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Comparative Analysis of Geological Disposal and Purpose-Built Storage Solutions for Safe Radioactive Waste Management

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KEYWORDS
Radioactive Waste Management, Purpose-Built Storage, Nuclear Waste Safety, Environmental Impact, Risk Analysis

ABSTRACT:
Introduction: Radioactive waste management is a critical aspect of nuclear activities, necessitating safe handling, storage, and disposal to minimize environmental and human health impacts. This paper explores the comparative effectiveness of geological disposal versus purpose-built storage facilities for radioactive waste, highlighting the stages of waste management and addressing key safety considerations.

Objectives: The primary objectives are to evaluate the advantages and disadvantages of geological disposal compared to purpose-built storage facilities, and to identify the optimal solution for safe radioactive waste storage that accounts for both anthropogenic and environmental factors.

Methods: The study involves a detailed analysis of radioactive waste management stages, including collection, characterization, treatment, conditioning, intermediate storage, and final disposal. A comparative risk analysis of geological disposal and purpose-built storage facilities is conducted using modelling software and finite element analysis. Exclusion criteria for geological formations and design considerations for storage facilities are also examined.

Results: Geological disposal offers long-term isolation with minimal maintenance but poses challenges in waste retrieval and geological stability. Purpose-built storage facilities provide flexibility and enhanced monitoring capabilities but require continuous maintenance and carry higher risks of operational failures. The modelling results suggest that purpose-built facilities can be adapted for various waste types and quantities, emphasizing the importance of engineered barriers and robust safety measures.

Conclusions: The decision between geological disposal and purpose-built storage depends on balancing long-term safety, environmental impact, and practical feasibility. While geological disposal relies on natural stability, purpose-built facilities depend on engineering controls and ongoing maintenance. Comprehensive risk analysis, technological advancements, and continuous monitoring are crucial for optimizing radioactive waste management strategies, ensuring safety, and allowing future waste handling and retrieval flexibility.

1. Introduction

Like all other human activities, nuclear activities inherently produce waste. Radioactive waste must subsequently be safely managed. Radioactive waste means any radioactive material, in any of its gaseous, liquid, or solid states, for which no further use is foreseen, both at the national level and at the level of the legal entity that produced it, whose decision in this regard is legally accepted, and which is registered and controlled by the National Commission for the Control of Nuclear Activities [1].

Nuclear and radioactive waste represents a category of waste with a significant impact on the environment and human health. In this regard, a National Strategy for the Management of Radioactive Waste has been developed, and a specific authority has been established for this purpose - the National Authority for Radioactive Waste (ANDRAD). Radioactive waste results from the

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activities of the nuclear reactors in Cernavodă, the use of isotopes in industry, research, medicine, and mining activities involving the extraction and processing of uranium ores.

Radioactive waste primarily results from three types of activities:

A. Extraction and preparation of uranium ores

1. Radioactive waste resulting from the mining and processing of uranium ores.

B. Production of nuclear-generated electricity

1. Spent nuclear fuel resulting from the operation of nuclear power reactors.

2. Radioactive waste resulting from the manufacture of nuclear fuel and the operation of nuclear power reactors.

3. Radioactive waste resulting from the decommissioning of nuclear facilities in the energy sector.

C. Institutional activities (applications of nuclear techniques and technologies in medicine, industry, agriculture, and research)

1. Spent nuclear fuel resulting from the operation of research nuclear reactors.

2. Radioactive waste resulting from the operation of research nuclear reactors.

3. Radioactive waste resulting from the production and use of radionuclides.

4. Radioactive waste resulting from the decommissioning of nuclear facilities in the institutional sector

5. Spent sealed sources.

Unlike other types of waste, radioactive waste follows a very rigorously controlled cycle, consisting of the stages presented in Figure 1.

