Technical Note
ERDO – LWC project
Final Report

INDEX

1 FOREWORD

Nuclear activities performed in the past have generated significant quantities of radioactive waste often treated and conditioned according to obsolete rules or simply stored pending a suitable management solution (conventionally called ‘Legacy Waste’ or ‘Historical Waste’ in some countries).

These Legacy Waste are often lacking sufficient physical-chemical radiological characterization data for envisaging possible re-treatment/re-conditioning processes in line with future Waste Acceptance Criteria (hereafter, WAC) and acceptance for disposal. In some countries, this issue is worsened by the lack of disposal options and relevant WAC. So many Countries must deal with Legacy Waste issues; therefore sharing information can be crucial.

The high-level objective of the ERDO LWC project is, indeed, sharing information and methodologies for a better characterization of Legacy Waste in view of possible future management activities and acceptance to disposal.

The Legacy Waste Characterization Project was launched on February 2020 within the ERDO Working Group (now ERDO Association) by 8 countries for 9 organizations.

The activities of the project are arranged in the following Tasks:

Task 1: Survey of existing main Legacy Waste streams.

Task 2: Minimum set of WACs for near-surface disposal of VLLW-LLW.

Task 3: Main properties of ILW packages potentially suitable for geologic disposal.

Task 4: Characterization of main Legacy Waste streams.

Unfortunately, it was not possible to carry out task 3 due to unavailability of data.

Expected impacts of the project outcomes were:

- gaining a better knowledge of the current situation of Legacy Waste and sharing the relevant common issues;
- trying to identify possible management solutions for legacy Waste packages and also for potential storage or disposal into national/multi-national facility;

- giving to waste producers early indications for characterizations, treatment and conditioning of waste generated in countries without a well-established disposal route and relevant WACs.

2 TASK 1

The aim of Task 1 was gathering information about the Legacy Waste streams currently stored in the interested countries and finding possible similarities and common issues [R1].

Main steps were:

- putting into evidence common waste streams and identifying analogies/ differences in classification, characterization, future treatment/conditioning, disposal destination;
- highlighting common weakenesses or strengths relevant to the characterization of such waste which may respectively jeopardize or promote shared management initiatives up to disposal;
- formulating preliminary considerations on characterization of these waste streams for optimizing their management/disposal.

For these reasons a survey was sent among interested countries.

A dedicated spreadsheet for gathering the needed characteristics of the legacy waste streams was arranged and circulated among the interested organizations in 7 countries:

- NES (Austria)
- FUND-NEK (Croatia)
- DD (Denmark)
- NCSRD (Greece)
- SOGIN (Italy)
- COVRA (Netherlands)
- NND (Norway)

ARAO (Slovenia) declared no Legacy Waste streams in the country.

The first evidence from the collected inventories are the similarities in many waste streams characteristics. So, single inventories have been arranged in a comparison table (see Tabella 1) by grouping the various kinds of legacy waste streams into 13 groups as homogeneous as possible.
The homogeneous groups were:

- Disused Sealed Radioactive Sources
- Solid Mixed Waste
- Powdery waste
- Sludges
- Ion exchange resins
- Solid Organic Waste
- Liquid Organic Waste
- Graphite
- Metals
- Alpha bearing solid waste
- Reactive Metals
- Chemotoxic materials
- Liquid Waste

In this way it was possible to highlight the most important features and common aspects (Evidence), critical elements (Weakenesses), favorable elements (Strengths) related to the definition of an adequate characterization strategy with the aim of facilitating their future management up to disposal (possibly using shared facilities).
The waste stream classification is based on each country's scheme; the classifications of a similar waste stream in different countries are therefore assumed to be not always comparable. It is assumed that VLLW and LLW can be disposed of in near surface repositories (although some countries have defined a disposal strategy that provides for their disposal in deep repositories), while ILW shall be disposed of in deeper repositories (i.e. medium depth and deep geological repositories, defined as 'Other' in the survey table, with respect to 'Near surface' disposal facilities).
As results:

- 93 waste streams have been gathered in 13 homogeneous groups of streams, based on the main characteristic of the stream potentially impacting on the safety of future predisposal and disposal activities.
- The survey and the relevant analysis revealed many similarities in the declared data of legacy waste streams and their envisaged future management.
- In particular, 8 over 13 groups (Sealed radioactive sources, Solid mixed waste, Powdery waste, Sludges, Ion exchange resins, Graphite, Alpha bearing solid waste, Chemotoxic materials) are common to at least 4 out of 7 countries.
- Except in one country and in the case of Sealed radioactive sources, the classification scheme is always defined but the lack or the low reliability of the radiological characterization (for more than 80% of the streams) make the classification quite uncertain.
- The planned characterization methodology for more than 40% of these streams has yet to be defined, while the remaining streams are planned to be characterized during the following sorting and treatment phases.
- Notwithstanding such uncertainties, more than 50% of the waste streams are declared as ILW unsuitable for near-surface disposal (probably due to the expected concentration of long-lived radionuclides in the waste).
- In a few cases the legacy waste streams have been conditioned according to obsolete rules and will require re-treatment and re-conditioning for complying with WAC when available; in all other cases the waste is simply packaged in raw (or pre-treated) conditions but the future treatment and conditioning activities are defined (mainly in the concept implementation phase) for less than 50% of the streams, and the remaining is declared as ‘not defined’ or ‘to be defined’.

The results of task 1 have highlighted that there are strong similarities in waste streams among countries and this, coupled with the limited quantities of waste declared and the common needs of characterization and treatment/re-treatment for disposal, suggests possible synergies, at least in pre-disposal management routes.

Additional chances of knowledge sharing or even pre-disposal facility sharing are linked

to R&D European project (PREDIS 5), innovative treatment processes on specific waste streams and the realization of a transportable in-drum grouting station declared by some countries.

The next ‘steps to sharing’ could therefore be strongly connected to the implementation of bilateral-multilateral detailed info exchange and agreement among organizations managing similar waste streams with common pre-disposal needs.

The following table is a summary of information collected.

