Preprint

STATUS AND TRENDS IN SPENT FUEL AND RADIOACTIVE WASTE MANAGEMENT

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FOREWORD

Radioactive material is used to treat cancer, monitor the quality of industrial products and generate electricity (among other beneficial uses). In common with all processes, some waste arises from these applications. The waste comprises various forms and materials, with different radioactivity levels and half-lives. Radioactive waste needs to be handled safely and eventually disposed of in a safe manner. Acceptable disposal routes depend on the level of radioactivity and established preferences and practices in different countries. Some waste contains such low levels of radioactivity that it can be released from regulatory control and disposed of as non-radioactive waste. However, for radioactive waste that presents a long term risk to people and the environment, its end point is placement in an appropriate package and disposal in a suitably engineered, multibarrier facility.

Status and Trends in Spent Fuel and Radioactive Waste Management is a collaborative project between the IAEA, the European Commission and the OECD Nuclear Energy Agency, with the participation of nuclear industry organization the World Nuclear Association, that aims to consolidate and complement the information gathered from different initiatives around the world. The objective of the Status and Trends in Spent Fuel and Radioactive Waste Management report series is to be the authoritative publication that systematically and periodically summarizes the global status and trends of programmes and inventories for spent fuel and radioactive waste management. The first report in the series was published in January 2018 [1], and covered the situation up to the end of December 2013. The second report was published in 2022 [2], and covered the situation up to the end of December 2016. This current report is the third edition and covers the situation up to the end of December 2019.

This publication provides an overview of current global inventories of spent fuel and radioactive waste, current arrangements for their management and future plans for their ultimate disposal where appropriate. Spent fuel is generated only by States operating nuclear power plants or non power reactors, whereas radioactive waste is generated in all States producing or using radioactive material in, for example, medicine, industry and research and the nuclear fuel cycle. It is the intention to update this publication at regular intervals, following the reporting schedule for the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management [3].

Institutional, organizational and technical aspects of spent fuel and radioactive waste management are explored, including: legal and regulatory systems; organization of waste management activities and associated responsibilities; and strategies and plans for ongoing management of different types of spent fuel and radioactive waste, from its generation through conditioning and storage to disposal. This publication compiles the quantities of spent fuel and radioactive waste that currently exist and explores forecasts for the coming decades. Significant trends and the corresponding challenges in the management of spent fuel and radioactive waste are also discussed.

Inventory estimates of spent fuel and radioactive waste in the world are based on information in the Spent Fuel and Radioactive Waste Information System[1] provided by 19 participating Member States. Data are supplemented by published reports to the Joint Convention. For most cases, the information provided corresponds to the end of December 2019; the data are based on information from States accounting for almost 92% of all nuclear power reactors in the world. On this basis, there is an estimated 301 000 tonnes of heavy metal (t HM) of spent fuel in storage worldwide. The current total global inventory of solid radioactive waste is approximately 32 million m^3, of which 26.6 million m^3 (83% of the total) has been disposed of permanently and a further 5.6 million m^3 (17%) is in storage awaiting final disposal. More than 92% of the volume of solid waste is classified as being very low or low level waste, with most of the remainder being intermediate level waste. In terms of total radioactivity, the situation is fully reversed, with approximately 95% of the radioactivity being associated with intermediate and high level waste.

[1] See sris.iaea.org

If naturally occurring radioactive material (NORM) is classified as radioactive waste, depending on the national waste management concept, this is usually considered to be very low level waste (VLLW) or low level waste (LLW). NORM waste is not specifically discussed in this publication, although some countries have reported NORM waste in the Spent Fuel and Radioactive Waste Information System.

It is evident that significant progress has been made globally in formulating national policies and strategies and in implementing legal and regulatory systems that define responsibilities for the ongoing safe management of spent fuel and radioactive waste. Most States expect to dispose of their waste in facilities located on their territories, with the main focus of international cooperation being on technology development. Disposal facilities for VLLW and LLW are already in operation in several countries. However, in many others, particularly those with small volumes of radioactive waste, disposal options still have to be developed. The most important remaining challenge is the development, public acceptance and long term funding of disposal facilities for high level waste and spent nuclear fuel considered as waste. Significant progress has been made in a few countries. In 2022 the construction licence for the deep geological repository (DGR) was approved in Sweden, the operational licence was submitted for a deep geological disposal facility in Finland and France recognized deep geological disposal facility as final disposal solution for high level and intermediate level long lived radioactive waste.

1. INTRODUCTION

1.1. BACKGROUND

Spent fuel and radioactive waste are by-products of the operation of nuclear reactors and related fuel cycle activities, and other uses of radioactive material in medicine, industry and research. Currently two strategies are employed for managing spent fuel from power reactors: either it is considered to be waste or it is considered to be an asset. In the latter case, additional treatment is necessary to recover uranium and plutonium, generating high level waste as a by-product. The radioactive waste comprises various forms and materials, with different radioactivity levels and half-lives.

According to IAEA guidance provided in Safety Standards Series No. GSG-1, Classification of Radioactive Waste [4], the management and disposal options for radioactive waste are dependent upon its classification: high (HLW), intermediate (ILW), low (LLW) or very low level waste (VLLW). The final disposal of the waste may range from geological disposal for HLW to near surface trench disposal for VLLW. The activity level and the nature of radionuclides in the waste, as well as waste properties, determine the conditioning needs of the waste before disposal. There are also possibilities, as the case may be, release from regulatory control.

“Status and Trends in Spent Fuel and Radioactive Waste Management” (hereafter referred to as the Status and Trends project) is a collaborative project between the IAEA, the European Commission and the OECD Nuclear Energy Agency (OECD/NEA), with the participation of nuclear industry organization the World Nuclear Association (WNA), that aims to consolidate and complement the information gathered from different initiatives around the world. The objective of this report series aims to be the authoritative publication that systematically and periodically summarizes the global status and trends of programmes and inventories for spent fuel and radioactive waste management. The first report in the series was published in January 2018 [1], and covered the situation up to the end of December 2013. The second report was published in 2022 [2], covering the situation up to the end of December 2016. This current report is the third edition and covers the situation up to the end of December 2019. The analysis presented is based on information as of December 2019 to be consistent with the information in reports submitted by 2020 under the framework of the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management (hereafter referred to as the Joint Convention) [3] and those provided to the European Commission in 2021 (if they are published by the Member States) in accordance with Council Directive 2011/70/Euratom of 19 July 2011, establishing a Community framework for the responsible and safe management of spent fuel and radioactive waste (hereafter referred to as the European Atomic Energy Community (Euratom) Waste Directive) [5]. The basic information in this publication has been collected through the submission to Spent Fuel and Radioactive Waste Information System (SRIS) and has been complemented with openly available Joint Convention National Reports. Approximately 90% of States with operating nuclear power plants submitted their data to SRIS or their Joint Convention National Reports are openly available, representing almost 92% of all nuclear power reactors in the world.

Some publications cover the subject on a partial or regional basis. The European Commission has published such information every three years since 1992 (see Ref. [6]). The OECD/NEA publishes profiles and reports about radioactive waste management programmes in member countries[2], as well as an annual Nuclear Energy Data report on nuclear power status in NEA member countries and the OECD area [7].

This publication goes further by providing an extensive overview of the management of spent fuel and radioactive waste worldwide and of the quantities involved. The volumes of different types of waste give an indication of the magnitude of the work needed for managing and disposing. A large volume

[2] See www.oecd-nea.org/rwm/profiles

does not, however, necessarily correspond to a large risk or environmental impact. In particular, when determining the potential impact of different materials and waste classes, the radioactivity content needs to be considered. Chemical and other hazardous properties of the waste also need to be considered.

1.2. OBJECTIVE

The purpose of this publication is to provide a global overview of the status of spent fuel and radioactive waste management programmes, inventories, current practices, technologies and trends. It provides overviews of national arrangements for the management of spent fuel and radioactive waste, of current waste and spent fuel inventories. Achievements, challenges and trends in the management of spent fuel and radioactive waste are also addressed. The data reported are fully dependent on the input from the Member States and by the assumptions made to transform these data into the waste classes defined by the IAEA Safety Standards Series in GSG-1 [4].

The anticipated audience for the Status and Trends publications include national policy and decision makers and their support staff, as well as professionals in the nuclear and other scientific fields who wish to get an overview of how the spent fuel and radioactive waste is handled in different countries. Although the publication is not directly written for a general audience, much of the information contained herein could be of interest to the public, including the media, researchers, educators and students.

1.3. SCOPE

This publication addresses the following: the institutional, legal and regulatory frameworks for the management of spent fuel and radioactive waste; spent fuel and radioactive waste management programmes, current practices and technologies; and spent fuel and radioactive waste inventories and forecasts. In addition, this publication provides an analysis of the trends and the achievements made in the frame of spent fuel management and radioactive waste management together with a view on the challenges that are yet to be overcome.

The publication includes all material that a Member State has declared as being radioactive waste, along with spent nuclear fuel (whether the spent fuel has been declared to be waste or not). The collection and compilation of information on spent fuel and radioactive waste reflects the different strategies for spent fuel management (open cycle, closed cycle or awaiting decision) pursued by various countries and involves several challenges, such as the use of different waste classification schemes in different countries, different statuses of waste conditioning and different stages of development of waste management systems.

The following types of radioactive materials are specifically excluded:

- Exempt waste that meets the criteria for clearance, exemption or exclusion from regulatory control for radiation protection purposes, e.g. as per IAEA Safety Standard GSG-1;
- Very short lived waste (e.g. since this is typically held for decay, then released);
- Authorized effluent releases;
- Radioactive materials and products that have not been declared radioactive waste;
- Radioactive waste from extractive industries (e.g. uranium mining, NORM) if they have not been included in the relevant national inventory;
- Waste from military/defence activities if they have not been included in the relevant national inventory; and
- Contaminated sites and related buildings, when these are not included in the relevant national inventory.

Other sources of information, in addition to the SRIS, include the following:

- Openly available National Reports to the Joint Convention, which are produced every three years in advance of the Review Meetings of the Contracting Parties. The IAEA provides the secretariat for the Joint Convention and the latest Review Meeting was held in 2022.
- Openly available National Reports to the European Commission in accordance with the Euratom Waste Directive. The latest reporting to the European Commission according to this Directive was due in August 2021.

1.4. STRUCTURE

This publication provides a global overview of current spent fuel and radioactive waste management and provides a compilation of policies, strategies and spent fuel and radioactive waste quantities on a regional and global scale. This is based on information in the SRIS supplied by the Member State or on information provided by the State in its report to the Joint Convention. Section 2 presents the relevant international legal instruments to improve the safety of spent fuel and radioactive waste management. Section 3 outlines the sources of spent fuel and radioactive waste. Sections 4 and 5 explore the frameworks for managing these and give a summary of current strategies, practices and technologies. Section 6 describes the inventories and presents future forecasts. Sections 7 and 8 provide analysis and achievements, as well as trends and challenges, and Section 9 concludes.

2. INTERNATIONAL LEGAL INSTRUMENTS AND SUPPORTING MATERIALS

There are several international instruments to ensure and improve the safe management of spent fuel and radioactive waste, and to protect people and the environment from the potential for negative effects of ionizing radiation. These instruments do include among others international conventions, standards, and peer reviews. All of them are supported by publications produced by the academic community, the organizations involved in the management of spent fuel and radioactive waste, different agreements between organizations and countries, etc. This chapter gives a short overview of the main legal instruments and supporting materials.

2.1. JOINT CONVENTION ON THE SAFETY OF SPENT FUEL MANAGEMENT AND ON THE SAFETY OF RADIOACTIVE WASTE MANAGEMENT

The Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management (Joint Convention) [3], which entered into force in 2001, highlights the importance given to spent fuel and radioactive waste management. The Joint Convention applies to spent fuel and radioactive waste created through the processes of civilian nuclear programmes, while spent fuel and other radioactive waste resulting from military or defence programmes fall under the Convention usually when they are transferred permanently to and managed within exclusively civilian programmes. As of October 2022, there were 88 Contracting Parties to the Joint Convention. The Contracting Parties meet every three years to discuss the National Reports, which are subject to a peer review process.[3] There have already been 7 review meetings, the last of which was held from 27 June to 8 July 2022 [8]. The next review meeting is scheduled in 2025.

2.2. COUNCIL DIRECTIVE 2011/70/EURATOM OF 19 JULY 2011 ESTABLISHING A COMMUNITY FRAMEWORK FOR THE RESPONSIBLE AND SAFE MANAGEMENT OF SPENT FUEL AND RADIOACTIVE WASTE

Council Directive 2011/70/EURATOM (the Euratom Waste Directive) [5], like the Joint Convention [3], requires appropriate national arrangements for a high level of safety in spent fuel and radioactive waste management. In particular, each EU Member State is required to develop a framework and a programme for the responsible and safe management of spent fuel and radioactive waste, and to implement this programme. This will ensure that an undue burden on future generations is avoided. The Euratom Waste Directive [5] is also intended to ensure adequate public information and participation in the management of spent fuel and radioactive waste. All 27 EU Member States are members of Euratom and are also Contracting Parties to the Joint Convention, as well as Euratom itself.

2.3. INTERNATIONAL SUPPORTING MATERIALS

The IAEA safety standards reflect an international professional consensus on what constitutes a high level of safety for protecting people and the environment from the harmful effects of ionizing radiation. They are issued in the IAEA Safety Standards Series, which has three categories: Safety Fundamentals, Safety Requirements and Safety Guides. IAEA Safety Standards Series No. SF-1, Fundamental Safety Principles [9], presents the fundamental safety objective and principles of protection and safety, and provides the basis for the Safety Requirements, which establish the requirements to be met to ensure the protection of people and the environment. IAEA has published additionally many informational

[3] Information on the Joint Convention [3], its latest status, documents and the results of Review Meetings are available at https://www.iaea.org/topics/nuclear-safety-conventions/joint-convention-safety-spent-fuel-management-and-safety-radioactive-waste

publications related to safe management of spent fuel and radioactive waste, including the from Nuclear Energy Series.

Many countries are having peer reviews performed on various aspects of their spent fuel management and radioactive waste management programmes with the aim of assessing and improving their policies and practices. Such reviews are, in fact, required under the Euratom Waste Directive. For transparency, the Member States usually make these peer review reports openly available. The international organizations offer their Member States numerous expert review services related to the peaceful uses of nuclear science and technology. These peer reviews are conducted at the request of member countries and the scope of such reviews is based on the needs of the country.

There is also wide support from academia, the community, national organizations involved in the management of spent fuel and radioactive waste, etc. As a result, there are scientific and technical publications available for the wider community.

3. SOURCES OF SPENT FUEL AND RADIOACTIVE WASTE

All industrial processes result in the generation of waste which subsequently needs to be managed safely and effectively. The operation of nuclear reactors, as well as their associated fuel cycles (uranium production, enrichment, fuel fabrication and reprocessing), generates radioactive material to be managed as radioactive waste. Radioactive waste also results from the use of radioactive materials in research, medicine, education and industry. This means that all States that engage in any kind of nuclear application have to consider the production and management of radioactive waste and to make sure it is managed in a safe manner, with due regard to the level of radioactivity and in compliance with national regulations, based on IAEA safety standards.

Spent nuclear fuel is generated as a result of the operation of all types of nuclear reactors, including power reactors, research reactors, isotope production reactors and propulsion reactors. The spent fuel can be considered to be a resource for reuse or to be waste, depending on the policy and strategy of the Member State.

3.1. RADIOACTIVE WASTE CLASSIFICATION

The activities connected to the safe management of radioactive waste are quite different depending on the type of waste involved. As the radioactivity content of different types of radioactive waste varies greatly, the waste can be assigned to different classes. Wastes is classified under national programmes according to their hazards and the available or planned management routes. Although different waste classification systems exist, the classification system used in this publication follows the definitions in para. 2.2 of GSG-1 [4], which classify waste as follows:

(1) Exempt waste (EW): Waste that meets the criteria for clearance, exemption or exclusion from regulatory control for radiation protection purposes.

(2) Very short lived waste (VSLW): Waste that can be stored for decay over a limited period of up to a few years and subsequently cleared from regulatory control according to arrangements approved by the regulatory body, for uncontrolled disposal, use or discharge.

(3) Very low level waste (VLLW): Waste that does not necessarily meet the criteria of EW, but that does not need a high level of containment and isolation and, therefore, is suitable for disposal in near surface landfill type facilities with limited regulatory control.

(4) Low level waste (LLW): Waste that is above clearance levels, but with limited amounts of long lived radionuclides. Such waste requires robust isolation and containment for periods of up to a few hundred years and is suitable for disposal in engineered near surface facilities.

(5) Intermediate level waste (ILW): Waste that, because of its content, particularly of long lived radionuclides, requires a greater degree of containment and isolation than that provided by near surface disposal. However, ILW needs no provision, or only limited provision, for heat dissipation during its storage and disposal.

(6) High level waste (HLW): Waste with levels of activity concentration high enough to generate significant quantities of heat by the radioactive decay process or waste with large amounts of long lived radionuclides that need to be considered in the design of a disposal facility for such waste. Disposal in deep, stable geological formations usually several hundred metres or more below the surface, is the generally recognized option for disposal of HLW.

Generally, the higher the hazard, the more elaborated and/or higher degree containment and isolation is included in the disposal concept. Depending on national polices, several waste classifications are sometimes grouped together for management in a single facility. In this case, the combined facility should be designed considering the safety of the highest class of waste it houses. The association between waste classes, activity levels and half-lives, with the boundaries between classes (shown as dashed lines) is illustrated conceptually in Fig. 1.

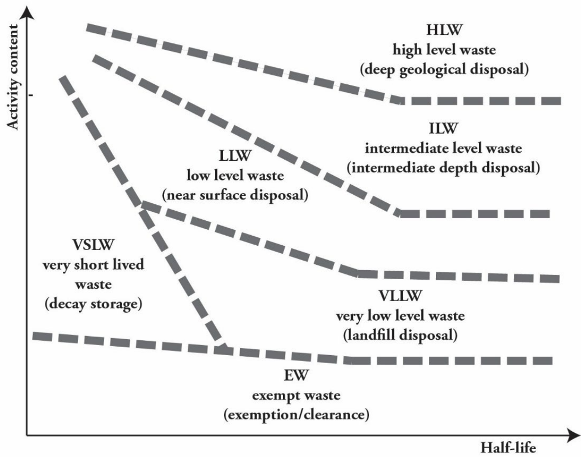

FIG. 1. Conceptual illustration of the waste classification scheme [4].

Some of the radioactive material has such a low content of radionuclides that the radiological impact is negligible, and it can be released from regulatory control ('clearance') in accordance with the State's regulations. This is the case for EW. Other properties, such as chemical hazards, may also affect the available management route. Some countries have a special classification ('mixed waste') that includes non-radiological hazards. An overview of national classification schemes is provided in Annex 1.

Most of the radioactivity associated with radioactive waste is ILW and HLW. While VLLW and LLW comprise more than 92% of the total volume of the waste (see Fig. 2), ILW and HLW typically comprise more than 95% of the total radioactivity.

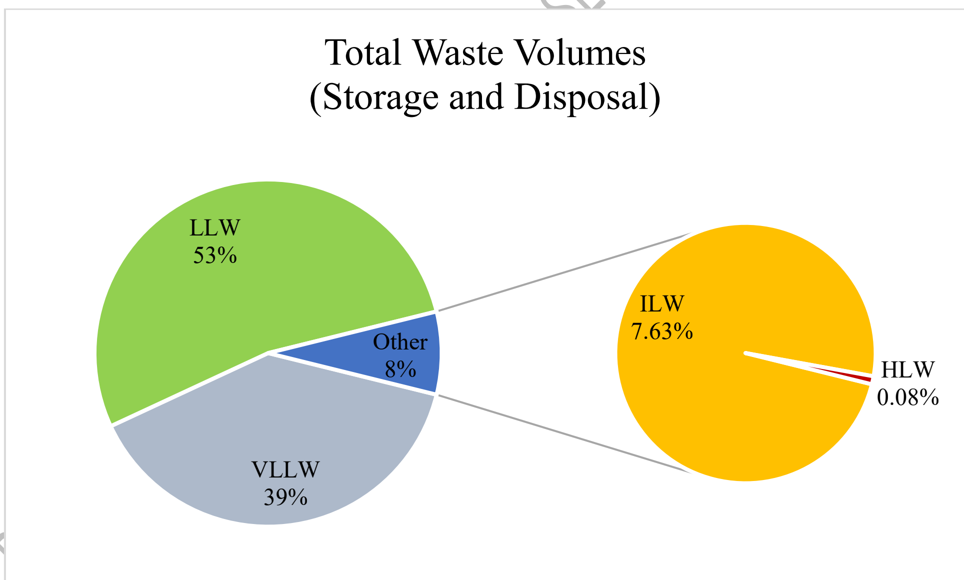

FIG. 2. Share of different classes of radioactive waste in total volumes in storage and disposal, based on the 2019 inventory data

3.2. NUCLEAR POWER PROGRAMMES

In 2019, 443 nuclear power reactors were being operated in 30 countries, generating about 10% of global electricity. Since 2019 there are 2 new nuclear countries: Belarus and the United Arab Emirates. Bangladesh and Türkiye are currently constructing their first nuclear power plants. Italy, Kazakhstan and Lithuania have shut down their nuclear power reactors, so they do not produce any more nuclear energy (see Table 1).

TABLE 1. IN OPERATION, UNDER CONSTRUCTION AND DECOMMISSIONING NUCLEAR POWER REACTORS, DECEMBER 2019 [10]

Member State	**In operation**		**Under construction**		**Decommissioning**	
	Number of units	Total net electrical capacity (MW)	Number of units	Total net electrical capacity (MW)	Number of units in decommissioning process	Number of units decommissioned
Argentina	3	1 641	1	25	0	0
Armenia	1	375	0	0	1	0
Bangladesh	0	0	2	2 160	0	0
Belarus	0	0	2	2 220	0	0
Belgium	7	5 930	0	0	1	0
Brazil	2	1 884	1	1 340	0	0
Bulgaria	2	2 006	0	0	4	0
Canada	19	13 554	0	0	3	0
China	48	45 518	11	10 564	0	0
Czech Republic	6	3 932	0	0	0	0
Finland	4	2 794	1	1 600	0	0
France	58	63 130	1	1 630	10	0
Germany	6	8 113	0	0	22	3
Hungary	4	1 902	0	0	0	0
India	22	6 255	7	4 824	0	0
Iran, Islamic Republic of	1	915	1	974	0	0
Italy	0	0	0	0	4	0
Japan	33	31 679	2	2 653	19	1
Kazakhstan	0	0	0	0	1	0
Korea, Republic of	24	23 172	4	5 360	2	0
Lithuania	0	0	0	0	2	0
Mexico	2	1 552	0	0	0	0
Netherlands	1	482	0	0	1	0
Pakistan	5	1 318	2	2 028	0	0
Romania	2	1 300	0	0	0	0
Russian Federation	38	28 437	4	4 525	6	0
Slovakia	4	1 814	2	880	3	0
Slovenia	1	688	0	0	0	0
South Africa	2	1 860	0	0	0	0
Spain	7	7 121	0	0	3	0
Sweden	7	7 740	0	0	6	0
Switzerland	4	2 960	0	0	2	1
Türkiye	0	0	1	1 114	0	0
Ukraine	15	13 107	2	2 070	0	0
United Arab Emirates	0	0	4	5 380	0	0

Member State	In operation		Under construction		Decommissioning	
	Number of units	Total net electrical capacity (MW)	Number of units	Total net electrical capacity (MW)	Number of units in decommissioning process	Number of units decommissioned
United Kingdom	15	8 923	2	3 260	26	0
United States of America	96	98 152	2	2 234	33	13

Source: Power Reactor Information System (PRIS).

3.2.1. Spent Fuel

After its use in a reactor, spent fuel is highly radioactive, emits significant radiation and heat, and is typically transferred to wet storage in a fuel pool for several years [11]. After this period (sometimes referred to as a cooling period), the spent fuel can be safely transferred to storage facilities, either wet or dry, or storages capacities in reprocessing facilities. The length of time spent fuel stays in various types of storage depends on its characteristics and intended disposition. For example, spent fuel intended to be reprocessed may spend very little time in storage (a few years), while spent fuel intended for direct disposal may spend several decades in storage, depending also on the availability of the disposal facilities.

