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Categorizing Operational Radioactive Wastes

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FOREWORD

Waste "categorization" pre-dates waste "classification," and the terms have often been used synonymously. Both categorization and classification are *systems of communication* for use among workers, organizations and nations. As such, they are dynamic, evolutionary processes, and their meanings have diverged as waste management technology has matured.

The adoption and usage of both terms remain nation-specific, although a standardized system of waste classification as an international communication tool has been fostered by the IAEA and has matured significantly. In contrast, categorization has remained elusive and non-standard, thereby providing little international communication benefit. Classification continues to focus on radioactivity concentrations and species (radionuclide content) as they relate to waste disposal; however, this falls short of being a comprehensive communication tool for operational waste management activities. Thus a need continues to exist for an enhanced, simple waste categorization scheme or "methodology" which can be used to address the operational aspects of waste management.

This publication seeks to improve communications among waste management professionals and Member States relative to the properties and status of radioactive waste. This is accomplished by providing a standardized approach to operational waste categorization using accepted industry practices and experience.

The IAEA last issued a publication on Standardization of Radioactive Waste Categories in 1970. At that time, categorization and classification were still used interchangeably; thus the publication was an early attempt to standardize a tool for communicating generic waste information. This current publication draws a clear distinction between the two terms, provides a modern approach to operational waste categorization, and replaces the 1970 report.

The IAEA wishes to express its appreciation to all those individuals that took part in the preparation and publication of this report. Particular acknowledgement is due to A. Morales who participated in the entire report development process, including both consultants meetings and the technical meeting. The officers at IAEA responsible for initiating and finalizing the report are J.L. González Gómez and J.J. Kelly from the Division of Nuclear of Nuclear Fuel Cycle and Waste Technology.

CONTENTS

1. INTRODUCTION

1.1. BACKGROUND

Waste “categorization” pre-dates waste “classification,” and in the 1960s and 1970s the terms were often used synonymously [1]. It is critical to recognize that both categorization and classification are *systems of communication* for use among workers, organizations and nations. As such, they are dynamic, evolutionary processes, and their meanings have diverged as waste management technology has matured.

The adoption and usage of both terms remain nation-specific, although a standardized system of waste classification as an international communication tool has matured significantly. In contrast, categorization has remained elusive and non-standard, thereby providing little international communication benefit. Classification continues to focus on radioactivity concentrations and species (radionuclide content) as they apply to waste disposal; however, this falls short of being a comprehensive communication tool for all waste management activities. Thus a need continues to exist for an enhanced, simple waste categorization scheme or “methodology” which is applicable to operational waste activities (e.g., segregation, treatment, conditioning).

Since Reference [1] was published in 1970, a number of schemes have evolved for categorizing radioactive waste according to its physical, chemical, radiological and, in some instances, biological properties. Typically the programmes are specific to individual facilities or nations, and the criteria and terminology vary significantly. This makes it difficult to communicate waste management practices effectively or to compare programme data. A clearly defined and communicated programme enhances the quality of information shared with other organizations and members of the public.

This publication categorizes wastes generically according to (1) their unconditioned, as-generated state, and (2) their conditioned state, as applicable. This simple categorization approach communicates the existing status of each waste stream and links it to the potential dispositioning options. This categorization concept is illustrated in Figure 1 and is addressed in greater detail with appropriate subcategories throughout this publication.

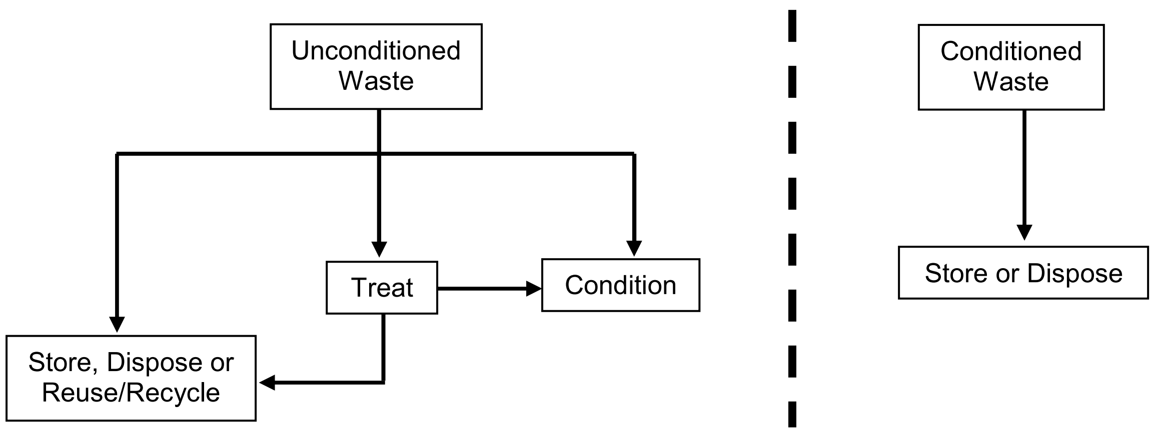

FIG. 1. Simple operational waste categorization overview.

1.2. OBJECTIVE

The primary objective of this publication is to improve communications among waste management professionals and Member States relative to the properties and status of radioactive waste. This is accomplished by providing a standardized approach to operational waste categorization using accepted industry practices and experience. It is a secondary objective to draw a distinction between operational waste categorization and waste disposal classification.

The approach set forth herein is applicable to waste generation by mature (major, advanced) nuclear programmes, small-to-medium sized nuclear programmes, and programmes with waste from other nuclear applications. It can be used for planning, developing or revising categorization methodologies. For existing categorization programmes, the approach set forth in this publication may be used as a validation and evaluation tool for assessing communication effectiveness among affected organizations or nations.

