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A Review on Nuclear Waste Management: Status, Challenges and Prospect of Bangladesh

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Abstract

Bangladesh's economy has grown at one of the fastest rates in the world owing to a demographic transition, stable socio economic conditions, foreign remittance and overall exports of domestic goods. As a whole, with the overall increase in industrialization and technological development, there are inevitably enormous prospects for nuclear energy development in Bangladesh's rapidly growing economic conditions. However, the radioactive waste produced by nuclear weapons, nuclear power plants and the production of medical isotopes is one of the most challenging wastes for modern society to manage. High radioactivity necessitates safe isolation from people and the environment until it ceases to be dangerous, which could take a million years or longer. This paper discusses the current nuclear waste status, significant progress, overall challenges and prospects of Bangladesh in the case of managing the most hazardous, radioactive waste management. Nuclear waste management is an ongoing procedure because radioactive decay processes constantly change the chemical composition and physical characteristics of nuclear waste. It is found that, due to numerous nuclear uses, Bangladesh produces Low-Level Radioactive Waste (LLW) and higher level radioactive waste will produce when the county's first Rooppur Nuclear Power Plant (RNPP) goes into action. Radioactive radiation is the main danger posed by human generated nuclear waste, which has two main side effects, genetic and somatic. For example, it has direct physical impacts to harm people in various ways, including chronic, acute and long term injury. Therefore, managing nuclear waste is a field of materials science and engineering problems that must withstand the test of time, from designing engineered facilities and it is reasonably necessary to take immediate actions concerning the legal and regulatory systems to keep the country safe in terms of nuclear waste management.

Keywords: Radioactive waste; Nuclear waste management; Nuclear waste hazards; Disposal methods; Nuclear power

Introduction

Hazardous waste that contains radioactive elements is known as nuclear or radioactive waste [1]. Numerous processes, such as nuclear medicine, the production of nuclear fuel, nuclear research, the production of atomic energy, the mining of rare earth minerals and the reprocessing of nuclear weapons, produce radioactive waste. For example, nuclear power plants produce nearly 11% of the world's electricity. This is expected to grow as interest in creating power through nuclear fission has been revived by demand for "low carbon" energy sources [2]. The fission process, which includes breaking Uranium (235) atoms after being struck by a slow neutron, is how nuclear energy is produced. First, the Uranium (235) atom is split, releasing heat energy that is used to produce steam that powers electricity generating turbines. Because splitting also releases more neutrons, which can then split more uranium nuclei, the reaction is self-sustaining Uranium (235). Next, the unstable Uranium atom splits into two smaller, less stable atoms. Fission byproducts and minor actinides, highly radioactive, are among these tiny atoms. Finally, nuclear energy generates waste, much like other methods of electricity production. This calls for the waste's handling, treatment and storage to be done in a way that minimizes the effects of radioactivity on the environment and human health [3]. This risk will diminish over time due to the radioactive decay of the waste's radionuclide to stable isotopes. Nevertheless, nuclear waste management is one of our society's most pressing and long term problems because this process can take at least a million years to complete. Nuclear waste is created by nuclear energy production and the widespread use of isotopes in science and medicine. In addition, as a byproduct of mining for minerals, waste is also produced. Due to the high risk of nuclear waste, it is essential to effectively manage the entire process of radioactive waste, minimizing the harm done to the environment and people by its radioactivity. Therefore, the study of nuclear waste management has significant theoretical and practical implications [4]. This review outlines the current global best practices for managing radioactive waste, established by the International Atomic Energy Agency (IAEA) and effectively applied by many nuclear-using nations and Bangladesh [5]. In light of these facts, the following section looks at the country’s nuclear waste management system including its current status and adverse effects of inappropriate waste management.

Literature Review

Types of radioactive waste

To facilitate regulation of handling, storage and disposal, radioactive waste is typically divided into a small number of categories based on the amount of radioactive material they contain and how long that material will remain radioactive. Although each country defines these categories differently, they can generally be categorized as highly low level, intermediate and high level waste. Figure 1 shows various types of nuclear waste per its percentage.

