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Advances in conditioning of low- and intermediate-level nuclear waste

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ABSTRACT

Radioactive waste with widely varying characteristics is generated from the operation and maintenance of nuclear reactors, nuclear fuel cycle facilities, research facilities and medical facilities and the through the use of radioisotopes in industrial applications. The waste needs to be treated and conditioned appropriately to provide wasteforms acceptable for safe storage and disposal. Conditioning of radioactive waste is an important step to prepare waste for long-term storage or disposal and includes the following processes:

- *Immobilization which may or may not also provide volume reduction, including*
  - *a) Low temperature processes and*
  - *b) Thermal processes;*
- *Containerization for*
  - *a) Transport,*
  - *b) Storage, and*
  - *c) Disposal;*
- *Overpacking of primary containers*
  - *a) Prior to disposal and*
  - *b) In a disposal facility as part of disposal process.*

Conditioning consists of operations that produce a waste package suitable for handling, transportation, storage and/or disposal and may be performed for a variety of reasons including standardization of practices and/or wasteforms, technical requirements for waste stability in relation to a repository design or safety case, technical requirements related to waste transportation, societal preferences, regulatory preferences, etc. This paper gives an overview of recent advances in conditioning of low- and intermediate-level radioactive waste.

The paper is based on the new IAEA Handbook "Conditioning of Low- and Intermediate-Level Liquid, Solidified and Solid Waste" which is one of eight IAEA handbooks intended to provide guidance for evaluating and implementing various characterisation and radioactive waste processing and storage technologies before final disposal

INTRODUCTION

Radioactive waste, with widely varying characteristics, is generated from the operation and maintenance of nuclear reactors, nuclear fuel cycle facilities, research facilities and medical facilities and the through the use of radioisotopes in industrial applications. The waste needs to be treated and conditioned as necessary to provide wasteforms acceptable for safe storage and disposal.

Responsible radioactive waste management is essential for stakeholder acceptance, environmental protection, and financial success of the waste generator, waste management provider, and waste disposal site operator, all of which benefit from early planning, evaluation of options, coordination, and life cycle optimization. Successful LILW management at both existing facilities and new facilities is essential for continuation and expansion of these industries.

Conditioning of radioactive waste is an important step to prepare waste for long-term storage or disposal and provides the link between raw or partially treated waste and the final wasteform suitable for storage or disposal.

NUCLEAR WASTE CONDITIONING

Conditioning may be performed for a variety of reasons including standardization of practices and/or wasteforms, technical requirements for waste stability in relation to a repository design or safety case, technical requirements related to waste transportation, societal preferences, regulatory preferences, etc. [1]. The reason for conditioning must be understood in order to select an appropriate method. Different storage and repository designs and/or regulatory regimes may impose specific requirements. For example, a deep geological repository or deep borehole may rely primarily on natural geological barriers for containment and isolation of the waste, while a near-surface repository relies more on the environmental setting (soils, rainfall, etc.) and engineered barriers. A near-surface facility may also impose structural requirements on wasteforms (e.g. to support a cover or capping system) more so than a geological repository, where the host rock bears the mechanical stresses. However, both types of repository may impose some structural requirements, e.g. for supporting stable stacks of waste packages to the required height.

A storage facility also has specific requirements for waste packages including retrievability, shielding and monitoring, etc., which may differ from those of a disposal facility.

A waste package is one component of a multi-barrier system to contain and isolate radioactive waste. Other barriers include engineered structures and/or the geological setting of the waste management facility. Each barrier element may serve one or more functions to ensure the safety of the facility. Different barriers may serve overlapping functions, thus providing redundancy.

As a prerequisite for selecting an appropriate conditioning method, the function or role of the conditioned wasteform and/or package in the overall safety case of the waste management system must be defined and understood. For example, in a near-surface repository, the waste package may have both a waste containment function to prevent or retard the migration of radionuclides and a structural function to support a repository cap or cover. For waste destined for a deep geological repository or borehole, the primary function may be related to isolation and containment rather than providing any form of structural support. Normally, liquids, sludges and/or loose materials must be conditioned to produce a stable, solid wasteform for transportation, handling, storage and disposal. The majority of disposal facilities have strict limits on the quantity and type of free liquids within their waste acceptance criteria.