This publication is intended for use by waste management professionals responsible for creating, implementing or communicating effective categorization, processing and disposal strategies. For the users of this publication, it is important to remember that waste categorization is a communication tool. As such, the operational waste categories are not suitable for regulatory purposes nor for use in health and safety evaluations.

1.3. SCOPE

This publication refers primarily to radioactive waste containing or contaminated with radionuclides at concentrations or activity levels greater than clearance levels. The applicable waste streams are those generated during operation of various nuclear facilities (such as nuclear power and research reactors), operation of fuel cycle facilities, and application of radionuclides in other fields (industry, research, education, medicine).

The characteristics of wastes generated during the initial stage of decommissioning are practically identical to operational wastes. In this publication, decommissioning wastes are not explicitly addressed; however, they may, in principle, be categorized using the same approach as for operational wastes. A principle feature of wastes from the later stages of decommissioning is a much higher volume generated over a short period of time, as well as a broader range of material types, specifically large components and structural materials. Although this adds additional complexity, the approach taken to operational waste categorization still apply. The high volumes and low radiological consequence of much of this material has resulted in the implementation of separate processing or dispositioning strategies for the very low level waste (VLLW) classification in some Member States. This may also result in the pursuit of unique waste forms for these waste streams.

Mill tailings and naturally occurring radioactive material (NORM) waste are excluded from the scope of this publication because of their quite different characteristics and nature. Disused sealed sources are also specifically excluded. Although there are specific issues with this particular waste type, it is recognized that the principal challenges posed by disused sources are associated with the source control and not with waste classification or categorization.

1.4. STRUCTURE

Section 2 of this publication defines categorization and its relationship to existing waste classification and management standards, regulations and practices. It also describes the benefits of a comprehensive categorization programme and fundamental record considerations. Section 3 provides an overview of the categorization process, including primary categories and sub-categories. Sections 4 and 5 outline the specific methodology for categorizing unconditioned and conditioned wastes. Finally, Section 6 provides a brief summary of critical considerations that support a successful categorization programme.

2. CATEGORIZATION

This section of the report defines the categorization concept and its relationship to existing international and national waste classification and management standards, regulations and practices.

2.1. DEFINITION OF CATEGORIZATION

International standards documents (and by default, national legislation) were designed *"to eliminate some of the ambiguity that existed in classification schemes for radioactive waste."* This has only been partially achieved in current publications and, therefore, ambiguity regarding the communication of radioactive waste classification and segregation information still exists in many Member States. Additionally, decisions are required during predisposal waste management steps (generation through waste conditioning) to produce safely and cost-effectively a final waste package acceptable for storage and/or disposal. Therefore a methodology is needed for operational waste categorization which is clearly unique from the disposal-based waste classification system in order to facilitate accurate communication and information exchange among stakeholders (generators, transporters, processors, nations, etc.).

Classifying wastes based solely on radioactivity concentrations and species content is plausible; however it has been proven that this approach is not viable for all waste types during every phase of the waste management process. In contrast, "categorization" of waste so as to include such factors as origin, physical state, type of waste, properties, and process options provides the basis for an improved, consistent approach.

This publication provides a simple categorization approach which is based on the two primary operational waste categories listed below.

(1) unconditioned, as-generated waste; and

(2) conditioned waste.

Each primary category has five components or "subcategories," which form the basis for the definition of categorization. Accordingly, for the purposes of this publication, categorization is defined as "***a method for grouping individual or combined waste streams based on the waste's point of origin, physical state, type, properties, and process options.***"

The bases for this definition are outlined in the five subcategories below. Additional detail for each of these is provided in the subsequent sections of this publication.

— *Point of origin* – source of the as-generated raw waste
— *Physical state* – liquid, gaseous, solid
— *Type* – dry solids, resin, sludges, slurry, metal, combustible, compactable, etc.
— *Properties* – radiological, physical, chemical (in some cases, biological)
— *Process options* – pre-treatment, treatment, conditioning.

This categorization approach supports safe and cost effective segregation and management of waste prior to and throughout treatment, conditioning and disposition.

Note: In order to avoid confusion which may arise from comparison of this publication with other IAEA publications on waste classification, the approach used in this publication will hereafter be referred to as waste "categorization."

2.2. REQUIREMENTS AND STANDARDS

International requirements, standards, and recommendations provide a basis for developing national legislation that may encompass specific regulations, rules and norms for radioactive waste management. Compliance with all relevant international requirements and national legislation constitutes a legal basis for operational waste categorization as discussed in this section. The following is a review of the key requirements and standards which form a technical basis for the primary operational waste categories and the associated subcategories.

2.2.1. International standards

Legal requirements established at the international level have a significant influence on radioactive waste management. Member States which are signatories to international conventions — such as the Joint Convention on the Safety of Spent Fuel Management and the Safety of Radioactive Waste Management [2] — are expected to comply with those requirements, recognizing that the requirements may restrict or require specific waste management activities or options.

2.2.1.1 ICRP

The International Commission on Radiological Protection (ICRP) develops recommendations aimed at the protection of human health and the environment from the hazards associated with any source of ionizing radiation [3, 4]. These recommendations are based on a substantial body of scientific knowledge and a wealth of experience in dealing with radioactive materials.

2.2.1.2 IAEA standards

The IAEA establishes or adopts standards of safety for the protection of health, life and property in the development and application of nuclear energy for peaceful purposes. These safety standards include the ICRP recommendations.