Spent fuel contains uranium, fission products, plutonium and other heavier elements. The exact composition of the spent fuel will depend on the initial fuel type (uranium-, thorium-, mixed oxide (MOX), etc.) its enrichment (i.e. percentage of fissile content) and the type and operating conditions of the reactor (e.g. thermal or fast neutron spectrum, burnup, etc.). In order to take advantage of the remaining fissile content of the spent fuel, some countries have adopted a closed or partially closed fuel cycle where the spent fuel is reprocessed, resulting in the extraction and reuse of the uranium and plutonium in new fuel, as well as the separation and conditioning of waste products (see Section 5.1).

3.2.2. Radioactive waste

During the operation of a reactor, different types of radioactive waste are generated. This waste includes filters used in water and air treatment, worn out components and industrial waste that has become contaminated with radioactive substances. This waste has to be conditioned, packaged and stored prior to its disposal. Most of this waste (by volume) has low levels of radioactivity (VLLW or LLW).

At the end of its operating life, a reactor is shut down and eventually dismantled. During dismantling, contaminated and activated components are separated, treated and if necessary managed as radioactive waste. The largest volumes of radioactive waste generated are in the VLLW or LLW classes. Smaller volumes of ILW are also generated. The majority of the waste (by volume) from dismantling is, however, not radioactive and can be handled as industrial waste, in accordance with the Member State's regulations.

Decommissioning of nuclear reactors and management of decommissioning waste is becoming more and more important, as the current global fleet of power reactors is ageing. There are more than 70 power reactors that have been in operation for more than 40 years and more than 250 power reactors that have been in use for more than 30 years (see Fig. 3). It is foreseen that an increased number of nuclear reactors will be closed over the next two decades. Furthermore, as shown in Table 1, many nuclear power reactors have been shut down worldwide. However currently, less than 20 have been completely dismantled. These have given useful experiences of complete decommissioning and handling of the radioactive components as radioactive waste. Several further units are in different stages of decommissioning, ranging from defuelling to actual dismantling. However, there are also reactors, that, after removal of the spent fuel, are awaiting future dismantling while being kept in safe condition. In such cases, decontamination and dismantling might be delayed for up to 50–60 years.

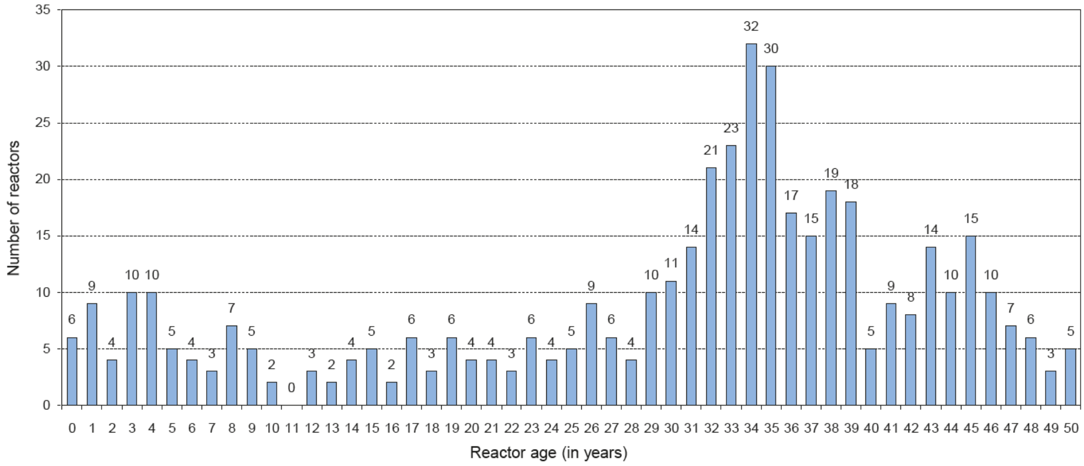

FIG. 3. Global number of operational reactors by age (as 31 December 2019) [10].

Success in decommissioning may be strongly influenced by the suitability of three key elements to complete an integrated approach: a regulatory legal framework [12], the necessary provisions with regards to the funding and availability of resources, and access to technologies and experience in this field including the presence of logistical and management solutions for the resulting materials, particularly radioactive waste.

Early planning is needed, prior to the start of actual decommissioning, to enable proper and timely treatment, conditioning, storage and disposal of the radioactive waste from decommissioning. It is important to ensure that wastes with no known safe disposition are not generated during the decommissioning process.

At different stages of the nuclear fuel cycle different materials are generated and some of them as possible waste. Since the base material, uranium, is radioactive and new radioactive elements are formed during reactor operation, radioactive waste is generated in all steps of the nuclear fuel cycle. Most of this is VLLW, LLW or ILW and is treated according the same principles as waste from nuclear reactors. The exceptions are waste from uranium (or thorium) mining and milling, which is described in more detail in Section 5.5.

Different stages of the nuclear fuel cycle result in radioactive waste and other by-products, as follows:

- Uranium mining and milling (UMM) generates naturally occurring radioactive material (NORM) waste. The waste rock is both the overburden rock, which contains only very low levels of NORM, and the rock from which the uranium bearing material has been separated, which contains residual uranium and other related naturally occurring radionuclides from the uranium decay chain. The mill tailing is the residue after the uranium has been extracted from the uranium bearing material to produce uranium concentrate powder or so called 'yellow cake'.
- Conversion of uranium oxide to uranium hexafluoride and back (as part of the enrichment process) generates VLLW and NORM waste.
- Enrichment generates uranium bearing waste (uranium with lower U-235 enrichment levels than natural uranium). Depleted uranium (DU) is stored safely (usually in a stable chemical state), although it is not always considered a waste because it can be a resource for MOX fuel, or for down-blending of high enriched uranium to lower enrichments. There are several countries (e.g. France, Russian Federation, United Kingdom), that require studying the management of DU as waste, if the option of reuse is not implemented on a sufficient scale to use up all of the DU.
- Fuel fabrication generates uranium bearing waste, which is mostly considered to be VLLW. Fuel fabrication from recycled uranium and plutonium also creates alpha bearing waste containing a range of Pu and U isotopes, as well as some of the minor actinides (Am, Np, etc.).
- Reactor operation and maintenance generates a range of waste from VLLW to HLW, mostly waste with activation products created by the neutron bombardment of reactor materials (e.g.

Co-60, Ni-59, Ni-63, etc). However, due to some fuel leakage or due to fissions occurring outside the fuel, this waste can also contain fission products and alpha emitters. The radioactivity circulates in the primary and secondary cooling systems as well as the spent fuel storage pools, most of it is captured by the cleanup circuits servicing these systems (e.g. filters, ion exchange systems, etc.).

- Water treatment and cleaning processes in spent fuel wet storage facilities may generate filters and resins contaminated with activation products and traces of fission products and alpha emitters.
- In reprocessing facilities, fission products generated in the reactor, are extracted from the spent fuel and incorporated into a glass matrix (normally HLW). Claddings and structural components of the fuels are normally considered to be ILW, as well as some technological waste and effluents from the chemical processes. The latter can also be mixed with the HLW in the glass canisters. Reprocessing facilities also generate LLW and VLLW with different radiological contaminants (activation products, fission products and low levels of uranium or plutonium) as part of routine operation and maintenance activities. Manufacturing of new fuel containing recycled uranium or a uranium/plutonium MOX also generates ILW.

3.3. RESEARCH, MEDICAL AND INDUSTRIAL APPLICATIONS

Research reactors are nuclear reactors used for research, development, education and training. Constructing a research reactor involves similarly to nuclear power reactors careful planning and preparation, as well as long-term investment of human and financial resources. The need for funding and government oversight extends well beyond the usual timescales for a capital project of similar size. Many research reactor projects involve a wide range of interests and sometimes their missions evolve over time. Based on Research Reactor Database[4] there are currently more than 200 operational research reactors, about 80 in temporary/extended/permanent shutdown, about 70 under decommissioning and almost 450 decommissioned. Both, operating and decommissioning of the research reactor will produce spent fuel and radioactive waste.

While most decommissioning programmes focus on nuclear reactors of various types, all facilities which contain or handle radioactive materials will eventually have to undergo decommissioning and dismantlement. This includes research facilities, waste treatment and conditioning facilities, storage facilities, nuclear application installations, fuel cycle facilities, etc. The scale of these projects is usually smaller than nuclear power plant decommissioning. However, some large and complex facilities, such as spent fuel reprocessing plants, can be equally, if not more so, challenging to undertake. These other types of facilities tend to be much more single event type projects with little experience to draw from. Consequently, the range of waste resulting from decommissioning of non-reactor nuclear facilities varies widely both in terms of quantity and radioactivity. Other hazards, such as chemical hazards, also require careful consideration in the planning process of these facilities.

Radiation can be used to improve the quality of life in many ways, so radioactive material continues to be used broadly, both nationally and internationally, for medical, research, sterilization, and other commercial applications. This means that radioactive waste is generated in a wide range of activities, including research, the use of radioisotopes as tracers in medical and industrial applications, irradiation of materials, e.g. for sterilization and polymerization. The typical life cycle of the radioactive material is presented in Fig. 4. Generally, the same types of treatment and handling and disposal methods are applied as for similar classes of waste resulting from nuclear power generation.

[4] https://nucleus.iaea.org/rrdb/#/home

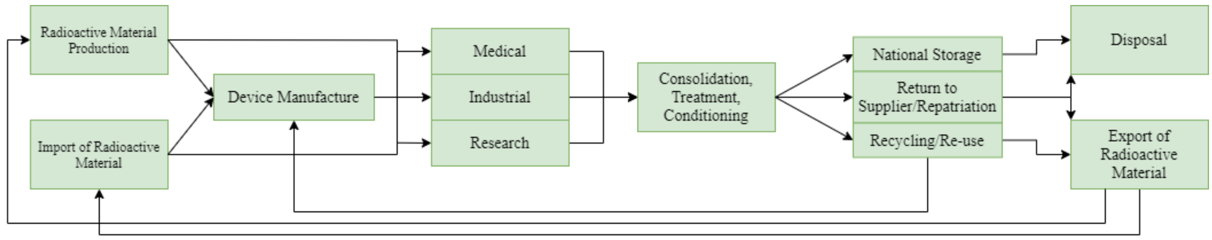

FIG. 4. Life cycle of radioactive material

The most common fields of application for radioactive sources in industry include the calibration of measuring devices, materials testing, irradiation and sterilization of products, and level and density measurements. In medicine, radioactive sources are mostly used for radiotherapy and for irradiation of blood. The working lives of the sources used vary considerably, on account of the wide range in the half-lives of the radionuclides used. In most countries, the devices (with the sealed source inside) are returned to the equipment manufacturer by the operator after end of use. The source manufacturer might check for the possibility of further use of the sources and reuse parts of them. Sources that cannot be reused have to be disposed of as radioactive waste. In many countries, disused sealed radioactive sources (DSRSs) are the primary or only type of radioactive waste.

The Code of Conduct on the Safety and Security of Radioactive Sources [13] aims at helping national authorities to ensure that radioactive sources are used within an appropriate framework of radiation safety and security. The Code is a well accepted, non-legally binding international instrument and has received political support from more than 130 Member States. The Guidance on the Import and Export of Radioactive Sources [14] supplements the Code and aims to provide for an adequate transfer of responsibility when a source is transferred from one State to another. The Guidance on the Management of Disused Radioactive Sources [15] provides further guidance regarding the establishment of a national policy and strategy for the management of disused sources and on the implementation of management options such as recycling and reuse, long term storage pending disposal and return to a supplier.

NORM waste can be also produced in different industrial sectors. The most important ones include the phosphate sector, the production of titanium dioxides, water treatment, geothermal energy, steel industry, the oil and gas industry, extraction of rare earths, etc. Depending on the classification of the waste used in the Member State, NORM might be considered as radioactive waste or not.

Many national and international government and nongovernmental organizations have contributed to the increasing visibility of alternative technologies as a way to reduce risks from radioactive sources [16]. Progress with developing alternative technologies has been uneven across different applications and radionuclides and in some applications, no suitable replacement technology has been developed.

3.4. DEFENCE PROGRAMMES AND OTHER POTENTIAL SOURCES

Military and defence activities involving nuclear material create radioactive waste in various forms, and in some cases account for the majority of waste produced in the Member State. Neither the Joint Convention [3] nor the Euratom Waste Directive [5] requires States to report this waste. However, some States have included military and defence waste in their Joint Convention reports. The aggregated tabulations in Section 6 include any waste being declared and managed as part of the national inventory of radioactive waste.

Other potential sources of radioactive waste include past activities that involved radioactive materials or waste generated by nuclear or industrial accidents. Usually this kind of radioactive waste presents a special challenge, as it may present an additional waste stream where the waste may range from large volume/very low activity to small volume/high activity. Waste forms may be also very variable, so waste management issues may result either from the nature of the radioactive materials (e.g. historical radium bearing waste sites) or from chemical and chemical-toxic aspects. The management needs particular attention if the quantities, location and/or characteristics of the waste exceed the existing waste management infrastructures. Two major nuclear accidents in the past decades have resulted in widespread contamination that requires significant remediation effort - Chernobyl and Fukushima Daiichi. Work at both sites is currently on-going and will likely be continuing for some time to come.

4. FRAMEWORKS FOR THE MANAGEMENT OF SPENT FUEL AND RADIOACTIVE WASTE

National arrangements for securing the safe management of spent fuel and radioactive waste also take into consideration international treaties and standards. A basic prerequisite, as stated in the IAEA's Fundamental Safety Principles [9], the Joint Convention [3] and the Euratom Waste Directive [5], is that the prime responsibility for ensuring the safety of spent fuel and radioactive waste management rests with the licence holder. It is also evident from those documents that the ultimate responsibility for ensuring that programmes are prepared for the management (including disposal) of radioactive waste rests with the State in which that waste arises. These obligations are implemented in each Member State through legislation and regulations in which the roles, responsibilities and reporting relationships of the relevant organizations are established.

4.1. NATIONAL POLICIES AND STRATEGIES

While the national arrangements for ensuring that spent fuel and radioactive waste are safely managed vary from country to country, there are some common features. The national legislative assembly is usually responsible for enacting legislation, which generally includes the establishment of a regulatory body and in many cases, an implementing body for spent fuel and radioactive waste management as well as defining the essential elements of the national policy and other related governance. Alternatively, national policy can be set out separately by governmental decree or ministerial directives. In some cases, a single policy covering both spent fuel and radioactive waste is adopted, while in other cases, there are separate policies are issued. The IAEA's guidance on Policies and Strategies for Radioactive Waste Management [17] states that a national policy typically addresses the following:

(a) Responsibilities within the country for spent fuel and radioactive waste management;
(b) Arrangements for financing the management (including disposal and decommissioning);
(c) Preferred management options for spent fuel, policies for waste disposal, import and export of spent fuel and radioactive waste;
(d) Decommissioning of nuclear facilities;
(e) Public information and public involvement in related decisions.

To implement the national policy, one or several strategies have to be developed, which is generally the responsibility of the implementers of waste management practices, such as national Waste Management Organisations (WMO), see Sections 4.4 and 4.5. In some cases, commercial entities and/or agreements with other countries are employed to implement the policy or strategy. Approval of the specific strategy by the regulatory body and/or responsible ministry is also often required.

The usual practice according to the national policy on spent fuel management and radioactive waste management is that final waste should be disposed of in the country where it is generated. This is also an expectation for Contracting Parties of the Joint Convention, as well a general requirement for EU Member States based on the Euratom Waste Directive [5]. Although spent fuel may be transferred for reprocessing to another country, the HLW or ILW from reprocessing are generally returned to the originating country for long term management.

This does not mean that countries should be precluded from fulfilling their national obligations through collaboration with other countries [18]. Some countries are seeking joint (or multilateral) solutions for the management of spent fuel and radioactive waste, including disposal in facilities that are operated jointly by, or on behalf of, several countries. The joint/multilateral disposal concepts should not be relied on as the only option for radioactive waste management in countries, due to the uncertainties involved.

The export and import of spent fuel and radioactive waste is subject to strict controls. Many States prohibit the import of spent fuel and radioactive waste. Other States, such as France, the Russian Federation and the United Kingdom (UK), allow the import of spent fuel from other countries, including those from research and other non-power reactors, for reprocessing services. The current practice is usually to return waste separated from recyclable materials in conditioned form to the country of origin.

There are several radioactive waste processing facilities, that are used by the waste producers from different countries.

States that are suppliers of sealed radioactive sources for use in medicine and industry, such as Canada, France, Germany, the Russian Federation, South Africa and the United States of America (USA), also accept the return of DSRSs.

Most countries have established national strategies for implementing radioactive waste and spent fuel management, which is in line with Requirement 1 of IAEA Safety Standards Series No. GSR Part 1 (Rev. 1) [12] and stipulated in the Joint Convention [3]. National Strategies include, for example, plans for implementing national policy, the development of the required facilities, the identification of roles and the setting of targets for the implementation of the policy. Many countries have well developed strategies and plans to manage all types of waste, from creation through to final disposal. The slow pace associated with moving towards disposal for ILW, HLW and spent fuel in many countries is dominated by the time required for performing the necessary research and site surveys, engineering, construction and gaining public acceptance of proposals to site facilities in specific areas. For these reasons, some States are progressively implementing their chosen national strategies, especially for the long term management of spent fuel and HLW. An overview of national strategies for spent fuel and different types of radioactive waste is provided in Annex 2.

4.2. LEGAL FRAMEWORK

IAEA Safety Standards Series No. GSR Part 1 (Rev. 1), Governmental, Legal and Regulatory Framework for Safety [12] states that:

“Requirement 2: Establishment of a framework for safety
The government shall establish and maintain an appropriate governmental, legal and regulatory framework for safety within which responsibilities are clearly allocated.”

This requirement is also reflected in Article 20(2) of the Joint Convention [3]. The legal framework should include provisions to ensure sufficient and timely funding of spent fuel and radioactive waste management activities — including providing management facilities and establishing requirements for public involvement in the decision making process. While legal instruments vary, they typically assign roles and responsibilities for nuclear activities, including radioactive waste management, to operating organizations, ministries and other governmental organizations. The information available on Country Profiles in Spent Fuel and Radioactive Waste Information System provide information on the national legal frameworks in each of the countries.

4.3. ALLOCATION OF ROLES AND RESPONSIBILITIES

Requirement 2 of GSR Part 1 (Rev. 1) [12] establishes the essential elements of a regulatory framework. At the government level, the ministries or departments of energy, industry, economy and development, with responsibilities for ensuring adequate energy supplies, often support the nuclear power industry in making arrangements for managing spent fuel and radioactive waste. The ministries responsible for ensuring that public health and the environment are adequately protected are typically responsible at the governmental level for issues related to the management of spent fuel and radioactive waste.

The role of the regulator is to ensure that nuclear activities are performed in a safe manner and in accordance with the legal and regulatory framework. For most EU and OECD/NEA members, nuclear safety regulators are now clearly separated from the national ministry in charge of energy or industry [19]. The basic responsibilities for ensuring the safety of spent fuel and radioactive waste management are assigned by all States involved in this study in accordance with the above norms, although in different ways — the differences are usually due to variations in national legislative and regulatory systems. In some countries, for example, the owner or licence holder of a spent fuel and radioactive waste management facility is a private entity and thus is responsible for ensuring safety. In other countries, the owner or licence holder might not be completely distinct from the government and so the responsibility for ensuring the safety of spent fuel and radioactive waste management essentially rests with the State.

4.4. WASTE MANAGEMENT ORGANIZATIONS

Usually, the producer of it is considered to be the first owner of the radioactive waste, so the primary responsibility for managing spent fuel and radioactive waste rests with the owner or licence holder of a facility, where the spent fuel and radioactive waste originates from. At each major decision point, the implications for the safety of the management of spent fuel and radioactive waste have to be considered and taken into account. In assessment of the safety several factors have to be considered, among these are public acceptability, cost, existing infrastructure and waste ownership.

Taking into account that the management of spent fuel and radioactive waste are considered long term activities compared to the activities, from where spent fuel or radioactive waste originated, there is a practical need for arrangements at the national level. Many States have created national radioactive WMOs that are responsible for developing arrangements for the disposal of spent fuel and radioactive waste. These WMOs may also be responsible for implementing management of spent fuel and/or radioactive waste (including HLW from reprocessed spent fuel). Once waste has reached WMO, the ownership of the waste might change, as it could be transferred from the producer to WMO or Member State. However, as the structure and role of WMOs in countries with a nuclear power programme varies, the ownership might stay with the producer as well.

In some countries, the generators of spent fuel and radioactive waste are responsible for all activities for the safe management, encompassing the disposal of radioactive waste (including HLW from reprocessed spent fuel) and spent fuel. In such cases, the waste generators have formed WMOs, that are owned and operated by them. This is true for the management of waste from nuclear power plants in Canada, Finland, Japan and Sweden, for example. In other countries, however, the State has created a separate state-owned organization responsible for waste disposal (including spent fuel and/or all applicable radioactive waste classes), while the responsibility for the interim management of spent fuel and radioactive waste remains with the spent fuel or waste producer. Such an approach is used for managing all radioactive waste in China, France, Germany, the Russian Federation and Switzerland. Other countries may have a mixed approach whereby, for example, private companies are responsible for the short term management of spent fuel, whereas a State-owned or State-controlled body is responsible for the long term management of spent fuel and/or HLW. The private companies might also be responsible in such cases for the management of radioactive waste (with exception of HLW) and/or decommissioning.

However, some countries with small quantities of radioactive waste, do not have dedicated WMO. The nature and role of WMOs is given in Annex 3.

4.5. FUNDING ARRANGEMENTS

The Joint Convention [3] requires that a Contracting Party has adequate financial resources available, among other things, to support the safety of facilities for spent fuel and radioactive waste management during their operating lifetime, for decommissioning and also for the activities needed for the operation/closure of disposal facilities. It is broadly recognized that those who benefit from using a source should pay for its disposition [14], this is generally recognized as the polluter-pays principle. This requires the establishment of a funding system for its spent fuel and radioactive waste management needs, and there are different options available. The country can choose and define the scheme suitable for its particular needs. In most countries, spent fuel and waste producers are responsible for the funding of all activities connected to the management of spent fuel (including direct disposal if it is regarded as waste or disposal of the resulting waste if it is reprocessed) and radioactive waste (including final disposal) and for the decommissioning of the facilities.

An overview of financing schemes and funding mechanisms in different countries is given in Annex 4. The data provided in Annex 4 shows that funding arrangements can sometimes include the costs for management and disposal of all the radioactive waste being generated in a country, while in other cases the funding is limited to the disposal of spent fuel or HLW and the decommissioning of nuclear facilities. In the latter, the costs of management and disposal of other types of waste are paid directly by the waste producers as an operating expense at the time when they occur. The funding arrangements described in Annex 4 mainly relate to spent fuel and radioactive waste from nuclear power plants. In some countries (e.g. Finland and Sweden), this fund also covers the costs of decommissioning the facilities and managing the waste from decommissioning. In other countries (e.g. Switzerland and the USA), separate funds have been established for decommissioning.

For nuclear activities operated by the State, e.g. nuclear research or use of radionuclides in medicine, or for countries having historical or legacy waste, dating from past nuclear activities, the State is also most often responsible for the management of the resulting waste. In many cases, the corresponding costs are covered by the State budget (e.g. Latvia). In most cases, no segregated funding arrangement was established. Instead, the funding for current and future waste management is, and will be, met directly from government sources. In some countries, similar arrangements have been implemented for small producers of radioactive waste (i.e. the waste producers pay for waste management and disposal). In other countries, the State takes responsibility for these costs in return for fees paid by the waste producers.