N	WASTE STREAM	COUNTRY	CLASSIFICATION	Waste Stream Radiological Characterization				EXPECTED DISPOSAL FACILITY TYPE (Near Surface/Other)
				Total Activity (Bq)	Main Radionuclides	Current packaged volume (m3)	Mass (kg)	
1	Disused Sealed Radioactive Sources (DSRS)	CROATIA	LLW/ILW	3,05E+12	Fe55, Co60, Kr85, Sr90, Ir92, Gd153, Kr85, Sr90, Cm247, Ni63,Tl204, Cm247, Ba133, Cd109, Cs137, Pm147, Eu152,154, Ra226, Ra226/Be, Am241/Be	N.A.	N.A.	Near Surface/Other
		DENMARK	No national classification scheme	N.A.	Charcterisation in progress	N.A.	N.A.	Other (DGR)
		ITALY	No national classification scheme	1,22E+15	H3, Cs137, Ra226, C14, Co60, U238, Kr85, Cm244, Ni63, Sr90, Am241, Ra226, alpha sources, beta sources	5,11E+02	1,35E+04	Other
		GREECE	LLW/ ILW	7,70E+09	Am241, Ra226, Co60, alpha sources, beta sources, neutron sources	1,80E+00	N.A.	Other (possibly multi-purposes borehole)
		NORWAY	LLW/ILW	Unknown	Ra226 or Am241	N.A.	N.A.	Near Surface/Other
		AUSTRIA	LILW-SL and LL (in case of Am-241 and Ra-226 sources)	24,8E3 GBq (not decay corrected)	Cs-137, Co-60, Am-241, Kr-85, Sr-90, H-3, Ra-226, Pm-147, Ir-192	130 drums	N.A.	To be determined
2	Solid Mixed Waste	CROATIA	LLW/No classification	N.A.	Ra226, Cs137, Bi207, Pb210, Eu152, U238, Th234, Co57, Co60, Am241, mixture	N.A.	3,06E+03	Near Surface
		DENMARK	No national classification scheme	6,00E+12	Charcterisation in progress	ca 5400 drums	Not compiled	Other (DGR)
		ITALY	ILW	4,37E+11	Cs137, U238, Cm244, Eu154, Pu238, Pu241, Sr90	4,38E+01	8,25E+02	Other
		GREECE	LLW/ ILW	N.A.	Cs137, Co-60, Ag-108m, Eu-152, Tc-99 etc, Ra-226, Am-241, Th232, Sr-90, deU	2,40E+01	N.A.	Near surface/ Other (possibly multi-purposes borehole)
		AUSTRIA	LILW-SL and LL	1,8E3 GBq (not decay corrected)	Sr-90, H-3, C-14, Cs-137, Pu-241, Am-241, Co-60	about 4000 drums	Not available before reconditioning	To be determined (Near Surface)
		NETHERLAND	LILW		Cs-137	not yet available		Other (GDF)
3	Powdery Waste	CROATIA	LLW	N.A.	Eu152	Not available	4,80E+02	Near Surface
		ITALY	VLLW/LLW	2,92E+10	Cs137, Eu154, Sr90, Pu241, C14, H3, U236, U238	1,55E+03	1,84E+06	Near surface
		GREECE	LLW	N.A.	Pu-238, Pu-239, Pu-240, Pu-241	6,00E-01	N.A.	Near surface
		NORWAY	ILW (long lived aplha activity concentration expected to be > 400 Bq/g)	Unknown	Unknown (various radionuclides including Actinides- Pu)	5,48E+01	82200 (dry desity of 1.5 t/m3)	Other
4	Sludges	DENMARK	No national classification scheme	N.A.	Charcterisation in progress	N.A.	N.A.	Other (DGR)
		ITALY	VLLW/LLW	1,33E+09	Ni59, Ni63, Co60, Cs137	1,16E+01	5,12E+03	Near surface
		GREECE	VLLW/ LLW	Unknown	Ni63, Co60, Cs137, Ag-108m, Eu-152	2,00E-01	N.A.	Near surface
		NORWAY	LLW/ILW	N.A.	Activation and fission Products e.g. Cs137, Fe55, Co60, Sr90, Uranium, Actinides (Am241, Pu239, Pu240, Pu241)	N.A.	N.A.	Near surface/Other
		AUSTRIA	LILW-SL and LL (in case of alpha nuclides in the ashes)	173 GBq (not decay corrected)	Co-60, Cs-137, Th-232, Am-241, Ra-226Eu-154, Ag-108m	about 3500 drums	360 kg per drum on average	To be determined (Near Surface)
5	Ion Exchange Resins	DENMARK	No national classification scheme	N.A.	Charcterisation in progress	N.A.	N.A.	Other (DGR)
		ITALY	VLLW/LLW/ILW	5,57E+13	Cs137, Fe55, Co60, Sr90, Am241, U238, Pu239, Pu240, Pu241, Ni59, Ni63	1,24E+02	1,81E+05	Near surface/Other
		GREECE	VLLW/LLW	2,50E+08	Cs137, Ag-108m, Co60, Eu-152	1,60E+01	1,58E+04	Near surface
		NORWAY	LLW/ILW	N.A.	Cs137, Fe55, Co60, Sr90, Am241	N.A.	N.A.	Near surface
		NETHERLAND	ILW & LLW		Cs-137. Sb-125, Cd-109, Co-60, Sr-90, Ni-63 Fe-55	3,80E+00	1,81E+04	Other (GDF)
6	Solid Organic waste	DENMARK	No national classification scheme	N.A.	Charcterisation in progress	N.A.	N.A.	Other (DGR)
		ITALY	VLLW	2,93E+08	C14, H13, Am241, Co60, Cs137, Eu152, Eu154, Ni63, Pu241	1,85E+01	5,62E+03	Near Surface
		NETHERLAND	LILW		PVC the problem, not the nuclides, which varies	few cubic meters,		Other (GDF)
7	Liquid Organic Waste	ITALY	VLLW/ LLW/ ILW	2,27E+11	U234, U235, U238, Cs137, Sr90, Ra228, Th228, Th232, Am241, Pu239, Pu240, Pu241	9,26E+00	3,86E+03	Near surface/Other
		NETHERLAND	LLW		C-14, Fe-55, H-3,Cl-36, Cd-109, Co-60, Sr-90, Cd-113m, Ni-63, Sb-125, Eu-154	4,36E+01	4,36E+04	Other (GDF)
		NORWAY	ILW	Unknown	Uranium, actinides (Am241, Pu239, Pu240, Pu241) and fission products Cs-137, Sr 90 etc. ?	3,00E-01	3,00E+02	Other
8	Graphite	DENMARK	As above	Not compiled	Charcterisation in progress	Not compiled	ca. 19 t	Other (DGR)
		ITALY	ILW	3,00E+14	C14, H3, Co60, Cs137, Cl39, Fe 55	1,61E+03	2,11E+03	Other
		GREECE	VLLW/ LLW/ ILW	4,50E+10	H3, C14, Co60, Cl36, Eu152, Eu154, Fe55	3,80E+00	6,10E+03	Other (possibly multi-purposes borehole)
		NORWAY	ILW	?	C14, H3, Co60, Cs137, Cl39, Fe55	?	?	Near surface/Other
9	Metals	ITALY	ILW	3,41E+14	Am241, Co60, Cs137, Ni63, Pu238, Pu239, Pu240, Pu241, Sr90	9,00E+01	3,38E+04	Near surface/Other
		GREECE	VLLW/ LLW/ ILW	N.A.	Co60, Ni63, Fe55, Cs137, Sr90, Pu238, Pu239, Pu240, Pu241	2,00E+01	–	Near surface/ Other (possibly multi-purposes borehole)
		NETHERLAND	ILW & LLW		Co-60, Ni-63 Fe-55			Other (GDF)
10	Alfa Bearing Solid Waste	DENMARK	No national classification scheme		Charcterisation in progress	Not compiled		Other (DGR)
		GREECE	LLW/ ILW	N.A.	Ra-226, Pu-238, Pu-239, Pu-240, Pu-242	1,00E+02	N.A.	Near surface/ Other (possibly multi-purposes borehole)
		NORWAY	LLW/ILW	N.A.	Uranium radionuclides, actinides (Am241, Pu239, Pu240, Pu241) and fission products Cs-137, Sr 90 etc. ?	N.A.	N.A.	Near surface/Other
		ITALY	ILW	1,79E+13	Pu238, Pu239, Pu240, Pu241, Pu242, Th232, U235, U238, Am241	3,21E+02	1,12E+05	Other
		NETHERLAND	LLW, ILW, HLW (depending on enrichment)		U,Pu, Under research	enrichment> 5%-100% = 0,18 m3	5,30E+01	Other (GDF)
11	Reactive metals	DENMARK	No national classification scheme	N.A.	Charcterisation in progress	Not compiled	Not available	Other (DGR)
		NETHERLAND	LILW		under research	NA	NA	Other (GDF)
12	Chemotoxic Material	DENMARK	No national classification scheme	N.A.	Charcterisation in progress	Not compiled	Not available	Other (DGR)
		ITALY	VLLW/LLW	5,32E+08	Ni63, Co60, Cs137, Sr90	5,10E+01	1,52E+04	Near Surface
		NORWAY	LLW	N.A.	N.A.	N.A.	N.A.	Near Surface
		GREECE	VLLW/ LLW/ ILW ?	3e12 long lived, 4,5E13 short lived and 6E14 H-3	Fe-55, Ni-63, Co-60, Mn-54, H-3, Be-10, Ni-59, Ag110m, Ag108m, Cd109	6,80E-01	6,57E+03	Near surface/Other (possibly multi-purposes borehole)
		NETHERLAND	HLW		under research	small		Other (GDF)
13	Liquid waste	CROATIA	LLW	N.A.	Co60, Cs137, Eu152	N.A.	4,80E+02	Near Surface
		ITALY	LLW/ILW	1,89E+12	C14, H3, Cs137, Eu154, Ni63, Pu238, Pu239, Pu240, Pu241, Am241, U235m	2,75E+00	1,12E+03	Near Surface/Other
		NORWAY	LLW/ILW	N.A.	Uranium, actinides (Am241, Pu239, Pu240, Pu241), activation and fission products Cs-137, Sr 90, Co60, etc. ?	N.A.	N.A.	Near Surface

Tabella 1 - Waste streams collected in task 1 for country

3 TASK 2

The aim of Task 2 was to derive a common minimum set of WACs to be respected by the legacy VLLW-LLW streams for a near-surface disposal [R2].

The objective had been achieved by:

- Gathering available information about WACs of near-surface disposal facilities.
- Establishing a minimum set of WACs for the legacy VLLW-LLW streams.
- Analyzing the methodologies for deriving the relevant measures (to be explored and described in Task 4).

Available information has been gathered about the main physico-chemical-radiological WACs currently applied to VLLW-LLW for disposal in operating near-surface repositories and preliminary WACs already in place in countries with a planned near-surface repository.