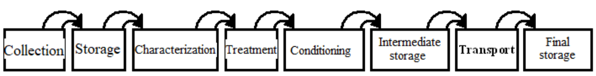

Figure 1 The Radioactive Waste Cycle

The objectives of the work are to highlight the stages that must be followed considering the type of waste, which are:

Collection and Sorting: Any operations, before characterization and treatment, also known as pre-treatment, including neutralization and decontamination.

Characterization: Determining the physical, chemical, and radiological properties of the waste to establish the treatment and conditioning needs or their suitability for handling, processing, intermediate storage, or final disposal [4].

Treatment: Operations performed to increase safety or for economic reasons by changing the characteristics of the waste. The objectives of treatment are volume reduction, removal of radionuclides from the waste, or changing its composition.

Conditioning: The operation by which the waste package is produced, suitable for handling, transport, intermediate storage, and/or final disposal. Conditioning may include converting the waste into a solid form, placing the waste in a container, and including it in an overpack.

Intermediate Storage: Placing the radioactive waste in a nuclear facility for isolation, environmental protection, and personnel control, to be recovered. The term intermediate storage is used equivalently.

Final Disposal: Placing and keeping the radioactive waste in a designated facility or location without the intention of being recovered [2,3].

2. Objectives

The main objectives of the work are to highlight the advantages and disadvantages of geological disposal compared to the storage of radioactive waste in purpose-built facilities and compliance with current legislation. Another main objective is to find the optimal solution, which will consider all anthropogenic and environmental factors in deciding on the safe storage of radioactive waste.

The burial of radioactive waste must take into account groundwater infiltration. The waste must be stored in stable geological formations where there are no seismic or volcanic influences. Since there is a degree of seismicity at any point on Earth, geological disposal presents a certain risk.

Geological disposal of radioactive waste is based on the principle of stable deep rocks unaffected by climate changes that occur over hundreds of thousands or even millions of years. In this environment, waste is stored that is isolated from human activity and the surrounding environment.

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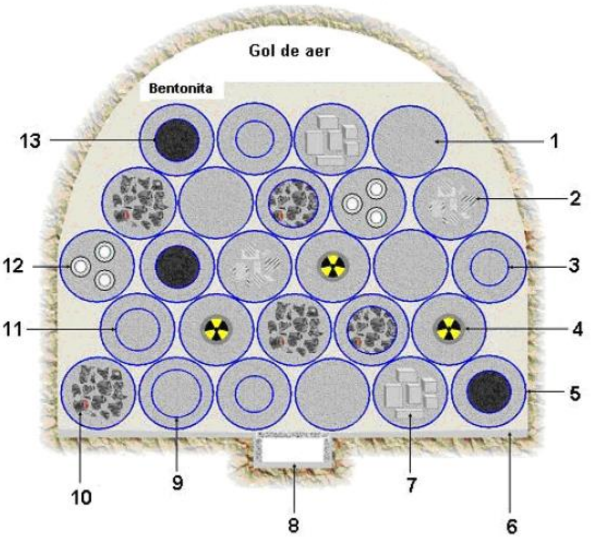

Figure 2 Arrangement of Containers in Rock Excavated Galleries

Legend:

1. Ash/sludges concentrated in a concrete matrix.
2. Contaminated and activated metals in a concrete matrix.
3. 60-liter drum made of mild steel.
4. Sealed sources in steel/stainless steel containers.
5. 220-liter drum made of mild steel.
6. Concrete base.
7. Graphite thermal columns in a concrete matrix.
8. Concrete drainage.
9. 100-liter drum made of mild steel.
10. Plastics, glass waste, rubber, metals, ash, ballast, lightly compacted, in a concrete matrix.
11. 80-liter drum made of mild steel.
12. Liquid waste in glass/plastic bottles with absorbent powder.
13. Spent ion exchange resins, bituminized.

Research and storage technologies have developed significantly in the last 30-35 years in Europe, as a result of international cooperation and efforts in this field [39].

International cooperation has gathered information to aid the evolution of radioactive waste storage in finding the natural barrier that can solve this problem. Geological repositories must be practical and efficient. It is essential that they can be built, used, and safely closed. It is very important that research and science demonstrate that radiological safety will function adequately over very long periods of time.

