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Radioactive Waste Management: Practices for Safe and Effective Disposal

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***Abstract*— Nuclear energy is an important source of electricity that can help meet the world's growing energy needs. However, the safe and effective disposal of radioactive waste generated from nuclear power plants and other sources remains a significant challenge. This waste poses a threat to both the environment and human health if not properly managed. In the global context, the United Nations has addressed the problem of radioactive waste management in the Sustainable Development Goals (SDGs) report, aiming to ensure the responsible management of chemicals and all types of waste throughout their entire life cycle. Inadequate management of these waste materials could result in devastating environmental consequences and risks to human health, making it necessary to analyze and implement safe disposal methods for radioactive waste. The purpose of this study is to explore methods for the safe and effective disposal of radioactive waste. This paper is expected to contribute to the analysis of safe options for radioactive waste disposal.**

***Keywords:* radioactive waste management, nuclear energy, sustainable waste management, waste disposal.**

***Resumen*— La energía nuclear es una fuente importante de electricidad que puede ayudar a satisfacer las crecientes necesidades energéticas del mundo. Sin embargo, la disposición segura y efectiva de los desechos radiactivos generados por las plantas nucleares y otras fuentes sigue siendo un desafío significativo. Estos desechos representan una amenaza tanto para el medio ambiente como para la salud humana si no se gestionan adecuadamente. En el contexto global, las Naciones Unidas han abordado el problema de la gestión de desechos radiactivos en el informe de Objetivos de Desarrollo Sostenible (ODS), con el objetivo de garantizar la gestión responsable de productos químicos y todo tipo de desechos a lo largo de su ciclo de vida completo. Una gestión inadecuada de estos materiales de desecho podría tener consecuencias ambientales devastadoras y riesgos para la salud humana, por lo que es necesario analizar e implementar métodos seguros para la disposición de desechos radiactivos. El propósito de este trabajo es explorar métodos para la disposición segura y efectiva de desechos radiactivos. Se espera que este documento contribuya al análisis de opciones seguras para la disposición de desechos radiactivos.**

***Palabras clave*: gestión de residuos radiactivos, energía nuclear, gestión sostenible de residuos, eliminación de residuos.**

I. Introduction

Nuclear energy is an important source of electricity that can help meet the world's growing energy needs. However, the safe and effective disposal of radioactive waste generated from nuclear power plants and other sources remains a significant challenge. This waste poses a threat to both the environment and human health if not properly managed. In the global context, the United Nations has addressed the problem of radioactive waste management in the Sustainable Development Goals (SDGs) report, particularly through Goal 12 'Ensure sustainable consumption and production patterns' [1]. This goal includes specific targets, such as target 12.4, which aims to ensure the responsible management of chemicals and all types of waste throughout their entire life cycle, in line with internationally agreed-upon frameworks.

The goal is to significantly reduce the release of these substances into the air, water, and soil to minimize their negative impact on human health and the environment. This goal thus calls for the sustainable management and efficient use of natural resources, including the safe disposal of hazardous waste. The magnitude of this challenge becomes evident when considering the massive quantities of radioactive waste generated worldwide annually, which has a long half-life and remains radioactive for a long time. Inadequate management of these waste materials could result in devastating environmental consequences and risks to human health, making it necessary to analyze and implement safe disposal methods for radioactive waste.

The purpose of this study is to explore methods for the safe and effective disposal of radioactive waste. To achieve this objective, this paper is organized as follows. Firstly, the sources and types of radioactive waste will be identified. Next, various methods for the safe disposal of radioactive waste will be introduced and described. Finally, these methods will be analyzed based on their effectiveness and practicality to determine the most efficient approach. This paper is expected to contribute to the analysis of safe options for radioactive waste disposal.

II. Management of Radioactive Waste for Environmental Protection and Human Health

The management of radioactive waste is crucial for protecting the environment and human health. This waste, which is produced by nuclear power plants and other sources, comes in many forms and can be classified into two main categories: high-level waste (HLW) and low-level waste (LLW). Proper management of this waste is essential to prevent harm to people and the environment.

A. High-Level Waste

Managing high-level radioactive waste is a major challenge in the nuclear sector. As stated in [2, p.2], this type of waste emits intense radiation and requires careful handling and treatment. It originates from the first stage of reprocessing spent nuclear fuel to extract plutonium and

uranium, and includes any material with a high concentration of fission products that generate heat and need cooling, such as actinides not separated from the waste. The primary objective of managing high-level waste is to isolate it from the biosphere and prevent significant leakage of radionuclides into the environment, which could pose serious risks to human health and ecosystems. This implies the need for the development and implementation of safe and effective disposal methods that ensure the long-term containment of the waste.

B. Low-Level Waste

Low-level radioactive waste is the most common type of nuclear waste and requires proper management to avoid environmental contamination. Following [3], it can be stated that this waste can be disposed of in land-based facilities soon after it is packaged for long-term management, meaning that for the majority of waste types (~90% by volume) generated by nuclear technologies, a satisfactory disposal means has been established and is being applied globally.

