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Nuclear Waste Management in the context of the Rooppur Nuclear Power Plant: Challenges and Opportunities for Bangladesh

Farzana Yeasmin[#]

[#]*Lecturer, Department of Applied Chemistry and Chemical Engineering, Bangabandhu Sheikh Mujibur Rahman Science and Technology University, Gopalganj, Bangladesh.*

Abstract

Economics, energy, and the environment are intricately bonded throughout the world from the ancient period. For a sustainable future, energy security is a must to bring about the desired economics, standards of living, and lately for any country's national security. Over the last fifty years, a significant amount of the world's electric supply has been ventured from Nuclear power plants (NPP). Bangladesh's government is firmly devoted to universal electrification in a secured and affordable way to persue "Vision-2021" and "Vision-2041". As a sustainable source of energy, Rooppur Nuclear Power Plant (RNPP) is a prospective solution for Bangladesh, which also imposes a big challenge at the same time in the safe disposal of the high-level radioactive wastes generated from the nuclear power plants. Bangladesh already has admirable amenities for the management of present radioactive waste. Still, it requires more technical improvement for the final disposal of the future radioactive waste arising from the country's first nuclear power plant, RNPP. This paper focuses on assessing the current trends in nuclear waste management worldwide and reviews the nuclear waste management plan in RNPP and the deficit in nuclear waste management of RNPP for the long term to acknowledge a theoretical study approaches to mitigate the problem in the future.

Keywords — *Rooppur Nuclear Power Plant, Nuclear waste management, High-level radioactive waste, Bangladesh.*

I. INTRODUCTION

Bangladesh's government is devotedly focused to elevate the country as a middle-income country by 2021 and as a front-ranking developed country by 2041 [1]. But it will be a challenging job for Bangladesh to meet its accumulative energy demand to cope with the rapidly growing economy, as there are discrepancies in the dissemination of the world's energy demand growth and resources. Currently, Bangladesh is dependent on the indigenous natural gas supply as fuel for 80% of the electricity. The present estimated 9 tcf of natural gas reserve in Bangladesh is not sufficient to meet the demand for the next 10-20 years [2].

After the Rooppur Nuclear Power Plant (RNPP) successful construction and operation, Bangladesh is going to be the 33rd country to produce nuclear power [3]. Nuclear power is a stable, sustainable, and safer energy source with reduced CO2 emissions, affordably generating electricity to overcome the environmental challenges from using fossil and other organic fuels. Giving utmost priority to diversified technology integration for cost-effective electricity generation and attaining energy security, Bangladesh is constructing the Rooppur Nuclear Power Plant (RNPP) after several feasibility studies over the years, taking technical supports chiefly from Russia. The byproducts and the wastes produced at different stages of nuclear power production bear radioactivity at different levels. Bangladesh has already conceived a proper plan to safely manage the low and medium-level waste of RNPP by itself giving safety an important priority and signing an agreement with Russia to take back the high-level waste [4].

A thought-provoking issue for Bangladesh is a well known "Not in my back yard" reaction of the public around the world regarding the disposal of nuclear waste [5]. International politics is involved in nuclear energy generation and radioactive waste management in a complex way. So, considering future safety and national security, Bangladesh cannot be solely dependent on Russia for high-level waste management. For the safe disposal of all type of radioactive wastes, a self-sufficient state of the art technological infrastructure will be inevitable for Bangladesh today or tomorrow.

II. Nuclear Power Plant: Current status throughout the world

With the rapid development of science and technology in every sector throughout the world, the huge demand for an uninterrupted electricity supply has now become a fundamental prerequisite of our daily life. To cope with this upsurging demand for power supply, nuclear power plants are considered a promising solution to the world's highly efficient and second-largest source of low-carbon power.

According to the report of the International Atomic Energy Agency, as of 2020, about 11% of the world's total electricity is supplied by 450 reactors at different nuclear power plants, while 329 new reactors are under considerations and the largest producer countries are the United States and France [6].