IAEA Safety Standards are not legally binding on Member States but may be adopted by them, at their own discretion, for use in national regulations in respect to their own activities. The IAEA Safety Standards are binding on the IAEA for application in relation to its own operations and to operations assisted by the IAEA. Guidance for developing and maintaining radioactive waste management programmes is provided in a number of IAEA publications; refer to the Bibliography and References section of this publication [5, 6].

2.2.1.3 IAEA waste classification

In 1970 and 1981, the IAEA published two documents regarding standardization or classification of radioactive waste: Technical Reports Series No. 101 [1] and Safety Series No. 54 [6]. In 1994, these publications were revised and updated as the IAEA Safety Guide on Classification of Radioactive Waste [7]. This Safety Guide provides a recommended method for defining a classification system using four classes of radioactive waste which are summarized in Table I.

TABLE I. IAEA RADIOACTIVE WASTE CLASSIFICATION SYSTEM

Waste Classes	Typical Characteristics	Disposal Options
Exempted waste (EW)	Activity levels at or below national clearance levels which are based on an annual dose to members of the public of less than 0.01 mSv (1 mrem)	No radiological restrictions
Low and intermediate level waste (LILW)	Activity levels above clearance levels and thermal power below about 2 kW/m^3	
Short lived waste (LILW-SL)	Restricted long lived radionuclide concentrations (limitation of long lived alpha emitting radionuclides to 4000 Bq/g (108 μCi/g) in individual waste packages and to an overall average of 400 Bq/g (10.8 μCi/g) per waste package)	Near surface or deep underground disposal facility
Long lived waste (LILW-LL)	Long lived radionuclide concentrations exceeding limitations for short lived waste	Deep underground disposal facility
High level waste (HLW)	Thermal power above about 2 kW/m^3 and long lived radionuclide concentrations exceeding limitations for short lived waste	Deep underground disposal facility

The IAEA has developed a NEWMDB (Net-Enabled Waste Management Database) [8] that supports the compilation of the inventory of radioactive waste in Member States based on a common disposal-based waste classification scheme.

The primary purpose of the IAEA waste classification system is to align classification schemes for radioactive waste among all Member States so as to facilitate communication and information exchange. Alternate objectives are to enhance development of the classification system, identify strategies for further quantification of waste classes, and provide methods for defining waste classification boundaries. Such data points also serve as precursors to broader communication efforts based on operational waste categorization.

It is important to note that, while a radioactive waste classification system may be useful to bound safety considerations, it is not a substitute for specific safety analyses when defining final waste form, packaging, or storage/disposal acceptance criteria. As an example, some Member States attempting to use the IAEA waste classification scheme for defining their waste disposal option discovered that it is difficult in practice to define disposal acceptance criteria based solely on waste class.

2.2.2. National legislation

Recognizing that the management of radioactive waste is a potentially hazardous activity, it should be controlled within a framework of national legislation. That legislation should be based on international standards, requirements and accepted practices. It typically addresses safety, security, radiological protection, environmental protection, and waste regulatory control requirements. These principles are further developed in Reference [5].

2.3. IMPLEMENTATION OF A CATEGORIZATION PROGRAMME

Ideally, an operational waste categorization programme should be implemented prior to generation of any waste. Establishing waste segregation practices early in the generation cycle are critical to ensuring the future, long term success of the programme. It is expected that the categorization process will be revised as the waste management programme evolves. Mature programmes may have an established protocol for operational waste categorization; this publication may be used for evaluating and validating programme objectives and results.

Of equal importance, categorization may be performed by the waste generator or by a waste processor. Categorization is typically based on the available technologies that support the desired final waste disposition criteria.

Figure 2 illustrates the relationship between types of nuclear programmes, their implementation status, and the source of compliance standards/requirements. These considerations are used to define the optimum categorization strategies and desired results.

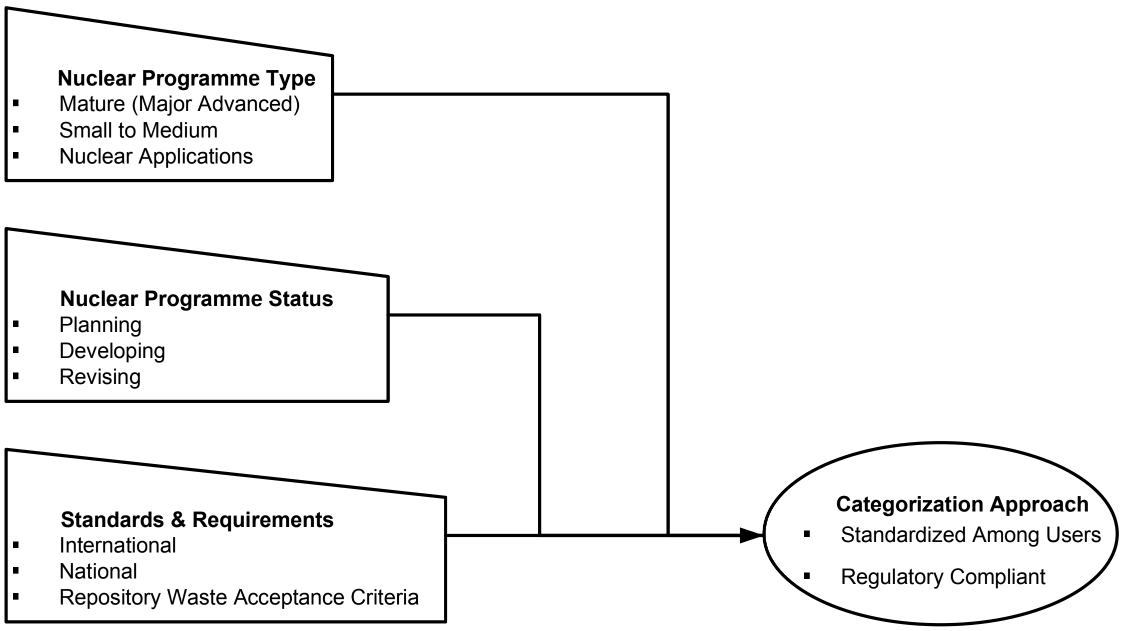

FIG. 2. Categorization programme relationships.