Various long-term waste management options have been explored worldwide to provide safe and environmentally sound solutions that are acceptable to the public. These options include near-surface disposal, where waste is placed in engineered facilities at or near the ground surface, and deep geological disposal, where waste is placed in repositories deep underground.

III. Safe Approaches to Waste Management

Once the different types of radioactive waste have been clearly presented, it is necessary to investigate the different ways of managing them safely and effectively. To this end, several methods have been selected.

A. Temporary Storage

This method involves temporarily storing radioactive waste in facilities that are designed to contain and isolate it from the environment. Depending on the level of radioactivity and the type of waste, these facilities can be located either above or below ground. The goal of temporary storage is to allow the waste to cool down and decrease in radioactivity before it is treated or disposed of permanently. This also provides time to develop and implement appropriate long-term disposal solutions [4].

An example of a temporary storage facility is the Centralized Temporary Storage (CTS), which can be seen in Fig. 1. It is being built in Spain to store spent nuclear fuel and high-activity waste.

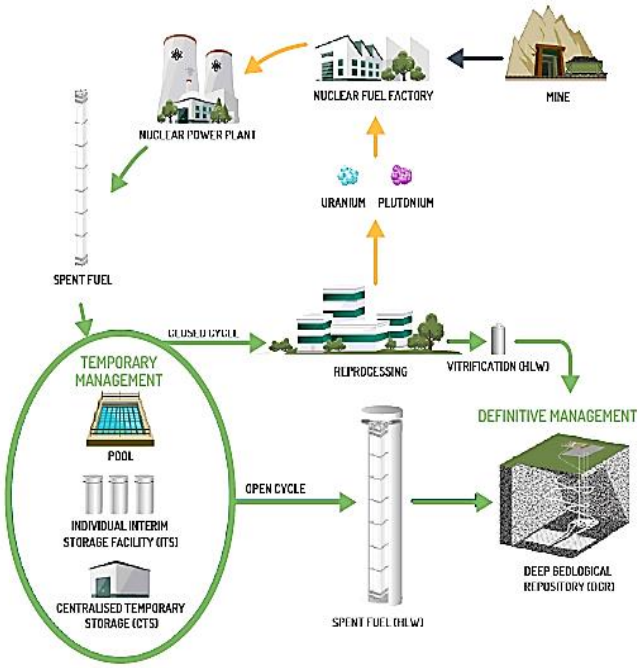

Fig. 1. Temporary Management [5]

B. Conditioning and encapsulation

This method involves transforming radioactive waste into a stable and solid form that facilitates its handling, transport, and final disposal. As described in [6], conditioning may involve processes such as compaction, incineration, vitrification, or cementation of waste. Encapsulation, in turn, involves introducing conditioned waste into metal or concrete containers that provide an additional physical barrier against the release of radionuclides into the environment. An example of conditioning and encapsulation is the process used to treat vitrified waste from spent nuclear fuel reprocessing.

Fig. 2. The process of compaction [6]

C. Final Disposal

Final disposal is a method that involves placing radioactive waste in facilities that are designed to isolate it from the environment for a period of time until its radioactivity decreases to acceptable levels. These facilities can be located on the surface, at an intermediate depth, or deep underground, depending on the level of radioactivity and the type of waste being stored. The goal of final disposal is to ensure long-term safety without the need for human surveillance or maintenance, as stated in [7].

An example of a final disposal facility is the deep geological repository being developed in Finland to store high-level radioactive waste and spent nuclear fuel, which can be seen in Fig. 3. This repository will be built at a depth of 400-450 meters and will have about 70 km of tunnels and shafts, where copper canisters filled with waste will be placed. It is expected to receive waste for about 100 years, after which it will be sealed.

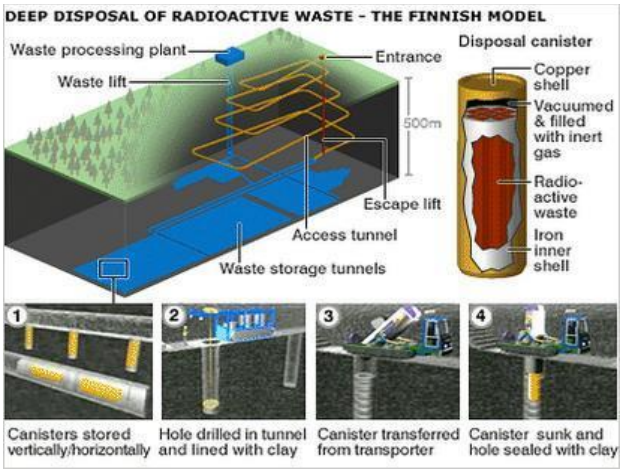

Fig. 3. Deep Disposal of Radioactive Waste [8].

D. Transmutation

Another way to deal with radioactive waste is to change the long-lived radionuclides into shorter-lived or more stable ones by using nuclear processes. As introduced in [9], this is called transmutation and it can be done by using nuclear reactors, particle accelerators, or external neutron sources. The aim of transmutation is to decrease the amount and danger of radioactive waste, as well as to reduce the time needed for its final disposal.