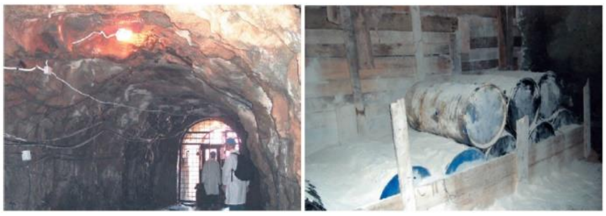

Figure 3 Main Gallery and Cross Gallery for Storage

The design of the repository for such waste was based on the ALARA principle - As Low As Reasonably Achievable, along with the safety condition assessments to achieve acceptable contamination levels.

To do this, you can use three basic protective measures in radiation safety: time, distance, and shielding.

“Time” simply refers to the amount of time you spend near a radioactive source. Minimize your time near a radioactive source to only what it takes to get the job done. If you are in an area where radiation levels are elevated, complete your work as quickly as possible, and then leave the area. There is no reason to spend more time around it than necessary [6].

“Distance” refers to how close you are to a radioactive source. Maximize your distance from a radioactive source as much as you can. If you increase your distance, you decrease your dose.

“Shielding” refers to putting something between you and the radiation source. The most effective shielding will depend on what kind of radiation the source is emitting. Some radionuclides emit more than one kind of radiation.

After the phase of identifying the location and its acceptance as a result of meeting all the requirements and standards that repositories must fulfil, and after determining the size of the repository, the construction phase follows.

In the proposed study, the warehouse was designed in such a way that the storage is done in retreat by closing the sections in which the storage has already been carried out. Thus, at the end of storage, there is the possibility that the first stored sections have reached their half-life, and thus the radioactive waste that initially required special storage will reach the properties of ordinary waste (no longer require special storage) and be relocated to storages with a lower degree of security. This is shown in Fig.4: the beginning of the storage is carried out in

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section 1a, and in time, after the filling of section 1j, the first section 1a should no longer constitute a danger.

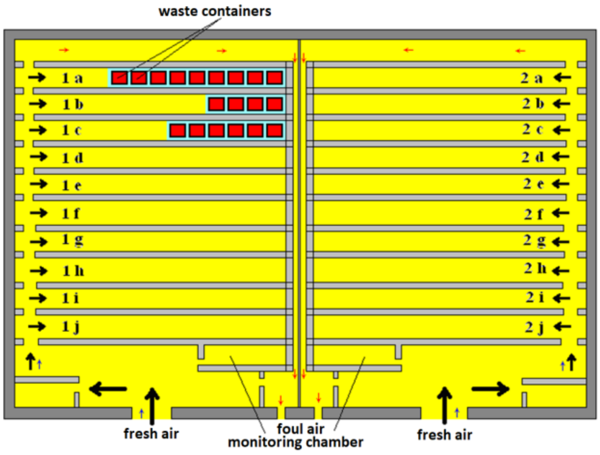

Figure 4 Waste storage plan diagram

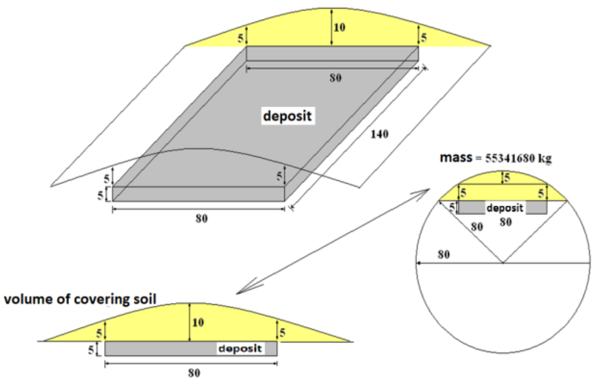

Figure 5 The waste deposit and covering soil mass

At the level of each section, the waste containers (barrels) are isolated from the construction walls by a multilayer barrier system (fig.6).