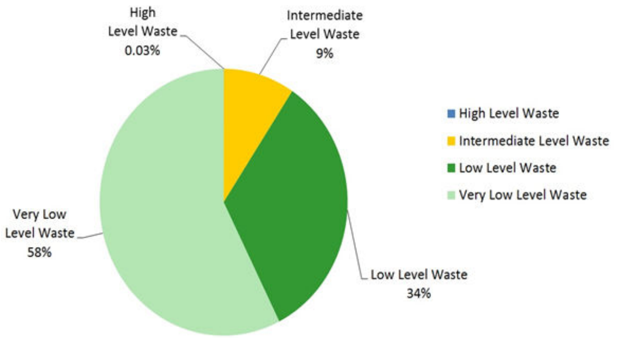

Figure 1: Types of nuclear waste.

Very low level waste

Radioactive materials are present in very Low Level Waste (VLLW) at a level that is not deemed hazardous to persons or the environment. It comprises materials destroyed during renovation or deconstruction projects at nuclear industrial sites, including concrete, plaster, bricks, metal, valves, pipelines, etc. VLLW is often disposed of in specially constructed disposal facilities that take the shape of clay pits with engineered coverings [6]. In addition, it is disposed of with other waste categories in other nations, such as Low Level Garbage (LLW). The choice of disposal strategy is typically based on economic and regulatory considerations [7].

Low level waste

In addition to the nuclear fuel cycle, Low Level Waste (LLW) is produced by businesses, laboratories and healthcare facilities. It includes paper, rags, equipment, clothes, filters, etc. Higher activity concentrations are present in LLW than in VLLW, but the concentration of long lived radionuclides or radionuclides with T1/2>30 years, is constrained. For up to a few hundred years, it necessitates seclusion from the biosphere [8]. Therefore, it is standard to dispose of LLW at facilities close to the surface. The majority of nuclear power, nuclear research and nuclear medical facilities produce LLW. Processing of LLW involves treating and conditioning LLW to get it ready for transit, storage and disposal. The alternatives for treatment and conditioning are selected while considering the intended way of storage and disposal [9]. This sort of storage's goal is to keep the waste in check until it can be disposed of (or used as a holding area between processing steps) [10].

Intermediate level waste

Radioactive waste that requires shielding but needs little provision for heat dissipation is classified as Intermediate Level Waste (ILW). Intermediate level waste contains a higher amount of radioactivity and may require special shielding. It typically comprises resins, chemical sludge, reactor components and contaminated materials from reactor decommissioning. ILW may contain long lived radionuclides, particularly alpha emitting radionuclides that will not decay to a level of activity concentration acceptable for near surface disposal during the time for which institutional controls can be relied upon. Smaller items and non solids may be solidified in concrete or bitumen for disposal. Worldwide it makes up 7% of the volume and has 4% of the radioactivity of all radio waste. Generally, short lived waste (mainly from reactors) is buried, but long-lived waste (from reprocessing nuclear fuel) is disposed of deep underground. Additional shielding may be required to limit radiation dose rates near ILW containers.

High level waste

Compared to ILW, High Level Waste (HLW) requires a higher level of containment and isolation from the accessible environment to assure long term safety because it contains such high quantities of short and long lived radionuclides. It produces a lot of heat and needs cooling and unique shielding when handled and transported. If the old fuel is reprocessed, the waste removed is vitrified by putting it within stainless steel canisters sealed with borosilicate glass for final disposal underground [6]. The entire fuel assemblies are regarded as high level waste if burned fuel is not recycled since all highly radioactive isotopes are still present. This high level waste and used power are highly radioactive, so anyone handling them must wear protective gear. These compounds are transported in special containers that insulate the radiation and won't burst in the event of an accident. Whether used fuel is reprocessed or not, the amount of high-level waste is negligible; for a typical large nuclear reactor, this amounts to 25-30 tons of wasted fuel for final burial deep below or approximately three cubic meters of vitrified waste per year.

Sources of radioactive waste in Bangladesh

In Bangladesh, several nuclear applications produce Low level Radioactive Waste (LLW). The 3 MW TRIGA Mark-II research reactor, the radioisotope production plant, the medical, industrial and research facilities that employ radionuclides and the industrial facility for processing monazite sands are currently the primary sources of radioactive waste in the nation. Table 1 shows that the Institute of Nuclear Medicine (INM) uses various radioisotopes in Bangladesh Table 2 shows that different process Industries in Bangladesh are also using multiple radioisotopes.