2.4. BENEFITS OF AN EFFECTIVE OPERATIONAL WASTE CATEGORIZATION PROGRAMME

A comprehensive, standardized operational waste categorization programme provides a platform for accurately assessing management options, including, but not limited to:

— Waste segregation;
— Preliminary waste characterization and classification;
— Selection of cost effective, regulatory compliant waste treatment and conditioning options;

— Mobile processing technology selection;
— Processing resource sharing with other facilities and/or countries;
— Validation of compliance with final repository waste acceptance criteria;
— Infrastructure investment sharing between facilities and/or countries with similar challenges and close proximity;
— Pursuit of alternative disposal options for materials of low radiological risk (e.g. in facilities that do not maintain a radioactive materials license including, but not limited to industrial or hazardous waste landfills).

Additionally, categorization of radioactive waste can be helpful at any stage between the point of generation and subsequent handling, transport, processing, storage, and disposal:

— At the conceptual level in:
  - devising waste management strategies;
  - planning and designing waste management facilities; and
  - routing radioactive waste for processing, storage and disposal;
— At the operational level by:
  - defining operational activities and in organizing the sequence of activities;
  - giving a broad indication of the potential hazards involved with the various types of radioactive waste;
  - facilitating record keeping;
— With communication:
  - by providing universally recognized terminology that improves communication between countries, the public, regulators, and finally generators and managers of radioactive waste programmes.

2.5. RECORDS

Categorization records should document the technical and economic bases for the facility-specific categorization plan; the objective being to accommodate future reference and revision. The documents should clearly communicate the analyses and thought processes used to develop the operational waste categorization strategies.

3. SUBCATEGORIES

This section describes the subcategories of unconditioned and conditioned wastes.

3.1. POINT OF ORIGIN

Radioactive waste is produced from a range of activities, and the waste streams vary by form, activity, physical state, etc. The sources (point of origin) of radioactive wastes considered in this publication include:

(a) The nuclear fuel cycle, including the refining and conversion of uranium concentrates (yellow cake), enrichment, fuel fabrication, and fuel reprocessing;
(b) Operation of nuclear power reactors;
(c) Support facilities, such as laboratories, research and development facilities, hot cells, maintenance and repair facilities and other specialized facilities;
(d) Production and various applications of radionuclides in commercial research, industry, education and medicine.

Additional detail related to the above waste generating activities is captured in IAEA and other industry publications. Categorization of a waste stream based on its point of origin provides valuable insights related to expected waste stream properties. This can reduce the burden associated with subsequent characterization analyses, processes, classification and disposition.

3.2. PHYSICAL STATE

This is perhaps the most obvious subcategory and is comprised simply of three physical states:

(1) Liquid

(2) Gaseous

(3) Solid.

3.3. TYPE OF WASTE

This subcategory is particularly useful in identifying potential treatment and conditioning technologies. In fact, waste type names are often established by the processing methods. In the case of waste to be disposed, the waste type often relates to a portion of repository, such as unstable or stable wastes. Examples of waste types include:

Physical waste types

— wet solid wastes – such as spent ion exchange resins, cartridge filters, filter media, sludge, concentrates

— dry solid wastes – paper, plastic, metal, concrete, building rubble

— major end items – large equipment, such as steam generators, core barrels, turbines, pressurizers, heat exchangers.

Process waste types

- combustible waste – paper, plastic, wood, organics
- compactable wastes – compressible materials, including solid combustibles and light metals (e.g. aluminum)
- metals – for melting, decontamination, recycling.

Storage/disposal waste types

- unstable – non-solidified bulk wastes, such as soil, rubble, and combustible and compactable wastes which are not solidified (grouted) or placed in a container which is inherently stable (e.g. a high integrity container)
- stable – solidified, encapsulated or grouted waste, or waste which has been placed in a container which is inherently stable (e.g. a high integrity container).

3.4. PROPERTIES AND PROCESS OPTIONS

The remaining two subcategories are heavily dependent upon the primary operational waste category (unconditioned or conditioned wastes). Accordingly, they are addressed in Sections 4 and 5 along with their respective operational waste categories.

4. UNCONDITIONED WASTE CATEGORY

This section defines the basis for categorizing unconditioned wastes. This begins with defining the waste properties, followed by a discussion of the process options.

4.1. PROPERTIES OF UNCONDITIONED WASTE

Prior to implementing unconditioned waste pre-treatment or treatment, an adequate waste characterization is required to define specific waste properties. To support accurate categorization, the radiological, chemical and physical properties should be characterized.

4.1.1. Radiological

A categorization of unconditioned waste based on the radiological properties has several objectives. It can be used to:

- Avoid mixing streams with different isotopic content or distribution.
- Select processing techniques, technologies, and equipment design.
- Prevent criticality.
- Design storage or disposal facility
  - Optimizing radiological protection, design of shielding, etc.
- Optimize characterization methods
- Define handling (transfer) and transport considerations.
- Minimize waste generation (including secondary waste).