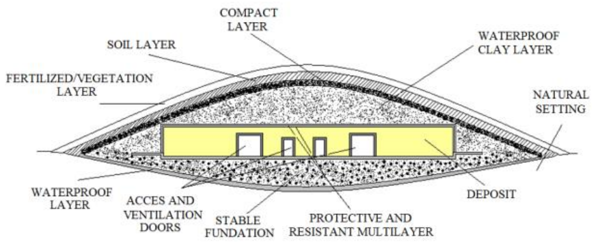

Figure 6 Deposit isolation

These waste filling and isolation materials must be chosen in such a way as to satisfy the radiological needs that are imposed (Fig.7). Thus, several types of materials with different properties can be used, and each of them fulfils a certain need from the point of view of the insulation of containers or barrels. The filling materials can be clays, tuffs, or bentonite rocks, which are provided not only as a storage of ions having a negative effect but also as a waterproofing material to prevent the circulation of aqueous solutions.

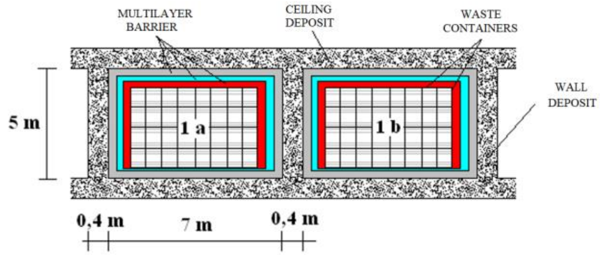

Figure 7 Section in the storage section

If one opts for temporary storage in that section, it is preferable not to intervene with protective barriers of a definitive nature or barriers that are difficult to remove in the case of waste relocation. If, for example, concrete is poured, its removal will be difficult, and the removal technology may disrupt the integrity of the warehouse (impact shocks may cause cracks in containers and warehouse walls).

Dividing the warehouse into sections allows for more rigorous control of possible accidents or radiation leaks from any container. For the proposed warehouse, the sections can be closed and isolated manually or automatically (Figure 8), in the event of an accident being reported, after which special equipment will gradually be used to remove or remedy the incident.

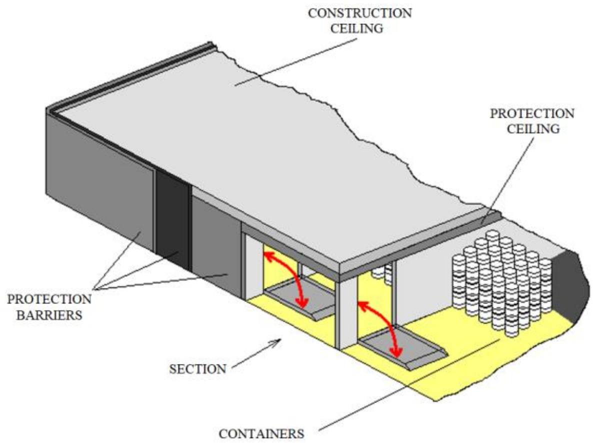

Figure 8 Securing the storage sections

Such a warehouse with a very long lifetime must be designed so that the storage technologies can be changed and, at the same time, be viable depending on the needs (Figure 9).

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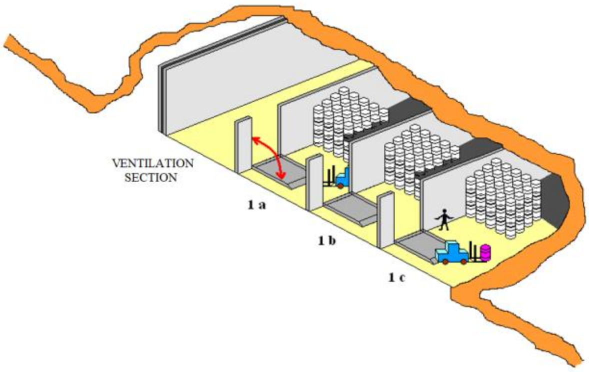

Figure 9 Depositing method

Handling machines and equipment should preferably not be embedded in the construction, in the walls or ceiling of the warehouse, because during such long periods of operating time, it is impossible not to have malfunctions.