These WACs have been compared and benchmarked for establishing a set of WACs representing the minimum mandatory quality requirements to be complied by the legacy VLLW-LLW streams for disposal.

The methodologies to be put in place or to be employed for deriving the relevant measures have been analyzed in the Task 4 of the project.

A questionnaire was arranged and circulated among the same task 1 countries.

Answers to the questionnaire were received from two countries; therefore, further information about WACwas obtained from other sources, such as the documentation of some international working groups or other free published documentation. At the end of the search, information was collected from 18 Countries.

The collected WACs were grouped into four groups, radiological, chemical, physical and mechanical.

What comes out from the analysis is that many countries have similar WACs, despite differences in production, waste and disposal facilities. This is because the main points for long-term safety in the management of radioactive waste repositories are the same.

From the collected data can be deduced that there must be a good knowledge of the radiological and chemical content of the waste; even before thinking about any treatment, waste must be adequately characterized and classified. Suitable techniques must therefore be identified to carry out such operations.

As regards to the radiological aspect, it is important to identify a list of main radionuclides to be measured and possibly limited in the waste packages.

With regard to the chemical aspect, it is important to identify any substance that is harmful to the stability of the packages and tomake sure that it is not present in the waste or it is adequately treated.

As regards to the mechanical aspect, it is necessary to define the minimum quality requirements of the conditioning matrix, the container and the waste package.

It is, therefore, important to develop procedures that enable the radiological and chemical characterization of the waste and the determination of a disposal strategy that allow for the final safe disposal of the legacy waste.

If the waste has already been treated, it is important to carry out an adequate radiological characterization or to identify procedures that permit to identify the relevant parameters, even indirectly, to demonstrate that the waste already treated is in any case acceptable for the final disposal.

The possible methodologies for measuring each aspect have been verified in task 4.

A table that resumes the proposed minimum set of WAC/Safety Aspect to be verified in order to perform a Legacy Waste Characterization (in appendix A are reported WAC collected) follows below.

PARAMETRS AND CHARACTERISTICS TO BE CHARACTERIZED FOR WAC DEFINITION

Parameter / Characteristic	Description	Limit		
		Package	Repository Unit	Total Repository
Radiological Characteristics				
Classification	The classification must be indicated in order to understand the categories of waste that each country assigns to surface disposal. This helps to understand if there can be a common waste management in different countries			
Radionuclide and radiological limits	Each radionuclide that can be accepted for surface disposal, whose radiological relevance has been derived from any safety analysis, carried out for the disposal plants, must be indicated for single packages (Bq/g), disposal unit (Bq/g) and repository (Bq)	Bq/g	Bq/g	Bq
Fissile e Fissionable Materials	For single package, Fissile and fissionable elements must be quantified (g)	g	g	
Sources	For single package, the presence of sources must be indicated, in terms of: - activity associated with each radionuclide; - number of sources. Dimensional category (small, medium, great) should be defined - mix of different sources (different radionuclides)	Bq	Bq	
Dose Rate	The dose rate resulting from the radiological content of the package must be indicated	mSv/h (Contact, at a 1 m)		
Surface Contamination	The surface contamination value must be indicated for each packges	Bq/cm^2		
Heat	The heat potentially generated by the radiological content of the package must be indicated	W/m^3		
Other				
Chemical Characteristics				
Organic material	Organic materials can lead to a degradation of the conditioning matrix and of the manufactured article. The quantity for each packages must be limited	Grams or Volume %		
Hazardus/Toxic material (Heavy Metals, Volatives, Pesticides)	Dangerous elements can determine health impacts on the population depending on the total quantity disposed of in the deposit. The quantities for each individual packages must be indicated, in order to be able to verify compliance with the total authorized limit for the repository system	g		g
Explosive materials	Explosive materials can destroy the enginnered barriers	NO Explosive		
Flammable materials	Flammable materials can destroy the enginnered barriers	NO Flammable		
Materials that produce gas	Gaseous waste or materials that can produce gas can induce pressures such as to damage the conditioning matrix and the package. These materials may be forbiden or allowed in small quantities	No gas or g - %		
Corrosive elements	The corrosive elements can induce degradation of the conditioning matrix and of the package. They must therefore be restricted in any package	Grams or Volume %		
Reactive elements	The reactive elements can induce degradation of the conditioning matrix and of the package. They must therefore be forbiden (strong reactive elements) or restricted in any package	No strong Reactive elements Grams or Volume % for Reactive elements		
Complexing agents	The complexing elements can favor the leaching of radionuclides. Their quantity must therefore be limited in each packahge	Grams or Volume %		

Chelating agents	The chelating elements can favor the leaching of radionuclides. Their quantity must therefore be limited in each packahge	Grams or Volume %		
Fermentable elements	Fermentable substances can generate gases or voids within the package. Their quantity must therefore be limited for each package	Grams or Volume %		
Putrescible elements	Materials made from animal remains. They can generate voids inside the package as a result of their disintegration, with the consequent formation of substances that can lead to a degradation of the conditioning matrix. They can also carry a bacteriological and viral risk.	No Putriscibile or Special Treatment		
Oxidizing elements	The oxiding elements can induce degradation of the conditioning matrix and of the package. They must therefore be restricted in any package	Grams or Volume %		
Biological	They can carry a bacteriological and viral risk	No Biological		
General				
Mechanical Characteristics				
Conditioning process	The conditioning process (Solution adopted to isolate radioactivity) must be defined in terms of: matrix used for conditioning, type of conditioning (homogeneous or heterogeneous), use of high integrity container with shielding capacity for gamma irradiation or isolation for beta / alpha contamination	Qualitative		
Qualification of the conditioning process	The conditioning process must be qualified. This means that the waste matrix (conditioning and waste matrix), container and product must be tested with specific tests in order to ascertain their long-term stability. Some examples of tests that can be performed are: - **waste matrix:** Compressive Strength, Thermal Cycling, Radiation Resistance, Biodegradation Resistance, Immersion, Fire Resistance, Permeability, Gas permeability, Leaching rate - **Container**: Resistance to degradation, Tightness - **Package**: Stacking, Lifting, Free liquids, Gas generation.	Specific limit for each test.		
Physical Characteristics				
Solid Waste	The waste must be described in order to choose the methodologies / techniques to be used to verify its characteristics. The description must concern the physical characteristics, the product category, the mix of different materials. Materials that are not radioactive waste (which could dilute the contamination) and any screens should be excluded			
Liquid Waste	Liquid waste is not accepted. They have to be treated (if necessary) and conditioned			
Container	The container must have structural and physical characteristics such as to guarantee the containment of the waste, help protect against the radiations emitted and promote mobility. Some aspect to be considered are: Materials, Geometry and Dimensions, Realease of gas, Resistance to degradation, Decontaminability			
Package	The product must demonstrate that it has chemical, physical and mechanical characteristics such as to guarantee compliance, over time, with a minimum set of requirements. Some of these can be: Mass, Outdoor dose rate, Absence of free liquids, Homogeneity of the waste form, Nuclear criticality.	Specific limit for each aspect		

Table2 - minim set of WAC/Safety Aspect proposed to be verified in order to perform a Legacy Waste Characterization

4 TASK 3

It was not developed due to lack of data.

5 TASK 4

This task's goal was to determine the necessary characterization data of the main Legacy Waste streams [R2].

The task 4 steps were:

- Checking the availability of characterization data of the Legacy Waste for acceptance to disposal;
- Looking at technologies and approaches for deriving the missing characterization data;
- Formulating early indications to waste producers to allow for the implementation of treatment/conditioning processes for generating waste packages in line with WACs and properties defined in Task 2.

Legacy waste characterization is, indeed, one of the pivotal challenges among the countries managing this type of waste. Moreover, an incomplete waste characterization forces to rely on unduly conservative assumptions, which are costly; on the contrary, a characterization correctly performed in the early period of waste lifecycle guarantees a better accuracy and is cost saving.

Different types of legacy waste generally share common features, such as the treatment processes, the properties of material used for conditioning or the radionuclide types and concentrations.

Moreover, little information is available about non-radiological hazards and about possible damages caused by long storage, as the initial waste features have changed over time because of physic-chemical (and biological) degradation processes, as well as radioactive decay.

The lack of information, due to poor or absent documentation, represents an important criticality for future management of this kind of waste.

However, it is important to precisely define their characteristics, to satisfy current regulatory requirements, and checking compliance with WAC of storage and disposal facilities. Therefore, it is necessary to evaluate the possible techniques and methodologies that have to be applied to gain the missing information.