Nuclear power plants utilize nuclear fission reaction to generate heat inside the reactor, which converts the coolant (water or gas or liquid metal, depending on the nature of the reactor) into steam inside a steam generator to spins a multi-stage steam turbine and a generator to produce electricity following the Rankine cycle [7].

The Obninsk Nuclear Power Plant in Obninsk of the Soviet Union is the world's first nuclear power station to generate electricity for a power grid, which started operations from June 27, 1954 [8]. Since then, nuclear energy has persisted as a valuable form of energy, making the United States, Russia, and Canada achieving the energy super-powers. Following the global statistics provided by the UN's International Atomic Energy Agency, a summary of the current status of the dependency on the nuclear power plant of top fifteen countries with bigger nuclear energy powers is represented by Table. 1.

Table 1: Scenario of electricity production by the nuclear power plant in the world [9]

No.	Country	No. of current nuclear reactor	Net capacity of production of nuclear electricity, gigawatt-hours	% of the total electricity produced by nuclear power plants
1	USA	100	770719	19
2	France	58	407438	74.8
3	Russia	33	166293	17.8
4	South Korea	23	143550	30.4
5	Germany	9	94098	16.1
6	China	17	92652	2
7	Canada	20	89060	15.3
8	Ukraine	15	84886	46.2
9	UK	18	63964	18.1
10	Sweden	10	61474	38.1
11	Spain	8	58701	20.5
12	Belgium	7	38464	51
13	India	20	29665	3.6
14	Czech Republic	6	28603	35.3
15	Switzerland	5	24445	35.9

Besides, Japan and Finland also have substantial nuclear enrgy power with 17230 gigawatt-hours and 22063 gigawatt-hours nuclear electricity supply. It is worth mentioning that, except Germany, Spain, Switzerland, and Spain, the rest of the other energy super-power countries are rigorously planning and developing newer nuclear power plants with the latest technologies [9].

III. Nuclear (Radioactive) waste

One of the major concerns of installing and running a nuclear power plant is the cost-effective and completely safe handling and management of radioactive nuclear waste, which otherwise may have a long-term detrimental effect on humankind and the environment. According to IAEA's Radioactive Waste Management Glossary, radioactive waste is defined as waste containing or is contaminated with radionuclides at concentrations or activities greater than a clearance level as established by the regulatory body [10].

Every stage of the nuclear fuel cycle is involved in producing radioactive wastes, such as the production of solid and liquid radioactive waste during mining and milling of uranium ore, during fuel fabrication and reprocessing, before fuel insertion into the cladding. Radioactive byproducts due to fission reaction and isotopes of actinide series due to neutron capture reactions in the fuel also produce radioactive waste at reactor operation. Further insignificant roots of radioactive waste production include spent ion exchange resin, cartridges and sludge of filter, liquid concentrates of washing, leakage, and solutions used of decontamination processes, active chemical waste, compactable (contaminated clothes, mops, bags, and gloves) as well as noncompactable trashes [11].

International Atomic Energy Agency (IAEA) categorizes radioactive wastes into six classes, which are as follows [12,13]:

A. Exempt waste (EW)

Exempt waste contains such little concentrations of radionuclides that it no longer require any radiation protection. Once the regulatory authority cleans it, the waste can be disposed of in any conventional landfill or recycled without further contemplation from a regulatory control viewpoint. According to IAEA, the primary radiological basis of activity concentration for exemption of radioactive wastes should be 10 μSv or less per year and an equivalent dose criterion of 50 mSv per year in case of skin exposure.

B. Very short-lived waste (VSLW)

Radionuclides of very short half-life with activity concentrations above the permitted levels are included in VSLW (mostly used for medical or research purposes) which can be stored up for some time to a few years, until the activity has dropped under the margins of authorized clearance, allowing for the cleared waste to manage as usual waste. Usually, the waste containing radionuclides with half-lives of the order of 100 days or less is stored with supervision, which ultimately will be considered as exempt waste through radioactive decay.