Most funding systems are based on the premise that the waste producer will pay all costs for the management of the spent fuel and radioactive waste produced and that these costs will be taken from the funds that have been built up. There are different ways to collect funds. In countries with nuclear power reactors the most common method is to levy a fee per kilowatt-hour produced; however, there are also other methods for building the funds, such as establishing a target value of the fund at the end of each year. It is important to keep in mind that many of the costs associated with the management of spent fuel and radioactive waste arise long after the revenue generating activities have ceased. Therefore, it is essential to establish mechanisms to gather and protect funds during the revenue generating phase. For nuclear services provided, e.g. reprocessing or disposal, the funding can be based on a cost per cubic meter of waste delivered or per activity content. Irrespective of which mechanism is used it is important that actual fee is based on the best available calculated costs.

For the establishment of fees, the activities to be covered by the funding should be defined and the expected costs for the necessary facilities and activities calculated. As the timescales are large and many of these costs will occur in the future, it is important to develop a scenario and a time schedule for the management of the spent fuel and radioactive waste. As the cost calculations will inevitably often be based on very early facility designs and operation descriptions, they will involve substantial uncertainties. Additionally, there could also be uncertainties caused by the time schedule. It is also important to address the possible unexpected costs and how to secure the funds for these possible needs. The inclusion of the uncertainties can be handled in different ways, e.g. as a contingency or through a statistical approach. A challenge in the cost calculations is to predict how different cost types will develop in relation to general inflation, and what influence technology development and competitiveness in the industry will have. To ensure that money will be available in the long run some countries have introduced guarantees in addition to payment of fees. The thinking is that guarantees should cover reduced incomes to the funds, e.g. due to lower power prediction than anticipated or higher than expected cost increases. A guarantee could be in the form of a bank guarantee or a guarantee by the mother company.

The choice of margins included in the calculated costs will be dependent on the safeguards required in the funding system and to what extent the State will take the final responsibility to cover deficiencies in the funding. There might be an extra contingency applied to safeguard against the unexpected costs. Alternatively, as is the case for Sweden, the fee should reflect the expected costs and unexpected costs should be covered by securities.

The collected funds can be managed in different ways. In most cases segregated funds have been established, whereby the management of the funds, i.e. collection, investment and payments are handled by a dedicated body, often under government control. In other cases, the funds are kept inside the organization and invested, although there are also cases where the funds become part of the State budget. A key question for management of the funds is the effective return on the funds and, in this connection what investment possibilities exist. To safeguard against cost increases due to inflation and to keep the fees at an appropriately low level it is important that the fund content is invested in such a way that a proper return on the money is achieved. Given that these funds are foreseen to be secured for a long time period, normally the flexibility in investments has been quite low and restricted to very secure investments such as State or property bonds. There are cases where a certain percentage of the funds could be invested in more profitable portfolios, such as shares. The possibilities and restrictions of the investment policy have a strong impact on the return of the funds, but they also influence the stability of the funds and the necessity of liquidity once the use of the funded money gets closer.

As the funds will exist for many decades the risk of disturbances is large. Such disturbances could include, for instance cost increases, time schedule changes, early reactor shutdown, international and national economic turbulence, bad fund management and companies ceasing to exist. As long as the waste producing activity generates a revenue, it should be possible to adjust the funding requirements through relatively frequent recalculations of the future costs, incomes and returns. This means that changes can be accommodated through a change of the levies on the future waste generation.

In the unlikely case of insufficient funds, for example if the funds are emptied before all activities have been completed, the approaches of each countries do differ. In some countries, the State takes over responsibility for covering unfunded costs, while in other countries the waste producer remains responsible for providing additional funding. In the latter case, the risk of insolvency of the waste producer also has to be considered, but in the extreme case it is always the State that takes the final risk. The risk of cost increases due to disturbances will thus be taken on for the future production of nuclear electricity through increased fees and ultimately by the government. Alternatively, one could consider a system such as that in Sweden, where the obligation to pay to the fund remains even after cessation of power production. There are also some cases where the responsibility for an activity and the corresponding funds are transferred from one organization to another, such as when specialist companies take over the dismantling of reactors, as has been done in the USA. Together with the transfer of funds there is also the takeover of all the obligations connected to the activity, including paying all the costs even if they are not covered by the funds.

4.6. PLANNING AND INTEGRATION

The ability of a country to deal with its spent nuclear fuel and/or radioactive waste is determined by the extent to which it has established a management policy and strategy, along with supporting infrastructure and legislative and institutional frameworks. The main objective of the system for management of spent fuel and radioactive waste is to avoid imposing an undue burden on future generations; this means that the generations that produce the spent nuclear fuel and/or radioactive waste have to develop and adequately provide for the implementation of safe, practicable and environmentally acceptable solutions for its long term management. Communication and information sharing between various organizations and various stages is important for minimization of waste generation and effective implementation.

In order to implement an adequate spent fuel or radioactive waste management system, a suitable degree of planning is required, starting with a basic understanding of what types of spent fuel and/or radioactive waste will arise, how much, where and when. The planning needs to be reviewed and updated periodically in order to verify that the planning assumptions are still valid and the overall management plan is still adequate and viable for the country.

Full integration of the spent fuel and/or radioactive waste management system may be challenging, especially in countries with large or complex nuclear industries or ones with a long history of nuclear applications. However, there are usually opportunities to integrate the various agencies responsible for different aspects of the management system, government policy and/or regulations, long-standing practices or infrastructure, etc. A typical practice in the past was to tackle the different types of waste individually. It should be noted that implemented in this fashion, the lowest cost solution for each individual waste stream may not be the optimal solution for the overall system. By taking advantage of possible synergies between different components of the management system and/or different waste streams, overall optimization may be achieved leading to a reduction in costs and resource utilization. For example, a national policy could be to send all waste to a single repository, which might be a geological repository suitable for the highest level of waste in the country. If each waste class is destined for a different repository (e.g. engineered land fill for VLLW, engineered near surface for LLW and geological for ILW and HLW), then more work goes into segregating the different classes of waste. The development of alternative routes to disposal requires efficient means in terms of treatment, decontamination and characterization. This issue is important, in particular, for the management of decommissioning waste where large volumes of VLLW or LLW will be generated. In general, a set of evaluation tools will need to be developed to support an integrated supply chain covering all aspects of waste production and management. There have been great successes in some countries such as in the UK, in diverting a significant part of LLW from the national LLW repository to alternative disposal routes such as licensed industrial landfill. Often the unavailability or the limitation of a disposal option and costs are good drivers to promote the minimization of radioactive waste or recycling of radioactive material, but sometimes, such as in France, the economic trade-off between direct disposal of the waste and waste treatment to reduce disposal volumes or to enable recycling can be difficult.

For countries that are just embarking on a nuclear power programme or national waste management system, there is an opportunity to build in integration right from the start [20]. The availability of existing infrastructure and resources needs to be considered in the planning. This may include collaboration or sharing of services with other countries, especially if there are suitable existing services in one of the countries that can be made available to other countries, rather than each country developing its own infrastructure. This may ultimately lead to the benefit of a much more efficient and cost effective radioactive waste management system in individual countries as well as globally.

Nuclear fuel cycle strategies need to be fully integrated with the overall spent fuel and radioactive waste management policy and infrastructure to ensure an optimal use of resources. Introducing efficiencies into individual steps in isolation can create additional challenges in subsequent steps. One of the main challenges is to maintain enough flexibility to accommodate the range of potential future options for the management of spent fuel, as well as to define and address the relevant issues in storage and transportation.

Optimization of available waste management infrastructure and disposal routes should be considered because of its influence on two main decommissioning schedule drivers: time and cost. Lack of a final waste management route (i.e. disposal) should not be an excuse for postponing decommissioning or preparation for it. However, the implications that may arise from early decommissioning under those circumstances need to be carefully considered in order to not jeopardize future necessary actions. Experience from past decommissioning projects shows the importance of optimizing the overall waste management approach, e.g. via a full understanding and use of the waste management hierarchy (See 4.8).

4.7. MINIMIZATION IN THE MANAGEMENT OF RADIOACTIVE WASTE

As radioactive waste is defined in the IAEA Safety Glossary [21] as material for which no further use is foreseen and that contains, or is contaminated with, radionuclides at activity concentrations greater than clearance levels as established by the regulatory body, it will be difficult to redefine the material once it has been declared to be radioactive waste.

Minimization of radioactive waste is the process of reducing the amount and activity of radioactive waste to a level as low as reasonably achievable (ALARA) [21]. This is important at all stages from the design of a facility or activity to decommissioning, and is achieved by design and operations to reduce the amount of waste generated by means such as recycling and reuse, and by treatment to reduce the waste's activity, with due consideration for secondary waste as well as primary waste. Minimization principles should already have been followed in the planning stages to achieve the best results.

Minimisation is crucial part of the circular economy, which returns products, parts and materials into use several times. UNIDO[5] defines circular economy to be based on principles that:

- Products are designed to last
- Value is maintained for as long as possible
- Generation of waste and pollution is minimized
- Renewable energy is used along value chains, as much as possible

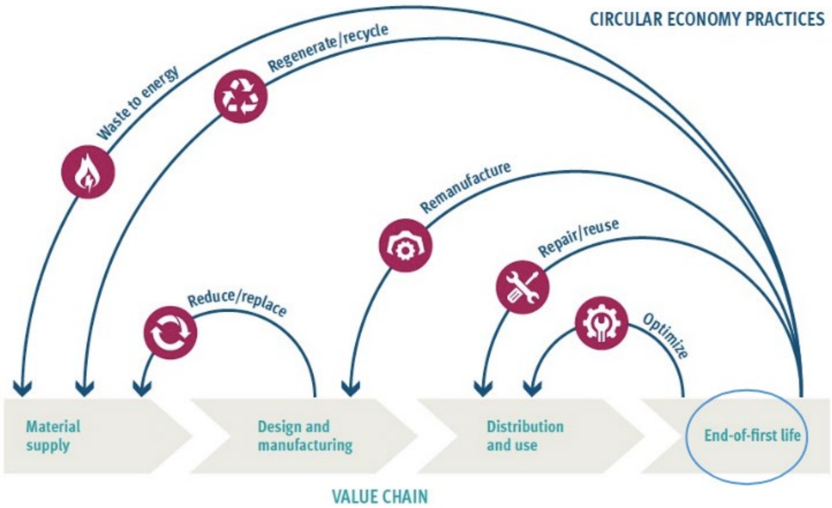

FIG. 5. Circular economy compared to linear economy [UNIDO]

The recycling of radioactive material is a process whereby material is converted into new products, so there is a reduction of wastage of useful materials, use of raw materials and energy use. This is in line with the principles of the circular economy to extend product lifespan through improved design and servicing and relocating waste from the end of the supply chain to the beginning—in effect, using resources more efficiently by using them over and over, not only once.

As much as possible, everything should be reused, re-manufactured or, as a last resort, recycled back into a raw material or used as a source of energy. However, there can be limited possibilities for recycling or reuse of radioactive material, especially if it is supposed to be done nationally. Reuse of radioactive material means that an item will be used again, either to perform the same function or a different function. It should be noted that there are different national approaches, depending on how the radioactive waste is defined. For examples in some countries, radioactive waste is considered only as the material going to disposal. There are several other criteria to consider in minimization, such as radiation protection and public acceptance. These can weaken the advantage of waste minimization because of doses to workers during waste processing. The opportunity for recycling of materials from a nuclear facility can also be restricted or reduced because of opposition from the public.

[5] https://www.unido.org/our-focus-cross-cutting-services/circular-economy

This means that for minimization in different phases of spent fuel and radioactive waste management there are different factors, that need to be considered, as follows:

- regulatory and licensing issues: compliance of the option with the applicable regulation;
- technical and operational issues: availability of technology and facilities to process waste;
- safety and ALARA issues;
- economic and schedule issues: costs, duration for implementation of solutions, compatibility with agenda of waste generation;
- public-acceptance and stakeholders' issues.

4.8. INVOLVEMENT OF INTERESTED PARTIES

Stakeholder involvement, which is an integral part of a stepwise process of decision making, may take the form of sharing information, consulting, dialoguing, or deliberating on decisions at different phases. It should always be seen as a meaningful part of formulating and implementing good policy.

It is important to secure stakeholder involvement through the life cycle of all nuclear facilities, including spent fuel storage facilities and final radioactive waste disposals. International experiences have shown that, especially in the case of disposal facilities, the project's progress often relies upon public support. Decision making on long term spent fuel and radioactive waste management is complex, as it not only concerns the current generation, but also future ones since the disposal facilities are designed to operate for many decades and to contain the hazard for thousands of years.

The stakeholders' expectations should be taken into consideration through different activities and interactions in order to enhance the satisfaction of interested parties [22]. It can be useful and helpful to involve the community early in the decision making process. This helps to build mutual trust between operators, government authorities and stakeholders, especially among the general public. Increased public participation in decisions can promote a greater degree of understanding of the issues related to nuclear power and spent fuel/radioactive waste management, especially with regard to actual risks and benefits. Public confidence is improved when issues that are raised by the public are taken seriously and are carefully and openly evaluated [23].

There are several possibilities for the involvement of interested communities in the siting and development of spent fuel and radioactive waste management facilities. Many siting programmes now incorporate local partnerships and there are even examples of waste management implementing bodies proposing to involve local stakeholders in joint studies, and in the interpretation and review of ongoing site investigation, assessment of the potential impacts on human health and the environment, and development of plans for monitoring these issues during facility operation and closure [24].

The typical steps for implementing stakeholder involvement programmes [22] can be listed as follows:

- Develop a strategy for stakeholder involvement;
- Develop plans for implementing this strategy;
- Ensure that the capacity to effectively implement these plans is available;
- Implement these plans;
- Continually monitor the effectiveness of these actions and look for ways to improve.

In order to earn trust with stakeholders, it is also important to have competent licensing authorities, as well as independent from political and industrial influence in their decision making and deliberation. Already many regulators incorporate public comment sessions in their licensing and review processes. It is also crucial to establish clear criteria for the decision making process, so it is understandable how and when, for example, the facility siting process can move from one step to the next. There needs to be clarity on the scope for decision making and identification of the point in the process when specific decisions are finalized and not subject to being revisited [25].

Although decision making processes vary considerably by Member State, depending on culture, history and governmental structure, stakeholder involvement is worthy of consideration. Stakeholder involvement is an essential component of various international conventions and treaties, most commonly related to the strategic environmental assessment and environmental impact assessment. The Convention on Access to Information, Public Participation in Decision-Making and Access to Justice in Environmental Matters, otherwise known as the Aarhus Convention [26], has more than 40 Contracting Parties and is not only an environmental agreement, but also covers government accountability, transparency and responsiveness. It grants the public rights and access to information. The Convention on Environmental Impact Assessment in a Transboundary Context, otherwise known as the Espoo Convention [27], has 45 Contracting Parties and sets out the obligations of the Parties to assess the environmental impact of certain activities at an early stage of planning and make sure that the stakeholders are involved in the process. It also lays down the general obligation of States to notify and consult each other on all major projects under consideration that are likely to have a significant adverse environmental impact across boundaries. At the same time the Euratom Waste Directive [5] ensures the provision of necessary public information and participation in relation to spent fuel and radioactive waste management while having due regard to security and proprietary information issues.

5. SUMMARY OF CURRENT STRATEGIES, PRACTICES AND TECHNOLOGIES

The previous sections covered the sources of spent fuel and radioactive waste, as well as the frameworks for their safe management. This section gives an overview of the current strategies, practices and technologies for safe management of spent nuclear fuel and radioactive waste. Other properties, such as chemical hazards, may also affect the available management route.

The preferred strategy for the management of all radioactive waste is to contain it (i.e. to confine the radionuclides to within the waste matrix, the packaging and the disposal facility) and to isolate it from the accessible biosphere [28]. Disposal is defined as intentional emplacement of the waste in a facility without the intent to retrieve that waste. Disposal options are designed to contain the waste by means of passive engineered and natural features and to isolate it from the accessible biosphere to the extent necessitated by the associated hazard. Figure 6 illustrates the disposal options based on the classes of radioactive waste [29].

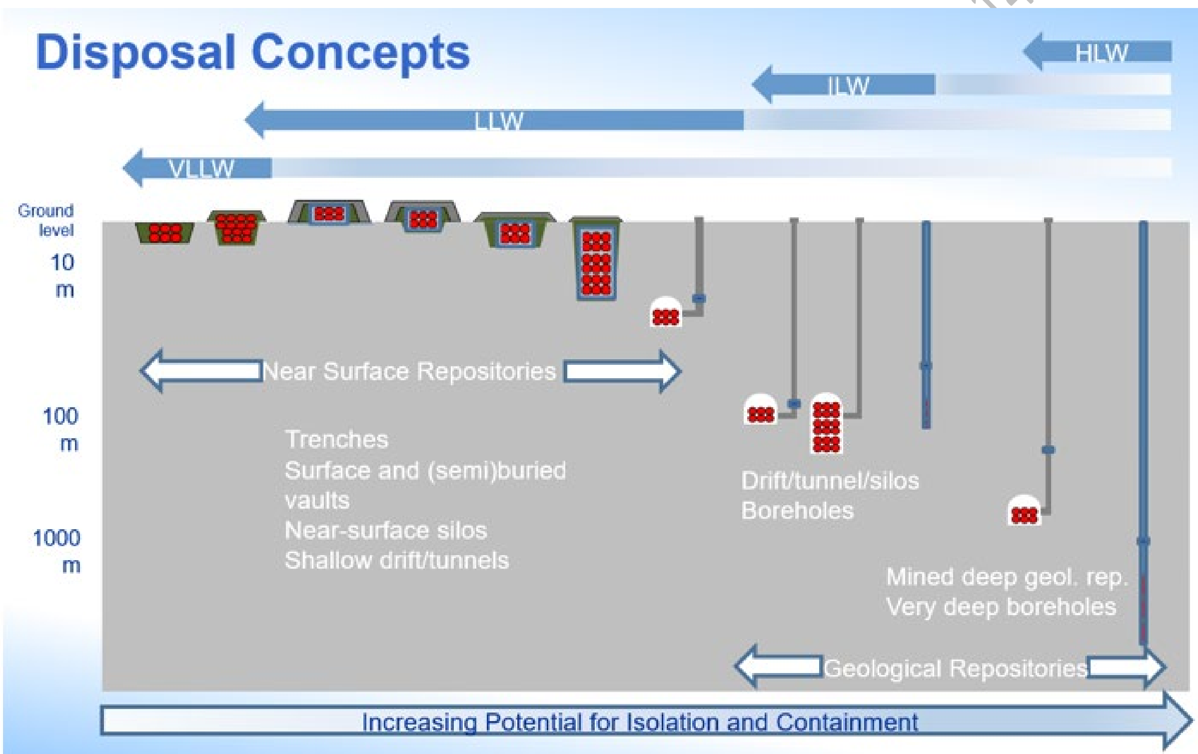

FIG. 6. *Conceptual illustration of disposal concepts for different classes of radioactive waste* [29]

5.1. SPENT FUEL AND HIGH LEVEL WASTE

Spent fuel is generated from the operation of nuclear reactors of all types, including research, isotope production, power production, district heating and propulsion reactors. By volume, HLW forms less than 1% of the global volume of radioactive waste, but it consists of about 95% of the total activity of the radioactive waste. The activity level of HLW is high enough that heat generation should be considered in the design of the waste management facilities. In countries where spent fuel is considered to be waste, it is classified as HLW.

5.1.1. The 'open cycle' and 'closed cycle'

The currently envisaged strategies to ensure a safe and cost effective overall management of spent fuel differ from one country to another and can be described as follows:

- The ‘open cycle’ or ‘once through” or ‘direct disposal’ strategy in which spent fuel is considered as waste;
- The ‘closed cycle’ (including the ‘partially closed cycle’) strategy, in which the spent fuel is considered to provide a potential future energy resource.

In the ‘open cycle’ option, spent fuel is stored for several decades to allow the decay heat to be reduced and also to optimize the operation of the deep geological disposal facility. After a period of storage, the spent fuel will be encapsulated in a robust, corrosion resistant container to meet disposal acceptance criteria and will be disposed of in a deep geological repository.

In the ‘closed cycle’ the spent fuel is reprocessed in order to recover valuable fissile materials (uranium and plutonium). In reprocessing spent fuel is separated into several main components: uranium, plutonium and HLW (containing minor actinides, fission and activation products). HLW contained in spent fuel is then stored to allow the decay heat to be reduced, pending future disposal, normally in a DGR. The uranium and plutonium can be recycled as nuclear fuel for reactors, while the minor actinides, fission and activation products are currently considered to be waste products. The minor actinide and fission product waste are conditioned in a stable vitrified matrix and stored in a very stable matrix purposely designed for storage, transport and disposal. The main activation products (hulls and end-pieces of fuel assemblies) are compacted and conditioned in steel canister, stored pending future disposal compatible for ILW. The spent fuel might go through one or more cycles of reprocessing in order to recover valuable material.

Currently, the countries that operate large scale reprocessing facilities are France, India and the Russian Federation. The UK formerly operated two reprocessing facilities. In 2022 all reprocessing facilities in UK ceased operations. China is operating a pilot plant and is looking to deploy an industrial facility. The reprocessing facility in Japan (Rokkasho-mura plant) is currently under safety review and planning to resume operations. Other countries, including Belgium, Bulgaria, Hungary, Ukraine, the Czech Republic, Germany, Italy, Japan, the Netherlands, Slovakia, Spain, Sweden and Switzerland, have used services provided by foreign facilities (in the UK, France and the Russian Federation (including during the time of the former USSR)) for the reprocessing of their spent fuel.

FIG. 7. Maintenance cell at ORANO, France (courtesy of Eric Larrayadieu).

The commercial capacity for reprocessing was 3500 tonnes of heavy metal per annum in December 2019 (see Table 2). The end of reprocessing operations in the UK in 2022 is reducing the worldwide availability of reprocessing capacity until new facilities in the Russian Federation, China and Japan come into operation.

TABLE 2. COMMERCIAL SCALE REPROCESSING FACILITIES (AS 31 DECEMBER 2019)

Member State	Facility	Capacity (t HM/a)	Status
France	UP2-400, La Hague	400	Under decommissioning
	UP2-800, La Hague	800	In operation
	UP3, La Hague	800	In operation
	UP1, Marcoule	600	Under decommissioning
Japan	Rokkasho-Mura	800	In commissioning
Russian	RT-1, Mayak	400	In operation
Federation	RT-2, Zheleznogorsk	60	Under construction
UK	NDA THORP, Sellafield	900	Ceased operation in 2018
	NDA Magnox Reprocessing, Sellafield	1 500	Ceased operation in 2022

Spent fuel reprocessing in another country is subject to strict controls and is performed on the basis of commercial contracts under the umbrella of bilateral national agreements. In most cases, these commercial contracts provide that the waste produces, as well as the valuable fissile material (usually in the form of fuel for recycling), together with the conditioned HLW from spent fuel reprocessing (as well as fuel component compacted waste in some cases) are sent back to the country from where the spent fuel originated.

Reprocessing spent fuel using aqueous separations results in a high level liquid waste, that is typically vitrified, i.e. conditioned to produce a chemically durable and heat and radiation resistant engineered solid matrix waste form. Several types of glass (e.g. borosilicate and phosphate) and some ceramics are used for the treatment and conditioning of HLW. The glass containing waste is poured into containers which are also used for storage. The vitrification process and all container handling operations are performed remotely in shielded cells. Significant experience has been obtained with the vitrification process in Belgium, France, Japan, the Russian Federation, the UK and the USA. The HLW is then stored for some decades to allow levels of heat generation to be reduced, in a similar way as for spent fuel. Following storage, HLW is to be disposed of in a DGR (See section 5.1.4). Some countries include fuel cladding and structural material which was separated during reprocessing within the HLW class.

The uranium separated during reprocessing, the so-called RepU, can be recycled as fuel in present-day reactors following conversion and re-enrichment if necessary. Recycling RepU from the reprocessing of LWR fuel in a pressurized heavy-water reactor, such as a Canada deuterium uranium (Candu) reactor, is also developed in China. As an example, natural uranium equivalent fuel is an innovative fuel designed to work in synergy with current and planned spent fuel reprocessing technologies in China. It blends RepU from LWRs with DU to create natural uranium equivalent fuel powder that is used to fabricate pressurized heavy-water reactor fuel [30].