An example of transmutation is the Multipurpose Hybrid Research Reactor for High-tech Applications (MYRRHA) project, which can be seen in Fig. 4. This project is being carried out in Belgium and researchers are studying the technical and economic feasibility of this method.

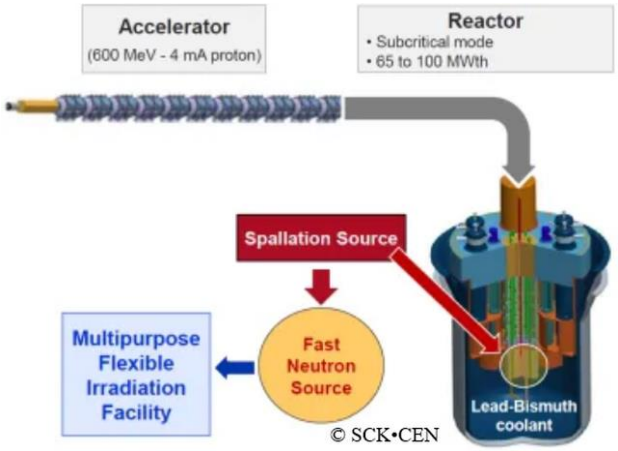

Fig. 4. MYRRHA (Multipurpose Hybrid Research Reactor for High-tech Applications) Project [9]

IV. Radioactive Waste Management: A Sustainable Approach

In this section, an optimal approach for handling radioactive waste is described, that is, a safe and effective disposal method. This method is all-encompassing, not just addressing the disposal of radioactive waste, but also safeguarding the environment and life in all its forms.

To implement this method effectively and yield the best results, several system enhancements can be introduced, as stated in [11]. First and foremost, a robust containment system capable of securely housing radioactive waste should be established. This system should be engineered to withstand natural disasters and prevent any leakage of radioactive substances into the environment.

The employment of cutting-edge materials like borosilicate glass, synthetic rock, or ceramic for encapsulating high-level waste is advised. These materials are recognized for their longevity and resistance to radiation, making them perfect for the long-term storage of radioactive waste.

A specialized surveillance and maintenance group should also be formed to avert any accidents. They must ensure the smooth operation of the containment systems and conduct preventive maintenance biannually. This maintenance should include a thorough inspection of the containment systems for any signs of deterioration or damage and replacing any components as required.

Moreover, this team should also be tasked with safely conveying the waste from nuclear facilities to the disposal site. They must adhere to stringent safety protocols during transportation to prevent any inadvertent release of radioactive substances.

Lastly, it is imperative to take into account the geological attributes of the disposal site. The site should be situated in a stable geological formation that is unlikely to be impacted by earthquakes or other natural disasters. Once an appropriate site has been pinpointed, it is necessary to compute how frequently the containment systems need to be replaced based on the half-life of the radioactive waste.

By adopting these methods and enhancements, safe and effective disposal of radioactive waste can be guaranteed. This may not only shield the environment but also lay the groundwork for sustainable nuclear energy production

V. Conclusion

In conclusion, the management of radioactive waste stands as a crucial challenge in the realm of nuclear energy and sustainable development. As underscored by the United Nations' Sustainable Development Goals, responsible waste management is integral to minimizing environmental harm.

This paper has explored the various facets of radioactive waste management, including waste types, disposal methods, and the need for safe, long-term solutions. High-level waste and low-level waste present distinct challenges, emphasizing the importance of meticulous handling and containment.

The global significance of this issue is evident, given the substantial quantities of radioactive waste generated annually, coupled with its enduring radioactivity. The pursuit of effective disposal methods must prioritize environmental protection and public acceptance.

Moving forward, continued research and development efforts are vital to identify more efficient, sustainable approaches. Long-term strategies, such as near-surface and deep geological disposal, warrant further exploration to ensure safe containment.

In the context of global frameworks and sustainable development goals, addressing radioactive waste management aligns with responsible resource utilization. As there are advances in nuclear energy, engineers' shared responsibility is to find safe, sustainable solutions, safeguarding our environment, and the well-being of present and future generations.

Acknowledgment

I wish to extend my sincere appreciation to Professor María Laura Sollier for her invaluable contributions to this research paper. Her expertise, guidance, and scholarly insights have significantly enriched the quality and depth of this work. Professor Sollier's thoughtful corrections and explanations have been instrumental in refining the content. I am deeply grateful for the opportunity to benefit from her mentorship and support throughout this endeavor.

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The present manuscript is part of the research activities in the Inglés II lesson at Universidad Tecnológica Nacional, Facultad Regional Paraná. Students are asked to research into a topic so as to shed light on a topic of their interest within the National Academy of Engineering's Grand Challenges or the United Nations' Sustainable Development Goals frameworks. If sources have not been well paraphrased or credited, it might be due to students' developing intercultural communicative competence rather than a conscious intention to plagiarize a text. Should the reader have any questions regarding this work, please contact Graciela Yugdar Tófalo, Senior Lecturer, at gyugdar@frp.utn.edu.ar