The survey performed within the activities of the task 1 provided evidence of different types of legacy waste related to different ERDO member countries. In particular, the work has highlighted the main 9 waste streams (disused sealed radioactive sources, mixed waste, powdery waste, sludge, ion exchange resin, liquid organic waste, graphite, alpha bearing solid waste, chemotoxic materials) in which the legacy waste may be grouped, which share similar features.

On the other hand, in addition to a comparative analysis among the various waste streams of the various countries, carried out in task 1 of the project, the results of the task 2 activity were also examined for defining a common characterization methodology.

At the end of the analysis most suitable characterization techniques were suggested (table 3).

The selection of the most appropriate radiological characterization techniques depends mainly on the type of waste, its physical phase, the possible presence of fissile or fertile material, the package size and geometry, the objective of characterization and the waste management strategy, the legislative and regulatory framework. A combination of radiological techniques guarantees the most efficient approach for the best characterization of any waste. A limitation in radiological characterization regards the possibility to assess the type and quantity of the hard-to-measure-radionuclides (roughly defined as radionuclides with little-to-none gamma emission); in this case, if destructive characterization techniques cannot be adopted, they can be indirectly calculated by means of the scaling factors ratio, based on the relationship between key gamma-emitters and hard-to-measure-radionuclides, whose ratio is characteristic of the specific plant or installation.

The goal of the physic-chemical characterization (as the radiological characterization) is assessing the source term of the waste, to verify compliancy with acceptance criteria and then to ensure that it is compatible with the management and disposal process as well as assuring their safety during the operations. The physical-chemical characterization regards all the aspects that have a role in the safety behaviour of the waste.

Some parameters of interest are:

- Density (determination of voids and waste distribution);
- Water content;

- Elemental composition;
- Organic molecules.

In the following table are shown some of the characterization techniques proposed:

Characterization purpose	Quantity	Characterization type	Applicability	Technique
Radiological	Gamma-emitter radionuclides	Non destructive	All waste	ISOCS
	Gamma-emitter radionuclides	Non destructive	All small size waste	LabSOCS
	Pu and U isotopic ratios	Non destructive	All waste	MGA
	Gamma-emitter radionuclides	Non destructive	Drums	OG, SGS, TGS
	Fertile material	Non destructive	All waste	Passive neutron counting
	Fissile material	Non destructive	All waste	Active neutron counting
	ha-emitter radionuclides	Destructive	All waste potentially contaminated by alpha-emitters; not applicable to sealed radioactive sources	Alpha spectrometry
	Alpha- and beta-emitter radionuclides	Destructive	All waste potentially contaminated by alpha- and beta-emitters; not applicable to sealed radioactive sources	LSC
	X-ray emitters; EC-decaying radionuclides (e.g., ^{55}Fe, ^{59}Ni, ^{99}Mo)	Non destructive	All waste	X-ray spectrometry
Physical	Density	Non destructive	All waste	Mass and volume
	Density distribution	Non destructive	All waste	Radiography, gammagraphy

Characterization purpose	Quantity	Characterization type	Applicability	Technique
	Density distribution	Non destructive	Drums	Transmission tomography
Chemical	Water content	Destructive	All waste; not applicable to sealed radioactive sources	Karl-Fisher
	Elements	Destructive	All waste; not applicable to sealed radioactive sources	AES
	Isotopes	Destructive	All waste; not applicable to sealed radioactive sources	MS
	Organic Compounds	Destructive	All waste; not applicable to sealed radioactive sources	GC-MS

Table 3: Summary of most suitable characterization techniques suggested for ERDO counries legacy waste. Full acronym definitions are reported in R3.

6 CONCLUSIONS

During the ERDO-LWC working group two surveys and consequent research and analysis have been performed among ERDO and non ERDO members countries.
At the end of this project, it is evident that legacy waste is a common issue in ERDO countries; a better knowledge of this type of waste and a mutual sharing of the relevant and common issues are important results of the developed work.
The main issues highlighted for the legacy waste were found in the characterizations and in the treatment options as well as in the lack of knowledge, especially on chemical characteristics for this type of waste.
At the end of the project, 3 deliverables have been published.

It is possible to deduce that the crucial issues are: characterization, classification, and treatment procedures with reference to the WAC. Therefore, having an available list of shared international recognized WAC could be useful for radioactive waste management, especially in those countries that have not yet developed a disposal program. The ideal

solution would also be to perform characterization operations in a time as close as possible to the production of the waste.

The main aim of the project was to identify a minimum set of WAC that can be a reference for those countries that have not yet developed their own list of WACs. The identification of some waste characterization techniques, useful to evaluate the waste characteristics and to verify compliance with the WAC, can be a starting point for implementing a multilateral info exchange and agreement among organizations managing similar waste streams. In the future, this could favour the development of a shared multinational disposal facility.

7 REFERENCES

[R1] DN SM 00117- ERDO-WG - LWC project – Task1 Report on main Legacy Waste streams in the interested countries;

[R2] DN SM 00120 - ERDO-WG - LWC project – Task2 – Minimum set of WACs for near-surface disposal of VLLW-LLW;

[R3] FSN FISS (01) 2022 – Legacy Waste Characterization project – Task 4: Characteriztion techniques of radioactive legacy waste.

ANNEX A: TASK 2 RESULTS

RADIOLOGICAL WAC and SAFETY ASPECTS

COUNTRY	FACILITY	STATUS	Classification	Radionuclide and radiological limits	Fissile e Fissionable Materials	Sources	Dose Rate	Surface Contamination	Heat	Other
Australia, Sandy Ridge	Near Surface Disposal Facility, LLW (+ NORM+ chemical)	?		**Individual Radionuclide Activity Concentration for:** - Bulk NORM Waste (Bq/g); - sealed sources (Bq/kg)		Sealed sources will, upon receipt, be stored in the radioactive waste warehouse, unpacked, inspected and verified. After verification, sources will be secured in a 60 L drum inside a 200 L drum. Cement slurry will be added to the 60 L drum to fill all the void spaces and to cover all the items. The cement filled 60 L drums will be placed in the centre of a 200 L drum, which will then be filled with concrete or equivalent materials.	**Dose rate requirements for ILW and LLW transport packages are:** - Non-exclusive use: restricted to ≤ 2mSv/h on surface, and ≤ 0.1mSv/h at 1 meter. - Exclusive use: restricted to ≤10mSv/h on surface, and ≤0.1mSv/h at 1 meter.	**Waste package surface contamination:** - 4 Bq/cm2 for β/γ emitting radionuclides; - 0,4 Bq/cm2 for α emitting radionuclides.		
Belgium	Dessel, LILW	Licenced		28 essential RN's Ra-226 + Th-232 ≤1 Bq/g	Fissile material (criticality risk + safeguard)					
Bulgaria										
Canada, Ontario	Near Surface Disposal Facility, LLW	Planned		**Limits for Bulk Waste & Non-Leachate Controlled Packaged Waste:** - 100 Bq/g for α radionuclides - 1.000 Bq/g for long-lived β/Y radionuclides (t1/2 > Cs-137) - 10.000 Bq/g for short-lived β/Y radionuclides (t1/2 ≤ Cs-137) - 100.000 Bq/g for H-3 **Limits for Leachate Controlled Packaged Waste:** - 400 Bq/g for α radionuclides - 10.000 Bq/g for long-lived β/Y radionuclides (t1/2 > Cs-137) - 10.000 Bq/g for Cs-137) - 10.000 Bq/g for Sr-90 - 10.000.000 Bq/g for H-3	Limits for Special Fissionable Material in Waste Placement Highly water soluble forms of Special Fissionable Material shall not be accepted for disposal.			External non-fixed surface contamination on Waste Packages must be less: - 3,7 Bq/cm² for β/γ emitting radionuclides; - 0,37 Bq/cm² for α emitting radionuclides.		
Croatia	To be defined	In study	LLW containing radionuclides with a half life less than 30 years	Alpha emitter activity is limited to 4.000 Bq/g			**Dose rate:** - Surface < 2 mSv/h - At 2 m distance < 0,1 mSv/h	**Waste package surface contamination:** - 4 Bq/cm² for β/γ emitting radionuclides; - 0,4 Bq/cm² for α emitting radionuclides.		LILW must have radiation stability so cumulative dose ≤ $10^6 - 10^7$ Gy