The separated plutonium can be recycled into MOX fuel, in which DU and plutonium oxides are combined. MOX fuel has been used for decades in LWRs worldwide and in a few Generation IV reactors (France in the past and today in the Russian Federation), where the energy value of the uranium and plutonium can be better utilized. At present only one country, France, has a commercial MOX fuel fabrication facility in operation for manufacturing of LWR fuel. This facility, MELOX, has provided MOX fabrication services, since 1995, for France and several other countries [31]. Belgium and the UK also operated MOX facilities (respectively called Belgonucléaire and SMP), which ceased operation in 2006 and 2011. MOX plants are also planned to come into operation over the next few years, as it is the case in Japan. Additional multirecycling options in LWRs are under development, such as the regenerating mixture (REMIX) fuel currently in the demonstration phase in the Russian Federation (recycling all the uranium and plutonium without separating them and topping up with some fresh uranium enriched to a higher level than 5%), as well as some other fuel concepts under study in France

(MOX2). Several countries implementing or considering reprocessing today have plans, at different stages of development, for future fast neutrons reactors, though at present only the Russian Federation operates such reactors at a commercial scale (BN-600 and BN-800).

In addition, there are ongoing initiatives to use DU as fuel or to recycle all recovered long lived actinides together (i.e. with plutonium) in fast reactors. This strategy would make it possible to increase utilizations of the uranium in nuclear fuel from less than 1% to well over 90%, which would result in waste containing mainly short lived fission products, thus reducing the waste disposal burden. New reprocessing technologies are being developed to be deployed in conjunction with fast neutron reactors that will burn all long lived actinides, including all uranium and plutonium, without separating them from one another.

A summary of the current fuel cycle strategies adopted in different countries is given in Table 3. It shows that a majority of countries have adopted or use for referencing the open cycle, while the countries with some of the largest nuclear programmes, e.g. France, the Russian Federation, Japan, India and China, have adopted the closed cycle. Some countries with a small nuclear fleet, like the Netherlands, have also opted for the closed cycle strategy, with reprocessing services provided by one or more of the larger countries with this capability. Table 3 shows also that although several countries have chosen open or closed cycle, there are also countries, that are keeping their options open.

TABLE 3. NUCLEAR POWER FUEL CYCLE STRATEGIES

Member State	Commercial scale reprocessing facility		Spent fuel currently in another country for reprocessing	Earlier reprocessing, but practice currently ceased	Planning direct placement of spent fuel in a repository	Keeping options open
	Existing	Planned				
Armenia						✓
Argentina						✓
Belarus			✓			
Belgium[1]				✓	✓	✓
Brazil						✓
Bulgaria[1]			✓			
Canada					✓	
China[2]		✓			✓	
Czech Republic[1]				✓	✓	
Finland				✓	✓	
France	✓					
Germany				✓	✓	
Hungary[1,3]				✓	✓	
India	✓	✓				
Italy			✓			
Japan[4]		✓	✓			
Korea, Republic of						✓
Lithuania					✓	
Mexico					✓	
Netherlands			✓			
Pakistan						
Romania					✓	
Russian Federation	✓	✓				

Member State	Commercial scale reprocessing facility		Spent fuel currently in another country for reprocessing	Earlier reprocessing, but practice currently ceased	Planning direct placement of spent fuel in a repository	Keeping options open
	Existing	Planned				
Slovakia				✓	✓	✓
Slovenia					✓	✓
South Africa						✓
Spain				✓	✓	
Sweden[5]				✓	✓	
Switzerland				✓	✓	
Türkiye					✓	
United Arab Emirates					✓	
UK				✓	✓	
Ukraine[6]			✓	✓		✓
USA				✓	✓	

1 Mixed policy: some fuel has been or will be reprocessed other fuel will or may be direct disposed.
2 The main policy in China is domestic reprocessing. However, some fuel, mainly from CANDU, reactors is planned for direct disposal.
3 Earlier fuel returns to the Russian Federation, but no requirement to return waste from reprocessing to Hungary.
4 Commercial scale facility at Rokkasho-mura has been constructed and is undergoing test operation.
5 Earlier reprocessing was done abroad
6 Some spent fuel is sent to the Russian Federation for reprocessing. Other fuel is stored awaiting a final decision.

5.1.2. Transport of spent fuel and high level waste

The management of spent fuel and HLW involves a number of transport steps between nuclear power plants or other facilities using nuclear fuel, storage facilities, encapsulation/packaging facilities and/or reprocessing facilities, as well as eventually to disposal facilities [32]. Most transport operations are performed within one country, but some journeys cross national frontiers. For countries reprocessing their spent fuel but having no reprocessing facilities of their own, such transboundary movements are necessary. Similarly, the transboundary movement of spent fuel is necessary for countries sending spent fuel from research reactors and other reactors back to the country of origin of the fuel.

Transport is typically undertaken in specially designed transport containers that provide security, shield workers and the general public, and perform other nuclear safety functions such as managing decay heat, ensuring subcriticality and providing neutron shielding [33]. These transport operations are strictly controlled according to national regulations, which meant to be based on the transport regulations in IAEA Safety Standards Series No. SSR-6 (Rev. 1), Regulations for the Safe Transport of Radioactive Material (2018 Edition) [34]. Each State involved in a transboundary movement has to take the appropriate steps to ensure that the transport operation is undertaken in an appropriate manner and with the authorization of the countries of origin, destination and transit.

5.1.3. Storage

After spent fuel has been discharged from the reactor, it is usually stored for some time in a water-filled spent fuel pool to cool it and provide shielding from its radiation. The length of the storage period varies from a few years up to several decades, depending on the spent fuel management strategy adopted. Usually when spent fuel is recycled, the storage period is generally relatively short — a decade or less. In countries that have decided on a direct disposal option or that have yet to make a decision, the storage period can be much longer. Storage systems include wet storage in storage pools or dry storage in storage casks, canisters or vaults built for the purpose. The overview of the storages used in different Member States is provided in the Table 4.

All nuclear power reactors have spent fuel storage pools for the initial decay heat cooling storage period upon discharge from the reactors. They were included in the original design of the reactors. Additional storage capacity, wet or dry, can be built to provide additional storage capacity as needed. The new storage facilities are built outside the containment building, known as away-from-reactor (AFR) stores, and can be either inside or outside the boundaries of the nuclear power plant.

Access to an AFR site may require transport over public roads, railways, sea lanes, etc. AFR facilities are typically purpose built, under a separate licence, for spent fuel storage located away from the main reactor buildings or site. They can be dedicated to one or multiple reactors or they can be a centralized facility serving more than one nuclear power plant. The storage technology for new AFR stores was initially wet storage (see Fig. 9), but dry storage techniques of different types have been developed (see Fig. 10) and are now widely adopted. Reprocessing facilities are normally equipped with large AFR pools at the reception for buffer storage before reprocessing. More information about the spent fuel storages, as well as the examples of them used, can be found in IAEA Guidebook [11].

TABLE 4. SPENT FUEL STORAGES, AS AT END OF 2019

Member State	Spent fuel storage type
Argentina	Wet and dry storage
Armenia	Wet and dry storage
Belgium	Wet and dry storage
Brazil	Wet storage
Bulgaria	Wet and dry storage
Canada	Wet and dry storage
China	Wet and dry storages
Czech Republic	Wet and dry storage
Finland	Wet storages
France	Wet storage, wet storage at reprocessing plants before reprocessing
Germany	Wet and dry storages
Hungary	Wet and dry storage
Japan	Wet and dry storage, wet storage at reprocessing plants before reprocessing
Kazakhstan	Dry storage
Korea, Republic of	Wet and dry storage
Lithuania	Wet and dry storage
Mexico	Wet and dry storage
Netherlands	Wet store before transport to France to reprocessing
Romania	Wet and dry storage
Russian Federation	Wet and dry storage Wet storage at reprocessing facilities before reprocessing
Slovenia	Wet storage
Slovakia	Wet storage
South Africa	Wet and dry storage
Spain	Wet and dry storage
Sweden	Wet storage
Switzerland	Wet and dry storage
Ukraine	Wet and dry storage
United Kingdom	Wet and dry storage
United States of America	Wet and dry storage

FIG. 8. The wet AFR storage of spent fuel at Clab, Sweden (courtesy of SKB).

FIG. 9. The dry storage hall at ZWILAG Zwischenlager Würenlingen AG (courtesy of ZWILAG).

The canisters for HLW (produced during reprocessing of spent fuel) are stored in air cooled vaults or casks similar to those used for spent fuel storage. Each reprocessing plant has large vaults for canister storage — mainly for its national HLW. In Germany and Switzerland, HLW is stored in casks, while Belgium, Japan and the Netherlands use dry vault storage technology, e.g. the HABOG facility in the Netherlands [35].

IAEA guidebook on spent fuel storage [11] provides guidance to Member States on spent fuel storage options, describing the history and observed trends of spent fuel storage technologies, gathering operational experiences and lessons learned; the evolving aspects related to higher burnup and mixed oxide (MOX) spent fuel, and the extension of the storage timeframes.

5.1.4. Disposal

There is a broad consensus among technical experts that the preferred method of ensuring long term safety for spent fuel and HLW is isolation in a DGR. Geological disposal facilities for long lived waste will provide passive multibarrier isolation and containment of radioactive materials. Emplacement in carefully engineered structures buried deep within suitable geological formations provides the long term stability typical of a stable geological environment [36] [37]. Countries, that need to dispose of their spent fuel and HLW are studying different available geological media for it [38].

In the case of the open cycle option, before being sent to the DGR, the spent fuel will have to be encapsulated in a corrosion resistant and mechanically stable container, which will provide isolation for a suitable duration. The vitrified HLW waste form in a stainless-steel canister is specifically designed for long-term durability in storage and disposal. In some countries an additional corrosion resistant overpack is also considered. The requirements for the container life and integrity depends on the DGR concept and the chosen geological medium.

Poisva Oy in Finland applied for the operational licence application for encapsulation plant and geological disposal facility in Onkalo site. The construction of underground access tunnels at ONKALO facility in Finland started in December 2016 and the construction of the encapsulation plant started in 2019. First construction phase of the deposition tunnels is finished (5 deposition tunnels excavated). In Sweden the Government approved ‘allowability’ of construction of encapsulation plant and disposal facility for spent fuel in January 2022. In France the detailed concept for HLW and ILW disposal project for Cigéo (the Industrial Centre for Geological Disposal) was achieved in 2020 and the Environmental Impact Assessment was issued in 2021. In 2022 it was recognized as final solution for management of HLW and ILW. It is expected that the construction licence for HLW deep geological disposal will be submitted in 2022.

There are formal site selection processes under way in several other countries, such as Canada, Germany and the UK [38]. In countries with both spent nuclear fuel and HLW for disposal, a single DGR for both materials is a typically adopted approach. Most other countries with spent nuclear fuel are working towards national solutions, although they are mostly at the early planning stage. Some countries have also indicated an interest in developing multinational disposal facilities, in addition to their own national programme.

Research related to DGR option has been undertaken for several decades using a range of underground research laboratories (URLs). These URLs have an important role in waste disposal programmes and are also valuable in building confidence in national programmes [39] [40]. Currently there are about 20 URLs in use, for example HADES in Belgium, KURT in the Republic of Korea, Krasnoyarsk URL in the Russian Federation.

5.1.5. Spent fuel from non-power reactors

The amount of spent fuel from non-power reactors is much smaller than from nuclear power reactors. Fuel from non-power reactors, however, raises some specific challenges as it sometimes has higher enrichment than, and a different composition from, power reactor fuel. Although non-power reactors are often built in countries with a nuclear power programme, these reactors are also operated in countries without nuclear power plants where non-power reactor fuel is one of the most important factors in waste management. The IAEA works with Member States to develop a variety of nuclear education and training programmes, one of which is the Internet Reactor Laboratory. This is a cost effective virtual reactor that provides the possibility to use research reactors remotely, so the Member States without an existing research reactor can develop their nuclear infrastructure.

At present, most non-power reactor spent fuel is returned to the country of origin of the fuel, mainly the Russian Federation and the USA, and thus does not require disposal in the country where it has been used. A few countries such as Australia, Belgium and Sweden, have decided to reprocess either part or all of their spent non-power reactor fuel. Some countries have to consider disposal of this spent fuel nationally and this might be a challenging task, especially, if they do not have a nuclear power programme. IAEA Nuclear Energy Series NW-T 1.11 provides an overview of the available reprocessing and recycling services for non-power reactor spent fuel [41].

5.2. INTERMEDIATE LEVEL WASTE

ILW generally contains significant amounts of long lived radionuclides and therefore requires disposal at depths that provide containment and isolation from the biosphere over the long term. ILW requires shielding during handling and storage. It should be noted that the definition of ILW used in GSG-1 [4] is used throughout this publication, which means that the ILW covered in the publication includes all forms of ILW that require a greater degree of containment and isolation than near surface disposal can provide.

5.2.1. Processing

The processing of ILW either takes place at the facilities where it is generated or at a purpose built facility (which can also be a centralized facility). Processing consists of collection, segregation, decontamination, volume or size reduction and stabilization prior to packaging [21] [42] [43] [44]. Drying, evaporation, high pressure compaction, melting and cementing are common technologies applied in the treatment and conditioning of ILW [45]. Care needs to be taken during treatment to make sure that radioactivity concentrations will not increase beyond the capability of the treatment facilities or packaging to handle the resulting radiation levels and the extent of heat emission.

Depending on its intended storage or disposal destination, ILW is often treated and conditioned by incorporating it into a matrix (e.g. cement) within a suitable container to provide the required radiation shielding [46]. In some cases, where additional matrices are not required to ensure safety, conditioning is limited to packaging. In other cases, the waste object itself (such as a large vessel with internal contamination) forms the container, once suitably sealed.

Concrete containers with steel reinforcement, steel drums and steel boxes are commonly used for waste packaging. Their dimensions are selected to meet safety requirements and to be compatible with the dimensions of transport casks and disposal vaults. ILW containers can either be self-shielded or rely on external shielding to provide the necessary radiation protection. Both design concepts are used extensively.

5.2.2. Storage

After processing, storage of the product is often necessary if suitable disposal facilities are not available. Storage for periods of up to 100 years or longer can be considered as an option provided that the waste containers will remain intact and are not subject to degradation. Attention needs to be given to the provision of adequate containment and shielding. Heat removal may also be required in some cases, although not to the same extent as HLW.

5.2.3. Disposal

The only licensed disposal facility for long lived ILW is the Waste Isolation Pilot Plant (WIPP), USA, where long lived, non-heat-generating waste from defence activities is disposed of in a geological repository built in salt beds. Elsewhere, ILW is held in storage until a disposal facility suitable for this material becomes available. Germany and Switzerland envisage that all LLW and ILW will be disposed of in one multipurpose, deep geological facility, obviating the need to separate waste containing short and long lived radionuclides before disposal. The Schacht Konrad facility is licenced and in construction in Germany. In France, long lived ILW will be disposed together with HLW in the planned Cigéo (Centre industriel de stockage géologique/Industrial Centre for Geological Disposal) facility.

5.3. LOW LEVEL WASTE

Taken together, VLLW and LLW typically account for more than 95% of the volume but less than 2% of the radioactivity of all radioactive waste. LLW does not generally require significant shielding during handling and interim storage. The waste is suitable for disposal in engineered near surface facilities. However, some countries, such as Germany and Switzerland, are implementing policies that do not foresee separate disposal facilities for every radioactive waste class and therefore their LLW might be disposed of at deeper facilities.

5.3.1. Processing

As with ILW, the treatment and conditioning of LLW either takes place at the facility where it is generated or at a purpose built facility (which can be a centralized facility). The waste is segregated, treated, conditioned, packaged, monitored and stored, as appropriate, before being transferred to the disposal facility. Drying, incineration, evaporation, high pressure compaction, melting and cementing are common processes applied to the conditioning of LLW [47]. Concrete containers, steel drums and steel boxes are commonly used for waste packaging. Subject to meeting all relevant safety requirements, their dimensions are selected to fit the dimensions and shapes of disposal spaces and transport packages.

5.3.2. Storage

Options for the storage of LLW are broadly similar to those for ILW (see Section 5.2.2). Storage for longer periods can be considered as an option provided that the waste containers remain intact and are not subject to degradation. However, as LLW disposal facilities are available in number of Member States (see Section 5.3.3), the storage periods for LLW can be quite short.

5.3.3. Disposal

LLW, most of which has a half-life of less than 30 years, is disposed of in near surface repositories in many countries (see Annex 2 and Figs 9-11). These are trenches or concrete vaults into which containerized waste is placed. An engineered cover system is placed over the waste to limit water infiltration and surface erosion and to prevent intrusion by humans or burrowing animals. The facilities are subject to surveillance until the hazard associated with the waste has declined to acceptable levels (typically a few hundred years). While disposal of LLW in a near surface facility is a typical strategy for many, some countries (e.g. Canada, Finland, Germany, Hungary, the Netherlands, the Republic of Korea, Sweden and Switzerland) have chosen, or are considering, the option of disposing of LLW in repositories at depths between 50 m and 1000 m. These facilities should not require long term surveillance. Several countries have both licensed and operated geological disposal facilities for LLW, either as purpose-built facilities (e.g. Bátaapáti repository in Hungary; Gyeongju facility in the Republic of Korea; Himdalen repository in Norway; and SFR, Final Repository for Short-Lived Radioactive Waste, in Sweden) or converted facilities from former mines of various types (e.g. Richard in the Czech Republic; Asse II and Morsleben in Germany; and Baita Bihor in Romania).

FIG. 10. LLW disposal facility in Olkiluoto, Finland (courtesy of TVO).

FIG. 11. LLW disposal facility in El Cabril, Spain (courtesy of Enresa).

FIG. 12. LLW disposal vault in Bátaapáti, Hungary (courtesy of PURAM).

A small number of countries are considering LLW's co-location in geological facilities with ILW, HLW or spent fuel. Co-disposal can result in a simpler waste management system because fewer facilities need to be developed. However, co-location can also introduce design complexity to avoid interferences between the waste types (e.g. decomposition of LLW can result in the generation of complexing agents that reduce the safety of higher level waste), as well as significant increases in the volume of material requiring handling at geological depths.

5.4. VERY LOW LEVEL WASTE

VLLW often exists in large volumes and is mainly generated during the decommissioning of a nuclear facilities or from the cleanup of contaminated sites. Typical VLLW includes concrete, soil and rubble. This class is currently recognized as a distinct classification by only a small number of States (e.g. France, Japan, Lithuania, Spain and Sweden). In most other country classification systems, it is included as part of the LLW stream.

5.4.1. Processing

VLLW is typically not subject to extensive processing, apart from its packaging, due to the very large quantities involved and the low content of radionuclides. In countries where the clearance concept is used, the volume of potential VLLW can be reduced by appropriate characterization to separate those components that can be released from regulatory control as cleared waste.

5.4.2. Storage

Generally, VLLW is stored at the site of its generation or in a centralized storage facility until it can be transported to a suitable disposal facility. During this stage, a simple shelter or temporary cover might be sufficient to provide protection from wind, rain, etc.

5.4.3. Disposal

In France, Slovakia and Spain, VLLW is disposed of in purpose built disposal facilities in shallow trenches with engineered covers, often near the site of generation to avoid the transport of large volumes of material (see Fig. 12). Sweden and Lithuania developed an above ground design using a concrete slab. In other countries it is disposed of together with other waste types, such as LLW, or in countries such as the UK with hazardous waste.

FIG. 13. VLLW disposal at the Cires facility, France (courtesy of ANDRA).

5.5. URANIUM MINING AND MILLING WASTE, NORM WASTE

Uranium mine waste rock and mill tailings are normally managed and disposed of close to the uranium mine or the uranium mill. The waste rock and tailings are not packaged, but rather are contained in nearby locations with suitable barriers (stable mounds with an appropriate cover system) to minimize their radiological and non-radiological impact on the surrounding environment. In some countries, UMM tailings and *in situ* leaching waste are not classified as radioactive waste. Hence, these countries do not report the waste as radioactive waste, while others do. UMM can then be classified as long lived VLLW or in some cases LLW. Uranium extraction by the *in situ* leaching method usually also generates smaller volumes of radioactive waste and different waste forms.

Radioactive residues are also generated from the oil and gas industries (e.g. scales and sludges), mining of other minerals and products (e.g. residues from extraction of thorium and rare earth elements), and the treatment and usage of drinking and process water.

If NORM is classified as radioactive waste, depending on the national waste management concept, this is usually considered to be VLLW or LLW. NORM waste is not specifically discussed in this publication, although some countries have reported NORM waste in SRIS.

5.6. DISUSED SEALED RADIOACTIVE SOURCES MANAGEMENT

Sealed radioactive sources are used widely in medicine, industry and agriculture and, because of this, they are found in almost all countries. For many countries, these are the only radioactive material to be handled, and they require storage and eventually disposal. The life cycle of a sealed radioactive source is presented in Fig. 13.

The management of disused sealed radioactive sources is covered in IAEA Safety Standards [48] and by Joint Convention [3]. However, on account of the special nature of DSRS and their widespread use, specific international standards have been developed for their management, including the following:

- Code of Conduct on the Safety and Security of Radioactive Sources [13];
- Council Directive 2013/59/Euratom of 5 December 2013 laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation, in particular Section 2 on control of radioactive sources [49];
- Council Regulation 1493/93/Euratom of 8 June 1993 on shipments of radioactive substances between Member States [50].

The Guidance on the Import and Export of Radioactive Sources was published in 2012 [14], and in 2018, supplementary Guidance on the Management of Disused Radioactive Sources [15] was developed and published providing more details on the effective management of DSRSs.

Depending on the intended use, sealed radioactive sources include a wide variety of radionuclides and activity levels. The Code of Conduct [13] and IAEA Safety Standards Series No. GSR Part 3, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards [48], categorize radioactive sources according to their potential to cause serious health effects (see Table 5).

TABLE 5. CATEGORIES OF SEALED RADIOACTIVE SOURCES [23]

Category	Risk in being close to an individual source	Examples of uses
1	Extremely dangerous to the person	Radioisotope thermoelectric generators Irradiators
2	Very dangerous to the person	Industrial gamma radiography sources High/medium dose rate brachytherapy sources
3	Dangerous to the person	Fixed industrial gauges Well logging gauges
4	Unlikely to be dangerous to the person	Bone densitometers Level gauges

5	Most unlikely to be dangerous to the person	Permanent implant sources Lightning conductors

At some point, sealed sources have to be replaced, usually because their activity level has declined below which the source is no longer suitable for its intended purpose. They are then considered to be ‘spent’ or ‘disused’ sources. DSRS are either managed together with other waste in a category commensurate with their hazard (e.g. LLW, ILW or HLW) or separately, again in a manner commensurate with their hazard. An overview of the national strategies used in DSRS management can be found in Annex 2.

There has been significant progress with regard to the management of disused sealed sources. While some Member States have a well-established regulatory framework for disused sealed source management, others are still facing challenges in that regard. Especially in regard historical waste, orphan sources or sources imported before enforcements of return policy remain a challenge for some States. Many Member States consider disused sealed sources as waste, while other recycle and reuse them. However, the safety of long-term management of disused sealed sources is still considered as a challenging issue.
One main issue is to create an inventory and a follow up system in the countries to provide a good knowledge of the sealed sources that are used and of who are the users. The management of orphan and disused sealed sources remains an overarching, as it has been considered during several Review Meetings of Joint Convention. In addition, a collecting system of disused sealed sources with a (financial) motivation for the user to use this system has to be implemented. There are several international initiatives for securing the safe storage of the disused sealed sources. Recognizing the need to assist Member States in the safe and effective and management of disused sources, the IAEA have focused on the development of a series of publications dealing with the handling, conditioning, storage and disposal of such sources. The guidance on the management of DSRS, including problems encountered and lessons learned are included in IAEA report [51] to support well informed progress and decisions in managing disused sources.