Isotope	Half life	Rad type	Use
Iodine-125	60 d	γ β	Radioimmunoassay (RIA)
Iodine-131	8 d	β	Thyroid cancer and imaging
Molybdenum 99	66 h	β	Generator of Tc-99 m
Rhenium-186	3.8 d	β	Imaging

Technetium 99 m	6 h	γ	Imaging
Cobalt-60	5.27 yr	γ	Radiotherapy

Table 1: Radioisotopes used by INM in Bangladesh.

Processes	Uses	Radioisotope
Manufacturing	The thickness of coatings, weight, moisture content, etc.	Gamma emitters: Co-60, Cs-134 Cs-137, Sr-90, Am-241 etc.
Chemical processing	Density, Sp. Gravity, pipe THICKNESS, corrosion, wear	Gamma; neutron sources Am-Be or Am-241
Construction	Moisture content, location of reinforcing bar, etc.	Gamma; neutron sources Am-Be or Am-241
Oil and gas	Column scanning, level measurement, etc.	Gamma; neutron sources Am-Be
Road research	Soil moisture measurements	Neutron sources Am-Be, Cf-252
Nondestructive Test	Weld, valves, parts, pressure vessels, aircraft structures, etc.	Co-60, Cs-137, Ir-192 etc

Table 2: Radioisotope used in industries in Bangladesh.

Hazards of nuclear waste

Nuclear energy generates little waste compared to other non renewable energy, but the waste it generates is significant and must be carefully managed. For short lived, low level waste, the preferred method of storing nuclear waste is near surface disposal, in which the waste is kept in specially designed trenches until it decays. For high level waste, the most long lived form of garbage and the challenging paper to store and handle, the preferred method of storing nuclear waste is deep geological disposal. The waste is buried considerably deeper underground at remote sites where the ground's geological makeup will aid in preventing any radiation from escaping while it decays. Radioactive radiation is the main danger posed by human generated nuclear waste. Genetic and somatic impacts are the two main consequences of radiation. The direct physical impacts are:

- Chronic injury brought on by low dose irradiation of long term, super allowable dosage limits.
- Acute injury is brought on by high doses of the human body in a short time.
- Long term consequences may include leukemia, aplastic anemia, malignant tumors, cataracts and impacts on early pregnancies. They also relate to effects that manifest more than six months after exposure.

Nuclear waste has the potential to harm the environment as well. Nuclear waste buried deep underground emits decay heat as radionuclides break down, the same as adding a heat source to the medium field. The presence of a heat source alters the underground medium field's temperature distribution first. This, in turn, changes the fluid migration by influencing the fluid viscosity and density as well as the chemical properties of specific substances, directly affecting the underground medium field's core. Mercury migration and temperature fluctuations may both lead to the fracture's opening and closing, which impacts the stress field below earth. Consequently, heat sources substantially impact the environment, but they are primarily localized in the adjacent area. Additionally, as groundwater migrates, the nuclides of the solidified solids may be leached from the packaging container and into the biosphere, damaging the environment around people.

Nuclear waste management principles

The administrative and technical processes involved in waste generation, processing, treatment, conditioning, storage, transportation, disposal and decommissioning are referred to as nuclear waste management. It consists in managing the entire process, from trash generation through disposal. Nuclear waste management must adhere to specific principles and protocols to ensure that nuclear waste is prevented as much as possible in the whole manufacturing and disposal process. Although each nation has unique management philosophies for handling nuclear waste, they share some fundamental characteristics.

- **Prevention:** The creation of waste should be prevented or reduced at the source (*i.e.*, minimized) as far as possible to secure the conservation of nature and resources, particularly waste that cannot be managed using current techniques or techniques under recent development.
- **Preparing for reuse:** Where waste cannot prevent, waste materials or products should, where appropriate, be reused directly or refurbished then reused;
- **Recycling:** Waste materials should be recycled or processed into a form that allows them to be reclaimed as a secondary raw material, where appropriate and authorized manner.

On a practical level, can categorize the activities necessary for managing radioactive waste properly in the following order of priority:

Minimization

Existing facilities can lessen the waste they produce with planning and sound procedures. In addition, new technologies and industrial layouts also strive to reduce waste by, for example, making maintenance requirements more straightforward.