In most cases, the wasteform is expected to perform a number of functions [1, 2]. Once the functions or roles of the wasteform/package are understood, technical specifications for its preparation and performance can be established and appropriate processes designed.

The storage and/or disposal facility waste acceptance criteria (WAC's) are used to prepare specifications for waste packages, including wasteforms and containers. Ideally, waste package specifications are facility and waste specific. They can be tailored to support the safety case of a specific facility. When the disposal facility is not yet identified, generic specifications (which may be overly conservative) are often adopted. This can lead to unnecessary expense and the possible need for future re-work if the disposal concept changes.

It is important to make a distinction between "conditioning" and "immobilization". The terms are often used interchangeably, but this is incorrect. Immobilization is only a part of conditioning (albeit often an important part). As per its definition in the IAEA Glossaries [3], conditioning includes immobilization, containerization and/or overpacking.

In addition, some treatment processes (such as vitrification or plasma arc processing) perform both a treatment function (e.g. volume reduction) and a conditioning function (e.g. produce a stable wasteform suitable for long-term storage or disposal) in a single process.

Table 1 summarizes the main treatment and conditioning options commonly applied to various types of low- and intermediate-level radioactive wastes. It should be noted that there is no "universal" treatment or conditioning method: the actual selection of technique(s) is done on a case-by-case basis, depending on the physical, chemical and radiological properties of the waste and its required acceptance criteria.

Table 1: Summary of treatment, conditioning and disposal options for radioactive wastes (adapted from [4])

Waste	Form	Treatment	Conditioning		Disposal options
			Immobilization	Packaging	
VLLW **Very Low-level waste**	Solid	Decay Storage	Not normally used	None or simple packaging	Surface trench, Landfill, Near surface disposal
	Liquid Sludge	Decay Storage Evaporation, Radionuclide Removal Membrane methods, ion exchange	Cementation, Polymer Sorption	Industrial packaging	Surface trench, Landfill, Near surface disposal
LLW **Low-level Waste**	Solid	Sorting, Volume Reduction Compaction, Super-compaction, Incineration, Melting	Encapsulation, Grouting	Industrial packaging Metal or concrete containers, High-integrity Containers	Near-surface disposal
	Liquid & Sludge	Chemical treatment, Evaporation Radionuclide Removal Membrane methods, Ion exchange	Cementation, Bituminization, Polymer Sorption, Geopolymer Solidification, Vitrification	Metal or concrete containers, High-integrity Containers	Near-surface disposal
ILW **Intermediate-Level Waste**	Solid	Sorting, Volume Reduction Compaction, Super-compaction	Encapsulation, Grouting	Metal or concrete containers, High-integrity Containers	Intermediate depth disposal, Deep Geological disposal

Waste	Form	Treatment	Conditioning		Disposal options
			Immobilization	Packaging	
	Liquid & Sludge	Chemical treatment, Evaporation Radionuclide Removal Membrane methods, Ion exchange	Cementation, Bituminization, Polymer Sorption, Geopolymer Solidification, Vitrification	Metal or concrete containers, High-integrity Containers	Intermediate depth disposal, Deep Geological disposal
NORM / TENORM	Solid	Storage as potential resource or considered as waste	Not normally used	Not normally used	Near-surface storage
	Liquid and residues from liquid treatment	Chemical treatment, Evaporation Radionuclide Removal Membrane methods, Ion exchange	Cementation	Industrial packaging	Near-surface disposal
High Volume Wastes	Environmental	Radionuclide Removal	Encapsulation Grouting	Not normally used	Near-surface disposal
	D&D Waste	Radionuclide Removal	Encapsulation Grouting	Not normally used	Near-surface disposal
	Accidental Waste	Radionuclide Removal	Encapsulation Grouting	Not normally used	Near-surface disposal
Special Wastes	Disused sealed radioactive sources (DSRS)	Decay Storage	Encapsulation	Seal welded metal containers	Near-surface disposal, Borehole disposal
	Reactive Metal	Decay Storage	Encapsulation	Vented metal or concrete containers	Near-surface disposal