C. Very Low-Level Waste (VLLW)

Wastes originating during the processing and decommissioning of nuclear facilities with activity concentration equal to or slightly above the permissible limit from regulatory control (IAEA), close to natural radioactivity with limited hazard, are considered VLLW. Such wastes have radioactivity drops to natural radioactivity after a few decades. So why are attuned with the regulation in near-surface landfill type facilities under some controlled supervisory mechanism? A sufficiently safe engineered surface landfill type facility is mostly used for VLLW disposal from nuclear installations, mining operations, and operations involving minerals processing and other activities.

D. Low-Level Waste (LLW)

Low-level waste typically comprises a small portion of long-lived radionuclides with high radioactivity, robust containment, and need for isolation for a short period to a few hundred years and can be deposited at limited volume near the surface level, at varying depths from the surface down to (25-30) meters. This class contains an extended range of radioactive wastes from the radioactive waste of radioactivity just above that for VLLW with no requirement of shielding and isolation to radioactive waste with marginal activity concentration involving shielding, robust containment, and isolation times up to several hundred years. In the case of long-lived alpha-emitting radionuclides, an average limit of 400 Bq/g (up to 4000 Bq/g intended for discrete packages) is approved in some countries.

E. Intermediate-level waste (ILW)

Intermediate-level waste contains higher amounts of long-lived radionuclides that need control and separation from the biosphere with no cooling but shielding. It is normally solidified in bitumen before storage. Disposal facilities with depths of a few tens to few hundreds of meters can give a period of isolation to ILW from the reachable environment overcoming both the natural and engineered barriers of the disposal system. Disposal at intermediate depths provides no unfavorable influence of erosion in a short to medium time period with lowered unintentional human interruption.

F. High-level waste (HLW)

High concentrations of both short and long-lived radionuclides usually originated as a byproduct of the reactions inside the nuclear reactors, showing the highest detrimental impact and requiring both cooling and shielding to be called high-level waste activity concentrations in the range of 104-106 TBq/m^3. Only 3% of the volume of the world’s radioactive waste obtained from reprocessing of spent fuel is HLW, which produces significant amounts of heat from radioactive decay over hundreds of years. With engineered barriers, a deep geological disposal facility is the right and safest solution for the containment and isolation of HLW from the accessible environment for long-term safety.

IV. Radioactive waste disposal methods currently in practice throughout the world

Nuclear waste management or radioactive waste disposal must be maintained strictly with safety and least damage to the environment, animal, and plant kingdom, considering that the half-life of certain radioactive waste can be in the range of 500,000 years and above. Several on-site treatment methods like chemical precipitation process, ion exchange process, cementation process, bituminization process, the molten salt oxidation process can be temporarily used for radioactive waste treatment. But for safety issues, implementation of any one or combination of several long term management processes is necessary for any nuclear power plant, which includes waste reprocessing for re-use, geological disposal, transmutation, and space disposal [14].

a) Reprocessing

In nuclear waste reprocessing, fissionable materials once parted out from the irradiated nuclear fuel are then driven further to the nuclear fuel cycle repeatedly, imparting nuclear proliferation. Considering the long-term management of nuclear waste, reprocessing and reuse is a feasible option depending on how easy the separation process is.

b) Geological Disposal

Geological disposal methods involve a stable location for burying the nuclear waste safely with the proper protection to prevent material leakage, measures to check the water level to avoid seepage, immediate action plan against any seismic event resulting in instant contamination, and during the long half-life of the radioactive waste, keeping out of human reach, along with significantly considering the availability for the terror attack. USA, Canada, Russia, Uk, Belgium, Japan, Finland, Sweden, France, and Germany have already achieved notable progress in deep geological disposal of radioactive wastes.

c) Transmutation

In this process, the radioactive nuclear elements are transmuted into other less radioactive elements naturally or due to external spur (the reaction material striked by proton) and become the non-fissionable material with little or no risk. Conversion of Potassium to Argon, Chlorine to Argon, etc., are frequently occurring examples of transmutation.

d) Space Disposal

Space disposal of nuclear waste using a space shuttle is a costly and quite impractical solution from technical aspects. The burden of high-level radioactive waste management can be escaped by disposing of solidified nuclear waste in an explosion-proof vehicle launching into earth orbit or the sun or maybe out of the solar system, using any of the electromagnetic launchers, gas guns, laser propulsion, or solar sails. However, it is a highly energy-intensive option with unexplored safety issues for radioactive waste disposal [15].

