, retaining walls, lower permeability, increased strength
High alumina cement	Rapid hardening and strength, marine construction and sewer infrastructure, increased resistance to sulfate and acid attack
Blast furnace slag cement	good resistance towards sulphate and chloride attack, greater durability and reduced permeability due to fineness

Ordinary Portland cement is the conventional type of cement that has been using in the nuclear power plant due to its high mechanical strength. In the cementation process, the waste, water, and additives are dosed from a tank into the fiber-reinforced concrete container or drum. Then cement is added to the waste loaded drum and mix with the waste carefully. The ratio of water and cement is generally 0.4 for an ideal mixer coating, which provides for better cleaning. Radioactive waste becomes half, and due to the volume increase by the cementation process. Through this process, low and intermediate level liquid waste can be processed conveniently without risk.

- Bituminization process

Bituminization is a common process for the treatment of low and intermediate-level waste. It is a hot process where radioactive concentrates are mixed with bitumen such as direct distilled, oxidized, emulsion at high temperatures. Insolubility in water, chemical inertness, high incorporation capacity, and reasonable cost are some advantages of the bituminization process. Batch bituminization and continuous bituminization processes are the two types of bituminization process.

Batch bituminization is the conventional process where liquid waste mixed with bitumen at about 200°C. If any water present, volatilization continues until reaching the required waste composition. After cooling, the mixture becomes solid and is then discharged into steel containers.

Though it has many disadvantageous over advantageous such as lower stability against radiation than cement, reacts with sodium nitrate, it decreases in viscosity at 70°C and few more made this process obsolete.

- Membrane process

Various membrane processes like ultra-filtration, dialysis, pervaporation, and reverse osmosis have been developed for the treatment of low-level (37–3.7×106 Bq/L) liquid waste. The removal of radioactive substances in membrane processes is convenient so that the nuclear industry adopts this process. Reverse osmosis is asymmetric 'skin type' membrane, which follows the diffusion mechanism method. Ultra-filtration is an asymmetric microporous type membrane that follows sieving mechanism method. Ultra-filtration processes can operate as highly efficient "sieves," capable of fractionating particle species according to size. Some advantages of this process are efficacious at low temperatures, lower energy requirement, simple to scale up, and most of all, no phase changes involved.

VII. Treatment of Solid Radioactive Waste

Radioactive solid wastes producing from the nuclear power plant are segregated into compressible or non-compressible and combustible or noncombustible. Compressible waste, e.g., paper, clothing, plastics undergo low-pressure compaction and non-compressible waste, e.g., scrap metal, rubble, and mineral insulating material undergo high-pressure compaction and are packed in suitable containers. These wastes are classified depending on the concentration of the wastes and half-life of the radioactivity. 95% of the total solid waste has low activity and convenient to handle rather than high activity. Some treatment and conditioning of solid radioactive waste are low force compaction, super force compaction, incineration, pyrolysis, plasma, metal melting, molten salt oxidation, thermochemical, etc. The schematic representation of solid radioactive waste management operations is given below:

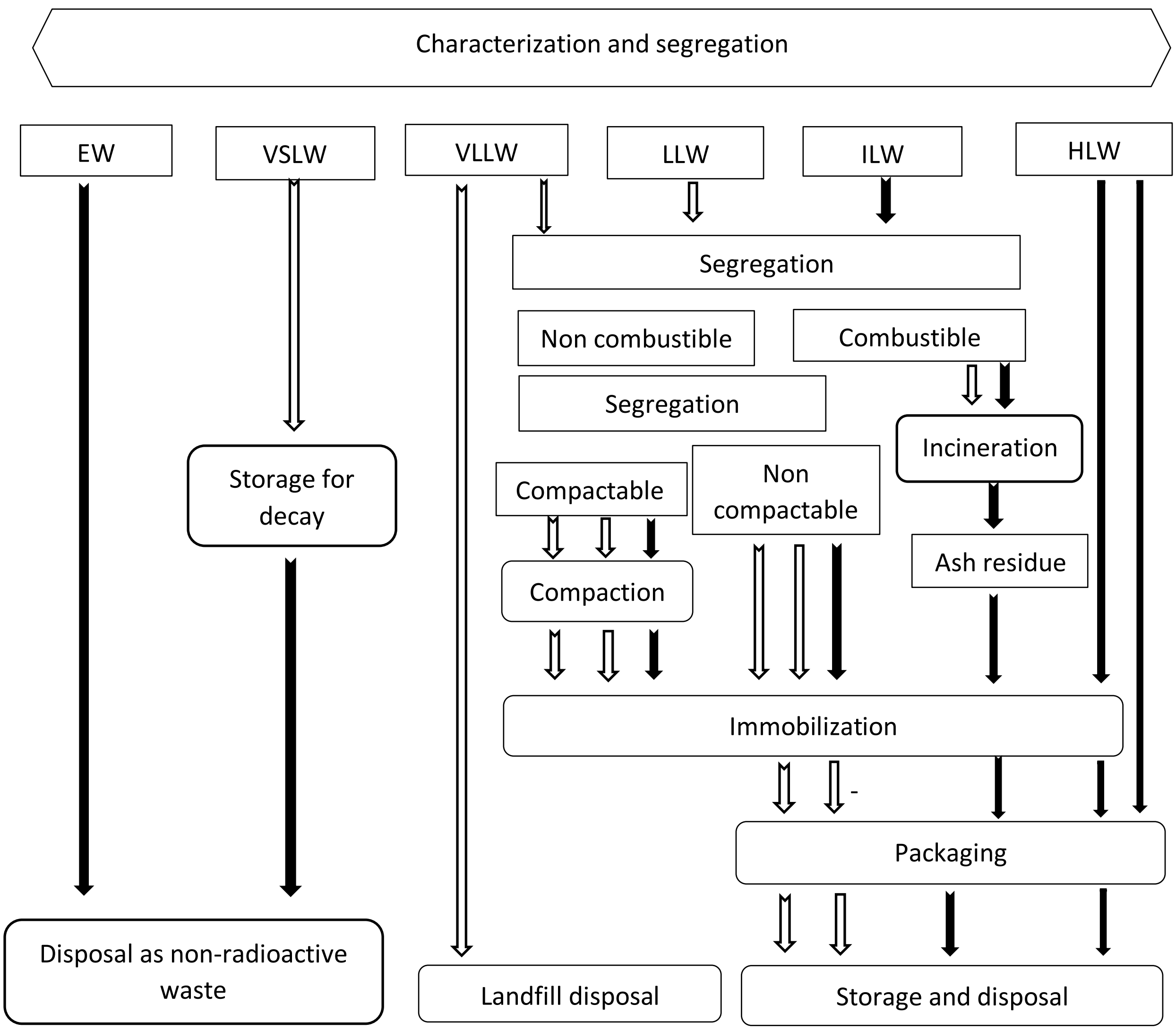

Fig. 5: Schematic representation of solid radioactive waste management operations.

- Low and super force compaction

Compaction reduces the total volume of LIL solid waste without changing physical and chemical properties and becomes economical for transporting. Low and super force are two types of compaction. Low force compaction is a renowned method for compactible low-level solid waste, and the compaction force is up to 50 tones. Radioactive solid waste can be compacted up to several levels by this method and the waste is collected in suitable containers. A volume reduction factor of low force compaction is (3-5), entirely depends on the volume and nature of the waste material. Though this process is facile to operate and relatively lucrative, its volume reduction factor is limited by spring back. Super force compaction is used for previously compacted waste as well as for incinerator ash, air filters, small metal pieces, soft plastics, thermal insulation materials. It has a high-volume reduction factor (5-10), and the compaction force is up to 2000 tons. Generally, this method is not lucrative for small amounts of waste because of its high equipment and maintenance cost.

- Incineration

Incineration is the well-proven technology, and combustible solids from nuclear power plants are reduced by this method. This provides a very high-volume reduction factor for combustible waste such as plastics, fabrics, paper, etc. and can be used for both solid and liquid wastes as well as for biohazardous and medical waste. Relatively high capital cost for investment, need to meet the environmental requirements for discharges, requiring a special regime for the treatment of alpha bearing waste are the main disadvantages of incineration method.