4.1.2. Physical and chemical properties

A categorization of unconditioned waste based on the physical and chemical properties provides a tool to define:

- Waste processing techniques
- Operational processing parameters.
- Waste handling, transfer and transport packages, containers, shields.
  - Dimensions, weight, materials, etc.
- Handling (transfer) and transport considerations.
  - Solid to liquid content ratio
  - Thermal enhancement to maintain solubility
  - Radiological and occupational safety
- Waste stream compatibility considerations
- Waste treatment equipment designs
  - Compatibility between waste and processing equipment construction materials.
  - Capacity, etc.

4.1.3. Biological and pathogenic properties

Some waste generating activities may produce a waste stream with biological or pathogenic characteristics of concern. This publication does not specifically address considerations for their categorization. Process specific biological and pathogenic management considerations should be integrated into national legislation, regulations, and facility-specific categorization programmes using guidance from existing IAEA and industry publications.

4.1.4. Additional property analyses

Individual waste stream properties may require re-evaluation during subsequent categorization and processing steps. For example, following initial segregation, waste streams may be combined to facilitate the most efficient treatment option. The characteristics of that combined waste stream may be different than those of the previously segregated streams.

4.2. PROCESS OPTIONS FOR UNCONDITIONED WASTES

4.2.1. Pre-treatment

Pre-treatment constitutes any or all of the operations prior to “waste treatment,” such as collection, segregation, chemical adjustment, and in situ decontamination [10]. Pre-treatment may result in a reduction in the amount of waste requiring further processing and disposal. It also includes actions performed to adjust the characteristics of the waste, to make it more amenable to further processing, and to reduce or eliminate certain hazards posed by the waste owing to its radiological, physical, chemical, or pathogenic properties.

For example, delaying segregation or processing activities until after pre-treatment can sometimes be an advantage and may be included in the categorization process. Storing waste with very short-lived radioisotopes (half-lives in the range of months or less) can result in reduced operator exposure and may create a waste stream that is acceptable for alternate processes, such as unconditional release or more cost effective processing techniques.

Pre-treatment activities should be conducted in a manner that minimizes the volume of primary and secondary radioactive waste requiring treatment and, ultimately, minimizes the volume of stored or disposed waste. Management options such as release, recycle, reuse and the removal of regulatory control from materials – in compliance with the conditions and criteria established by the regulatory body – should be used to the extent practical [11].

Collection and initial segregation

The first operation in pre-treatment is to collect wastes, then segregate them as necessary on the basis of the waste stream’s physical state (liquid, gaseous, solid) and total activity. Radioactive waste should be segregated as soon as practical after generation to avoid mixing waste streams. Radioactive waste containing predominantly short-lived radionuclides should not be mixed with waste containing long-lived nuclides. If waste streams with significantly different activities are combined, the cost and management benefits associated with processing lower activity wastes may be diminished. For example, if exempt waste becomes mixed with LLW, then the commingled waste stream will usually require treatment as LLW.

Also, it is generally not advisable to mix waste streams, especially when the streams should follow separate routes to facilitate downstream processes. However, there are situations when mixing of streams is an advisable or acceptable practice. Examples include:

— Where streams from two different sources are to follow the same process or disposition route and are chemically and physically compatible.

— Where there is not a sufficient waste volume from one or more of the individual sources to justify investment in infrastructure (collection, process, licensing, etc.) to support segregated collection or routing.

The segregation strategy should also address whether regulatory control can be removed from the waste (e.g., clearance) or whether it can be recycled or discharged, either directly or after some period of decay.

Additional pre-treatment

To facilitate further treatment and enhance safety, several options may apply. A second waste segregation step may play an important role in defining subsequent waste routing, minimization and final processing strategies. This second waste segregation effort should only be undertaken if the materials are to be directed to different routes. Similarly, chemical adjustment or decontamination may be required to facilitate subsequent waste processing steps.

4.2.2. Treatment

Treatment consists of operations intended to provide safety or economic benefit by changing the characteristics of the waste. Three basic treatment objectives are: volume reduction; removal of radionuclides from the waste; and change of physical or chemical composition. (The treatment of *hazardous* waste and the hazardous constituents of radioactive waste are beyond the scope of this publication.)

Treatment of *radioactive* waste may include:

(a) A reduction in waste volume by incineration of combustible waste, compaction of solid waste, segmentation or disassembly of bulky waste components or equipment, etc.
(b) Decontamination.
(c) Removal or concentration of radionuclides (evaporation or ion exchange for liquid waste streams and filtration of gaseous waste streams).
(d) Change of form or composition by chemical processes.

Liquid waste treatment

Methods for the treatment of aqueous waste include evaporation, membrane processing (e.g. reverse osmosis, ultrafiltration, non-precoat filters), electro deionization, ion exchange, chemical precipitation, filtration, centrifugation, electrodialysis and incineration. In each case, treatment limitations should be included in the categorization process. For example, carefully consider the impact of corrosion, scaling, foaming, and the risk of fire or explosion in the presence of organic material, especially with regard to the safety implications of operations and maintenance. If the waste contains fissile material, the potential for criticality should be evaluated and eliminated by means of design features and administrative features.

Spent ion exchange resins are usually transferred as a liquid slurry and subsequently managed as a wet solid waste. Some operators employ technologies to remove interstitial liquids, treating the waste resins as a dry solid. Categorization should also consider the precautions related to prolonged waste resin storage prior to conditioning; the potential exists for radiolytic or chemical reactions generating combustible gases, causing physical degradation (resins sticking together), or producing exothermic reactions during dewatering.