In these cases, to change with new ones or of another generation, the structure of the construction or the anchoring of the equipment must be changed, something that can endanger the integrity of the warehouse construction (for example, to change a monorail transport installation, work must be carried out in the ceiling of the warehouse). Handling is preferable to be done with machines that can be easily replaced in case of failure or to have several such machines in the warehouse. At the same time, in cases of contamination or accident, such machines can be easily decontaminated or decommissioned.

3. Methods

The analyses began with the application of exclusion criteria for each formation, criteria that include a minimum of requirements regarding depth, total surface, thickness, tectonic and micro fissuring aspects, and mineralogical and petrographic homogeneity or permeability.

The modelling of the warehouse for optimal and real dimensioning was done with the help of the Solid Edge software, and the analysis with finite elements was done with the COSMOS DesignSTAR software (figures 10–13). To dimension the structure of the warehouse and model the warehouse, the approximate total mass that will cover the warehouse in its completion phase was calculated. To find out the optimal size of the warehouse walls, forces equal to the load of the covering earth will be applied over the entire surface of the warehouse.

Figure 10 Deposit discretization

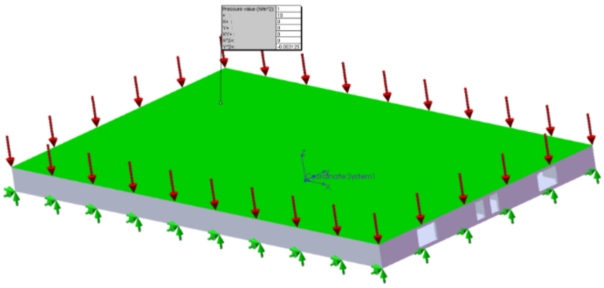

Figure 11 Applying forces

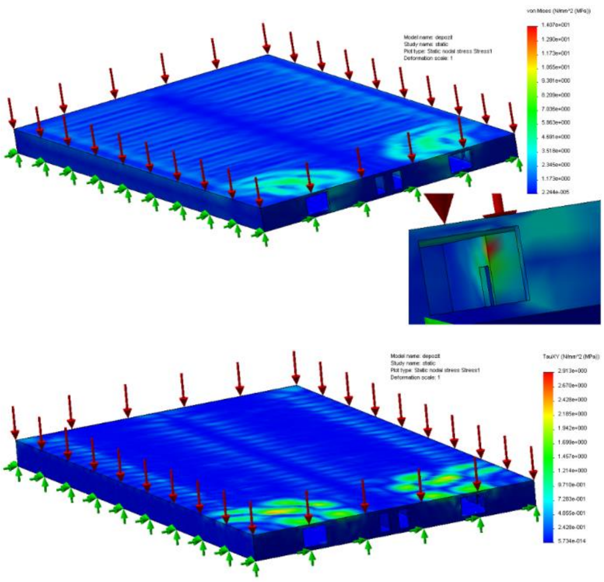

Figure 12 Maximum and minimum strength points

After simulating the displacements, a construction size of 40 cm for the inner walls and 80 cm for the outer walls was obtained.

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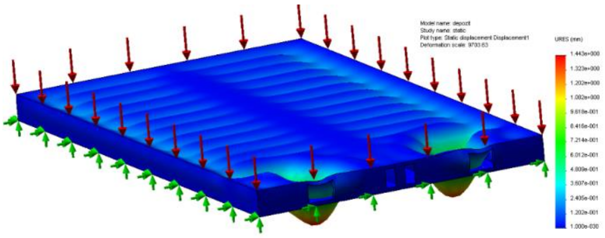

Figure 13 Displacement simulation

The minimum requirements for the geological formations studied as possible for the location of the Geological Deposit concerned the following aspects: general geological, hydrogeological and seismic conditions, the existence of mining operations or hydropower installations, climatic conditions, land use, transport distance and distance to inhabited areas from the region.