COUNTRY	FACILITY	STATUS	Classification	Radionuclide and radiological limits	Fissile e Fissionable Materials	Sources	Dose Rate	Surface Contamination	Heat	Other
Czech Republic	Litomerice	Operational		**Activity of unsolidified waste in a double overpacks and solidified RAW in a simple overpacks (Bq):** - H3 = 2.0E+12; Sr90 = 3.0E+11; Cs137 = 3.0E+10. - C14 = 6.0E+09; Cl36 = 2.0E+08; Tc99 = 1.0E+08; I129 = 4.0E+06. - Long Lived Alpha emitting Rn = 2.0E+07 **Activity of solidified waste in a double overpacks (Bq):** - H3 = 1.0E+13; Sr90 = 3.0E+11; Cs137 = 1.0E+11. - C14 = 3.0E+10; Cl36 = 1.0E+09; Tc99 = 5.0E+08; I129 = 2.0E+07. - Long lived Alpha emitting Rn = 1.0E+08 **The activity of lump RAW (Bq/kg):** - H3 = 3.0E+09; Sr90 = 1.0E+08; Cs137 = 1.0E+08; - C14 = 1.0E+07; Cl36 = 3.0E+06; Tc99 = 1.0E+05; I129 = 1.0E+04; - Long-lived Alpha emitting Rn = 3.0E+04				**Waste package surface contamination:** - 0,3 Bq/cm2 for β/γ emitting radionuclides. - 0,03 Bq/cm^2 for α emitting radionuclides;		
France	l'Áube, LILW, near surface	Operational		The radionuclides of which the total quantity (Bq) and the quantity per package (Bq/g) accepted for disposal is limited, was: 3H, 14C, 22Na, 36Cl, 41Ca, 54Mn, 55Fe, 59Ni, 60Co, 63Ni, 65Zn, 79Se, 90Sr, 93Zr, 93Mo, 94Nb, 99Tc, 106Ru, 107Pd, 108mAg, 119mSn, I25Sb, 129I, 134Cs, I35Cs, 137Cs, 144Ce, 147Pm, 152Eu, 204Tl, 210Pb, 227Ac, 234U, 237Np, 238U, 238Pu, 239Pu, 240Pu, 241Am, 241Pu,						
Germany	Konrad, LLW, near surface	Operational		Limits on radiation activity (total alpha and total beta activity, activity for a series of radionuclides plus U-total, Pu-total activities)			Gamma & neutron dose rate at container surface and 1m distance		Total heat-power per container and container-averaged heat decay constant.K15	
Hungary	Püspökszilágy	Operational		**Maximum activity-concentration (Bq/drum):** 3H = 7.32E+13, 14C = 5.58E+12, 36Cl = 5.20E+09, 54Mn = 1.34E+11, 55Fe = 1.01E+12, 58Co = 2.80E+12, 59Ni = 5.70E+12, 60Co = 1.99E+10, 63Ni = 2.40E+12, 90Sr = 1.72E+10, 94Nb = 2.34E+10, 99Tc = 3.24E+11, 110mAg = 4.46E+11, 124Sb = 2.02E+11, 129I = 2.62E+09, 134Cs = 1.03E+10, 137Cs = 1.36E+10, 141Ce = 2.80E+13, 144Ce = 2.80E+13, 234U = 1.02E+10, 235U = 4.36E+10, 238U = 2.94E+10, 238Pu = 1.28E+10, 239Pu = 1.14E+10, 240Pu = 2.80E+11, 241Am = 1.42E+10, 242Cm = 2.22E+11, 243Am = 1.41E+10, 244Cm = 2.30E+10 **Limit the activity concentration of individual waste packages:** - for isotopes with half-lives of 5-6 years < to the upper limit of intermediate level waste category - for isotopes with halsf-lives of 6-30 years < 5*10^6 Bq/g.+ **Average concentration for the whole facili**ty < of the limit of low-level wastes category.			Contact dose rate < 10 mSv/h on the drum's surface	**Surface contamination of an overpack with RAW must not exceed:** - 4 Bq/cm^2 for β/γ emitting radionuclides; - 0,4 Bq/cm^2 for α emitting radionuclides.	If the heat generation is higher than 20 W/m3, the effects must be analysed	

COUNTRY	FACILITY	STATUS	Classification	Radionuclide and radiological limits	Fissile e Fissionable Materials	Sources	Dose Rate	Surface Contamination	Heat	Other
Italy	Near Surface disposal facility (for VLLW and LLW)	In study	The classification include: - VLLW (Short lived Rn total A < 100 Bq/g) - LLW (short lived Rn with A < 5 MBq/g and long lived Rn with A < 400 Bq/g) - ILW (short lived Rn with A > 5 MBq/g and long lived Rn with A > 400 Bq/g) - HLW (spent fuel or vitrified fuele reprocessing residue) No classification for radioactie sealed sources	**At the near surface disposal facility will be accepted only waste packages with activity concentration of radionuclides:** - short lived (with half life < 31years) <= 5 MBq/g - long lived (with half life > 31years) <= 400 Bq/g - Ni59/Ni63 <= 40 kBq/g		Disused sealed sources disposal will have to be assessed on a case-by-case basis	**Dose rate:** - on surface < 2 mSv/h - at 2 m distance < 0,1 mSv/h	External non-fixed contamination levels on the Transport Container at the time of consignment shall be as low as reasonably practicable and in any case, not more than: - 0.4 Bq/cm^2 for all α-emitting radionuclides - 4 Bq/cm^2 for all other radionuclides	At the repository will not be accepted heat producing waste	
Iran				In the near surface disposal facility, it is not permitted to dispose High-level and long-lived waste						
Lithuania	LILW near surface facility		Radioactive waste are classified in: - VLLW-SL (Class A) - LILW-SL (Class B + C) - LILW-LL (Class D + E) and Spent Sealed Sources (Class F)							
Poland	Rozan	Operational		Radiological parameters in WAC are specified the radionuclide composition and characteristics (very low and low level waste; short and long-lived radionuclides)			Maximum gamma dose rate on the surface of packaging and at the 1 m distance	Unbounded contamination on the packaging surface.		
Romania	Cernavoda	Operational		Max limits are imposed for a list of individual radionuclides.	Radioactive waste containing fissile radionuclides are not accepted for disposal.		Contact gamma dose rate is limited by the transport norms and for operator safety.	Surface removable contamination of the waste packages is limited by the transport norms and for operator safety.		
Slovakia	Mochovce, near surface LILW	Operational		Basic limitations on the acceptability of waste for near surface disposal include the specific activities and total quantities of radionuclides in the waste as they were determined on a basis of sitespecific long term safety assessment for the following 19 nuclides: 1l4C, 41Ca, 59Ni, 63Ni, 79Se, 90Sr, 93Mo, 93Zr, 94Nb, 99Tc, 107Pb, 126Sn, 129I, 135Cs, 137Cs, 15lSm, 238Pu, 239Pu and 241Am. Short term safety assessment (handling, transport) was performed for next three nuclides: 3H, 55Fe and 60Co.						
Spain	El Cabril, LILW	Operational		**Level 1 (Bq/g):** - Total alpha < 1.85 *10^2; - 3H < 7.4*10^3; 60Co < 3.7*10^3; 137Cs < 3.7*10^3; **Level 2 (Bq/g):** - Total alpha < 3.7 *10^3; - 3H < 1*10^6; 60Co < 5*10^7; 137Cs < 3.3*10^5						