Liquid waste treatment may result in a secondary waste stream that requires additional treatment prior to recycle (reuse) or release to the environment. The categorization process should address the impact of those treatments including considerations such as filtration of suspended materials, chemical adjustment of acidic or alkaline liquids, toxic, or other waste streams with chemical constituents. Additional considerations include the impact of International and National health and safety and environmental protection regulations. [12]

Gaseous waste treatment

Gaseous waste treatments may include removal of radioactive particulates and aerosols by high efficiency filtration. Similarly, iodine and noble gases may be removed by filters or adsorber beds charged with activated charcoal and scrubbers used for removal of gaseous chemicals, particulates and aerosols.

The categorization process should ensure that the physical and chemical properties of the used process media (filters, adsorbers, etc.) are compatible with each waste stream's subsequent treatment and conditioning processes.

Solid waste treatment

Solid waste treatment may lead to the generation of secondary waste. Incineration is an acceptable solid waste treatment process. However, its use may result in accumulation of radionuclides in residues within the incinerator chamber, gas cleaning system, or ash; those streams may require further conditioning.

Compaction is suitable for reducing the volume of certain types of waste. The characteristics of the material to be compacted and the desired volume reduction should be well defined and controlled.

Segmentation or disassembly and other size reduction techniques may be required for waste that is bulky or oversized (e.g. large components or structural debris) to facilitate treatment by the intended processing equipment.

For solid waste which is both non-combustible and non-compressible, and for which decay or decontamination are not viable options, direct conditioning without treatment should be considered.

Typical decontamination processes remove contamination using a combination of mechanical, chemical and electrochemical methods. Waste metal melting results in homogenization of the activity and accumulation of that activity in the secondary, slag waste stream. Similar to the treatments associated with other wastes, the categorization process for these techniques should ensure that the characteristics of the secondary waste are compatible with subsequent treatment and conditioning steps.

4.3. UNCONDITIONED OPERATIONAL WASTE CATEGORIZATION TABLES

The categorization considerations for all waste processes prior to conditioning are similar. Therefore, these steps have been combined under the category "unconditioned waste." Tables II – VI list the important properties for liquid, gaseous and solid wastes that may be taken into account to categorize unconditioned wastes on a case-by-case basis.

TABLE II. RADIOLOGICAL PROPERTIES OF UNCONDITIONED LIQUID WASTES

Radiological properties	Categorization parameter	Possible category	Determination method	Categorization is aimed to define:
Total activity	Bq	High activity Intermediate activity Low activity Releasable	Direct measurement, calculation, estimation	Segregation. Type of treatment. Possibility of discharge.
Activity concentration	Bq/kg or Bq/m3	High activity Intermediate activity Low activity Releasable	Direct measurement, calculation, estimation	Segregation. Type of treatment. Possibility of discharge.
Radionuclide composition	List of radionuclides (detected and declared)	Short lived Long lived Long lived α	Direct measurement, calculation, estimation	Segregation. Type of treatment. Possibility of discharge.
Fissile mass and criticality safety	Mass of fissile materials in g	Fissile or non-fissile	Direct measurement, calculation, estimation	Segregation to prevent criticality
Origin of the activity and operational history	Facility and operations that generated the waste	Normal or abnormal operations	Information from waste generator. Operational records	Segregation. Type of treatment. Possibility of discharge.

TABLE III. PHYSICAL AND CHEMICAL PROPERTIES OF UNCONDITIONED LIQUID WASTES

Physical and chemical properties	**Categorization parameter**	**Possible category**	**Determination method**	**Categorization is aimed to define:**
Solid content	Concentration (g/l, ppm, etc.)	High solids or low solids	Analytical	Possibility of using filtration, precipitation, or ion exchange techniques.
Compatibility	pH	Acid or alkaline	Analytical	Need to adjust pH
Volatility	Concentration of volatile materials, kg/m^3	With presence of volatile materials	Sampling, testing	Off-gas and confinement design.
Miscibility	No chemical reaction	Miscible or not	Sampling and test	Possibility of mixing.
Heat generation	kW/m^3	Heat generating or non-heat generating	Calculation, direct measurement	Need of cooling to limit thermal power
Chemical composition	g/l, pH	Corrosive/non-corrosive Toxic/non-toxic Hazardous/non-hazardous Chemical reactive or not Containing chelating agent or not Flammable/non-flammable Explosive/non-explosive	Sampling and Analytical methods	Need of chemical adjustment
Gas generation	g/l/d	Gas generating or not	Analytical methods Information from waste generator	Ventilation or off-gas treatment design.

TABLE IV. RADIOLOGICAL PROPERTIES OF UNCONDITIONED GASEOUS WASTE

Radiological properties	Categorization parameter	Possible category	Determination method	Categorization is aimed to define:
Total activity	Bq	Dischargeable / non-dischargeable	Calculation, estimation	Type of Processing, Authorized discharge
Activity concentration	Bq/kg or Bq/m3	Dischargeable / non-dischargeable	Direct measurement, calculation, estimation	Type of Processing, Authorized discharge
Radionuclide composition	Radionuclides	Short lived Long lived	Direct measurement, calculation, estimation	Type of Processing, Authorized discharge
Origin of the activity and operational history	Facility and operations that generated the waste	Normal or abnormal operations	Information from waste generator. Operational records	Type of Processing Authorized discharge
Particulate content	Percentage	High or low content	sampling and analysis	Filtration / Authorized discharge
Chemical composition	g/l	Hazardous/non-hazardous Flammable/non-flammable Corrosive/non-corrosive Humid/Dry Toxic/non-toxic	Sampling and Analysis	Type of processing (material selection, parameters) / Authorized discharge
Explosive	Percentage	Presence of explosive gases or not	Analytical or Info from waste generator	Needs for dilution. Authorized discharge