Conditioning and packaging

It is frequently possible to super compact solid LLW and ILW into substantially smaller volumes. Liquid waste must convert into solids before disposal. Using ion exchange or filtration, radioactive materials can be extracted from the liquid, dried, absorbed into a fixing medium or consolidated in concrete. ILW and LLW can be packaged for temporary storage or disposal in steel drums or containers after such treatment. However, HLW generated during reprocessing must be converted from a liquid to a solid for long term storage and disposal, often through verification.

Interim storage

High Level Waste (HLW) and Intermediate-Level Waste (ILW) are usually stored in Interim Facilities (HLW). In the beginning, spent nuclear fuel that has not been reprocessed is submerged in a storage pool, typically at the reactor site. It can be put in specialized containers for temporary storage or disposal after a specific time. To allow for the initial very high level radiation and heat generation to decline, interim storage is always required for HLW.

Final disposal

Disposal is the final step in radioactive waste management. Short lived ILW and LLW are disposed of routinely at numerous sites in many countries; some areas have already been filled and closed. It is expected that for about 100 to 300 years following the closure of an ILW/LLW disposal site, active or passive controls will be applied, including groundwater monitoring, restrictions on access, periodic maintenance and restrictions on further land use. After this period, the radioactive isotopes will have decayed to negligible levels.

Disposal methods of radioactive nuclear waste

The subsequent subsections will discuss the many conventional and cutting edge techniques for disposing of radioactive waste. It will discuss which sorts of radioactive nuclear waste are suitable for each approach and the accompanying benefits and drawbacks. The installation of waste packages in rock tunnels and filling the space left by the destruction with compacted betonies clay constitute one possible design for disposing of spent nuclear fuel and waste. The waste packages would provide heat for the bentonite backfill, while the host rock would provide moisture. Each notion's feasibility and limitations will also be examined as they pertain to abstract techniques for disposing nuclear waste. According to the radiation level, radioactive waste disposal is depicted in Figure 2 and various disposal methods of radioactive nuclear waste will be discussed in the subsequent paragraphs.

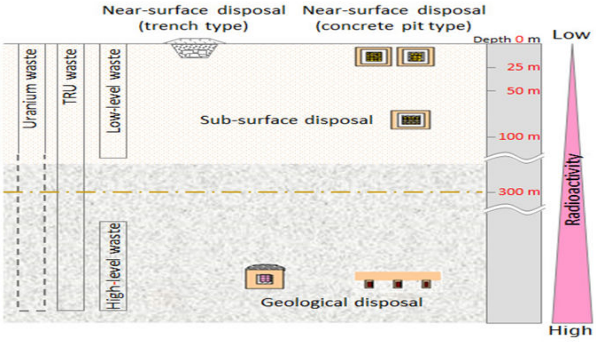

Figure 2: Disposal of radioactive waste based on the amount of radioactivity.

Conventional methods

Nuclear waste is typically disposed of either near surface or deep geological techniques. Geological disposal is often used to manage HLW in forms like SNF. Near surface removal is best suited for the disposal of LLW and ILW, which do not generate considerable heat and focus on short lived isotopes.

Near surface disposal

The primary method of disposing of low and intermediate level radioactive waste (LILW), often with half-lives of no longer than 30 years, is near-surface disposal, formerly known as "shallow land" and "ground disposal" in scientific literature. Examples of protective layers include a concrete vault, an impermeable membrane cap covered in topsoil and a backfill. In some designs, drainage and gas venting systems may also include. One issue with near surface disposal facilities is that institutional governance and oversight of the plant may come at a hefty post closure expense.

Deep geological disposal

HLW and occasionally, LILW and SNF are currently disposed of primarily through deep geological disposal. Deep geological disposal attempts to contain the waste within "engineered and natural barriers (rock, salt, clay)," given the longevity and high heat created by HLW and SNF, to shield the biosphere and humanity from the damaging effects of the radiation. Although deep geological facilities may not need active monitoring, maintaining institutional management and surveillance after closure may be expensive for safety related reasons.

Novel methods

Novel waste containment and disposal techniques have been put forth and tested in controlled situations as technology and the material and chemical sciences continue to advance. This article has covered some of the most promising techniques, such as deep boreholes and geopolymer storage.