COUNTRY	FACILITY	STATUS	Classification	Radionuclide and radiological limits	Fissile e Fissionable Materials	Sources	Dose Rate	Surface Contamination	Heat	Other
Switzerland										
United Kingdom (combustible waste treatment)	Drigg	Operational		**Activity Limits for Combustible Waste Packages are for acceptance:** - Alfa < 0,5MBq; C14 < 3.000 MBq; H3 < 40.000 MBq; - All other Beta/Gamma < 10MBq. **Activity limits for likely to be accepted are:** - Alfa < 8MBq; - All other Beta/Gamma < 40 MBq. **Activity limits for maybe accepted are:** - Alfa < 15 MBq; C14 < 100.000 MBq; H3 < 100.000 MBq; - All other Beta/Gamma < 8.000 MBq. **Where waste arising from the Combustible Waste treatment service** is to be disposed of as Secondary Waste at the LLW Repository, the activity of any Waste consignment shall not exceed the following values: - 4 GBq/t for all Alpha-emitting radionuclides - 12 GBq/t for all other radionuclides		**This object are restricted**: - Sources (ceramic beads, pellets or smoke detectors); - radioactive lightening conductors; - Anti-static devices containing radiation source	The dose rate limit for a Waste Package must not exceed 7.5 µSv/h. The maximum radiation level at any point on the external surface of the Transport Container shall not exceed 2 mSv/h and 100 µSv/h at 2 metres.	External non-fixed contamination levels on the Transport Container at the time of consignment shall be as low as reasonably practicable and in any case, averaged over an area of 300 cm^2, not more than: - 0.4 Bq/cm^2 for all α-emitting radionuclides - 4 Bq/cm^2 for all other radionuclides		
United Kingdom (metallic waste treatment)				**Activity Limits for Metallic Waste Items are for acceptance:** - All Alfa < 0.5 GBq/t; - Il Beta/Gamma < 0.5 GBq/t. **Activity limits for likely to be accepted are:** - All Alfa < 1 GBq/t; - All Beta/Gamma < 10 GBq/t. **Activity limits for maybe accepted are:** - All Alfa < 4 GBq/t; - All Beta/Gamma < 12 GBq/t. **Where waste arising from the Metallic Waste treatment service** is to be disposed of as Secondary Waste at the LLW Repository, the activity of any Waste consignment shall not exceed the following values: - 4 GBq/t for all Alpha-emitting radionuclides - 12 GBq/t for all other radionuclides		Sealed Sources are restricted	The average surface dose rate of any Waste Item must not exceed 0.2 mSv/h. The maximum radiation level at any point on the external surface of the Transport Container shall not exceed 2 mSv/h and 100 µSv/h at 2 metres.	Items will be acceptable if the maximum external non-fixed contamination on surface is less than: - 5 Bq/cm^2 for all α-emitting Rn - 100 Bq/cm^2 for all other Rn. Service Supplier specific criteria may apply. Specific restrictions will be determined through the Waste Enquiry Process. External non-fixed contamination levels on the Transport Container at the time of consignment shall be as low as reasonably practicable and in any case, averaged over an area of 300 cm2, not more than: - 0.4 Bq/cm^2 for all α-emitting Rn - 4 Bq/cm^2 for all other Rn		
United Kingdom (supercompaction waste treatment)				**The Activity of any Waste Consignment consigned** for disposal as LL W at the LLW Repository shall not exceed the following values: - 4 GBq/t for all alpha-emitting radionuclides - 12 GBq/t for all other radionuclides **Some radionuclide limits:** - Waste shall not contain Th-232 in excess of 1 MBq/t. This limit may be exceeded but only on approval of a Waste Consignment Variation Form - Waste containing Am-241, Am-242m and / or Am-243 may be consigned if the Consignment does not contain more than 0.1 GBq/t of each of these radionuclides. - Waste containing Np-237 may be consignedif the Consignment does not contain more than 4 GBq/t - Waste containing plutonium may be consigned if the Consignment if the total Pu Alpha (i.e. Pu-238 + Pu-239 + Pu- 240 + Pu-242) does not exceed 0.1 GBq/t. - Waste containing U-235 may be consigned if the Consignment meets the following requirements: • All the uranium present is either natural or depleted uranium, or • The U-235 content of any Waste Consignment does not exceed 60 g						

CHEMICAL WAC and SAFETY ASPECTS

COUNTRY	Organic material	Hazardus/Toxic material (Heavy Metals, Volatives, Pesticides)	Explosive materials	Flammable materials	Materials that produce gas	Corrosive elements	Reactive elements	Complexing agents	Chelating agents	Fermentable elements	Putrescible elements	Oxidizing elements	Biological	General
Australia, Sandy Ridge				Flammable materials are excluded		Non reactive								All LLW and ILW waste packages will be chemically stable and safe for disposal in the LLW vaults. If chemicals with harmful properties are in waste, they have to be and/or limited. Dilution with non waste material has to prevented. The hazard categories which will be controlled are reactive, explosive, oxidising, corrosive, chelating, chemotoxic and hazardous properties. The requirement is to make such materials passively safe (so the waste packages do not require human actions to be safe).
Belgium	Max. 100 g of cellulose per waste drum				Maximum 12 g sulphates per kg of waste	Mass of chloride in waste ≤ 0,4 m.% of cement mass								
Bulgaria			Explosive materials: those are not allowed in the waste.	Combustibility and fire resistance: waste forms shall be packaged in such a manner and have such characteristics that the risk of self ignition is negligible.			Chemical reactivity: substances that might jeopardize the stability of the waste packages or the barrier functions of the repository are not allowed.	The complexing agents also shall be avoided as far as possible.						
Canada, Ontario		Hazardous waste are not permitted unless they are treated using methods for land disposal described in Ontario Regulation 347		Ignitable waste are not permitted unless they are treated using methods for land disposal described in Ontario Regulation 347		Corrosive waste are not permitted unless they are treated using methods for land disposal described in Ontario Regulation 347	Reactive waste are not permitted unless they are treated using methods for land disposal described in Ontario Regulation 347 Fluorine, Magnesium and Bismuth are restricted to ≤ 20% by mass over a single waste unit (i.e. 1500 kg). Beryllium, Deuterium and Graphite are restricted to ≤ 0.1% by mass combined over a single waste unit (i.e. 1500 kg)		Chelating agents in waste shall be restricted to less than 0.1% by mass over a single waste unit (i.e. 1500 kg)					
Croatia	Organic material content must not exceed 3% of the package weight.	For toxic/hazardous substances, depending on the type of hazardous material the limitation should be taken from the relevant regulations.	No explosive substances	Self ignitable, easy ignitable and ignitable materials are not permitted in LILW.	Depending on type of gas and mixture, limitation must be below lower limit of explosivity/ignitability	**pH value must be:** 4< pH <9 for waste form, < 11 for cement. **Corrosive materials** content must be ≤ 1% of package weight.		Chelating and complexing agents must be: ≤ 0,1% package weight						
Czech Republic														
France														

COUNTRY	Organic material	Hazardus/Toxic material (Heavy Metals, Volatives, Pesticides)	Explosive materials	Flammable materials	Materials that produce gas	Corrosive elements	Reactive elements	Complexing agents	Chelating agents	Fermentable elements	Putrescible elements	Oxidizing elements	Biological	General
Germany		Chemical toxicity & hazards have to be considered		No flammble materials	No gas	Corrosion has to be controlled (humidity)								No swelling are admitted No chemical kinetics are acceptable. Nuclide vector and material vector (metallic, ceramics, rubble) have to be declared.
Hungary					Gas generation Hydrogen and other explosive gases organic and elementary gases: Pressure higher than 0.5 bar cannot occur	Corrosive materials: Less than 1% weight		Chelating and complexing agents: Max. 0.3% of the waste being conditioned						
Italy		Inventory of the CMR substances (carcinogenic, mutagen, toxic for reproduction) present in the waste is needed	Waste shall not contain strong reactive retails, explosive, strong oxidising agents, pressurised gas receptacles and aerosols, ion exchange material biological, pathogenic or infectious materials. Quantities of this materials must be limited for waste package: complexing and chelating agents, organic, powders, fibers and ceramics, oils and paraffins, absorbent materials, soluble											
Iran		Chemical substances of toxic characteristics, corresponding to class (extremely hazardous) and class II (highly hazardous) of hazard;	Conditioned waste packages shall not contain Substances capable of detonation or explosive decomposition;	Conditioned waste packages shall not contain Flammable and explosion and fire hazardous substances;	Conditioned waste packages shall not contain Substances that contain or are capable of generation gasses, vapours or sublimates resulting in loss of integrity of engineering barriers	Conditioned waste packages shall not contain Corrosion active substances of concentration that may result in corrosion destruction of containers, disposal cells and other components of the waste NSF	Conditioned waste packages shall not contain Substances, entering into exothermic reaction with water, that is accompanied by the explosion	Conditioned waste packages shall not contain Substances forming complex compounds of concentration, that may sufficiently impact on the processes of radionuclides migration into the environment				Conditioned waste packages shall not contain Strong oxidants and chemically unstable substances;	Conditioned waste packages shall not contain Poisonous, pathogenic and infectious substances, Biologically active substances	
Lithuania														
Poland	Waste containing following substances shall be stored separately from each other and from the waste: organic solvents, extractants and oils detergents in concentration exceeding 10 mg/dm^3							Waste containing following substances shall be stored separately from each other and from the waste: complexing agents in concentration exceeding 10 mg/dm3 dissolved substances and deposits with content of dry residue exceeding 10 g/dm3						
Romania	The waste that are accepted with restriction, based on a case by case decision are wood		Compounds which present alone or in contact with air or water, risks of explosion or ignition are forbidden to be disposed. The auto ignition temperature of all waste shall not be less than 300°C.		The waste that contain or are capable of generating toxic gases, vapours or smoke during transport, handing or storage are not admitted for disposal.		Compounds which present alone or in contact with air or water, risks of reaction as alkali metals, metal fines, powdery magnesium, uranium, aluminium, explosives, unstable chemicals, strong reducers (hydrazine, borohydride, fuel, alcohol, phosphorus...) are forbidden to be disposed. The waste that are accepted with restriction, based on a case by case decision are waste which react with the matrix, waste which react with water (aluminium, zinc, uranium, magnesium)		The waste that are accepted with restriction, based on a case by case decision are cholatants				Radioactive waste containing hazardous, biological (organic), pathogenic or infectious agents must be treated, conditioned and packed in such a way as to minimize the danger that would be caused by the disposal of these types of waste.	
Slovakia														