- Pyrolysis

Pyrolysis is a common way to process the high organic content waste such as charcoal, resins, plastic, etc. It is an irreversible process which occurs at temperatures above 800°F in the absence of oxygen and under pressure. Retention of radioactivity in the pyrolyzer residue is > 99.99% and has low gas flow rates compared to incineration. So that, this process easily manages the end product. The processes can be heated externally, thus minimizing gas flows, which would otherwise require radiological control. Slow, flash, and fast pyrolysis are the three types of the pyrolysis process. Slow pyrolysis occurs at a slow heating rate; low temperatures range from 32.18 to 35.6°F per second. Flash pyrolysis occurs at a high heating rate; high temperatures compared to slow pyrolysis ranges from 752 and 1112°F per second. When the amount of radioactive waste is excessive fast pyrolysis process is effective. Fast pyrolysis occurs at an extremely high heating rate, and high temperatures range from 1202 to 1832°F.

- Plasma

The plasma process temperature is up to 1800°C, which allows the melting of LIL radioactive waste. This process is suitable for long term storage and disposal. The final waste form is robust and free of organic material. Volume reduction factors of this process can range from 6:1 to 10:1 for metallic waste, while for other combustibles, the volume reduction factor (VRF) can rise as high as 100:1. But the process is a bit expensive to construct and not that easy to operate.

- Molten salt oxidation

Molten salt oxidation is an emerging technology that is an alternative to traditional incineration of organic waste. This process can be used for the destruction of organic content. Low temperature is required to operate this process. But it requires specialized techniques for adequate conditioning of the salt product. Limitation to small and medium solid waste programs and not capable of handling high-level waste materials are the major disadvantages.

VIII. Treatment of Gaseous Radioactive Waste

Noble gases (^{41}Ar, ^{85}Kr, ^{133}Xe), halogens, tritium, the radioiodines-129, and -131 and carbon-14 are the most principal volatile radionuclides as a form of radioactive gaseous waste is generated in the nuclear power plant. The amount of gaseous waste production entirely depends on the reactor type. Among the noble gases, ^{133}Xe, with its short half-life, is less dangerous and can be dissolved easily. The gaseous radioactive waste should be treated rightly before discharge to the surroundings. Because external exposure can cause severe damage to human tissue and can create other skin diseases. Ventilation and air cleaning system is the first and foremost process to remove most of the radioactive components before discharging. By this process, almost all radioactive particles remove (about 99.9%). The cryogenic segregation method is becoming popular nowadays for the removal of ^{85}Kr and ^{133}Xe. The procedure of charcoal or adsorption can also remove the radioactive iodine. Oxidization is the convenient removal process for tritium to remove from waste effluents and converting the tritium to T_2O. Caustic scrubbing is used to remove carbon-14 from the gaseous effluents, and high-efficiency filtration techniques can be applied for the removal of radioactive particulate matter. After completing those tasks, the gas is contained into gas tanks and should be sealed for storage up to 60 days (depends on their radioactivity). Then release to the atmosphere properly through the ventilation system.

IX. Storage Facilities

Storage facilities for radioactive waste material are the crucial consideration of RNNP. Radioactive wastes are stored to make surrounding harmless and to avoid any subtle risk. Tons of radioactive waste are produced per month per nuclear reactor all over the world. So, it is assuming that tons of radioactive materials from RNNP needs temporary storage facilities. After storing high-level radioactive wastes, Russia will take back those waste for reprocessing. These days, different types of storage policies are taken all over the world. Discussion on some suitable storage facilities for RNPP are given below:

- Storage ponds

Centralized facilities such as CLAB in Sweden are using this type of storage system. This pond is generally 7-12 meters deep, and initial radioactive waste is kept under the water to conserve radioactive materials cool. The storage pond is specially situated at the reactor site and designed for the cooling of the fuel rods. Such ponds are robust constructions made of thick reinforced concrete with steel liners. This pond provides protection shielding from radiation, can storage fuel 10 to 20 years easily, and then send for disposal or reprocessing.

- Dry cask storage

Dry cask storage has been using in one-third of the overall nuclear power plant in America. It is a well-known method of storing high-level radioactive materials using certain shielded transfer casks. It is designed as a safer solution to store radioactive waste that is better than storage ponds. This method is very functional for storage as well as transportation. Spent nuclear fuel that has already been cooled in ponds for at least five years can easily be stored in dry cask storage. Currently, the USA, Canada, Germany, Bulgaria, Lithuania, Russia, Ukraine are adopting this storing facility for high-level radioactive waste.