Geopolymer storage

Geopolymer storage is an innovative way to store specific waste kinds inside geopolymer material. Fast dewatering, stability up to 1000°C and the capacity to entrap radioactive elements within a "zeolitic geopolymeric framework, improving the innocuity of the confinement" are only a few of the two key benefits of geopolymer cement.

Deep boreholes

The drilling and capping of deep boreholes is an alternative to mined repositories, as discussed in Section 6.3, deep geological disposal. This procedure calls for drilling a hole to a depth of approximately 5 kilometers and inserting 400 steel canisters, each measuring 5 meters, containing vitrified or SNF wastes in the first 2000 meters of the hole.

Conceptual methods

If mishandled, radioactive waste will pollute the environment and seriously endanger human health for a very long time. Researchers from several countries constantly look for more effective ways to manage radioactive waste. This section discusses some abstract techniques that have been investigated in depth.

Sub seabed disposal

One of the most popular ways to dispose of radioactive waste for a long time was by sea disposal, which entails pouring packaged radioactive material into the ocean. The organization for economic co-operation and development determined the dumping of high level waste in deep ocean sediments was technically possible in 1988.

Ice sheet disposal

The idea behind ice sheet disposal is to spread heat generating Hazardous Waste (HLW) out over solid ice sheets so that the heat will melt the ice around it and cause the garbage to sink into the ice sheet. The substantial ice layer will be a barrier to separating the radioactive waste from the biosphere when the water above the containers refreezes.

Challenges of Bangladesh in nuclear waste management

Considering Bangladesh's rapidly expanding economy, it is evident that nuclear energy development has great potential. However, a few restrictions and difficulties still exist to assure the optimal application of nuclear technology.

Regulatory and legal concerns

The primary law regarding nuclear power projects is the nuclear power plant act 2015. The Act sets up the Nuclear Power Company of Bangladesh (NPCB) to operate the plant. However, BAEC will remain the owner of the power plant. However, the law does not contain any provisions for the consequences of any nuclear power plant disaster. Therefore, Bangladesh needs a comprehensive law on nuclear power production, which is necessary to guide future safe energy production.

Ensuring reactor safety through technological means

The government of Bangladesh wishes to develop, expand and enhance the internationally advanced fission technology and achieve localization. However, fission technology will not provide efficient production without the proper domestic introduction and demonstration of such technology. In general, the lack of experts in nuclear technology can constitute a significant challenge to the efficient production of nuclear power in Bangladesh.

Nuclear waste treatment

Nuclear waste and spent fuel accumulation are rapidly growing. By some estimation, the world now contains 180,000 tHM of atomic waste. The new agendas of Europe and America present a negative impression of nuclear technology and thus, they are closing down some of their nuclear power plants. Such decisions in Europe and America will indeed impact nuclear waste disposal and it is estimated that the growth of atomic waste can cease.

Worry about the security of nuclear material

Although the Government of Bangladesh will strictly supervise nuclear materials, there remains a particular concern due to the increasing terrorism activities in the region. Only about 3% of uranium-235, the core atomic fuel, is used in nuclear power plants to generate electricity. The usage of 3% of uranium-235 is far below that of nuclear weapons (more than 90%). Furthermore, a fission chain reaction in nuclear power production has different control technologies, which are very dissimilar from the technology used to design nuclear weapons.

Nuclear energy's low economic competitiveness

In addition, power generation through oil and coal has also reached a commercially mature stage. Therefore, nuclear power projects might not be so efficient for a short time when compared with fossil fuel power generation. In the case of Bangladesh, the nuclear energy project has become more expensive because of the technology, which needs to be imported and localized to ensure the effectiveness of power generation.

Shortage of uranium resources

Bangladesh's share is a paltry 0.25%. In addition, the deposits of uranium ore in Bangladesh are relatively small and of low category. The average ore of 0.1% and 0.2% grade available in Bangladesh cannot be efficiently used.