COUNTRY	Organic material	Hazardus/Toxic material (Heavy Metals, Volatives, Pesticides)	Explosive materials	Flammable materials	Materials that produce gas	Corrosive elements	Reactive elements	Complexing agents	Chelating agents	Fermentable elements	Putrescible elements	Oxidizing elements	Biological	General
Spain	RW producers sent yearly information on chemical analyses of the main components of the LLW homogeneous wet waste (evaporator bottoms and sludge). This information will assure the waste meets following limitations or must notification: - organic substances: EDTA, NTA, DTPA, TTHA, oxalates, citrates, acetates, TBP, ethylene, diamine...etc., others like sulfonates; - organic liquids conditioned by incorporation into a solid matrix of hydraulic binder, should not contain organic liquids above 3% by volume of matrix.	An inventory of the toxic substances present in the storage is needed, and the producers must submit to ENRESA annually, the contents of the following elements: lead, copper, aluminium and asbestos.	Explosive material are forbiden	Easily flammable or flammable Material are forbiden	Waste with animals have to be treated to prevent the generation of gas Waste with gas (neon tubes, non-empty aerosols, etc.) are forbiden	Corrosive material are forbiden.	Pyrophoric or strongly reactive metallic materials (magnesium powder, sodium or sodium alloys).	RW producers sent yearly information on chemical analyses of the main components of the LLW homogeneous wet waste (evaporator bottoms and sludge). This information will assure the waste meets following limitations or must notification accelerators of leaching processes: the producer will identify, before packaging, waste containing complexing agents above 8%, such as chlorides, fluorides, nitrates, sulphates, carbonates;		Fermentable materials are limited above 3% by total mass of the batch of packages (WAC specific for VLLW), or 10% by individual package (both types)	Waste with animals have to be treated to prevent the generation of gas.	Oxidizing material are forbiden.	Infectious products are forbiden.	
Switzerland														
United Kingdom (combustible waste treatment)	**There is a list of solid materials that are restricted**: PCBs, **There is a list of solid materials that are provisionally acceptable**: Plastics (halogenated including PVC); Rubber; Grease	There is a list of solid materials that are restricted: Toxic materials (including mercury, PCBs, cyanides); Asbestos; Metal (including steel, lead, chromium, cadmium, mercury, beryllium, uranium metal, thorium metal).	Pyrophorics or explosive substances including free sodium are restricted		Pressurised gas receptacles or aerosols are restricted						Putrescent material including carrion are provisionally acceptable		Biological, Infectious or Pathogenic materials, are restricted.	**There is a list of solid materials that are restricted**: Concrete; Blasting materials (including sand, grit, glass, beads, pearls); Materials with sharp edges such as knives, glass, needles; Luminous items. **There is a list of solid materials that are provisionally acceptable**: Filters; Graphite; Cables and thin gauge metals; Fibreglass, Mineral wool; Halogenated waste; Ion exchange resins; Mud (non-pumpable).
United Kingdom (metallic waste treatment)	Non-metallic materials such as rubber; plastic or other organic materials are restricted	Toxic and hazardous materials and wastes (as Mercury and asbestos) are restricted	Explosives are restricted.	Self-igniting are restricted.	Pressurised containers e.g. redundant gas bottles and fire extinguishers are restricted.		Reactive metals or materials are restricted.	Complexing agents are restricted.	Chelating agents are restricted.		Putrescible Waste are restricted.	Strong Oxidising Agents are restricted.	Biological, Infectious and Pathogenic Materials are restricted.	**There is a list of solid metalic materials that are restricted**: Zinc galvanised metal **There is a list of solid non metalic materials that are restricted**: Soluble Solids; Bituminous or other linings; Boron; Armoured cables; Pyro-cables and cables containing tensioning wires; Ion exchange resins; organic as well as inorganic resins; Cans of paint; grease; aerosols.
United Kingdom (supercompaction waste treatment)		Materials that are likely to, or actually, possess one or more Hazard Properties shall be assessed and where present be excluded from the waste or made safe prior to any conditioning or mixing with other materials. Customers should use process knowledge to demonstrate that materials do not contain the components listed in a Table (limits for leaching tests) before resorting to material testing. For the material to be made safe, the hazards or risks shall be removed or reduced. Waste containing Hazardous Substances and Non-Hazardous Pollutants may be accepted for treatment and disposal but only on approval of a Waste Consignment Variation Form Waste containing lead may be accepted for treatment and disposal but only on approval of a Waste Consignment Variation Form	Waste shall not contain explosive material.		Waste shall not contain pressurised gas receptacles.		Waste shall not contain reactive retals.	Waste shall not contain chemical complexing agents.	Waste shall not contain chelating agents.		Putrescible Materials in the waste and, in any case, the total weight within a Waste Consignment must not exceed 1% of the total weight of waste.	Waste shall not contain strong oxidising agents.	Waste shall not contain biological, pathogenic or infectious materials.	Waste shall not contain soluble solids, ion exchange material.

MECHANICAL WAC and SAFETY ASPECTS

COUNTRY	Conditioning process	Qualification of the conditioning process
Australia, Sandy Ridge	Wasteforms (the physical form of the waste following treatment/conditioning) must be physically solid and stable, and resistant to degradation.	
Belgium	Mass of hardened cement ≥ 10 m.% of cement mass Minimum amount of conditioning mortar: 85% Immobilisation matrix unsensitive to ASR/DEF	
Bulgaria		Leaching properties have to be in accordance with the requirements for long-term safety of the repository.
Canada, Ontario		
Croatia	Treatment and conditioning technologies must be approved by the regulatory body. LILW must be evenly distributed in metal and concrete container. Heterogeneous and non conditioned LILW is not allowed to be disposed.	**Proposed value for the compressive strength of LILW for:** - waste form is 5 Mpa; - concrete container 60 MPa. **Tensile strength for:** - waste form should be 1 Mpa; - concrete container 5,5 MPa. LILW must be resistant to thermal cycles. Thermal cycles are referred to temperature differences in the range between -40 to +60°C For permeability, an orientation limit of 5x10e-18 m2 (nitrogen) is proposed. Porosity is suggested not to exceed the value of 0,5% of the RCC volume. Leachability index (LIX) LIX ≥6, za diffusion coefficient 5×10-3 cm2/day, a leachability rate 3×10e-5 g/cm2/day.
Czech Republic		
France		
Germany	All RW have to be solidified The grouting material is concrete	No leaking and no leaching are acceptable.
Hungary		Compressive strength is greater than 10–30 N/mm^2 Leaching rate: Max. 5*10-5 g/cm2 s (evaluated based on ASTM C1308-95 standard)