V. Nuclear Power Plant (NPP) in 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 big impediment for further development of the country with increased demands in the future. At present, most of the country's electricity is supplied through natural gas from a few coal- and oil-based power plants. The steady growth of prices of coal, oil, and fossil fuels throughout the world and the depleting reservior of natural gas point out the power struggle of Bangladesh for energy demand [16]. Moreover, 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 the 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 [17]. From this viewpoint, nuclear power plants can be a permanent solution to mitigate the upcoming energy crisis and simultaneously reduce fossil fuel consumption. Tremendous technological development in the field of fission technology already made nuclear power generation plants more environment friendly with substantially lower emissions of pollutant 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) [18].

So, the Bangladesh government has planned to go for nuclear power plant and taken a project called Rooppur (alternatively Ruppur) Nuclear Power Plant Project (RNPP), the first nuclear plant of Bangladesh, by the agreement of Bangladesh Nuclear Power Action Plan in 2000 outlining what actions are to be taken, ascertaining the responsible entities for each of them along with proposing the guidelines for implementation of nuclear power plant (NPP) [19]. All the data related to RNPP are outlined in table 2, as follows:

Table 2: Rooppur Nuclear Power Plant (RNPP), Bangladesh at a glance [20]

Location	Rooppur, adjoining Paskey, Ishwardi, Pabna, Bangladesh. On the bank of the river Padma, 140 km west of Dhaka.
First proposal	In 1961
Construction started	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	October 2023
Power unit	Rooppur NPP Unit 1 & Rooppur NPP Unit 2
The nuclear power plant model	VVER-1200/523, latest Generation III+ nuclear reactor (for both unit)
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

As a developing country, Bangladesh has to face challenges related to technically sound human resources shortage, overall expenditure, nuclear disaster management capacity in the RNPP project, which hopefully can be tackled over time. But a major concern is how such a densly populated small country like Bangladesh will handle tons of radioactive wastes derived from RNPP. Though a TRIGA research reactor is being operated safely since 1984 under the control of the Bangladesh atomic energy commission (BAEC), with efficient radioactive waste management, Bangladesh Government still needs to be more focused on stable management of nuclear waste cost-effective way [21].

VI. Radioactive waste management of Rooppur Nuclear Power Plant (RNPP)

A variety of solids, liquids, and gases radioactive wastes will be produced during the nuclear reactor operation in RNNP, improper disposal or recycling, which will impart irradiation resulting major complications for human health and the environment in the long run. As estimated, around 50-60 tons of high-level wastes per year will be generated during the operation of RNPP, which demands sophisticated handling of shielding, cooling, and storage before disposal. A bilateral mutual agreement between Bangladesh and Russia has been signed, making Russia responsible for radioactive waste management, along with subsequent decommissioning on November 2, 2011 [3].

The power plant model of RNNP, VVER-1200/523, is one of the cutting-edge Generation III+ nuclear reactors, with layered safety barriers designed to ensure zero escape of radioactive material from the reactor. So, a comparatively reduced amount of radioactive wastes will be produced during the operation of RNPP [2]. Initially, the waste produced is categorized to determine its physical and chemical states for an appropriate way of demobilization, recycling, and transfer for disposal. Following the super compaction method, both low and intermediate level solid waste can be reduced into much smaller volumes. Membrane-filtration processes or ion exchange processes can be applied to remove radioactive material from liquid wastes, followed by transformation into solid via different immobilization methods like solidification into cement or polymer, suitable for low and intermediate-level radioactive waste and vitrification into a glass in case of the high-level liquid waste matrix. Low and intermediate-level waste can then be wrapped appropriately in steel containers placed further in a concrete cylinder. These protective coverings inhibit the spreading of radiation surrounding nuclear waste in a relatively easy and inexpensive way, which emancipates the need for special transportation or specific storage facilities.