5.6.1. Storage and conditioning

States with nuclear power facilities are likely to have the capacity for long term storage or disposal of DSRSs together with other types of radioactive waste. For many small countries, however, storing or disposing of the sources safely and securely presents an ongoing challenge. The management practices for DSRSs are very similar to the management of LLW and ILW.

Sources with short half-lives (e.g. ^{192}Ir, half-life of 74 days) can be stored until the radioactivity in the source decays to low enough levels to allow release from regulatory control (i.e. clearance); while others (e.g. ^{226}Ra, which until recently was widely used) remain potentially hazardous for tens of thousands of years. Where disposal options are not available, long term storage facilities are required for many types of DSRS. Effective management involves repackaging the source, checking the condition of the source or source container regularly, and providing appropriate safety and security measures.

5.6.2. Return to supplier, reuse and recycle

Recycling for further use is preferred option for managing disused sealed sources. If the preferred option is not possible, the option is to return it to its supplier [51]. As a result of the challenges associated with disposing of DSRS safely, especially in countries with little or no radioactive waste management infrastructure, current good practice is to return the sources to the manufacturer for refurbishment, recycling or storage/disposal. A number of countries insist upon this as a condition of the import and sale of sealed sources within their territory.

There are many programs to collect disused sources for reuse or recycling, or for transfer to another licensee. Typically, a prior arrangement with the user, and in some cases a “one-for-one” exchange where the user returns a disused source and concurrently purchases a replacement source is needed for returning a source to the manufacturer or supplier. This kind of practices are very common in some application areas, for example with industrial radiography, panoramic irradiators and other irradiators that use cobalt-60, teletherapy, and brachytherapy.

There can be several arrangements agreed between the user and supplier. Often then the used source is replaced for a new source, there can be no cost associated for taking the used source back by the supplier or manufacturer. However, the return of a disused source to a manufacturer or supplier can be challenging even when there is a return program in place. One of the challenges can be related to the documentation requirement, for example then the user needs to provide documentation of the country of origin of the source and where manufacturing occurred. Other challenges can arise in relation of the fact that the source manufacturers may have production facilities in several countries and different components of a source are manufactured in facilities in different countries, thus making it difficult to determine to which country the disused sealed radioactive source should be returned. There are other additional challenges - limited availability of certified transportation containers, required certification for the sources, etc [16].

Recycling is an effective way to delay the actual disposal of a source until another option becomes available. Even then both reuse and recycle have been implemented effectively, it is still only a small percentage of the large number of sources that require disposal.

There are various recycling methods available, such as recovery of the sealed source or transmutation by linear accelerator. Production of ^{225}Ac for cancer therapy by photon-induced transmutation of ^{226}Ra is one of the recycling examples. Recycling reduces the amount of radioactive material that needs to be produced; however, at the same time it should be taken into account that these actions have to be cost effective and technically feasible.

Whilst the return of the DSRSs to the supplier is a widely used option, it is not always possible, as the original supplier may, for example, be unknown or no longer exist, or the transport means, regulatory framework or financial resources may not enable transportation of the sources.

Recycling of DSRS is always a technically demanding task that requires particular expertise and authorization.

Most States have the strategy of returning disused sealed sources to the manufacturer and the country of origin or are in the process of developing centralized facilities. The overview of the national management strategies for disused sealed sources is provided in the Annex 2.

5.6.3. Disposal

If no further use is foreseen and it cannot be otherwise removed from regulatory control, the only sustainable long term option is disposal. As such, disused sources for which no recycling or repatriation options exist should be declared as radioactive waste and should be managed as such, in compliance with relevant international legal instruments, safety standards and good practices.

For those disused sources that cannot be returned to a supplier or reused and that cannot be stored until they decay to clearance levels, disposal is the final step in their management. Some countries, particularly those with a nuclear power programme, may have the option to co-dispose their disused sources in a near surface or geological disposal facility. It will, however, need to be verified that the sources comply with the waste acceptance criteria set up for those facilities.

Where co-disposal is not possible, disposal in one or more boreholes may offer a solution. Disposal in boreholes offers a safe and secure disposal solution. The concept of borehole disposal of disused sources has been extensively studied and developed over the last two decades. In that time, it has evolved from a conceptual idea into a mature disposal solution. Today, projects on the borehole disposal of DSRSs are ongoing in Ghana and Malaysia and are being considered in several other countries.

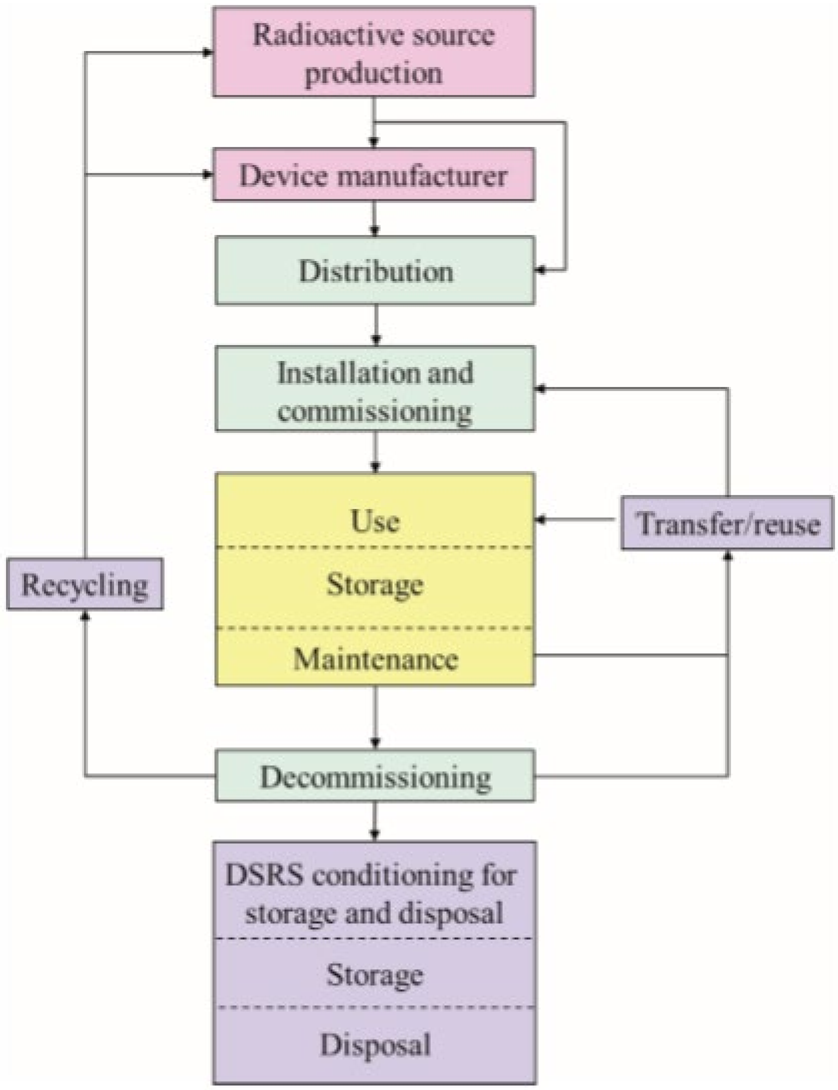

FIG. 14. The life cycle of a sealed radioactive source

6. INVENTORIES

6.1. DATA SOURCES

The main sources of information used for inventories and forecasts are Spent Fuel and Radioactive Waste Information System and publicly available Joint Convention National Reports. In the case of some EU members, their openly available National Reports on the implementation of the Euratom Waste Directive were used as well. The National Profiles, Joint Convention National Reports and EU National Reports cover almost 92% of all nuclear power plants in the world. This provides a good basis for making regional and global aggregations of waste volumes. Nuclear power plants generate significant quantities of spent fuel and radioactive waste, and by comparison, countries without nuclear power plants generally have much smaller amounts of radioactive waste (and of spent fuel if they operate research reactors).

The estimation of the global inventory depends on the availability of the inventory data for countries with nuclear power plants. All countries have some radioactive waste, which in many cases entirely comprises DSRSs. The aggregated numbers have been rounded for presentation purposes and the United Nations country groupings were used for regional aggregation of the data.

6.1.1. Spent Fuel and Radioactive Waste Information System

Spent Fuel and Radioactive Waste Information System provides a good structure for data collection, which could be also used for aggregation of data at regional or global levels and facilitates data analysis. The data fields include among others amounts of spent fuel and radioactive waste, together with transformation matrices to enable the transfer of the volumes given in national classification systems to the classification in GSG-1 [4]. A total of 19 Member States have submitted data to SRIS[6].

6.1.2. Joint Convention National Reports

Joint Convention National Reports are produced triennially and Contracting Parties to the Joint Convention are encouraged to publish their National Reports.[7] Data were used from this source for Member States that did not submit data to SRIS.

The Joint Convention National Reports include listings of spent fuel and radioactive waste management facilities in the Contracting Parties. They also provide inventories of spent fuel and radioactive waste in the States based on their national waste classification systems. Forecasts of spent fuel and waste storage and disposal are, however, not provided. National Reports vary in the level of detail provided and in the measurement units used, requiring translation of the waste quantities presented according to national classification into equivalent GSG-1 waste classification.

6.1.3. Euratom Waste Directive National Reports

The Euratom Waste Directive requires submitting a triennial report to the European Commission on the implementation of the Directive. These reports should give a comprehensive but concise high level overview of how a Member State complies with the Directive, with an emphasis on major changes and progress made since the previous report [52]. The inventory dates and timing of these reports are similar to the Joint Convention National Reports for several Member States.

[6] See sris.iaea.org
[7] See www-ns.iaea.org/conventions/results-meetings.asp.

EU Member States are required to provide in their national programme an inventory of all spent fuel and radioactive waste and estimates for future quantities, including those from decommissioning, clearly indicating the location and amount.

6.2. DESCRIPTION OF DATA AGGREGATION

As noted previously, the precise definition of what constitutes radioactive waste and its classification into levels or categories varies widely among countries, which creates some inherent difficulties in aggregating inventory data regionally and globally. This section describes the approach taken to data collection and the model used to aggregate data from different countries into a common framework.

6.2.1. Conversion to IAEA waste classification

This publication uses the waste classification in GSG-1 [4] to present global values. This classification is based on the disposal route required to provide long term safety. However, some States intend to dispose of waste in facilities normally reserved for waste that presents a greater long term hazard (e.g. disposing of LLW in a geological repository). Furthermore, the boundaries between different classes are not defined by quantitative activity levels, but instead depend on the safety case for a specific facility. On that basis, waste of a particular class in one country might not have precisely the same level of activity as the same class of waste in another country — although the differences at the margins are typically not significant. Note that the total amount of all classes of waste remains the same and can be stated with a good degree of accuracy, and only its allocation between different classes or categories may be subject to variation.

To assist the conversion to the waste classification in GSG-1 [4], while reporting inventories in SRIS, the respondents were asked to include a conversion matrix, indicating the proportions of waste from a national class corresponding to the appropriate waste classification in GSG-1. In case of data taken from the publicly available National Reports under the Joint Convention [3], estimates were made for a conversion matrix if the national waste classification differs from waste classification in GSG-1 [4].

6.2.2. Constraints in determining global inventory

The data presented in the SRIS and Joint Convention National Reports has provided the basis for preparation of the global and regional aggregated data presented in this publication. However, this process involves some additional uncertainties. For example, the waste volumes can also be presented in different ways and the determination of 'as disposed' waste volumes requires assumptions to be made, which inevitably involves the use of approximations, concerning the waste processing and disposal strategies. This step tends to be particularly complex in the case of liquid waste.

The recognized gaps and uncertainties in the estimation of global inventory data include the following:

- Lack of data on some countries. This will result in an underestimate of total inventories.
- Uncertainties in the translation of data from national waste classification systems to waste classification in GSG-1 [4] for aggregation purposes. This will affect the distribution of waste volumes among the various waste classes (VLLW, LLW, ILW and HLW), but will not affect the overall total amount of waste.
- Differences in the way that various States report waste volumes (e.g. 'current as stored' volumes versus forecasted 'as disposed' volumes, use of actual physical volume of waste packages, versus the volume envelope it might occupy in a repository). This will affect the reported volumes of waste. On average, however, the overall effect on accuracy of the global inventories should not be significant due to offsetting increases and decreases as well as rounding of the aggregate numbers.
- Different reporting dates will affect the accuracy of a 'snapshot' for a given date. However, most of the reporting dates are within a year or two of the selected reference date for this

publication (31 December 2019). Given that in most cases the accumulated waste and spent fuel volumes do not grow very quickly, and given the very large residual inventories in countries with large programmes, the overall effect on the accuracy of the global inventories should not be significant.

- Different approaches to the clearance of radioactive waste.
- The inclusion of unprocessed liquid waste in the totals. In some cases, no distinction was made in country reports for unprocessed liquid waste versus solid waste. The potentially large volumes of liquid waste can distort the overall data if not accounted for separately. Therefore, where a country has distinguished between liquid and solid waste, either by direct statement or inference from a waste classification, liquid waste quantities are handled separately from solid waste quantities in all relevant tables of this report.

The project supporting the development of this publication did not include a quantitative analysis of the level of uncertainty in the presented information. Lessons learned in the collection and analysis of data for this publication will be incorporated into later phases, and modifications will be sought to improve accuracy and to minimize uncertainties in the aggregated data.

6.2.3. Conversion to disposal volumes

The input for SRIS requests waste volumes to be presented corresponding both to the current state of the waste and its anticipated volume for disposal. To help minimize the inconsistency in volumes, this publication uses ‘as disposed’ volumes where available, followed by ‘as stored’ when only this has been reported. Estimations are, however, necessary to calculate the ‘as disposed’ volume, taking into account the repository requirements and the conditioning and packaging plan.

For some countries, with a known or assumed conditioning and disposal route, it is possible to transform the storage volume to the disposal volume. For States without established plans for a repository and corresponding waste package geometries, several assumptions need to be made, for example concerning what further conditioning and packaging will be required for ‘disposal ready’ packages. In such situations, greater uncertainty may exist concerning the disposal volumes. This uncertainty might increase if there is a possibility that conditioned waste packages are eventually placed in larger containers or overpacks for disposal.

The Status and Trends project includes an initiative by the IAEA, the OECD/NEA and the EC to harmonize the spent fuel and radioactive waste inventory data reported to the different agencies for various purposes to reduce the reporting burden on Member States and to ensure the consistency of data reported. It was agreed that the volumes of conditioned waste ready for disposal should be used. This is also recommended by the European Nuclear Safety Regulators Group [52]. However, it should be noted that there is no universal agreement on the definition of ‘disposal volume’. For any given country, the definition and/or calculation method is usually embedded in regulations, national policy or a facility licence.

6.3. CURRENT INVENTORIES OF SPENT FUEL

The spent fuel inventories provided in this publication do not distinguish between fuel that is considered to be a waste in the responding State and fuel that is considered to be an asset (i.e. intended to be reprocessed). The global totals include all countries where information is available. The data include spent fuel from nuclear power plants, demonstration and research reactors and other kinds of reactors (e.g. isotope production). The amount of spent fuel is presented in tonnes of heavy metal (t HM) and describes the mass of heavy metals (e.g. plutonium, thorium, uranium and minor actinides) contained in the spent fuel.

It should be noted that spent fuel that has been sent for reprocessing but has not yet been reprocessed is included in the amount of spent fuel currently in storage in the country to which it has been sent.

Additional data on historical amounts of spent fuel that have been reprocessed have been extracted from other sources, such as the annual reports from commercial reprocessing facilities. Spent fuel that has been reprocessed is no longer in the form of fuel, but has been separated into various types of waste and recyclable components. The unit of measure for waste from the reprocessing of spent fuel is the cubic metre, and is included as part of the LLW, ILW and HLW as appropriate. Fuel that has been reprocessed is included separately in the tables under ‘sent for reprocessing’ to give a total of all the spent fuel that has been produced since the beginning of the nuclear power age.

6.3.1. Nuclear power plant spent fuel

The aggregation in Table 6, as well as those in subsequent tables and charts, gives a global summary of inventories. It is also divided into subtotals by UN country geographic regions as well as giving a global total. It shows subsets of the global total for the Member States of the Joint Convention, EU and OECD/NEA. These subgroupings allow the reader to see the aggregated amounts for various Member State groupings. Details for individual countries can be found in the Country Profiles located on the web site accompanying this publication.

TABLE 6. REPORTED SPENT FUEL IN STORAGE, AS OF 31 DECEMBER 2019

Region	Wet storage (t HM)	Dry storage (t HM)	Not specified (t HM)	Total (t HM)
Africa	1100	50	n.a.[a]	1150
Americas	78 800	71 100	n.a.[a]	150 000
Asia	36 400	8100	8500	44 500
Europe	47 200	15 400	102 700	201 500
Oceania	n.a.[a]	n.a.[a]	n.a.[a]	1
Global total	163 500	94 600	33 800	302 000
Joint Convention Contracting Parties	163 500	94 600	33 800	302 000
EU Member States	37 200	13 000	4 000	60 600
OECD/NEA members	144 000	85 200	33 800	269 300

About one third of all spent fuel discharged from nuclear power plants has been sent to be reprocessed, remaining is stored, pending processing or disposal. Most spent fuel is held at nuclear power plant sites in wet storage in the reactor pools. Fuel inside the reactor core is not included in the inventory, since it is not considered to be spent until it has been discharged from the core.

After initial storage for cooling for at least a few years in the reactor pool, some spent fuel has been transferred to dry storage or to centralized wet storage facilities. The total amount of spent fuel in storage was about 302 000 t HM as of the end of 2019. Figure 14 shows the share of spent fuel stored either in dry or wet storage [11].

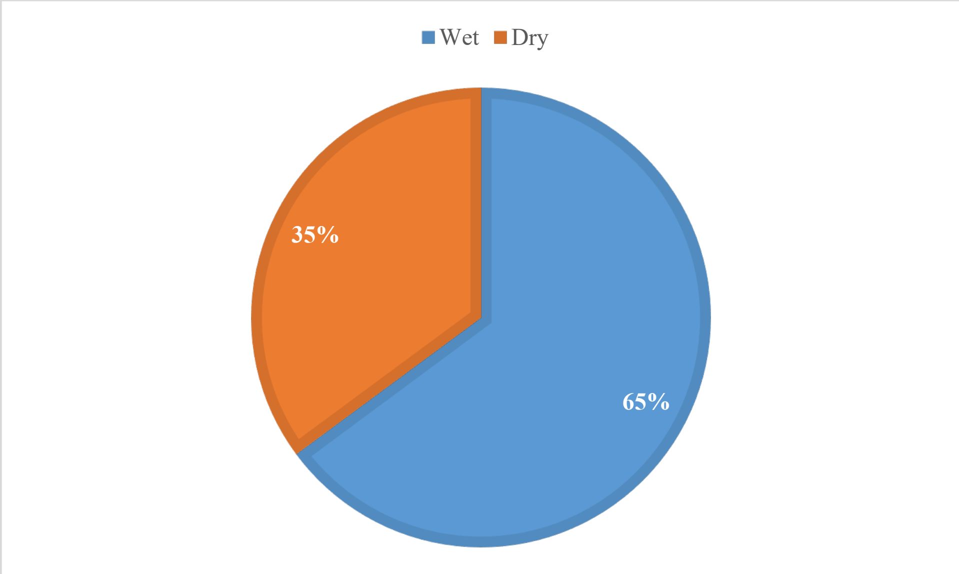

FIG. 15. Nuclear power plant spent fuel storage by type.

6.3.2. Spent fuel from research and other reactors

A number of States operate non-power reactors, such as research, isotope production, experimental, prototype or propulsion reactors. The national inventories of spent fuel from these reactors are summarized in Table 7. It is noteworthy that these amounts are less than 1% of the amount of spent fuel that originates from nuclear power plants. It should also be noted that the fuel quantities from non-nuclear power plant reactors are generally not publicly reported to the same level of detail as for nuclear power plants. However, a typical research reactor has a core capacity in the order of a few kilograms of uranium fuel, whereas a commercial nuclear power plant might have a core of 100 tonnes or more. Isotope production reactors may have a capacity of a few tonnes.

There can also be a difference in the enrichment of the fuel in ^{235}U. Many research reactors and isotope production reactors were originally designed to operate using high enriched uranium (HEU) fuels, whereas power reactors utilize low enriched uranium fuels (roughly 0.7–5%), leading to a potential difference in the amount of uranium that is discharged in the spent fuel. This also depends on the amount of 'burnup' of the ^{235}U. In many cases, the research reactors have been converted to operate with low enriched uranium. For example, the policy of the USA has been the minimization, and ultimately elimination, of HEU in civilian research reactors worldwide since 1978 [53].

TABLE 7. REPORTED SPENT FUEL STORED FROM RESEARCH AND OTHER REACTORS, AS OF 31 DECEMBER 2019

Region	Wet storage (t HM)	Dry storage (t HM)	Not specified (t HM)	Total (t HM)
Africa	0	0.1	n.a.[a]	0.1
Americas	34	2437	n.a.[a]	2471
Asia	159	n.a.[a]	300	459
Europe	184	54	73	311
Oceania	n.a.[a]	n.a.[a]	n.a.[a]	0
Global total	377	2 491	373	3241
Joint Convention Contracting Parties	377	2 491	373	3241
EU Member States	16	23	73	112
OECD/NEA members	376	2490	73	2939

The majority of the spent fuel in storage from non-power reactors is in North America. This is because spent fuel from prototype power reactors is considered under the research reactor category in Canada and the USA. Most spent fuel from research and other reactors in many countries has been returned to suppliers for reprocessing or disposal (usually the USA or the Russian Federation), and in these cases that spent fuel will become part of the inventory of the receiving country.

6.4. CURRENT INVENTORIES OF RADIOACTIVE WASTE

Most of the radioactivity present in radioactive waste (up to 95% of the total) is present in HLW (including spent fuel, when declared as waste). In terms of volume, the situation is reversed and more than 95% of the total volume of waste comprises LLW or VLLW. The hazard presented by any toxic agent is a complex combination of the quantity, the particular chemical components and their respective concentrations in the waste (in this case mainly the radionuclides), the physical and chemical form of the waste, the radioactivity level and the exposure scenarios. Generally, chemical and physical forms of waste that are mobile in the environment are more hazardous. Limiting its mobility is therefore an important reason for conditioning waste prior to disposal, as well as for selecting suitable geology when siting a disposal facility.

Solid waste and liquid waste are described separately. This differentiation is important because of the significant volume of liquid waste and the large volume reduction achievable from processes such as evaporation, filtration, vitrification and others, depending on the chemical composition and amount of water. Typically, liquid waste is processed for solidification soon after it has been generated, rather than placing it in storage. In States that follow this approach, only a small part of the national radioactive waste inventory exists in liquid form. In some countries, a past practice was to store some waste in liquid form with the intention of processing and converting it to solid form at a later stage, and as a result, the waste still exists in this form at many sites.

Most radioactive waste is either in storage awaiting the development of a suitable disposal facility, awaiting further treatment pending disposal in a licensed facility, or has already been disposed of. In general, only solid waste is placed into disposal facilities, although past practices in some countries included direct injection of liquid waste into underground formations for disposal. This strategy is still practised in the Russian Federation and is also practised in non-nuclear industries in many countries, such as for the disposal of waste from oil and gas extraction, which may contain important concentrations of naturally occurring radionuclides.

Disposal is defined as intentional emplacement in a facility without the intent to retrieve. Although some States require the possibility of retrieving the disposed waste for some period of time after disposal, this is still considered to be disposal for the purposes of this publication.

6.4.1. Solid radioactive waste

Solid waste includes inherently solid materials, such as metals, plastics and other dry materials, as well as solidified liquids. In the case of unprocessed waste, and in some States, 'solid waste' can also include small amounts of liquids or 'wet solids' (such as filter cake or dewatered ion exchange resins). The solid radioactive waste include the disused sealed radioactive sources if the Member State considers them as radioactive waste. Figure 15, based on the National Profiles, shows the global totals of different types of solid radioactive waste in storage and disposal, as of 31 December 2019. The data shown in Fig. 15 represent 'as disposed' volumes, based on the conversion matrices provided by respondents (see Section 6.2.3 for a discussion of the uncertainties inherent in such an approach).