TABLE V. RADIOLOGICAL PROPERTIES OF UNCONDITIONED SOLID WASTES

Radiological properties	**Categorization parameter**	**Possible category**	**Determination method**	**Categorization is aimed to define:**
Total activity	Bq	High activity Intermediate activity Low activity Releasable	Direct measurement, calculation, estimation	Segregation. Type of treatment. Possibility of free release.
Activity concentration	Bq/kg or Bq/m3	High activity Intermediate activity Low activity Releasable	Direct measurement, calculation, estimation	Segregation. Type of treatment. Possibility of free release.
Radionuclide composition	List of radionuclides (detected and declared)	Short lived Long lived Long lived α	Direct measurement, calculation, estimation	Segregation. Type of treatment. Possibility of free release
Fissile mass and criticality safety	Mass of fissile materials in g	Fissile or non-fissile	Direct measurement, calculation, estimation	Segregation to prevent criticality
Surface dose rate	mSv/h	High contact dose rate waste or Low contact dose rate	Direct measurement	Shielding design
Surface contamination and type of contamination	Bq/cm2	Contaminated or not contaminated Fixed or loose	Smear test	Possibility of decontamination
Origin of the activity and operational history	Facility and operations that generated the waste	Contaminated or activated Normal or abnormal operations	Information from waste generator. operational records	Segregation. Type of treatment. Possibility of free release.

TABLE VI. PHYSICAL AND CHEMICAL PROPERTIES OF UNCONDITIONED SOLID WASTES

Physical and chemical properties	**Categorization parameter**	**Possible category**	**Determination method**	**Categorization is aimed to define:**
Size, weight and volume	m, kg, m^3	Processable or not processable Bulky or not bulky	Direct measurement or calculation	Size reduction to optimize volume of waste form.
Type of material	Name of presented material	Metallic, concrete, plastic, etc.	Information from waste generator, visual inspection	Segregation. Size and volume reduction. Possibility of melting for metallic components.
Compressibility	Volume reduction factor	Compressible, non-compressible	inspection	Segregation. Compaction.
Dispersibility in air	Size of granules	Dispersible, non-dispersible	Sampling, testing	Confinement of fines
Volatility	kg/m^3	presence or not of volatile materials	Sampling, testing	Design of confinement system.
Solubility in water	g/kg	Soluble, non-soluble	Sampling, testing	Needs to prevent water contact or humidity
Heat generation	kW/m^3	Heat generating or non-heat generating	Calculation, direct measurement	Need of cooling to limit thermal power
Chemical composition	g/l	Hazardous or not hazardous	Sampling and analytical estimation	Segregation. Chemical adjustment
Combustibility	kJ/kg	Combustible, non-combustible	Sampling and analytical estimation	Segregation. Fire protection. Treatment through incineration.
Explosive materials	kg	explosive or not explosive materials	Visual inspection, sampling and testing	Segregation / isolation
Pyrophoric, self-ignitable,	Percentage	Ignitable or not	Sampling/ analysis	Segregation .Isolation. Destruction of pyrophoricity
Gas generation	liters/kg-day	Gas generator or not	Analytical methods Info from waste generator	Ventilation or off-gas system design.
Toxicity	g/l	Toxic or not	Analytical methods, Information from waste generator	Segregation / isolation / stabilization
Sorption capacity	g/l	Sorbent or not	Analytical method	-

5. CONDITIONED WASTE CATEGORY

This section defines the basis for categorizing conditioned wastes. As with Section 4, this section focuses on the properties of waste and the process options.

5.1. CONDITIONED WASTE OVERVIEW

Conditioning consists of those operations that produce a waste package suitable for handling, transport, storage or disposal. Similar to categorizing unconditioned waste, the conditioned waste categorization process includes consideration of waste properties, conditioning processes, and the final waste form.

5.2. PROPERTIES OF WASTE

Prior to implementing conditioning processes, adequate waste characterization is required to ensure the final waste form will comply with storage or disposal acceptance criteria. To support accurate categorization and final waste classification, the radiological, chemical and physical properties should be characterized.

5.2.1. Radiological

A categorization of conditioned waste based on the radiological and safety properties has several objectives:

- Optimize final waste form activity determination methods.
  - Dimension, density, shape, etc. should support efficient determination process.
- Define handling conditions.
- Select appropriate conditioning and packaging technologies.
- Minimize waste generation (including secondary waste).
- Design the facility for either long term storage or disposal.
  - Optimizing radiological protection, design of shielding, etc.

5.2.2. Physical and chemical

A categorization of conditioned waste based on the physical and chemical properties is an adequate tool to define:

- Waste conditioning techniques, technologies and equipment design.
- Operational processing parameters.
- Waste form and package compatibility.
- Waste packages.
  - Dimensions, weight, materials, etc.
- Handling and transport conditions.
- Compatibility between waste form and waste acceptance criteria.
  - Chemical, thermal, structural, mechanical and radiation stability.

5.3. PROCESS OPTIONS

5.3.1. Conditioning

Conditioning may include the conversion of the waste to a solid waste form, enclosure of the waste in containers, and if necessary, providing an overpack.

Prior to conditioning radioactive waste for storage or disposal, the waste acceptance criteria have to be considered to ensure compliance with the disposal site requirements. Where *final* disposal criteria do not yet exist, disposal criteria assumptions should be defined and incorporated into categorization plans.

Liquid waste is often converted into a solid form by solidifying it in a suitable matrix, such as glass, cement, bitumen or polymer. Solidification may also be achieved without a matrix material; for example by drying sufficient to form a solid monolith, and the product is then enclosed in an outer container. Solid waste can be immobilized (e.g. embedding, encapsulation) by surrounding it with a matrix material in order to produce a waste form.