COUNTRY	Conditioning process	Qualification of the conditioning process
Italy		**Cement waste form qualification tests for LLW waste:** - Compressive Strength: After 28 days curing f c 5 Mpa - Thermal Cycling: After 30 cycles (+40 C ÷ 40 C) there must be no cracks and f c 5 MPa Radiation - Resistance: After an integrated gamma dose of 10^6 Gy there must be no cracks and f c 5 MPa - Biodegradation Resistance: After fungi and bacteria incubation there must be no cracks and f c ≥ 5 MPa - Immersion: After 90 days of immersion in water there must be no swelling or cracks and f c ≥ 5 MPa - Gas generation: Identification and quantification of gases produced by radiolysis or other chemical physical reactions - Fire Resistance: Incombustible or self extinguishing - Water - Permeability: Water penetration 20 mm - Gas permeability: must be evaluated - Leaching rate: Li ≥ 6 for Cs 137
Iran		
Lithuania		
Poland		The rate of leaching with distilled water of solidified radioactive waste, after 28 days of leaching in static conditions, cannot exceed the prescribed levels depending on waste classification
Romania	**No raw waste is accepted for disposal:** - Homogeneous waste has to be solidified; - heterogeneous waste has to be immobilised.	
Slovakia		
Spain	**Level 2 RW, the WAC require the assurance for activity confinement:** - for compactable waste - packages are super compacted and immobilized CE-2a container with a shield higher than 5 cm thickness of hydraulic binder (the same shield thickness is required for cartridge filters and dispersible waste; - for non-compactible waste – the gaps in packages are filled with hydraulic binder of 30 kg/cm2 compression resistance, before to be conditioned in CE-2a concrete container with a shield above 5 cm thickness of hydraulic binder; - cartridge filters and dispersible waste are immobilized in metallic containers (packages), with a shield thicker than 5 cm of hydraulic binder (250 kg/cm2 compression resistance; flex traction or indirect traction ≥ 10 kg/cm2; resistance to nuclides diffusion, values are transformed at leaching rate in aqueous medium; - wet homogenous waste (spent resins, evaporator bottoms, sludge) - are conditioned by incorporation into matrix of hydraulic binder, which need to meet specific criteria regarding the compression resistance, compression after 7 days of water immersion and, flex traction (indirect traction).	**Level 1 RW mechanical strength is limited:** - compactable waste - packages are super compacted (1,200Tn pressure) and immobilized (with hydraulic binder of 30 kg/cm2 compression resistance), in concrete container called CE-2a (7 cubic meter infernal capacity); - non-compactable waste – the gaps in packages are filling with hydraulic binder of 30 kg/cm2 compression resistance, before to be conditioned in CE-2a concrete container; - cartridge filters and dispersible waste are immobilized in metallic containers (packages), with a shield above 5 cm thickness of hydraulic binder (75 kg/cm2 compression resistance), before to be conditioned in CE-2a concrete container; - wet homogenous waste (spent resins, evaporator bottoms, sludge) - are conditioned by incorporation into hydraulic binder matrix, which need to meet specific criteria for compression resistance and compression after 7 days water immersion.

COUNTRY	Conditioning process	Qualification of the conditioning process
Switzerland		**For cemented waste:** - After hardening, waste product samples are exposed to mechanical loading. - The samples have to withstand a minimum load of 10 MPa. **Leaching**: Leach rates for the key test nuclides Co-60 and Cs-137 determined over a period of 150 days should be below 5 E-6 m/day. Tests are performed in demineralised and saturated gypsum water. **For cemented waste** - Water (and sulphate) resistance: Investigation of the stability of waste products upon water infiltration. Only when the compressive strength of the sample exposed to an aqueous medium is (still) above 10 MPa and the volume increase is less than 5% is the waste product considered water- (and sulphate-) resistant. **For bituminized and polystyrene waste**, the following information are required: Flash burning, ignition point; Softening point; Viscosity.
United Kingdom (combustible waste treatment)		
United Kingdom (metallic waste treatment)		
United Kingdom (supercompaction waste treatment)		

PHYSICAL WAC and SAFETY ASPECTS

COUNTRY	Solid Waste	Liquid Waste	Container	Package
Australia, Sandy Ridge	**For Safeguards material**: Australian Safeguards and Non-proliferation Office (ASNO) approval is required for conditioning - Safeguards material shall be available on request for international inspection.	Containers with liquid are not accepted	For ILW, including all disused sealed sources and safeguards material, container shielding can be used to comply with radiation dose requirement.	• Not have a total measured weight of more than the Safe Working Load. • Be clearly labelled with the waste owner's name and identification number and material description/name on opposite sides of the waste package. • Allow no leakage during normal transport and handling operations. • Be capable of containing all the waste whatever the orientation of the package. • Be capable of being disposed of with the waste. • Be filled so as to contain no significant voids. • Be free of ruptures at the point of delivery. • Be free of external contamination at the point of delivery. • Not significantly deteriorate during the duration of storage, transport and handling when in contact with the waste. • Remain intact during normal transport and handling procedures. • Be strong enough to be walked on if required. • For ILW, including all disused sealed sources and safeguards material, the waste package identifier will be readable for an extended period of around 50 years.
Belgium		No free liquids		
Bulgaria				
Canada, Ontario	6 types of waste based on physical properties Special Waste and Waste Electrical and Electronic Equipment (WEEE) will likely require additional processing to ensure compliance with land disposal requirements prior to placement; therefore, all Special Waste and WEEE is to be segregated from other waste streams and clearly labelled.			
Croatia	Density and weight of LILW must ensure structural stability.	Free liquid content ≤ 1% package volume.	Depends on choice of storage-disposal container. The orientation limit for weight of filled container is 15 t or ~3,5 t/m3 density. Metal containers and waste package should withstand external fire. According to IAEA recommendations for transport of LILW packages (30 min at a 800 °C temperature)	Waste packages must be labeled in accordance with the requirements of the regulatory body. Structural stability of disposal units for 300-year period must be ensured
Czech Republic				
France				
Germany		No liquid	Mass, size, centre of mass, container type/category Drop, fire, pressure, explosion, collision, resilience	Craning, stacking...

COUNTRY	Solid Waste	Liquid Waste	Container	Package
Hungary	**Homogeneity:** The waste types cannot be mixed. This can be accomplished by sorting and separately packaging the single waste types **Dust Content:** - Maximum 1 % of particles smaller than 10 µm; - Maximum 15 % of particles smaller than 100 µm.	Free liquid: Max. 1 volume%		Void volume max. 10%
Italy		No free liquids	Weight limit on waste container	**Each waste package must be equipped with a specific label / identification code (possible barcode) that allows:** 1) an easy and immediate identification of the artifact and of the waste that contains the link to more detailed waste information (including photographic); 2) the traceability of processes applied to waste. **Control of the barycenter of the waste package** **Voids for waste package must be:** - homogeneous conditioning <5% - heterogeneous conditioning <10%
Iran		Content of liquid in the package shall not exceed 3%.		
Lithuania				
Poland		Unbounded water < 1% mass		
Romania		The solid or solidified radioactive waste has to contain as less as possible free liquid (max 1% from their volume) and this free liquid has to be noncorrosive. The liquid radioactive waste has to be solidified or packaged in sufficient absorbent material that is capable of absorbing a volume twice as large as the liquid volume.		A maximum of 10 % (volume) of voids is allowed in packages.
Slovakia				
Spain	**The following material are forbiden:** - Dusty materials that are not conditioned in suitable packaging to prevent their dispersion under the handling and storage conditions; - Waste whose temperature is higher than 60° C;			

COUNTRY	Solid Waste	Liquid Waste	Container	Package
Switzerland				
United Kingdom (combustible waste treatment)	Where materials must be added to the waste, the customer shall use reasonable means to limit the quantity of non-waste materials present in a Waste Consignment. It is not acceptable to purposely dilute waste or add shielding materials for the sole purpose of achieving compliance with the requirements of WAC	**There is a list of liquid materials that are provisionally acceptable:** - Liquids containing suspended solids; - Sludge (packaged); - Borated concentrates; - Paint; - Fire resistant oils based on phosphate esters or equivalent.		
United Kingdom (metallic waste treatment)	Reasonable means shall be used to segregate Metallic Waste into the following categories within a Waste Consignment: Stainless Steel, Carbon Steel, Galvanised Steel, Cast Iron, Lead, Copper, Aluminium, Brass	Free liquids are restricted		
United Kingdom (supercompaction waste treatment)	Sharp objects and glass shall be contained within additional packaging or containment within a Waste Package such that they could reasonably be expected to remain contained during routine mechanical handling of the Waste Package and in the event of a rupture of the Waste Package during Supercompaction Waste shall not contain heavy gauge metal, such as steelwork, or other items which could reasonably be expected to offer a significant and / or non-uniform axial resistance during Supercompaction. Waste capable of generating powder or dust shall be contained in a breathable polycotton sack such that air can escape through the fabric but the powder or dust is retained during Supercompaction. The quantity of Reassertable Waste (rubber boots, gloves, plastic sheeting etc.) in each drum must not exceed 30% by volume.	Waste shall not contain any Free Liquid or liquids with flashpoint less than 21 °C, absorbed on solid materials and, in all instances, waste shall not release more than 1 % of liquid by volume during Supercompaction. Any non aqueous content of any liquid in the waste shall be conditioned, using a method approved in advance by LLW Repository Ltd, so that the volume of liquid that will be released during Supercompaction does not exceed 0.05% of the volume of the waste.		Any drums that exceed 300 kg must be clearly identified on the Waste Consignment Information Form