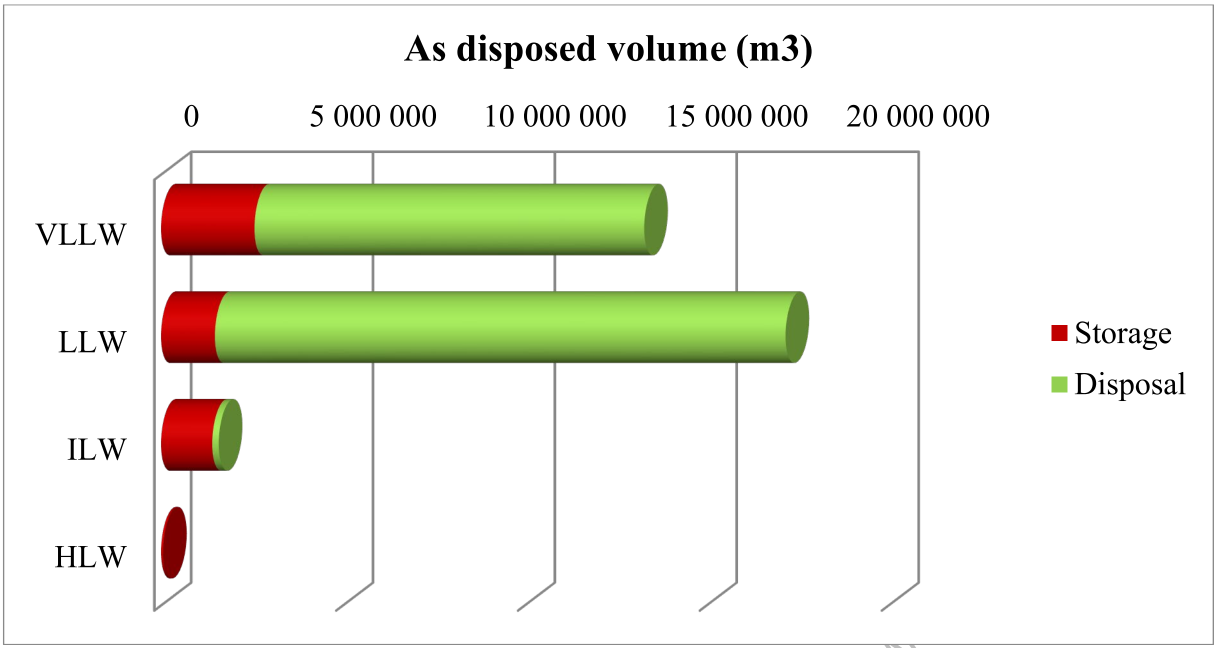

FIG. 16. Summary of reported global solid radioactive waste inventories (m^3). HLW storage volume is 54 000 m^3.

It is evident that the majority of the volume of waste consists of VLLW and LLW. VLLW has a smaller volume than LLW because often this category of waste was created more recently in a country's classification system and was not retroactively applied to radioactive waste that was already disposed of. As noted above, most of the radioactivity is contained in the much smaller volumes of ILW and HLW. For VLLW and LLW, the majority of the waste generated has already been disposed of. For ILW and HLW, however, the majority of the waste so far generated is currently in storage awaiting the development of appropriate disposal facilities.

Table 8 summarizes the volume of solid radioactive waste in storage and Table 9 summarizes the volume of solid radioactive waste in disposal, as of 31 December 2019. The values for the waste classes are as defined by the individual countries and the totals have been rounded to the nearest 1000 m^3.

TABLE 8. REPORTED SOLID RADIOACTIVE WASTE IN STORAGE, AS OF 31 DECEMBER 2019

Region	**VLLW (m^3)**	**LLW (m^3)**	**ILW (m^3)**	**HLW (m^3)**
Africa	14 000	27 000	1000	0
Americas	2 309 000	471 000	7 000	7000
Asia	2 000	248 000	103 000	27 000
Europe	301 000	733 000	1 255 000	20 000
Oceania	0	5000	2000	0
Global total	2 626 000	1 527 000	1 415 000	54 000
Joint Convention Contracting Parties	2 624 000	1 483 000	2 740 000	54 000
EU Member States	292 000	392 000	321 000	3000
OECD/NEA members	2 542 000	1 100 000	1 430 000	53 000

TABLE 9. REPORTED SOLID RADIOACTIVE WASTE IN DISPOSAL, AS OF 31 DECEMBER 2019

Region	**VLLW (m^3)**	**LLW (m^3)**	**ILW (m^3)**	**HLW (m^3)**
Africa	0	31 000	0	0
Americas	9 832 000	12 251 000	91 000	0
Asia	2 000	111 000	0	0
Europe	453 000	3 003 000	88 000	0
Oceania	432 000	24 000	0	0
Global total	10 719 000	15 690 000	179 000	0

Region	VLLW (m^3)	LLW (m^3)	ILW (m^3)	HLW (m^3)
Joint Convention Contracting Parties	10 719 000	15 660 000	179 000	0
EU Member States	453 000	1 077 000	14 000	0
OECD/NEA members	10 717 000	14 697 000	105 000	0

It can be seen that 85% of the already generated VLLW and LLW has been disposed of, as there are disposal options available for most of the generated VLLW and LLW has disposal options available. For ILW, the fraction already disposed of is about 10%, and for HLW there is no disposal option available. Since the 2013 edition of this publication, the fraction of disposed VLLW and ILW has increased, and the fraction of disposed LLW has decreased.

6.4.2. Liquid radioactive waste

While most States process liquid radioactive waste into solid form within a short time of it being generated, a few — notably, the USA and the Russian Federation — have large volumes of liquid waste in long term storage. Much of this waste results from defence activities and is only now being dealt with through the design, construction and licensing of liquid waste treatment facilities.

Generally, amounts of liquid waste are given 'as stored' volumes. It generally does not include liquids held in short term storage awaiting processing. It is difficult to estimate the final 'as disposed' volumes, since this will largely depend on the eventually selected processing and conditioning methods. In most cases, this will result in a very large reduction in the final volume for disposal, assuming that evaporative or filtering type processes will be used to separate or concentrate the radioactive elements from the bulk liquid. In other cases, the liquid waste might be conditioned in situ (e.g. by cementation), which can result in a volume increase. In addition, the classification of the final waste package to VLLW, LLW, ILW or HLW will also depend on the length of time (i.e. radioactive decay time) that the waste has been in storage, the efficiency of the treatment process and the degree of volume reduction achieved.

6.5. FUTURE FORECASTS

In order to plan adequately for the long term management of radioactive waste, it is necessary to forecast the waste quantities and qualities expected in the future. This is a task that needs careful attention, especially for States with numerous and diverse activities that result in the creation of radioactive waste and with many different organizations involved in producing and managing it. For many States, radioactive waste generation is closely related to electricity production from nuclear power plants, and thus future forecasts are closely related to predictions of the future use of nuclear power.

These countries, which were nuclear pioneers and were involved in the initial development of nuclear power, may also need to deal with significant quantities of waste associated with the decommissioning and remediation of these early facilities and sites. Usually, the amounts of waste arisings from operation and decommissioning of the older facilities are much higher than similar waste arisings from the present day nuclear power generation industry. Higher waste arisings have been noted on several occasions, including in China, France, the Russian Federation, the UK and the USA.

It is nevertheless important to make predictions regarding future waste arisings and to update them at regular intervals. This is important for the planning of facilities needed for storage, treatment and disposal and for establishing adequate funding for future waste management. It should also be recognized that precise numbers are not required to establish a reasonable basis for predicting future needs, as long as the inherent uncertainty in the quantity of future waste arisings is acknowledged. In due course, more precise data on waste volumes and radioactivity levels will be needed at the time of licensing of such facilities.

Defining the planning assumptions also requires proper consideration and attention. A major aspect to consider is the timeframe for the forecast: the longer the forecast, the less accurate it will be. The amounts and composition of waste from different practices will vary according to the following:

— How facilities operate;
— Industrial and technical processes that generate the waste;
— Policy and regulations governing the industry, technology and waste management;
— The economics of different areas of the waste management cycle and waste management philosophies.

In developing forecasts of future waste quantities, the following considerations need to be addressed:

(a) Planning scenarios for future generation of electricity from nuclear energy (e.g. high, low, and best estimates and constraints);
(b) Future operating strategies for the facility, such as the merits of waste minimization versus cost minimization;
(c) Timing of activities that impact on waste arisings, such as short term versus delayed strategy for remediation actions and solutions;
(d) Practical tools for creating forecasts (e.g. historical data, data from similar countries and facilities, and engineering estimates);
(e) Modelling and process mapping (e.g. understanding the route through different waste management systems and the impacts of this on forecasts);
(f) Accuracy requirements (e.g. significance of impact on the waste owner or WMO if estimates are significantly too high or low).

In general, a ‘bottom up’ forecasting approach provides the greatest accuracy and facilitates the highest degree of flexibility. Using this approach, individual waste streams or categories are estimated at a facility level and then aggregated with other waste streams to produce an overall estimate. Initial estimates for planning purposes can also be derived by extrapolating past history, taking into account the number of facilities operated and their lifetimes; this latter approach is often simpler and more pragmatic. Estimates of future waste arisings should include all activities and life cycle phases of a facility that result in the production of radioactive waste, such as operation, maintenance, refurbishment and decommissioning.

Compared to LLW and ILW, spent fuel arisings are somewhat easier to forecast. The amount of spent fuel produced is broadly proportional to the amount of energy extracted from it. With knowledge of the number and type of reactors and their historical fuel burnup levels, a reasonable forecast can be made of future spent fuel arisings for the remaining lifetime of a reactor.

In some countries, the forecasting of waste volumes has been performed over many years and is regularly published. Other States have only recently begun to undertake rigorous forecasting activities. Consequently, not all States have reported forecasts in their National Profiles. It should be noted that the Joint Convention [3] does not require the reporting of forecasts, only values of presently stored and disposed waste. However, the Euratom Waste Directive [5] requires that forecasts of the future generation of radioactive waste be reported.

7. SYNTHESIS OF ACHIEVEMENTS AND OVERARCHING ISSUES

The first publication in this Status and Trends series [1] was more focused on collecting the information about the spent fuel and radioactive waste management practices and inventories, while the second publication provides an additional analysis of the global trends. The first revision [2] included also discussion on significant achievements; discussion and analysis of current and emerging issues; and reports on progress in addressing previously identified issues. This current revision is providing update on that analysis, so this section focuses on a discussion of the achievements and general issues related to spent fuel (whether it has been declared to be a waste or not) and to the various radioactive waste categories.

7.1. MANAGEMENT OF SPENT FUEL AND HIGH LEVEL WASTE

The information about the implementation of the back-end of the nuclear fuel cycle is presented in Section 5. Several countries have made decisions on the policy to recycle or to dispose of the spent fuel, however, the options are kept open or the topic is still under discussion in many countries. There are different factors which influence Member States in choosing open or closed cycle.

A theoretical study by OECD NEA [54] looked at the economics of the back end of the nuclear fuel cycle comparing on higher level idealized systems of “open” and “closed” cycle. The main factors that influence Member States in choosing their spent fuel management strategy, could be divided into following groups:

- Political/Social
- Strategy
- Economic
- Environmental impact
- Non-proliferation/security considerations

The spent fuel management policy is defined at the national level, even if the nuclear operators are privately owned companies. The main factor leading to the choice of a spent fuel management policy in the frame of a long-term vision is usually the nuclear power policy and strategy. Several countries have acknowledged that policy may change based on developments in technology, economics, public perception and environmental considerations. Flexibility in a spent fuel management strategy and/or nuclear waste management strategy may be an additional desired factor in the decision-making processes, especially in case of newcomer States to nuclear power.

In general countries with very large nuclear programmes, such as France, the United States, Japan, China, Russia and United Kingdom, have implemented their spent fuel management strategy with a long-term view based on country-specific considerations. The United States and United Kingdom are following “open cycle” policy, others have made the choice of the “closed cycle” with the long-term view of the implementation of Gen IV reactors. Delays in such implementation could occur and may raise some concerns related to the management of the recovered materials if not recycled in the Gen III reactor fleet. Countries choosing the *“open cycle”* have generally no immediate interests or purposes in using the uranium and plutonium recovered from the reprocessing of the spent fuel.

The approaches of small to medium size nuclear power countries are diverse. Most of them have opted for the “open cycle” route considering both non-proliferation and economic aspects. This is the case for instance for Sweden and Finland. Some others, like the Netherlands, have chosen the “closed cycle” route with full recycling of the valuable materials, the drivers being the cost certainty and the environmental impact of storing/disposing of HLW instead of spent fuel. This provides also additional flexibility towards possible shared disposal solution in the future. Looking at possible future flexibility, other countries, like Czech Republic, Hungary, Slovenia and South-Africa have chosen the “open cycle” as reference but examine alternatives.

Some countries, like Argentina, Belgium, Brazil and Ukraine have chosen to implement storage of spent fuel whilst maintaining the flexibility to decide in the future for a "open cycle" or "closed cycle" policy. However, it should be kept in mind, that storage is just an intermediate step of the spent fuel management and cannot be considered as an end point.

Although the rate at which spent fuel was reprocessed was more or less constant, the trend lately has been that fewer States send their spent fuel for reprocessing overseas and that the amount of spent fuel in long term storage is increasing. Reprocessing capacities have been lowering due to the fact that there are a few new plants in construction and several reprocessing plants are closed or nearing the end of their lifetime. The development of the nuclear programmes in China, India and the Russian Federation could change this trend. However, recycling of spent fuel continues to play an important role and there is a focus on developing multi-recycling technologies to be applied using thermal reactors that can provide a sustainable solution for the transitioning period from once-through recycling (currently implemented industrial cycle) to a fully closed fuel cycle with fast reactors. There are examples of countries considering innovative recycling technologies to reduce the burden of generated wastes and footprint of disposal facility, by recycling long-lived products for medical applications. Unfortunately, implementation of fast reactor based closed fuel cycles is being delayed in many countries, although research and development activities on large reactors and associated fuel cycles continue in some countries [55].

Long storage periods introduce several challenges in terms of technical aspects (e.g. changes of technologies, aging management of facilities, etc.), licensing (changes of regulation), organization (changes in the nuclear industry) and funding (accuracy of costs in the long term and availability of funds) and the challenge is thus to ensure the long-term safety and integrity of the storage facilities and the spent fuel/HLW for many decades to come. Number of national strategies reflect the need to make available sufficient spent fuel storage capacity to bridge the gap between the generation of spent fuel and the foreseen commissioning and operation of deep geological disposal facilities. There is evidence of greater attention being given to impacts of fuel cycle on disposal and vice versa, especially with uncertainties on the requirements and acceptance criteria of the disposal facilities. There is an urgency on working to understand and optimise the whole backend and to actively implement these strategies on the ground [55]. However, such challenges are properly managed, and countries have decades of experience with spent fuel storage, both in wet and dry storage facilities. There are also active programmes in place to monitor the condition of the spent fuel and its storage environment to ensure it can be safely stored for the required length of time. This already motivates improvement of existing storage facilities, for example in Finland. Requirements and issues related to spent fuel storage are discussed in further detail in [11].

As the requirements for storage capacity increase, new storage is built outside of the reactor buildings. Due to the need for longer storage, there have been successful implementation of storage facilities, which are planned, built and operated, either in the vicinity of the reactor building or as a centralized facility in the country [11]. Most of these are facilities for dry storage, but some pool facilities are also in operation. Depending on the strategy for spent fuel management, Away From Reactor (AFR) facilities using wet or dry storage technologies have been licenced and built. There are AFR on-site facilities for example in Hungary, Belgium, Canada, Spain and USA and centralized off-site AFR facilities in Switzerland, Germany, Sweden and Netherlands. Currently around 80% of the AFR facilities are based on dry technologies and this is mainly due to their modular and passive nature. In order to be economic, a wet storage pool, generally needs to be large hence has fixed capacity. Dry storage facilities, especially of the cask type, can be built to any size scale and can be expanded incrementally over time. This means that not all the cost is required up front as it is in a fixed capacity wet pool.

Some recent progress and achievements in development of the deep geological disposal facilities include:

- In Finland, the operational licence application for encapsulation plant and geological disposal facility in Onkalo site was submitted to government in 2022. This is a first of a kind in the frame of a DGR. The construction of underground access tunnels at ONKALO facility in Finland started in December 2016 and the construction of the encapsulation plant started in 2019. First construction phase of the deposition tunnels is finished (5 deposition tunnels excavated).

- In January 2022 the Swedish Government licensed encapsulation plant and disposal facility for spent fuel.
- In France the detailed concept for HLW and ILW disposal project was achieved in 2020 and the Environmental Impact Assessment was issued in 2021. The project was recognized as a final disposal solution for the most radioactive waste produced in France in 2022 and it is expected that the construction licence for HLW deep geological disposal will be submitted in 2022.
- In Canada the site selection process has progressed from 22 to 2 communities with a single preferred site to be identified in 2023.
- In Switzerland the proposed site was announced in 2022. A general licence application is expected to be submitted around 2024 and the government decision is expected by 2029. There is a possible national referendum on disposal facility. The plan is to build pilot disposal facility, which will be closed after testing and the real disposal facility will be built in neighbouring rock.
- In United Kingdom the process to identify a suitable site for DGF in England or Wales is underway. Four voluntary communities are engaged through community Partnerships. Non-intrusive seismic investigations to gain better understanding on geology off coast of Cumbria started in 2022.
- In China the construction of the Beishan Underground Research Laboratory in Gansu Province to support research into geological disposal of HLW in crystalline host rock, started 2021 and is expected to be completed in 2027. Aim is to construct a geological repository by approximately 2050.
- In Hungary there is ongoing Siting Survey Framework programme for national DGR, siting in the Mecsek region.
- In Belgium the legal process for adoption of geological disposal was launched in 2022.
- In Lithuania a general DGR concept will be developed by 2023, the selection criteria for siting are in preparation and the site should be selected by 2047 and facility is planned to be operational by 2068.

The site selection approaches taken by the Member States can be different – some are taking a technical siting approach, while others are taking a voluntary approach or a combination of technical and voluntary. In all cases, the importance of public acceptance has been recognized and all of the programmes include extensive public consultations at various points in the process. Thus, the DGR time schedules have been revised taking into account the realistic time scales for the siting activities; public acceptance; technical implementation and regulatory activities due to challenge caused by the lack of experience of licensing such facilities, etc. Several countries have had to restart their site selection process for a DGR, having not been successful in gaining public support. Proposed timelines for the operations of DGRs varies from country to country but to-date the estimated earliest and farthest year for opening DGR are 2024 and 2160, respectively.

It is obvious that for some countries with a limited inventory, in particular for countries that are operating only research reactors, the cost of development of disposal facilities may be very high compared to the benefits from their operation. At present several countries return the research reactor fuel to the country of origin of the fuel if possible, and thus it does not require disposal in the country where it has been used. The Russian Federation and the United States of America have had agreements to take back the research reactor fuel from the countries where it was used. There are some countries, which have decided to reprocess research reactor fuel, such as Belgium and Australia for instance, which have made the choice to reprocess in France. The international experience accumulated from research reactor fuel take back programmes for high enriched uranium has been collected and presented in IAEA report [41].
When most of the storage systems were put into operation, they were designed to last between 20 and 50 years. Over the last six decades of wet storage, and four of dry storage, good performance has been reported and valuable operational experience gained. As these systems reach the end of their original, intended lifespans, work is underway to develop additional monitoring and inspection techniques to support ongoing safe spent fuel storage, as well as the licensing or re-licensing of these activities.

Ongoing research and development (R&D) is an important and integral part of most radioactive waste and spent fuel management programmes. Nuclear power countries have extensive programmes for research and development in spent fuel and radioactive waste management. R&D is carried out by a variety of entities, including facility operators, regulators and technical support organizations as well as by independent organization, such as universities and research institutes. The specific goals of the R&D can vary from basic science fundamentals to applied research for developing specific technical solutions. Some of the current and proposed research is centred on development and demonstration of technical equipment required for repository construction and operation (e.g. construction methods, waste handling/emplacement equipment, tunnel sealing, etc.). Collaborative work is also on-going in areas such as ageing management, predisposal management, spent fuel characterisation, high burnup issues, partitioning and transmutation, which could have an impact on the development of advanced fuel cycles as well as the types and quantities of waste to be disposed of. Development and potential deployment of new reactor types, such as small modular reactors, will also affect the need for and type of fuel cycle and waste management facilities in countries wishing to deploy such technology.

There is ongoing R&D to reduce volume and potential hazard of HLW, for example separation and transmutation/conversion of actinides would help to reduce of hazards related to management of spent fuel, especially long term storage or disposal. For example, an advanced fuel cycle which includes Partitioning and Transmutation in addition to the re-use of uranium/plutonium, e.g. in Generation-IV fast reactors or Accelerator-Driven Systems, could provide benefits to geological disposal by reducing the radiotoxicity and thermal output of the final waste inventory, thereby positively impacting the required footprint of such a repository. However, it should be noted that, since such a fuel cycle is still in the R&D phase, the actual benefits for the fuel cycle in general and geological disposal in particular is difficult to estimate. There is R&D related to different aspects of Small Modular Reactors and Generation IV reactors. For example, Belgium has approved Myrrha (Multipurpose Hybrid Research Reactor for High-tech Applications) project and the construction is expected to begin in 2026.

The safety case is the collection of all arguments that contribute to demonstrate the safety of the facility and includes the calculation/modelling (quantitative safety assessment), especially as because of the very long time frames covered by the safety cases for radioactive waste management and spent fuel management, the safety cases are generally based on mathematical modelling and simulation and/or by comparison to suitable natural analogues, rather than by direct observation of repository performance. In order to develop, test and calibrate the models, research and development is generally required to establish model parameters and boundary conditions (e.g. diffusion rates, radionuclide transport processes and corrosion mechanisms under repository conditions; design parameters, such as rock strength and other properties; etc.). In the shorter term, R&D may also be required to demonstrate the various technologies required to construct and operate a disposal facility; create optimized waste forms; develop technical specifications and waste acceptance criteria, etc. The exact requirements for R&D will vary by country and by waste type and their planned management routes. Often, a certain amount of initial R&D is required in order to be able to decide the appropriate management route.

As stated previously, the length of the storage period could be many decades. There can be regulatory provisions and technical measures defined, which should be followed if it is needed to ensure continued safe storage over the longer term. A future challenge is related to handling of the spent fuel and its integrity after several decades of storage, especially in dry storage conditions where it is not possible to directly observe the fuel since it is sealed/bolted in casks or canisters.

Sharing knowledge and experiences need to be encouraged among the countries under the auspices of international organizations such as the IAEA, OECD NEA, EC and WNA. Some examples are provided below.

The IAEA has conducted and is conducting a series of activities and Coordinated Research Projects on different topics related to spent fuel management as: on spent fuel performance (SPAR-I to IV Series), on spent fuel research and assessment (SFERA), on ageing management programmes for dry storage systems (AMP), on performance assessment of storage systems for extended durations (PASSED) or on challenges, gaps and opportunities for managing spent fuel from small modular reactors.

The behaviour and integrity of spent fuel and cladding materials is paramount since it is the first barrier for radioactivity containment during long term storage and subsequent fuel handling operations. Summary of the results were published in successive IAEA technical publications [56] [57], including an IAEA technical document summarising the most relevant findings in the context of today's implementation of the technology [58].

Over the last decades, national and international R&D programmes have been conducted on the development of advanced sustainable nuclear fuel cycles associated to Gen-IV reactors in order to improve the utilization of uranium resources, maximize energy production, minimize waste generation, improve safety and limit proliferation risks. Advanced fuel cycles are devoted to recycling most of the long-lived minor actinides, minimizing not only the volume of the high level waste to be finally disposed of, but also its radiotoxicity as well as the decay heat, thereby lowering the burden of the waste and the 'repository footprint'.