Starting from the internationally known concepts, different sections of the storage tunnel were analysed, as shown in Figure 14, for hard rocks and, respectively, for soft rocks (clays), which were considered optimal for the study in the future.

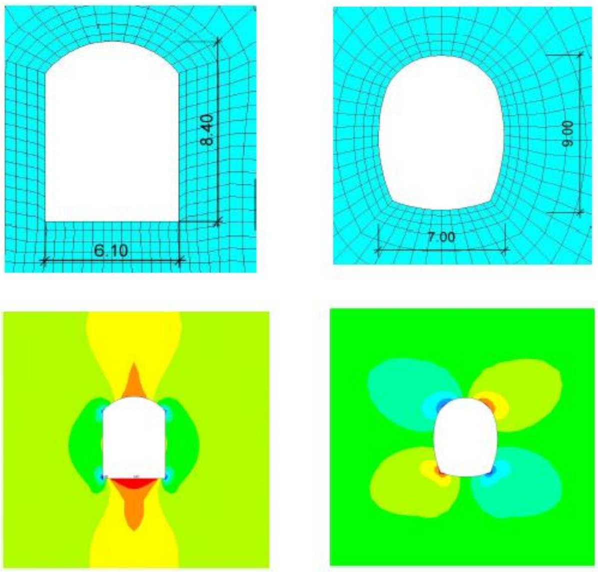

Figure 14 Sections of the burned fuel storage tunnels: a) hard rocks b) soft rocks (clays)

The sources of information, which were the basis for the identification of the geological formations proposed for hosting a Geological Deposit, were: geological maps, technical publications on mineralogical, petrographic, geochemical, geophysical, tectonic, hydrogeological and rock mechanics issues; public documents regarding the economic potential of the respective regions, both from the point of view of the accumulations of useful minerals, as well as the perspectives related to this aspect; recommendations of university specialists in the field; publications relating to the state of research in different countries regarding the same types of geological formations as those selected in the desired territory.

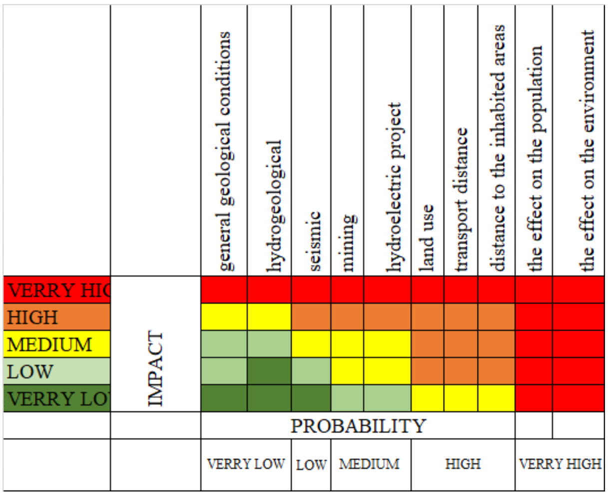

Figure 15 Risk analysis for a geological deposit

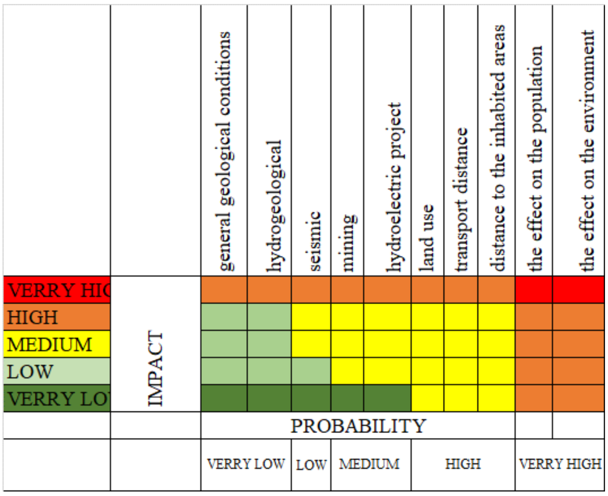

Figure 16 Risk analysis for a purpose-built warehouse

Both geological disposal and purpose-built storage have their unique sets of risks and benefits. The choice between them depends on balancing the long-term safety and environmental considerations with the practical aspects of waste retrieval and management. Rigorous safety protocols, continuous monitoring, and technological advancements are essential to mitigate the inherent risks associated with radioactive waste management, ensuring protection for both current and future generations.