After storage, the most challenging step of nuclear waste management in the long term safe disposal of them into an appropriately selected deep and stable geologic location far away from the human approachability and guarantee of complete protection from leakage in case of any geographical casualties. As a third-world country, Bangladesh might have to endure obstacles in safe disposal of nuclear waste. Many other developed countries are still spotting different oceans, space, or deep geological disposal of radioactive wastes as permanent solutions [23]. Generally, nuclear fission reactions remain hazardous for many years due to longer half-lives, so why these highly volatile wastes remain extremely risky for generations after generations if there occur any accident unexpectedly. Any accidental leakage of nuclear waste can be spread out via dust storms into public areas, contaminate drinking water, other water bodies, or underground reservoirs. It is worthy of mentioning that the Padma river is near the RNPP and is economically very important for both Bangladesh and India. Keeping the Padma completely safe from any radioactive waste spillage is very crucial for the countries.

Though Russia agreed to take away the high-level waste radioactive wastes of RNPP back to their country for final disposal, Bangladesh's technical soundness for the safe transport of this waste and its cost is doubtful and questionable. Despite sufficient precautions, radioactive waste spillage due to knocking, bumping, or crashing during transportation is not uncommon. And the cost of complete cleaning, associated with any accidents during nuclear waste management is too high in terms of money, times, environmental pollution and obviously and animal health. Not only nature, but humans also require years to come back to normal life with sound health, as the cleaning process is complex and costly [18]. Bangladesh's government needs to be aware of these issues to manage all possible accidental events with amplified technical proficiency. So from the theoretical framework, the following suggestions can be impactful for the safe management of nuclear waste from RNPP-

1. Strong guidelines concerning the effective disposal of nuclear waste and spent nuclear fuel must be established following scientifically authorized, environmentally sound, financially, and socially acceptable ways in Bangladesh's context.

2. The government should involve highly skillfull personnels and nuclear scientists from home and abroad, specially of Bangladeshi origin, in the development and operation of RNNP with long term planning.

3. The concerned authority needs to communicate regarding long-term management of radioactive waste straightforwardly and spent nuclear to maintain cooperation and coordination with countries with long-term nuclear energy experience like Russia, China, USA, India, Pakistan, etc., for exchanging knowledge of nuclear science and technology.

4. Bangladesh should develop practical solutions to dispose of high-level waste on its own as an alternative, if Russsia ever fails to take the nuclear waste back, breaking the agreement signed between Bangladesh and Russia.

5. The government may think of expanding the investment to explore more natural gas in the Bay of Bangal and increase hydropower capacity for augmented power generation. Improving the technology of wind power and solar energy in Bangladesh might give away to relieve energy crises as an alternative energy source.

6. Exporting electricity from neighboring countries like-Nepal and Bhutan at a cheaper cost can also be a functional alternative for Bangladesh to escape the hassle of nuclear waste management.

VI. CONCLUSIONS

A bitter truth for Bangladesh is that there is still a lack of research and policymaking regarding any comprehensive solution for the nuclear waste disposal of RNPP. The country can be self-standing in dealing with the critical issues of nuclear waste. As Bangladesh is planning to produce a limited amount of electricity, nuclear waste generated from

RNPP will manage. But the scenario can be changed into a larger dimension in the future considering Bangladesh's rapid economic growth. Moreover, any slight lacking during the safe disposal of radioactive waste or transportation will hardly strike the workers' health, nearby people, and the surrounding environment. Considering the repercussions of improper nuclear waste management on Bangladesh, the government, and the nuclear industry, the Bangladesh Atomic Energy Commission must collaborate to design and implement an extensive regulatory system for safe disposal of radioactive waste and consider the above suggestions sincerely.

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