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Editorial

Storage and Disposal Options for Nuclear Waste

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Nuclear technology has multiple applications that are fundamental to our daily life. It is impossible to list all the uses of ionizing radiation. It is adopted for medical diagnostics and therapy, the sterilization of medical equipment, the generation of low-carbon electricity, agriculture and food production, and hydrology. Modern life is filled with technologies generating radioactive waste. Radioactive waste is potentially hazardous to health as it releases radiation; thus, it has to be managed suitably, safely, and effectively to protect people and the environment. Most radioactive waste comes from nuclear electricity production, and the management and disposal of radioactive waste represent some of the most problematic aspects of the nuclear fuel cycle today. Advanced fuel recycling technologies are focused on efficiently removing and transmuting the most radiotoxic long-lived portions of used nuclear fuel (UNF). Substantial progress is needed globally to manage radioactive waste. Efficient solutions for radioactive waste management operations are already available or are in advanced phases of development. More progress could be expected in the near future. However, issues of nuclear waste management are not only technical but also social. Therefore, the popularization of the common knowledge of the methods used in waste management is an important issue.

This Special Issue contains six papers that relate to the management of radioactive waste.

The general rule is "the less radioactive waste needs to be managed, the better". Fuks et al. [1] review possible ways to reduce the volume of waste by thermally treating radioactive waste. In the paper, commonly used thermal techniques are introduced and a few examples of the installations are disclosed. Thermal treatment also has another advantage. During that process, hazardous organic substances are destroyed. Pyrolysis, gasification, and combustion are the main thermal techniques used to treat radioactive waste. However, liquid radioactive waste is often purified using evaporation/distillation techniques. In the next stage, the residues are processed in a form that protects against the release of radionuclides into the environment. It is suitable for safe storage and disposal. They are usually enclosed or solidified in bitumen, glass, or synthetic rock due to proper thermochemical processes. Popularizing knowledge around the methods of nuclear waste processing can affect the growing social acceptance of nuclear energy.

Kiegiel et al. [2] present the final part of the HTGR fuel cycle. The review presents many methods that could be employed to ensure the sustainable, feasible management and long-term storage of HTGR nuclear waste in order to protect the environment and society. Three main options for the management of TRISO spent fuel were analyzed: (1) reprocessing, (2) geological disposal, and (3) long-term on-site storage. Currently, the most suitable option for spent TRISO fuel management looks to be its direct disposal. It should be noted, however, that reprocessing will enable the recycling and reuse of fusible materials, thus reducing the mass of the disposed of high-level waste. The production of large amounts of irradiated graphite is a serious problem in the exploitation of HTGR. Recycling appears to be a sensible approach to consider due to the need for decontamination and volume reduction. It is worth noting that the selection of an appropriate disposal method requires a balance between safety and economic aspects.

Korea is currently considering two alternatives: the direct disposal of spent nuclear fuel in deep underground rock mass and pyro-processing to recycle spent nuclear fuel. Each of

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these two alternatives has both advantages and disadvantages. It is impossible to intuitively choose the preferred alternative. Kim et al. [3,4], based on evaluation criteria, such as safety, technology, environmental impact, economic feasibility, and nuclear proliferation resistance, made detailed studies using various benefit–cost ratio (BCR) analyses. The results of these analyses are ambiguous. The pyro-processing alternative is preferable to direct disposal when using the results of the analytic hierarchy process (AHP) and the technique for order preference by similarity to ideal solution (TOPSIS) method. However, direct disposal was more profitable than the pyro-SFR fuel cycle when the results of the preference ranking organization method for enrichment evaluations (PROMETHEE) method were used. It is necessary to note that the ranking of these two considering alternatives has been reversed according to the economic feasibility assessment method. This demonstrates the limitations of the multi-criteria decision-making (MCDM) method and offers significant recommendations for the future.

The spent fuel contains large amounts of various radioactive nuclei that emit gamma rays across a broad range of energies. The amount of fission products is strictly related to the burn-up and is relative to this variable in a nearly linear way. Knowledge about the concentrations of long-lived actinides in spent fuel is of great importance from the point of view of disposal in final geological repositories. Experimental techniques allow parameters such as fuel burn rate and cooling time to be calculated or verified through radiochemical measurements of the isotope composition. These parameters can also be calculated using computational simulation. Oettingen [5] validated the NFCSS burnup system developed by the IAEA. In this work, data from the destructive analysis of the 254 PWR fuel samples from 15 reactors were used. The isotopic composition obtained in the radiochemical measurements of these samples was compared with the results of the numerical modeling. The results obtained are very significant. They have proven that the NFCSS should not be used as a reliable tool for the spent fuel burn-up calculation. This simulation represents the source of the first approximation results that can be used as the basis for further and more advanced calculations.

It is commonly known that spent fuel needs to be isolated for hundreds of thousands of years as its remains are highly radioactive for such a long time. Finsterle et al. [6] carried out an extensive safety analysis of the spent nuclear fuel disposal in a deep vertical borehole repository. Authors have developed an integrated simulation model of the engineered and natural barrier systems which was used to examine various scenarios of the release of radionuclides from the canisters, transport them through engineered and natural barrier systems, and finally extract potentially contaminated drinking water from an aquifer. Undoubtedly, these two works are of great importance in the context of spent fuel management for an extended period.

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