Discussion

Prospects of Bangladesh

As a developing country with a fast-growing economy, Bangladesh is facing a slightly tumultuous situation of uninterrupted power supply, which will undoubtedly be a significant impediment to the further development of the country with increased demands in the future. Currently, most of the country's electricity is supplied through natural gas from a few coals and oil based power plants. However, the steady growth of prices of coal, oil and fossil fuels throughout the world and the depleting reservoir of natural gas point out the power struggle of Bangladesh for energy demand. Moreover, the emission of toxic gases such as carbon dioxide, carbon monoxide, sulfur dioxide, nitrogen oxides as well as lead and particular matters into the atmosphere as a result of combustion from non renewable fossil sources like oil, coal and natural gas imports serious pollutions to the surrounding environment in the long run, which cannot be discounted. From this viewpoint, nuclear power plants can be a permanent solution to mitigate the impending energy crisis and simultaneously reduce fossil fuel consumption. Moreover, tremendous technological development in the field of fission technology has already made nuclear power generation plants more environment friendly with substantially lower emissions of pollutants discharged throughout the service period when compared with all other noticeable renewable sources of energy (like hydro electric, biomass, solar energy, wind power, etc.), which is evident from the research outcomes of the World Nuclear Association (WNA). The Rooppur Nuclear Power Plant (RNPP) will be the nation's first nuclear power plant. The first of two units are now being built. The Russian ROSATOM State Atomic Energy Corporation is constructing it. The two devices producing 2.4 GWe anticipated start dates are 2023 and 2024. This shows all the data related to RNPP are outlined in Table 3, as follows:

Location	Rooppur, adjoining Paskey, Ishwardi, Pabna, Bangladesh. On the bank of the river Padma, 140 km west of Dhaka.
First proposal In 1961	First proposal In 1961
Construction started Infrastructure development by	30.11.2017 (currently under construction)
Infrastructure development by	- Rosatom State Atomic Energy Corporation, Russia (critical infrastructure) - MAX Group, Bangladesh and the Hindustan Construction Company. India (Non-critical infrastructure)
Commission date	Oct-23
Power unit	Rooppur NPP Unit 1 and Rooppur NPP Unit 2
The nuclear power plant model	VVER-1200/523, the latest Generation III+ atomic reactor (for both teams)
Capacity	2.4 GWe (1.2 GWe by unit 1 and 1.2 GWe by unit 2)
Reactor type	Pressurized water reactor (PWR)
Cooling source	The Padma river through the natural draft tower

Table 3: Bangladesh's Rooppur Nuclear Power Plant (RNPP) in a nutshell.

It is to be motioned that Bangladesh has created a waste management system compatible with other developing countries. However, Bangladesh does need an iron clad regulatory system if it intends to have proper maintenance regarding nuclear particles and wastage. Accelerate the establishment of site selection requirements and basic guidelines for low and medium level waste near surface disposal. The current temporary storage pools are near saturation. The site selection, construction and operation of low and medium level waste disposal libraries should be made as soon as possible. For the disposal of high level waste, it is best to choose the vertical borehole stacking method for the deep ground roadway or the lying way disposal method. This is a deep defense multiple barrier isolation system.

Conclusion

The analysis of present status, challenges of nuclear waste management has been reviewed for Bangladesh perspective in this review paper. It is to be mentioned that the applications for radiation and radioactive materials range from power generation to use in industry, agriculture and medicine. The sources of radioactive waste are increasing day by day with the rapid industrialization. Therefore, it is essential to evaluate and, if necessary, control any radiation dangers that these applications may pose to the environment, workers and the general public. In this regard it is quite necessary to follow and implement the waste management principle to minimize, interim packaging and finally disposing off the waste. However, the creation of radioactive waste must also be kept to a minimum. In order to make sure that producers appropriately dispose of their radioactive waste, relevant regulations must be made and enforced. Moreover, governments and the nuclear sector must work together to enable safe disposal of the hazardous radioactive waste to create a green environment. The key findings from the present analysis may be summarized as follows:

- Numerous nuclear uses in Bangladesh result in Low level Radioactive Waste (LLW). After installing the county's first Rooppur Nuclear Power Plant (RNPP) will result higher level radioactive waste.
- The major threat posed by human generated nuclear waste is radioactive radiation. The two main effects of radiation are genetic and somatic which may create chronic, acute and long term injury to human.
- Necessary steps regarding legal and regulatory systems will strengthen the nuclear waste management system. Therefore, future prospects of Bangladesh in terms of nuclear waste management can be most effective way to minimise the unclear hazards.

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