- Interim surface storage

Specially designed interim surface storage facilities are currently using to store 7000-8000 tons of spent fuel all over the world. It is one of the best temporary solutions to ensure the safe storage of IHLW for long-term disposal and convenient to monitor continuously. This storage facility not only allows spent fuel to cool but also uses as a final destination for reprocessing waste. The most radioactive waste is currently stored in France by this surface storage facility.

X. Disposal Options

Disposal of radioactive waste is the most challenging task for Bangladesh. Bangladesh relies on Russia that they will take back high-level radioactive waste from RNNP. Disposal of low and intermediate-level waste is quite simple to handle in terms of high-level waste. Almost 97% of radioactive waste is LILW, and the remaining 3% is difficult to store and dispose of. Disposal is the last and crucial part of the radioactive waste management process. When there is no intention to reprocess radioactive waste, the best option is disposal. It is mandatory to choose a disposal site suitably so that no natural disaster can cause a catastrophe. Based on sub-soil investigation and analysis on the natural disaster of Bangladesh, RNPP and its surrounding area of above 0.20g to 0.25g should withstand 7.5 to 9.5 Mw earthquakes easily. Finland, Sweden, France have made the most progress on final disposal. Recently Germany is working on a high-level radioactive waste disposal system, and they are expecting to place radioactive waste in a long tunnel from 2027. Some commonly accepted disposal options that Bangladesh can implement in the near future are given below:

- Near-surface disposal

Near-surface disposal facilities at ground level are on or below the earth's surface where the protective covering is of the order of a few meters thick (at depths of tens of meters). These facilities are suitable for handling low-level and intermediate-level waste types with limited amounts of short-lived activity. Generally, each nuclear facility has its near-surface disposal facility. Waste containers are stored in installed vaults and backfilled when the vaults are filled. Many countries, including Finland, the Netherlands, Sweden, Spain, France, the UK, and the USA has implemented this facility for LLW and ILW.

- Deep geological disposal

Deep and stable geologic location (at depths between 250m and 1000m for mined or somewhat more than 1000m) is the appropriate selection to store long-lived ILW and HLW for the long-term. Most countries have researched deep geological disposal, and now it is an official policy in several countries. In this process, a suitable geological site must first be chosen and excavated to form long concrete tunnels under the ground using conventional mining technology. And the concrete tunnel route will be perfectly closed by a cement bridge so that radioactive isotopes can disintegrate. Deep geological disposal system is implemented in the USA and the preferred sites selected in several countries, including Belgium, Canada, Finland, France, Japan, Russia, Spain, Sweden, the Czech Republic, Argentina, Australia, and the United Kingdom.

XI. Results and Discussions

Rooppur Nuclear Power Plant is based on the generation-3+ VVER-1200 model that has modern safety management. It is anticipating that RNPP can add up 2,400MW of electricity to the national grid by 2023, and that is needful to supply an adequate amount of electricity for Bangladesh. This research paper is based on a theoretical framework, and the objective is to demonstrate what would be the treatment of radioactive waste of forthcoming RNPP. RNPP will produce tons of radioactive waste, which is hazardous for humankind and the surroundings. Perfect reprocessing, packaging, storage and disposal is required to ensure the safety of the surroundings. LLW doesn't require shielding during handling, and so its disposal system is quite easy. But the remaining ILW and HLW waste require both indefectible storage and disposal facilities to avoid further any chance of radiation, which can devastate the environment. And inhaling ionizing radiation at high dose levels can increase the risk of cancer. Russia has agreed to take back the high-level radioactive waste from RNPP. However, Russia may charge Bangladesh the cost of transportation and reprocess of HLW. Though handling, storage, and disposal of LLW and ILW pose no serious problem, Bangladesh will manage those radioactive waste. Bangladesh can also be self-standing in the management of HLW by doing the above procedures efficiently.

XII. Conclusion

The government of Bangladesh expressed its firm commitment to build a nuclear plant to reduce its dependence on conventional resources and provide a great amount of electricity. Radioactive waste is a byproduct of a nuclear power plant, and radioactive waste management is the biggest concern for Bangladesh. Bangladesh would certainly face up some limitations, such as costing a lot of money to transport radioactive waste; the waste might emerge even if put into geological respiratory and radiation risk to workers, etc. Bangladesh's government should take the necessary steps to overcome those limitations and ensure safety. So, the government, BAEC, and nuclear industry should work together to deliver perfect reprocessing, packaging, storage and disposal facilities, and ensure the safety of surroundings.

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