Waste	Form	Treatment	Conditioning		Disposal options
			Immobilization	Packaging	
	Graphite	Decay Storage, incineration	Annealing	Metal or concrete containers	Near-surface disposal, Intermediate depth disposal, Deep Geological disposal
	Sodium Waste	Chemical treatment	Encapsulation	High-integrity Containers	Near-surface disposal
	Biological Waste	Decay Storage, incineration	Encapsulation Grouting	Metal or concrete containers	Near-surface disposal

While many of the conditioning techniques have been practiced on an industrial scale for many years (e.g. cementation), research is still on going on several fronts, such as:

a) Development of specific formulations for problematic waste streams (e.g. reactive metals);

b) Optimization of waste loadings (e.g. to minimize volume increase);

c) Development of new matrices (e.g. geopolymers) which offer superior performance and/or lower cost;

d) Adaptation of formulations to incorporate commercially available ingredients (e.g. commercial cement formulations are evolving, usually due to demands from the construction industry which is the dominant market);

e) Considerations of new or anticipated radioactive waste streams such as from innovative nuclear fuel cycles, or utilisation of nuclear fusion.

IAEA SUPPORT ACTIVITIES

The Waste Technology Section of IAEA (WTS) widely supports processing technologies aiming to ensure a high level of safety of handling, transportation, storage and disposal of radioactive waste [5, 6]. While the Agency does not conduct any in-house R&D activities, its Coordinated Research Projects (CRP's) foster R&D in Member States on topics of mutual interest and importance. Participation is broad based, involving both developed and developing Member States, and serves as an effective mechanism for exchange of technical information and data on the CRP topic. Coordinated research projects are typically 3 to 5 years in duration, and involve 2 to 3 research co-ordination meetings for all principal investigators. The results of CRPs are published as Agency TECDOC's – see e.g. [7]. CRP's contribute to the solution of existing and anticipated future problems related to processing techniques, properties of matrices, and characterization of waste forms. With regards to waste conditioning, CRP objectives are to encourage further research and development and exchange of information amongst Member States on: (a) improved processing techniques to ensure more effective performance of existing plants and to address future needs, arising from problematic waste streams; (b) formulation of matrices for immobilization of waste to achieve higher waste incorporation, better processing features, enhanced durability, and to address new waste compositions; and (c) characterization of waste forms.

WTS has deployed a number of Networks purposely to increase efficiency in sharing international experience in radioactive waste management, decommissioning of nuclear facilities, and site remediation. These are aiming on Decommissioning (IDN); Environmental Remediation (ENVIRONET); Underground Research Laboratories for Geological Disposal (URF), Near-surface disposal (DISPONET); Waste Characterization (LABONET) and The International Predisposal Network (IPN) [8]. Moreover the IAEA is completing preparation of one of eight topical handbooks including the "Conditioning of Low- and Intermediate-Level Liquid, Solidified and Solid Waste". The Handbook overviews the requirements for pre-disposal management, gives the information on waste inventory, overviews of conditioning options with details on selecting wasteforms and packages, aligns processing technologies with details on processes and waste acceptance requirements.

CONCLUSIONS

Conditioning improves safety and security, e.g., by converting waste into a more stable form to contain radionuclides for extended periods until it no longer pose a risk to workers, public, and the environment. LILW conditioning produces wasteforms and waste packages that meet the technical and regulatory requirements of the respective Member States for the safe and secure storage, transportation and disposal (including compliance with the disposal site safety case).

Conditioning includes immobilization using either ambient temperature or thermal processes, containerization for storage and/or disposal and/or overpacking prior to disposal. In-situ conditioning refers to the installation of engineered barriers at the disposal facility itself.

There is a wide variety of conditioning processes and immobilization matrices. Waste characteristics and volumes also vary greatly. Therefore, there is no universally applicable process for conditioning. For this reason, it is essential that the waste characteristics, the conditioning processes, and the requirements and properties of the resulting wasteforms and packages are well understood.

Research and development in waste conditioning for problematic and new waste streams is ongoing in many countries and is resulting in considerable improvements in management of legacy wastes and in planning new facilities.

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