The OECD NEA has several working groups and some to mention in the relation to the safe management of spent fuel and radioactive waste are:

- The Integration Group for the Safety Case on the deep geological disposal, particularly for long-lived and high-level radioactive waste. The mission of the IGSC is to assist member countries to develop effective safety cases supported by a robust scientific-technical basis. There is also an Ad-Hoc Group on Transfer and Return of Gained Experiences on Safety cases for other disposal facilities (TARGES)
- Expert Group on Building Constructive Dialogues Between Regulators and Implementers in Developing Disposal Solutions for Radioactive Waste has performed among other things an report on "Building Constructive Dialogues between Regulators and Implementers in the Pre-Licensing Phase of a Deep Geological Repository" [reference] and works on establishment of a generic roadmap towards licensing of DGR facilities.
- Horonobe International Project aims to develop and demonstrate advanced technologies for use in accordance with DGRs design, operation and closure as well as realistic safety assessment, recognised as common international challenges.

WNA has created a dedicated Working Group on the sustainable development of used fuel management, with main objectives to gather the views of the nuclear industry and stakeholders (including newcomers) on the back-end of the fuel cycle. The Working Group considers how the industry can best respond to these needs, as well as explains how effective spent fuel management contributes to the sustainability of nuclear energy and supports development and implementation of it. The working group on waste management and decommissioning is covering a wide range of topic they will work also on incorporating waste management and decommissioning lessons learned into SMR design as well as circular economy in nuclear industry, through the prism of Material and Waste Management

In addition to the formal research programs, the IAEA, NEA and WNA all host and support peer-to-peer networks and expert working groups on a range of topics related to radioactive waste management, spent fuel, fuel cycles and decommissioning. These networks and working groups facilitate the exchange of information and experience among their members.

7.2. MANAGEMENT OF RADIOACTIVE WASTE

Globally the volumes of ILW are small compared to LLW and VLLW, typically less than 5% of the total. Many industrial scale methods exist for safe processing, packaging and storage of ILW. Many countries (Belgium, Czech Republic, France, Japan, UK and Switzerland for instance) plan to develop an underground disposal facility for ILW co-located with HLW. There are some new combined ILW and LLW disposal facilities in operation. Additionally, one is under construction (Konrad in Germany is licensed and under construction. The commissioning is scheduled for 2027) and 2 in the regulatory approvals process (CIGEO in France, SFL in Sweden which is planned for the late 2030s). In Canada the proposed facility for disposal of LLW and ILW at Bruce site was cancelled after non supportive vote from local Indigenous communities.

Special challenges are connected to some categories with relatively larger volumes (e.g. graphite from gas cooled reactors and radium bearing waste from earlier radium production). Although the radioactivity levels in some of the waste can be relatively low, it is composed mainly of long-lived radionuclides, such as ^{14}C and ^{226}Ra together with its decay products and is therefore managed as ILW. The issue is to develop a solution proportionate to the actual hazards of these wastes, which are less active than some other ILW waste.

Historically, disposal solutions have been developed first for low level waste. The classification and the safety criteria, in particular for the long term, have been established gradually and they have been addressing mainly operational waste. There are number of countries with the disposal facilities for LLW, however due to the planned decommissioning of their nuclear installations, there might be need for additional capacities in the near future.

The amount and characteristics of waste and other materials to be generated by a given decommissioning project is related to several factors including, reactor type and design, unit history, decommissioning strategy, safety and environmental regulations and radioactive waste management routes. However, typically decommissioning activities imply the generation of large volumes of materials that need to be properly managed. Only a small fraction of that waste will generally be classified as radioactive waste. The amount to be declared as radioactive waste will vary by country, according to their laws, regulations, practices and available waste management infrastructure. For example, it is estimated that about 104 000 tonnes of materials will be managed throughout the duration of the José Cabrera nuclear power plant dismantling project in Spain. Approximately 4% of them will be classified as radioactive waste.

For those materials from decommissioning that are not considered as radioactive waste, it is common to follow reuse and recycling approaches. The main fraction of residual materials generated during these activities will normally become "conventional" wastes that will be managed through standard industrial waste management routes and outside of nuclear regulatory control. Specific attention is required over those non-radioactive wastes having toxic or chemical hazard (e.g. heavy metals, asbestos).

Radioactive decommissioning waste is mostly similar in terms of radiochemical hazard and risk to the radioactive operational waste. Similar approaches and technology are being used for its treatment and conditioning. However, dedicated waste streams may be generated requiring specific consideration.

Most disposal facilities for LLW are surface or near surface facilities, including relatively shallow depth, underground caverns. The surface or near surface facilities can be found for example in France, Romania, Spain. However, in several countries like Hungary, Germany, Sweden and Switzerland, the choice has been made for disposal of this waste in deeper rock formations.

The development of disposal facilities dedicated to this waste is progressively continuing in the world, some examples are provided below:

- In Brazil the selection process, as well as the facility's conceptual design for disposal facility (National Center for Nuclear and Environmental Technology (CENTENA)) is in the final stages.
- In China Longhe near surface disposal site (within a region of the Gobi Desert) confirmed and approved as a centralised disposal site for LLW from NPPs. The facility is expected to start operation July 2022. Extensions have been implemented at existing LILW disposal sites in China (Northwest and Feifengshan).
- In Bulgaria there is the national near surface disposal facility for LLW at construction stage.
- Italy is looking for the site for LLW and ILW disposal and the eligible areas were published in 2021. This process will seek interest from local communities at one or more from a list of identified candidate sites.

- In Republic of Korea the disposal site at Gyenongju. Engineered shallow land disposal facility is under regulatory review for construction and operation.
- In Russia the first section of near-surface disposal facility for solid RW Class 3 and 4 at UECC site, Novouralsk, in operation, second stage under construction. Licensing process for near-surface disposal facilities at Chelyabinsk and Tomsk has been started. Near-surface disposal facility in Sergeiev Posad near Moscow in the planning stage.
- Slovenia plans to start the construction of the LILW repository in 2022.
- El Cabril disposal facility in Spain submitted application for capacity extension in 2022.
- The Extension of the SFR repository in Sweden for short-lived L&ILW has been approved in 2021. The main reason for extension was need to accommodate decommissioning waste.
- In United Arab Emirates the application for a near surface waste disposal facility in 2022.
- LLWR is for disposal of UK LLW, landfill sites are also available for the least hazardous LLW.
- Several new disposal facilities have been expanded. The examples include facilities in Hungary (Bátaapáti), where second disposal chamber is completed.
- LILW storage and disposal facility at Himdalen, including plans for assessing future capacity.
- There are also several site selection processes going on. For example, in Australia, Malaysia, Pakistan.

As existing disposal facilities are considered as valuable assets that are difficult to replace, waste minimization is an important issue in order to expand their lifetime: for the LLWR (Low Level Waste Repository) facility in the United Kingdom the lifetime has been expanded through a successful waste diversion programme (up to 85% of new waste being diverted, resulting in the diversion of some 50 000 m^3 during the period 2008 - 2016). The operator promoted decontamination and recycling options as well as the diversion to VLLW landfills. This is a shared concern by all disposal facility operators. Waste minimization approach is also being applied in other countries by the definition of VLLW as a sub-class that allows to develop dedicated management and disposal facilities for such wastes (e.g. France and Spain).

Waste minimization is indeed a challenge as decommissioning waste streams are increasing. To face this issue, an expansion of the SFR facility in Sweden to accommodate decommissioning waste is in the licensing stage. In Korea, optimization is planned by expanding the existing silo type disposal facility at Wolsong with the addition of a near surface facility for LLW.

The construction of a dedicated disposal facility for LLW in countries with small quantities of waste may be difficult, owing to the relatively high initial fixed cost to site, design, licence and construct a repository. Alternative solutions, such as borehole disposal, may be more practical and cost effective to implement.

According to GSG-1 [4], very low-level waste (VLLW) is a waste that “does not need a high level of containment and isolation and, therefore, is suitable for disposal in near surface landfill type facilities with limited regulatory control”. Some States consider VLLW as a subclass of LLW and dispose of them in different areas of the same facility (e.g. Spain, United States). Others created separate facilities for the two types (e.g. France, Lithuania, Sweden,). Others still licensed appropriately permitted landfill sites to accommodate VLLW (e.g. the Netherlands, United Kingdom). The implementation of disposal facilities dedicated to very low-level waste is the result of a desire for optimization and to reserve LLW disposal facilities for wastes that truly require the higher level of engineered barriers and isolation provided by them.

The relevance of this category will increase during dismantling operations of nuclear facilities: large volumes of VLLW are indeed expected in the future as a result of decommissioning and dismantling programmes of nuclear power plants (See 3.2.1.). Preparedness to accommodate large quantities of waste for disposal over a fairly short period of time will be important — particularly in countries that foresee an accelerated decommissioning programme for nuclear power plants. In addition, much of the waste produced as a result of dismantling a nuclear facility is different than normal operational waste, as it has higher proportion of minimally contaminated metals (e.g. equipment) and building rubble. Cost effective disposal solutions that still provide adequate safety for this class of waste have been and are being developed in various countries.

There are already several examples of activities to increase the disposal capacities for VLLW. Often the site or planned area will not be changed, but with the optimization of the disposal, the capacity will be increased. For example, in France the licence application to increase disposal capacity of VLLW disposal facility is planned to be submitted in 2022. Hungary introduced VLLW subwaste class

However, despite this relevance, it should not be forgotten that, as for LLW, disposal facilities for VLLW are rare assets and that their availability has to be preserved as long as possible. There is indeed a risk of early saturation of disposal capacities in some countries, such as France. Therefore, countries are also focusing on alternative solutions:

- Waste minimization at the source: characterization may be a significant challenge as the lower the activity, the longer and the more difficult activity assessment is. Reliable industrial assessment is required. Generally, characterization of VLLW is also connected to free release issues, to segregate waste to be managed in this specific radioactive route from exempted waste. These challenges are approached by related research and development, supporting operational experience;
- In several countries, it is possible to avoid partially production of radioactive waste, by implementation of recycling of radioactive material. Again, adequate characterization is a major consideration and also there have to be clear regulatory processes. It has been successful in some countries as Spain, UK or Sweden, illustrating the impact of national policy and regulatory frameworks, however there are also countries, where recycling of radioactive materials is not permitted.

Management of large components constitute a dedicated point of interest as this activity is usually particular to decommissioning. Different approaches have been taken to date in response to the peculiarities of individual project and associated management routes. For example, in some countries, such as the United States, large components can be disposed of in one piece, perhaps after stabilization by filling them with grout. In other countries, such as Germany, the prevailing practice is to cut the large components into smaller segments that will fit inside a "standard" waste package.

Most operating radioactive waste disposal facilities are for a given class or type of waste and will accept waste from any source as long as it meets the acceptance criteria for the facility (e.g. it can take waste from either operation or decommissioning of a nuclear facility). However, there are several cases in which such facilities are licensed for operational waste but not for decommissioning waste (e.g. Finland, Japan, Sweden) and others in which technical modifications have been needed to enable a more efficient use of available disposal capacity (licensing of "larger decommissioning packages"), e.g. Spain.

The disposal of DSRS is still a challenge in most countries, and new concepts are currently being developed. Most Member States still only have arrangements in place for storage, sometimes as a long term solution. There are several ongoing international initiatives to safely manage DSRS and one of them includes the construction of the first borehole disposal for DSRS in process. The final disposal solution for DSRS (e.g. borehole, near surface, geological…) has to be optimized taking into account social, economic, technical and safety aspects. The Malaysian Nuclear Agency received a license application for the borehole disposal of its inventory of disused sealed radioactive sources in 2019. In 2022 IAEA contracted a drilling company to construct the borehole with implementation through Malaysian Nuclear Agency and an IAEA team assembled on-site a mobile facility that will be used for conditioning the DSRS into the disposal packages. The actual disposal operations are expected in the end 2022 or beginning 2023.

Some examples of current R&D in the field of long-term radioactive waste management include:

- Country specific R&D: very active R&D programs in several countries (e.g. Canada, France, Sweden, Switzerland, United Kingdom, United States)

- these normally focus on demonstrations of equipment and technology, improving the science and understanding of issues related to long-term safety (e.g. corrosion of containers, behaviour of engineered barrier materials under repository conditions, geosphere characterization, etc.)
- Some are individual country work, some are collaborative between several countries. There is a move towards collaboration, since costs to develop, operate and maintain facilities are high. Most of the work is common to a number of programs anyway, so there is cost benefit to collaborate and leverage funding.

- The framework programme in the management and disposal of radioactive waste under the Euratom Horizon 2020 programme;
- NEA NI2050 programme on waste & decommissioning – waste related issues are recognized as important for sustaining the nuclear power industry into the future;
- IAEA coordinated projects – these cover wide range of topics: from development of a standardized framework for the borehole disposal of DSRS and small amounts of low and intermediate level waste to spent fuel storage.

7.3. OVERARCHING ISSUES

The radioactive waste and spent fuel management programmes in the different Member States have unique characteristics and aspects related to the peculiarities of the programmes, such as size of their power programme or their degree of maturity. Likewise, it is also possible to identify aspects and issues of common interest for many of these national programs (overarching issues) that invite the development of joint actions to overcome them. This aspect has been developed by the subsequent Joint Convention review meetings which, at its last meeting in June 2022, highlighted these eight among the proposals in the working sessions:

- Competence and staffing linked to timetable for spent fuel management and radioactive waste management programmes. Effective and efficient implementation of policies and strategies for spent fuel and radioactive waste management depends on the availability of suitably qualified and experienced human resources across all organizations involved in the management of spent fuel and radioactive waste. The Contracting Parties discussed and emphasized the importance of the knowledge management while recognizing the extended timelines involved in safe storage of spent fuel and radioactive waste and development of disposal facilities.
- Inclusive public engagement on radioactive waste management and on spent fuel management programmes. The importance of inclusive, open and transparent engagement with the public as well as understanding the role of all organizations involved in the process was emphasized as key factors to enhance public trust. The Contracting Parties discussed and highlighted the value of undertaking an inclusive approach by not only focusing on disseminating information but in engaging and listening to the public and relevant stakeholders in the discussions.
- Funding of long-term projects: The discussions in several of the Country Groups highlighted challenges with respect to securing of funding for radioactive waste management and spent fuel management, noting the long timescales and the slow realization of disposal facilities. The Contracting Parties during the discussions recognized that the provision of funding is required under the Joint Convention, Article 22. Thus, there is already an obligation for Contracting Parties to report on this issue.
- Management of radioactive waste and spent fuel from new technology applications as well as planned new projects using existing technologies. Contracting Parties underlined the need for proactive work to conduct research and to develop strategies for the management of novel spent fuel and radioactive waste arising from new NPPs or new technologies. However, some Contracting Parties noted that this topic was not applicable to all Contracting Parties. It was suggested that this topic be considered for the Topical Session at the Eighth Review Meeting, subject to the agreement of Contracting Parties at the Organizational Meeting of the Eighth Review Meeting.
- Legacy wastes linked to decommissioning and remediation projects. Several Contracting Parties reported progress in the decommissioning of legacy facilities and the remediation of legacy sites.

Some Contracting Parties identified the need for the establishment of a national strategy for dealing with legacy sites including the need to build new facilities for the safe management of the waste arising. Some Contracting Parties have reported that the remediation of uranium mines has remained a major technical and financial challenge.

- Ageing management of packages and facilities for radioactive waste and spent fuel, considering extended storage periods. This issue was linked to the absence of the timely availability of disposal facilities as well as the fact that some Contracting Parties have national policies regarding spent fuel being considered as an asset, resulting in extended periods of storage. It was further noted that this topic is relevant to the intergenerational equity which is covered in the text of the Joint Convention.
- Realization of disposal facilities. The Contracting Parties considered this issue linked to one above. While near surface disposal facilities are in place in several Contracting Parties, only few geological disposal facilities are under consideration or implementation by some Contracting Parties. In this context, it was underlined that decisions and actions for the realization of disposal plans should be thoroughly considered and driven by safety objectives.
- Long term management of disused sealed sources, including sustainable options for regional as well as multinational solutions. The Contracting Parties considered that the management of orphan and disused sealed sources remains an overarching issue since the Fifth Review Meeting. The availability of disposal routes and uncertainties in availability of trans-border solutions for disused sources was highlighted in the Country Group discussions. It was noted that many Contracting Parties consider disused sealed sources as waste, while others recycle and reuse them. Nevertheless, the safety of long-term management of disused sealed sources was identified as a challenging issue, which would be worthy of increased attention at the Eighth Review Meeting.

8. ANALYSIS OF TRENDS

This is the third Status and Trends publication of the series and the main purpose of it is to highlight both status and noted trends. The general trends are presented based on information provided in the National Profiles, in discussions during the Seventh Review Meeting of the Contracting Parties to the Joint Convention (held in 2022) [8], and in the Report from the Commission to the Council and the European Parliament on progress of implementation of Council Directive 2011/70/EURATOM and an inventory of radioactive waste and spent fuel present in the Community's territory and the future prospects [6]. Inputs from the different international working groups (for example Technical Working Groups on Radioactive Waste Management and Technologies and on Nuclear Fuel Cycle Options and Spent Fuel Management) were used as well.

The section of trends is divided into three subsections. Firstly, there are general trends, followed by the subsections in relation to the trends related to radioactive waste management and to the trends related to spent fuel management. This section outlines some generally recognized trends that have been identified since the publication of the first revision of publication [2]. For convenience, they are grouped into a number of functional areas or themes.

8.1. GENERAL TRENDS

- **Policy and strategy**

The policies and strategies of radioactive waste, spent fuel management, and decommissioning are generally developed and set by government ministries or agencies. Defining long term aims in the policies usually helps to ensure successful and optimized implementation of strategies. Many countries have successfully established policies and strategies that have been stable over several decades and good progress has been made towards their implementation. An overview of defined aims can be found in Annex 2. Maintaining a stable policy and strategy over time can be a challenge for various reasons. For example, the decision made in Germany to phase out nuclear energy will also affect its spent fuel and radioactive waste management. In other cases, a national policy may have evolved around practices that have been established for decades, but these approaches or strategies might no longer be preferred given the circumstances of today. As the possible management options can be changed as well, this means that revisiting the decisions made in the past is also important (e.g. waste diversion programme Low Level Waste Repository in the UK). Spent fuel management is a long term commitment and the strategies adopted for managing the spent fuel produced by power reactors need to keep some flexibility to enable potential changes in policy decisions.

More and more countries are developing, or at least considering, integrated and holistic approaches to spent fuel and radioactive waste management. This has benefits including more effective use of resources, such as disposal space, as well as reducing overall costs. For nuclear newcomer countries, this is a very important consideration to ensure that spent fuel management and radioactive waste management systems are established in an optimal way right from the beginning. More attention and corresponding effort are put into ensuring consistency and safety in predisposal and disposal activities in radioactive waste management. Similar efforts can also be seen related to spent fuel storage and disposal activities.

Some overall tendencies can be seen in national decisions in spent fuel and radioactive waste management. Often countries opt for a single solution for management of the same type of waste or for all waste producers in a country. The siting process for disposal sites is usually undertaken by national waste management organizations, which are often independent of the waste producers/owners (Annex 3). The siting process is often a broad community consent based engagement process, in which a lot of factors are taken into account. There are safety related questions, but additionally the selection process includes estimation of the environmental impact, transportation issues, cost, etc.

- **Governance**

Continuous improvement is a key component of radioactive waste and spent fuel management programmes. There are several review services available for the Member States and there is a clear tendency that these services are used more than in the past. There are several reasons for that, including that there is an increased recognition of the expert peer reviews organized by international organizations such as the IAEA and the OECD/NEA. In fact, such regular peer reviews are legally required for EU Member States under the Euratom Waste Directive [5].

The IAEA's Integrated Review Service for Radioactive Waste and Spent Fuel Management, Decommissioning and Remediation (ARTEMIS) is an integrated expert peer review service for radioactive waste and spent fuel management, decommissioning and remediation programmes. This service is intended for facility operators and organizations responsible for radioactive waste management, as well as for regulators, national policy makers and other decision makers. Between launching the service in 2016 and the end of April 2023, 23 review missions were conducted.

For newcomers in nuclear energy there is, for example, the IAEA Integrated Nuclear Infrastructure Review (INIR) [59], which is a holistic peer review to assist countries in assessing the status of their national infrastructure for the introduction of nuclear power. The review covers the comprehensive infrastructure required for developing a safe, secure and sustainable nuclear power programme. The topics covered also include nuclear fuel cycle and radioactive waste management. Since then, INIR missions for the different phases of developing a nuclear power programme were hosted by the following Member States: Bangladesh, Belarus, Egypt, Ghana, Indonesia, Jordan, Kazakhstan, Kenya, Malaysia, Morocco, Niger, Nigeria, the Philippines, Poland, Saudi Arabia, Sri Lanka, Sudan, Thailand, Türkiye, Uganda, the United Arab Emirates, Uzbekistan, Viet Nam and South Africa.

Another key aspect is the growing interest of the public and other stakeholders in nuclear activities in general and radioactive waste and spent fuel management in particular, leading to an increased awareness of the role played by society in effective implementation of radioactive waste and spent fuel management programmes and projects, in particular related to disposal. This has led to many countries adopting a more open and transparent system for communicating with the public and other stakeholders, as well as to the development of more participatory regulatory review processes. The challenge is for the decision makers to balance technical considerations with socio-political and economic considerations.

- **Funding and financing aspects**

The successful implementation of a radioactive waste and spent fuel management programme (and/or nuclear decommissioning programme) requires adequate and stable funding, often over many decades or longer. While most of the countries with nuclear power programmes have established dedicated funds to support these programmes and ensure that undue burden is not passed on to future generations, the challenge is to ensure that the funds remain viable, secure and available over the long time periods required. The situation in each country will be different, and various mechanisms have been established in different countries to ensure the future adequacy of the fund. One important aspect common to many countries is the requirement for periodic review and assessment of the fund and its management. This includes a review of both the cost estimates and the investment strategy for the fund, as well as any economic parameters used in calculating the adequacy of the fund (e.g. inflation rates, interest rates, financial discount factors, taxation implications, etc.). It is clear that increased social and political interest will help to guarantee the adequacy and sufficiency of the funds available for the safe management of spent fuel and radioactive waste.

- **Regulatory framework**

The Joint Convention [3] and several safety standards [28] [21] are documents that define the basis of international agreements for the safe management of spent fuel and radioactive waste. In order to secure the safety of the public and workers, a regulatory framework has been put in place in the majority of countries. There has to be collaborative effort between the implementer and the authorities for the licensing of spent fuel or radioactive waste management activities and facilities, although the regulator has to remain independent from the implementer. Experience has shown that licensing processes for radioactive management facilities, and in particular for geological disposal facilities, are complex and often carried out over very long timeframes. They are also generally limited in number in any one country (i.e. it is unlikely that any single country will have more than a few repositories for radioactive waste or spent fuel). As such, a major challenge is for both the regulator and the implementer to build up and maintain the expertise and competencies required for licensing, constructing and operating a disposal facility. Because of this 'one-off' nature, early interaction between the implementer, the nuclear regulator and perhaps other regulatory bodies can have benefits in clarifying the licensing process. An integrated approach to the regulatory process (e.g. considering all aspects at once: nuclear safety, environmental issues, health and safety, mining law, etc.) maintains clarity. In practice, regulatory interaction could be achieved by a multistep licensing process.

- **Socio-political acceptance**

The attainment and maintenance of a socio-political consensus that enables the implementation of technical solutions for the safe management of radioactive waste and spent fuel is an open question. There is still a lot of discussion in relation to the management of the spent fuel and radioactive waste. Many States have disposal facilities for radioactive waste, but a very large number of States still need to develop them. For the management of the spent fuel there are States, which have defined their policy, but there is still no operational disposal facility for spent fuel. The successful operational experience acquired to date becomes a fundamental element to forge and maintain society's trust in the system and so in the operators. The first HLW disposal facility in Finland is close to operation. However, the introduction of new facilities is almost always a controversial issue both for States with this experience and for others thinking of building their first facility. This challenge is commonly tackled by means of the establishment of swift, intense and interactive dialogue with society, with the aim of facilitating informed and responsible decision-making.