In some instances, benefit can be derived from mixing final waste products to optimize packaging efforts. Replacing non-radioactive stabilization or overfill products with other radioactive materials may result in volume reduction or economic savings and should be considered during the categorization process. This is most relevant when the conditioning process results in a net waste volume increase. For example, when grouting to overfill solid waste forms, it may be possible to use radioactive liquid waste in the cement formulation. Alternatively, consider the use of secondary wastes, such as residue or decontamination grit blast media, for waste container overfill.

5.3.2. Packaging and transportation

The waste package is the product of conditioning that includes the waste form, any container, and any internal barrier prepared in accordance with the requirements for handling, transport, storage and disposal. Waste classification/categorization should be done in accordance with the proposed IAEA Radioactive Waste Classification System [9] the national regulations, and disposal acceptance criteria.

Packages containing radioactive waste intended for transport shall comply with limits established in the IAEA Transport Regulations and any applicable national legislation [12]. Criteria to meet handling and emplacement requirements at the disposal facility, and to facilitate the identification of waste packages, shall also be considered in the categorization process.

In some instances, the final waste form may be the final waste package and requiring no additional processing. At other times the waste form may require additional packaging, e.g. a container or an overpack. Since transport of the final waste package may be required, packaging and transport considerations should be included in the conditioned waste categorization process.

Storage may be required where final waste repositories have not been developed. Similar to waste form, packaging and disposition, storage facility design and licensing requirements should be considered when developing national and site-specific categorization programmes.

5.4. CONDITIONED OPERATIONAL WASTE CATEGORIZATION TABLES

Tables VII–X provide the criteria for categorizing waste following conditioning. The table properties are directly related to disposal waste form and acceptance criteria.

TABLE VII. RADIOLOGICAL PROPERTIES OF CONDITIONED WASTE FORM

Radiological properties	Categorization parameter	Possible category	Determination method
Total Activity	Bq	High activity Intermediate activity Low activity	Direct measurement, calculation, estimation
Activity concentration	Bq/g	High activity Intermediate activity Low activity	Direct measurement, calculation, estimation
Homogeneity	Percentage variation in homogeneity	Homogeneous or non-homogeneous	Direct measurement, calculation, estimation
Radionuclide composition	List of radionuclides (declared)	Short lived Long lived Long lived α	Direct measurement, calculation, estimation
Fissile mass and Criticality safety	Mass of fissile materials in g	Fissile or non-fissile	Direct measurement, calculation, estimation

TABLE VIII. PHYSICAL AND CHEMICAL PROPERTIES OF CONDITIONED WASTE FORM

Physical and chemical properties	Categorization parameter	Possible category	Determination method
Heat Generation	kW/m^3	Heat generating or non-heat generating	Calculation, direct measurement
Radiation stability	Capacity for sustaining mechanical and confinement properties following irradiation	Radiation Stable or not stable	Direct measurement, calculation, estimation
Permeability	Ratio between hydraulic conductivity of porous media with fluid density and dynamic viscosity	High permeability /or Low permeability	Direct measurement, calculation, estimation
Porosity	Ratio of aggregate volume to total volume	High or Low	Analytical methods
Leachability	Bq/cm^2.day	Acceptable or non-acceptable	Direct measurement
Density	Ratio of mass per volumekg/m^3	High or Low	Analytical methods, Calculation
Chemical compatibility with Package material	Testing	Compatible or non compatible	Direct measurement, calculation, estimation
Gas generation	Liters / h / kg	Gas generator or not	Analytical methods Info from waste generator

TABLE IX. MECHANICAL PROPERTIES OF CONDITIONED WASTE FORM

Mechanical properties	Categorization parameter	Possible category	Determination method
Compression resistance	Pressure threshold for deformation, MPa	Acceptable or non-acceptable	Direct measurement, calculation, waste form sample testing
Dimensional stability	Metric measurements Percentage change	Acceptable or non-acceptable	Direct measurement, calculation, waste form sample testing

TABLE X. THERMAL PROPERTIES OF CONDITIONED WASTE FORM

Thermal properties	Categorization parameter	Possible category	Determination method
Fire resistance	Duration of exposure to high temperature before fragmenting	Acceptable or non-acceptable	Direct measurement, calculation, waste form sample testing
Thermal conductivity	kW/cm/degree	Acceptable or non-acceptable	Direct measurement, calculation, waste form sample testing

6. CONCLUSIONS

This publication provides a practical categorization approach that supports safe, cost effective radioactive waste management. The approach is based on waste stream segregation using two primary categories (unconditioned and conditioned wastes) and five subcategories (point of origin, physical state, type, properties, and process options). It should assist Member States in planning, developing or revising their waste management programmes, as well as communicating and comparing common waste aspects among waste management professionals, organizations and nations.

While using this publication, it is important to remember that categorization, like classification, is a communication tool. As such, the operational waste categories are not suitable for regulatory purposes nor for use in health and safety evaluations.

There are four primary considerations associated with this operational waste categorization approach.

(1) Programmes that are being planned, developed, or revised will benefit from this comprehensive, end-to-end operational waste categorization programme.

(2) An operational waste categorization programme should be implemented prior to generation of any waste. Early, pilot waste categorization and management processes will help to ensure the future success of the programme. The categorization process is expected to be revised as the programme evolves.

(3) Accurate characterization of the as-generated waste type and its properties is critical to successful categorization.

(4) Where applicable, the process is intended to support creation of a conditioned waste form that meets international and national standards and repository waste acceptance criteria.

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