4. Results

As a result of the experience and results obtained by various projects adopted at the international level, a proposal was made to solve the problem of radioactive waste storage, generally valid for underground storage.

In this work, it was proposed to create a warehouse that can be placed in almost any location, given the fact that the safety of the warehouse is not based on geological and natural factors but, to a large extent, on anthropogenic factors. The realised concept can be modified and adapted depending on the types of waste that will be stored and their quantity.

An advantage of surface storage is the ease of retrieving the material if it is decided to do so. The possibility of recovering the stored material is easier to achieve with surface installations than with underground ones. This solution avoids making decisions that have irreversible effects as a result, thus delaying to some extent the decision to lose the waste, allowing future generations more flexibility in making these decisions, but without the waste being a burden for them.

Isolation of the waste from the environment must be done at the source; that is, the radioactive waste must be embedded in an environment created by humans and not naturally. The storage of radioactive waste in cavities dug in the ground without protection is risky due to the geological conditions in the country. Taking into account the time required for radioactive waste to no longer affect the environment or to fall within the imposed limits, its storage will be done for a very long period, during which there is no certainty that the natural environment can retain its initial characteristics. The management of radioactive waste must be done in a controlled manner, and continuous monitoring is needed, which cannot be easily achieved if the radioactive waste is stored geologically.

5. Discussion

To take into account, the safety of people when storing radioactive waste, it was taken into account how many factors can influence people's health.

As a starting point for the geological deposit concept: it is a definitive deposit, of the geological deposit type, without the option of further recovery.

The management of radioactive waste requires a balanced approach that considers long-term safety, environmental impact, and practical feasibility. Geological disposal offers a stable, long-term solution but comes with uncertainties related to irretrievability and geological changes. Purpose-built storage facilities provide flexibility and enhanced monitoring but require continuous maintenance and pose higher operational risks.

Ultimately, the decision must be based on a comprehensive risk analysis, technological advancements, and the evolving understanding of geological and environmental factors. Ongoing research, international cooperation, and the development of advanced safety measures will be crucial in optimizing radioactive waste management strategies for future generations.

References

1. Apted, M.J., Ahn, J. (2010). "Radioactive waste management in geological formations." Woodhead Publishing Series in Energy, 123-158. DOI: 10.1533/9780857090409.2.123.
2. Chapman, N.A., McKinley, I.G. (2008). "Geological disposal of radioactive waste: An overview." Progress in Nuclear Energy, 50(2-6), 188-198. DOI: 10.1016/j.pnucene.2007.10.006.
3. Birkholzer, J., et al. (2012). "International Approaches for Deep Geological Disposal of Nuclear Waste: Geological Challenges in Radioactive Waste Isolation." Elements, 8(3), 183-188. https://doi.org/10.2113/gselements.8.3.183.
4. European Commission. (2003). "Waste Management Research Report: Disposal of Radioactive Waste in Deep Geological Formations." EUR 21027 EN. Brussels: European Commission.
5. Ewing, R.C. (2015). "Challenges in the management of radioactive waste." Elements, 11(5), 323-328. DOI: 10.2113/gselements.11.5.323.
6. Faur F, Apostu I.M., Lazar M., Reassessment of the Stability Conditions in the Lignite Open Pits of Oltenia (Romania) in Relation to the New Local Seismic Context as an Imperative for Sustainable Mining,Volume 16 Issue 4 DOI10.3390/su16041384.