Vitrification: Using thermal methods to increase long-term stability of geological disposal of radioactive waste

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Nuclear power provision has grown over past decades to keep up with consumer demand for a renewable and clean energy future. To generate this electricity, nuclear fission of uranium-235 atoms causes a chain reaction resulting in vast amounts of heat/radiation energy being released. These reactions produce unwanted radioactive materials (*e.g*. spent fuel rods) or waste, which is extremely harmful to humans[1], animals and the environment.

Radioactive Waste Disposal

Between 1949-1983[2], many radioactive waste materials, especially those that are low-level (LLW) and intermediate-level (ILW), such as protective clothing, were disposed of in the oceans[3]. How these are now disposed of can be seen in **Figure 1**. Within the UK, the most preferred way of radioactive waste disposal is using deep geological disposal facilities (GDF). An alternative disposal in space[4] could provide permanent safety and solve the problem of demand but is dependent on complex technology advances.

To achieve GDF, suitable locations for long-term stability must be found away from humans, animals and the environment. This is primarily for the safety of high-level waste (HLW) (*e.g.* spent fuel rods); with the last Nuclear Decommissioning Authority (NDA) report stating ~3,200 tonnes of HLW were generated in 2019[5]. These are currently stored in overground spent fuel tanks as interim storage[3], but plans are being made in the UK for deep GDF (**Figure 1**). The idea is that GDF will ensure the long-term stability of radioactive waste disposal, and this can be achieved through thermal methods.

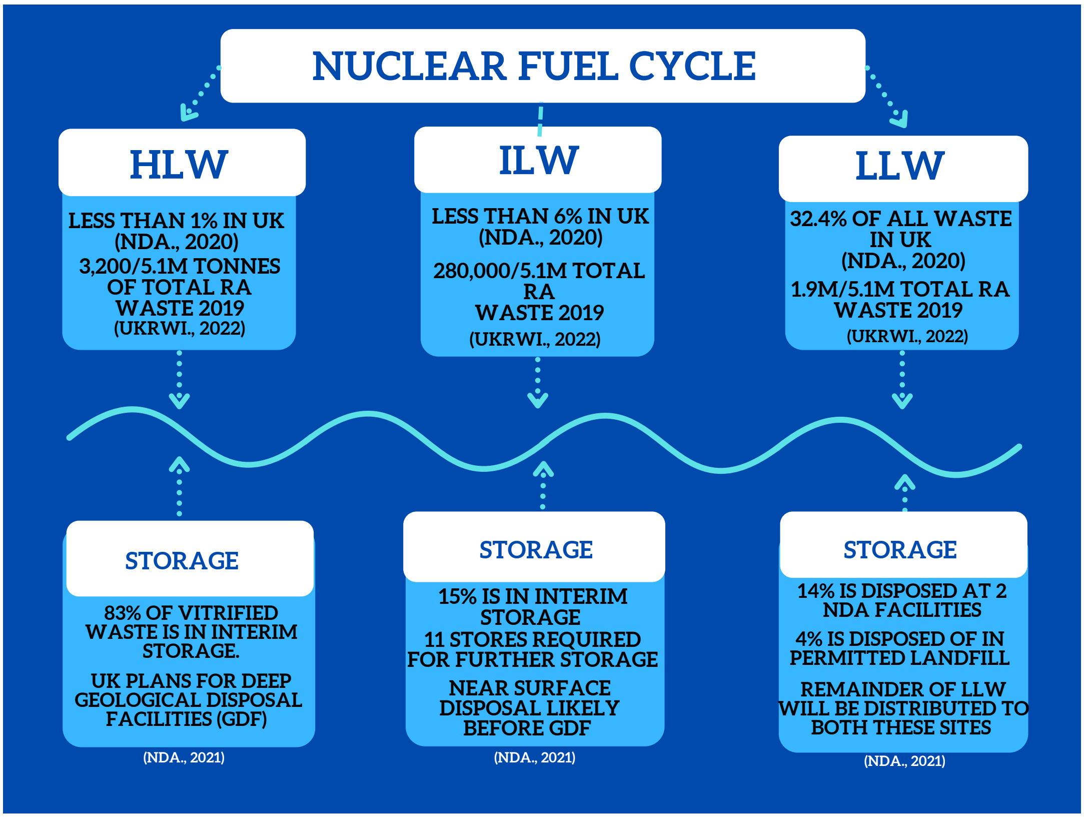

Figure 1. *Flow chart showing the types of radioactive waste generated and how they are stored/disposed of within the UK.*

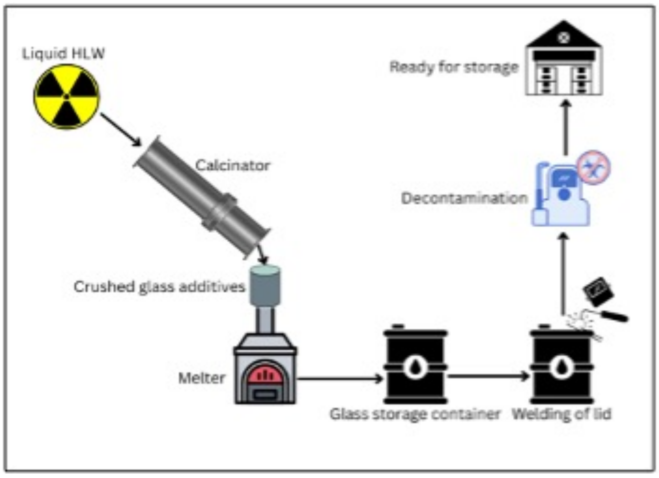

Figure 2. *Ex situ vitrification (ESV) process converting radioactive waste to a storage-suitable material.*

Thermal Methods

Thermal treatment of radioactive waste involves any technology using high temperatures to reduce the total mass of the radioactive waste, eliminate hazardous organic substances, and stabilise harmful components – these tend to be leach-resistant *i.e.* glass or ceramic. Thermal processing decreases mass, whilst also preventing any leaching from other water streams onto the waste. Processes include vitrification, incineration, distillation, and pyrolysis to separate toxic components from liquid solutions. This enables mass reduction of volume through combustion within an advanced filtering system[6].

~3,200 tonnes of HLW were generated in 2019. Vitrification process shows a more efficient disposal route.

Vitrification

Vitrification is the most important method within waste management as it increases the long-term stability of geological disposal. It describes the conversion of a material into a glassy matrix whereupon radioactive waste may be stabilised before it is stored underground. For deep geological storage of radioactive waste, *ex situ* vitrification (ESV) is necessary to produce a storage-suitable product. It uses a melting furnace where the liquid waste is heated through a calcinator (**Figure 2**), which is then cooled after excretion. Calcinated materials with crushed glass are added to the melter to bond the radioactive waste to the glass, thus immobilising hazardous waste for thousands of years[6].

This process has been successful in France, with the Marcoule Plant, and in the UK at the Sellafield Plant, following a £240 million investment and research confirming reduced volume, improved safety, and long-term stability of vitrified radioactive waste material[7].

Conclusion

Using vitrification as the thermal method of HLW disposal has been shown to be safe and efficient, with the possibility of retaining radionuclides for hundreds of thousands to possibly millions of years.

References

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Table 1. *Advantages and disadvantages of* ex situ *vitrification . Data from Reference* [6]*.*

Advantages	Disadvantages
High volume reduction of up to 90%	High initial investment/ operating costs
Efficient and fast acting	Appropriate geological disposal location is needed for approval first which is difficult to locate
Increases long-term stability	Volatile radionuclides in ESV system may cause danger to staff and environment in process.