Socio-political acceptance has been and remains today the greatest obstacle facing programmes for the disposal of spent fuel. Is it possible that the start-up, over the next few years, of the first facilities of this type can overcome this question? It would seem that this element, together with the continuous efforts to develop mechanisms for social participation in decision-making, can be key to a change towards effective understanding of the need for and suitability of this type of facility.

- **Knowledge system sustainability**

It has long been recognized that the workforce in the nuclear industry is ageing, and a considerable fraction of workers are at or near retirement age. A challenge facing the industry is how to attract enough trained and skilled staff in all disciplines, and transfer knowledge from the current generation to the new generation of workers. This issue is faced by all organizations involved, including implementers, regulators, technical support organizations, researchers, support industries, etc.

While the responsibility for the safety of radioactive waste or spent fuel management is primarily that of the waste generator, national programmes require a degree of national capability to be in place. The availability of the scientific, engineering and legal skills necessary to implement and regulate national programmes requires educational and training provisions to be in place. Expertise in specialist scientific disciplines needs to be available and research capabilities are required. Bearing in mind the timeframes associated with the development, operation and closure of radioactive waste/spent fuel management facilities, in particular for storage and disposal facilities, this matter of human resources is of fundamental concern to all countries, as is an understanding of the necessary skills base and experience in maintaining such skills. The availability of sufficient financial resources remains a challenge for many spent fuel and radioactive waste management programmes, and is particularly important for the back end activities of decommissioning and disposal. The availability and feedback of knowledge and experience on costing and financial provision for both back end activities and legacy situations is of considerable value.

Important factor in the knowledge system is also record keeping. Taking into account the long time scales of concern for the management of spent fuel and radioactive waste, especial attention should be given to secure the records for the longer periods.

International cooperation, either between different organizations or under the umbrella of international organizations, has an enhanced role in sharing knowledge and in securing the safe management of spent fuel and radioactive waste.

- **Impact of/on newcomer programmes**

The safe management of spent fuel and radioactive waste is particularly important for those States that are considering the development and implementation of a new nuclear programme or have adopted one recently. In this regard, the experience accumulated by mature nuclear programmes is offered and made available to these "newcomer" States by means of mechanisms to transfer knowledge overseen by international organisations. This seeks to enable States to analyse and develop the institutional and infrastructure frameworks necessary for the safe management of the responsibilities inherent to a nuclear programme, including the management of radioactive waste and spent fuel. Accordingly, most States in this situation are adopting measures for the swift enactment of the institutional, regulatory and financial framework, the training of staff, and the logistics and facilities necessary for the responsible and safe management of the back-end of the nuclear cycle.

The States that have recently introduced a nuclear programme (Belorussia, Türkiye, United Arab Emirates etc.) have been assisted by the international organisations so as to transfer the necessary experience and knowledge for the early adoption of the decisions required for the creation of a national infrastructure capable of taking on-board the national and international responsibilities inherent to nuclear activity.

8.2. TRENDS IN RADIOACTIVE WASTE MANAGEMENT

The development of radioactive waste management programmes rests on certain global and commonly accepted principles, and on best practices that may be applied to different cases and national realities. Furthermore, we can identify approaches and developments that are being adopted and implemented in a significant number of radioactive waste management programmes to improve the safety and management of the corresponding inventories.

- **Radioactive waste storage and disposal needs are increasing globally**

As the use of nuclear power and nuclear applications is continuing, there is need to manage safely the radioactive waste produced. The international scientific community agrees that the definitive disposal of radioactive waste is the ultimate goal of national management programmes. Technical solutions developed or to be developed, vary depending on the type, quantity, and nature of the radioactive waste. Although solutions exist for the management, in particular disposal of radioactive waste the remaining topics are the duration and requirements of the demonstration of safety of the facilities and activities as well as public acceptance and this impacts the implementation of facilities and activities in particular disposal facilities. Over recent years there has been increasing progress in the development of and improvement in legislative and regulatory frameworks, political and social dialogue and in technical development with the aim to enable the implementation of policies and strategies that facilitate the adoption and development of measures and actions to build facilities for final waste disposal. However, it is also often the case that the adoption of these measures requires time for their implementation and hence, in the vast majority of cases, it becomes necessary to rely on storage capabilities for radioactive waste until the final disposal route becomes available.

This trend applies to many of the national programmes that either do not have final disposal capabilities for each class of radioactive waste and for those that, although they currently have these capabilities, but which are insufficient for the entire inventory that is/will be generated.

Firstly, due to the need to manage decommissioning waste for its safe disposal, but also due to additional needs (e.g. the management of waste produced outside of regulated activities or post-accident), along with the improvement of the efficiency of existing capabilities, many existing facilities for the storage and disposal of radioactive waste are being adapted and improved. These improvements include the introduction of new techniques and technologies, such as facilities for the decontamination of waste, metal smelting plants and the use of new containers and configurations for the storage and disposal of this type of waste. This trend also impacts also in the design of new facilities that adopt the lessons learned in these more mature programmes.

- **Management of VLLW and LLW (including disposal) as an industrial practice**

The management, which includes, among others, the sorting, treatment, and conditioning of VLLW or LLW, is a question that has been resolved from a technical and practical perspective. The technologies exist for the safe management of all the streams of VLLW or LLW, with some specific exceptions, also the routes of final management and their facilities. Considering that the VLLW class was introduced only in the beginning of 2000s, this concept has matured rapidly. Many States have established national systems and specific facilities to manage this type of waste and many of them have one or more disposal facilities to implement these programmes. We should state that the disposal facilities in most States are centralised and unique, and fall under the responsibility of operators which, in most cases, are governmental agencies, although cases of private operators also exist. In some States, sometimes due to the size of their nuclear programme or to the extension and distances within the State itself, different disposal facilities also exist (China, Russian Federation and United States of America). However, it should be kept in mind that even in case of such an industrial practices, the factual safety has still to be addressed and demonstrated.

- **Disposal of ILW and HLW as a promising challenge**

Although the solution is not implemented yet, several countries are well advanced, some have been granted licenses for construction and operation and it is reasonably expected that Finland will have operational HLW disposal facility in operation in next few years. It has to be taken into account, that these solutions require a long period of construction and operation which should not bias the perception that those waste are and will be safely managed. States and international organisations continue to work on this matter, which is facing sever social acceptance difficulties in most States, whereby achieving and maintaining a “social licence” continues to be the Achilles’ heel of these processes. In this regard, efforts are geared to the development and implementation of mechanisms for social, early and continuous participation in decision-making which, in the end, facilitates the construction and operation of this type of facility.

- **NORM waste as an emerging question**

Different industries not related to nuclear fuel cycle can generate NORM waste that, in recent years, has been the subject of growing interest. One of the reasons for related to the fact that usually the waste volumes produced by these industries can be significant. Taking into account long time frames of operation, the accumulated inventories can be massive. In these cases, such circumstances converge as the reappraisal of their radiological, health and environmental risk, the geographic location of these industries and the change in the social perception of these activities and how to manage them. NORM waste management is usually addressed with common approaches that include a combination of proven technical solutions, together with active dialogue in decision-making that includes social stakeholders and interested parties in fields that are not just related to nuclear activity. This extended scope includes health and environmental authorities, and industrial corporations that were initially outside of the scope of nuclear activities.

- **Radioactive waste from decommissioning is the main waste stream in many States**

As indicated in the chapter 3 on the Sources of Spent Fuel and Radioactive Waste, these are generated by a combination of activities that primarily include the operation of nuclear facilities and any other facilities that use radioactive materials for different regulated activities, such as the nuclear cycle, but also other uses in different industries, research and medicine. Over recent decades, and very significantly in the last few years, the end of operation of a large number of these facilities is generating significant inventories of different classes and types of decommissioning radioactive waste that have become the most important stream from a quantitative perspective. This situation, shared by different countries (Germany, Italy, Japan, Spain, United States etc.) has driven the development of specific solutions on such aspects as characterisation, their treatment and conditioning, and the associated logistics. In this regard, a general coincidence can be pointed to in identifying the questions associated with this waste, although the solutions adopted in each programme and project are more specific to their characteristics and contexts.

- **Waste hierarchy and circular economy becoming more important**

During the last decades our society has become more aware of the importance of issues related to environmental awareness and sustainability. In the nuclear field, since early years, the management of radioactive waste has had as one of a key priority the minimisation of the quantities and volumes to be managed. The reuse of equipment and materials and/or their recycling, as phases prior to their consideration as waste, are processes in use at all relevant facilities and in their programmes to manage radioactive materials and waste. There are increasing efforts to reduce the waste to be managed to the minimum possible, along with initiatives to recover radioactive materials that may be subject to reuse or recycling. These practices are commonly used in the operation of facilities, where radioactive material/waste is managed, as well as in planning the decommissioning projects where the generation of candidate materials to be classified as waste can be significant in mass as in volumes.

- **Clearance as key element in radioactive waste management**

The option to clearance of radioactive waste that falls under the threshold for classification offers very interesting opportunities to reduce the volume of the inventories to be managed. To this end, a growing number of States have developed their regulatory frameworks by establishing the limits and conditions under which this practice may be implemented. These legislative and regulatory enactments are backed by the initiatives of competent international organisations in the field of radiological protection – International Commission on Radiological Protection, IAEA and the EC.

These developments have a particular impact on the programmes and projects for the decommissioning of nuclear facilities since they facilitate the safe and significant reduction of the inventories of radioactive waste from decommissioning to be managed and disposed of at specific facilities.

- **Need for innovation: new techniques and technologies for greater efficiency**

In addition to the global extension of the practice of clearance, other means are being used to achieve greater efficiency in radioactive waste management programmes that even lead to an improvement in their alignment with the principles of the circular economy. In relation to this aspect, innovation in technologies and practices seem to offer a margin to improve the efficacy and efficiency of these activities.

This aspect - based on experience and the needs of final users – of the initiatives of the operators themselves with the collaboration of entities from the world of research, encounters collaboration in the programmes and activities promoted by international organisations.

- **Specific challenges for States with small inventories**

The experience of more mature programmes shows that the safe management of radioactive waste is a question that requires the convergence of a series of elements: suitable legislative and regulatory frameworks, access to knowledge and technology, availability of facilities and infrastructures, qualified personnel, financial resources and a socio-political consensus. These are essential elements for safe management, as we have set out in Chapter 4 - the implementation and adaptation of which require an effort at a demanding and continuous State level. The attainment of these conditions in States with small inventories of radioactive waste is even more complex since such other elements as prioritisation with the needs of the State and a funding limitations or lack of awareness of social and environmental importance come into play. Despite these difficulties, it has been observed that a growing number of States have been completing and modernising their structures and infrastructures, including the definition and establishment of national policies and the creation of independent regulatory bodies.

8.3. TRENDS IN SPENT FUEL MANAGEMENT

- **More Member States supporting Open than Closed Cycle for spent fuel management. Closed cycle supported by MS with large programmes and foreseeable continuity**

The choice between open or closed cycle for management of spent fuel is a strategic question that tends to be adopted at a State level (Chapter 5.1.1). In some cases, an initial decision in favour of one or the other option has been revised over time, resulting in the current adoption of a different option to the original one. In both cases, the final aspect of the management involves the geological disposal of those radioactive materials with no ultimate use envisaged.

Some States have not yet decided which option is the most suitable for their programme. Many States opt for an open cycle and some for a closed cycle. In this regard, we should state that most of the larger programmes (China, France, India, Japan, Russian Federation and United Kingdom) have opted for the closed cycle because these States are committed to the continuity of their nuclear programmes in the long term. As regards the open cycle, this is the option chosen by most of the small- and medium-sized nuclear programmes (Finland, Spain, Sweden, Switzerland).

- **Implementation of disposal programmes – news from Finland, Sweden, France and Switzerland**

Deep disposal in stable geological formations is, according to the scientific community, the best solution for the safe confinement for spent fuel and other long lived radioactive waste which, due to its radiological characteristics, can be assimilated by this solution. Although the solution is not implemented yet, several countries are well advanced. Based on the national reports to the Joint Convention, it can be concluded that several revisions of strategies and programmes have suffered decades of delays in relation to the dates initially set. However, over the last two years, two elements seem to be altering this trend: the substantial progress made on several national plans with cases where these facilities are expected to enter into service in next ten years - Finland and Sweden – and the revisions of calendars for several national programmes that have reduced their initial deadlines for introduction.

- **Global need to increase storage capacities**

Following several decades in operation, the pool of nuclear reactors has generated a significant inventory of spent fuel, which increases yearly; accordingly, temporary storage is a need that goes beyond the choice of an open or closed cycle. Over recent years, many States have needed to extend their temporary storage capacity to accommodate these inventories by means of the extension of existing facilities or the construction of supplementary facilities.

- **Wet versus dry storage**

Although some countries have opted to extend wet storage capacities by means of the construction of new storage pools (Finland, Sweden), it is more common for these to be dry storage facilities under the different technical existing types.

- **Individual storage versus consolidated/centralised storage**

Furthermore, the trend is for individual rather than centralised storage facilities. Although some States have centralised storage facilities (the Netherlands, Sweden, Switzerland, etc.), most States propose management strategies that involve individual temporary storage (Japan, Republic of Korea, Spain, United States, etc.), often as a result of the difficulties in forging a social consensus for the construction of centralised storage facilities.

- **Interface between storage and disposal**

The progress made by the most advanced national disposal plans has led to a growing awareness of and interest in the institutional and technical aspects relating to the interface between storage and disposal phases. This trend is under discussion at different international and national forums with the aim of facilitating a common understanding of the necessary developments.

- **Specific challenges for MS with small inventories – including research reactors**

Those States that have small inventories of spent fuel resulting from the operation of research reactors or small fleets of powerful reactors, face additional challenges to the large programmes. In these cases, difficulties often exist in the allocation of technical and financial resources while the management programme itself may be seen as a lower priority.

The repatriation of spent fuel from research reactors has been a common practice that is now declining. In the case of small fleets of powerful reactors, different approaches have been observed that include an unclear definition of the strategy (Mexico), reprocessing (Italy), along with several States that promote international or regional agreements for the disposal of spent fuel and high level waste (the Netherlands, Slovenia, etc.).

In many cases, these States are backed by the action of international organisations to develop and integrate the resources and capacities needed for safe management.

- **Compatibility between new nuclear developments and designs (SMR, Gen IV) and current management routes**

Some of these new, and other already existing, national nuclear programmes (Canada, United Kingdom, etc.) are considering the construction of nuclear reactors with novel designs. Their technical characteristics aim to employ new types of nuclear fuel that impact the nature and properties of the spent fuel and radioactive waste that they generate. This question has generated a growing interest that is being channelled by means of early dialogue with the agents involved (developers, authorities and operators), geared to taking these characteristics into account in the design of new management facilities and the modification of existing facilities.

9. CONCLUSIONS

This publication provides an overview of the status of spent fuel and radioactive waste management globally, and presents global estimates of the amounts of residual radioactive material accumulated by nuclear activities. Significant progress has been achieved, particularly during the last 10–20 years, in the treatment, conditioning and storage of spent fuel and radioactive waste and in developing national inventories. Radioactive waste and spent fuel are safely managed all over the world, and great progress has been made on a global scale in, providing more transparent and credible information.

There has also been progress in emplacing certain types of radioactive waste, as a proportion of VLLW and LLW has been disposed of using well known solutions. However, spent fuel, HLW and the major part of ILW remain in safe storage as disposal solutions are delayed. Research undertaken over several decades has progressed to the point that at least three DGRs should start operation in the next ten years. All three are located in Europe. For countries with small inventories, the development of disposal facilities can be a challenge, not only for spent fuel or HLW waste and for this reason there has been more discussion about the possible sharing of efforts.

The data presented in Section 6 provide a comprehensive overview and a best available estimate of the amounts of spent fuel and radioactive waste that currently exist in the world. The main source of information used for inventories is Spent Fuel and Radioactive Waste Information System, as well as the reports submitted by the Contracting Parties to the Joint Convention.

Worldwide, there is an estimated 300 000 t HM of spent fuel in storage. Currently, about 7 000 t HM are discharged every year. There is a decline of fuel management by reprocessing; as UK is in the process of stopping reprocessing activities. This trend may change in the future with the development of nuclear energy and associated fuel cycle facilities in countries such as China. Therefore, special attention should be paid to setting up storage capacities and keeping them safe over time, the storage period generally being several decades. This also applies for HLW packages from reprocessing. Some countries have decided to use centralized storage, while others store spent fuel on-site. About 70% of spent fuels is currently stored in pools, but as a new development is that most of the new spent fuel storage facilities are dry storages.

The overall worldwide generated volume of solid radioactive waste at the end of 2019 is was about 35 million m^3. Most of it this waste (92%) is VLLW or LLW, and 30 million m^3 have already been disposed of, and while a further 5.6 million m^3 are in storage awaiting final disposal.

Available data are sufficient to provide a clear representation of the global situation in terms of the overall challenge represented by the radioactive waste that currently exists, and to provide an indication of the challenges that will arise in the future as facilities still in operation, or planned, come to the end of their useful lives. There remain some uncertainties about total global amounts of radioactive waste, as information about the spent fuel and radioactive waste inventories of all countries is not available. Additional uncertainty in the aggregated data for individual waste classes results from the need to convert data presented according to national classification systems into a common system based on the waste classification scheme of GSG-1 [3]. Finally, uncertainty also arises from the need to present waste quantities according to the anticipated 'as disposed' volumes.

Due to the age of many nuclear power plants, decommissioning will become a more and more important activity. The first generation of nuclear power plants are reaching the end of their design lives. This will be reinforced by changes in nuclear policy in some countries that require the shutdown of reactors. In addition, many countries are now making concerted efforts to clean up past nuclear legacy sites. Therefore, the availability of disposal routes, in particular for VLLW, will become more and more important. In parallel, as disposal of any waste should not be the most preferred option and as disposal facilities for radioactive waste and/or spent fuel are rare assets, there is the challenge of promoting and implementing waste minimization techniques or recycling after decontamination, in an overall optimization approach.

The availability of disposal routes is also highly important for the management of waste generated by nuclear accidents. In Ukraine and in Japan, significant progress has been made towards the remediation of the damaged nuclear facilities (e.g. implementation of shelters, retrieval of spent fuel, etc.) and the surrounding areas (decontamination). These works have generated large amounts of liquids and solid waste, that have to be managed with a long term perspective.

DSRSs do not present a challenge with respect to their volumes. However, they present a safety issue due to their quantity (some millions) and because they are widely distributed around the world for industrial uses. Some countries already have a system of follow-up of sealed sources in order to enable and motivate their recovery after use.

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ANNEX 1. SUMMARY OF WASTE CLASSIFICATION SYSTEMS

<table>
<tr><th>COUNTRY
[REFERENCE]</th><th>CLASSIFICATION SYSTEM</th></tr>
<tr><td>Argentina
[A-1]</td><td>Uses the IAEA classification system (see below).</td></tr>
<tr><td>Australia
[A–2]</td><td>Uses the IAEA classification system (see below).</td></tr>
<tr><td>Austria
[A–3]</td><td>Transition radioactive waste -Type of radioactive waste (mainly from medical origin) which will decay within the period of temporary storage and may then be suitable for management outside of the regulatory control system subject to compliance with clearance levels. (Waste in the transition phase, e.g. short-lived decay waste from medical applications containing ^{125}I, is put into decay storage prior to free release).

Low and intermediate level waste (LILW) - In LILW, the concentration of radionuclides is such that generation of thermal power during its disposal is sufficiently low. These acceptable thermal power values are site specific following safety assessments.
- Short-lived waste (LILW-SL): This category includes radioactive waste with nuclides half-life less than or equal to those of ^{137}Cs and ^{90}Sr (around 30 years) with a restricted alpha long lived radionuclide concentration (limitation of long lived alpha emitting radio nuclides to 4000 Bq/g in individual waste packages and to an overall average of 400 Bq/g in the total waste volume).
- Long lived waste (LILW-LL): Long lived radionuclides and alpha emitters whose concentration exceeds the limits for short-lived waste.

High level waste (HLW) - does not arise in Austria.</td></tr>
<tr><td>Belarus
[A–4]</td><td>By specific activity, liquid and solid radioactive wastes are divided into 4 categories: very low-level, low-level, intermediate-level and high-level. Liquid radioactive wastes are divided into 3 categories: low-level, intermediate-level and high-level.

Solid:
• Very low-level: <10^3 β, <10^2 α, <10^1 transuranic (Bq/g)
• Low-level: 10^3 – 10^4 β, 10^2 - 10^3 α, 10^1 – 10^2 transuranic (Bq/g)
• Intermediate-level: 10^4 – 10^7 β, 10^3 – 10^6 α, 10^2 – 10^5 transuranic (Bq/g)
• High-level: >10^7 β, >10^6 α, >10^5 transuranic (Bq/g)

Liquid:
• Low-level: <10^3 β, <10^2 α, <10^1 transuranic (Bq/g)
• Intermediate-level: 10^3 – 10^7 β, 10^2 – 10^6 α, 10^1 – 10^5 transuranic (Bq/g)
• High-level: >10^7 β, >10^6 α, >10^5 transuranic (Bq/g)</td></tr>
<tr><td>Belgium
[A–5]</td><td>Category A - waste is short-lived, low-level and intermediate-level conditioned waste containing limited quantities of long-lived radionuclides. It poses a risk to people and the environment for several hundreds of years. It can be considered for surface or near-surface disposal. It corresponds to low-level waste in the IAEA 2009 classification. The radiological criteria and limits for the category A waste will be defined in the safety report and licensing conditions for the planned disposal facility in Dessel.

Category B - waste is low-level and intermediate-level conditioned waste contaminated with such quantities of long-lived radionuclides that it poses a risk to people and the environment for several tens to several hundreds of thousands of years in some cases. Note that sealed sources must be managed as radioactive waste end up in category B after treatment and conditioning. Its thermal power is potentially significant at the time of its conditioning, but</td></tr>
</table>

<table>
<tr><th>COUNTRY
[REFERENCE]</th><th>CLASSIFICATION SYSTEM</th></tr>
<tr><td></td><td>it will emit too little heat after the storage period to be classified as category C waste. It corresponds to intermediate-level waste in the IAEA 2009 classification.

Category C - waste is high-level conditioned waste containing large quantities of long-lived radionuclides and which, like category B waste, poses a risk for several tens to several hundreds of thousands of years in some cases. After the period currently considered for its storage (around 60 years of cooling required, in the event of subsequent disposal in poorly indurated clay), its thermal power still causes a significant increase in the temperature of the repository’s host rock. It corresponds to high-level waste in the IAEA 2009 classification. Category C waste includes vitrified waste from the reprocessing of spent fuel from commercial nuclear power plants (and from the BR2 research reactor) and non-reprocessed spent fuel declared as waste, except for certain fuels from research reactors, which belong to category B.

<table>
<tr><th></th><th>Low activity</th><th>Medium Activity</th><th>High Activity</th></tr>
<tr><td>Short-lived waste</td><td>A</td><td>A</td><td>C</td></tr>
<tr><td>Long lived waste</td><td>B</td><td>B</td><td>C</td></tr>
</table>

The above waste categories are further subdivided in waste classes and waste streams.</td></tr>
<tr><td>Bosnia and Herzegovina

[A-6]</td><td>Uses the IAEA classification system (see below).</td></tr>
<tr><td>Botswana

[A-7]</td><td>Cleared material/waste: Waste containing levels of radio-nuclides at concentrations less than the clearance levels established by the Radiation Protection Inspectorate;

Low level (short lived)/Decay waste: Low level radioactive waste containing short lived radio-nuclides only (e.g. with half-lives less than 10 days) that will decay to clearance levels within three years after the time of its generation;

Low and intermediate level short lived waste (LILW-SL): Waste which will not decay to clearance levels within 3 years and contains beta/gamma emitting radio-nuclides with half-lives less than 30 years and/or alpha emitting radio-nuclides with an activity less than 400 Bq/g and a total activity less than 4000 Bq in each waste package;

Low and intermediate level long lived waste (LILW-LL): Radioactive waste containing radio-nuclides with concentrations above those for LILW-SL, but which does not generate heat at above 2 kW/m³ of waste</td></tr>
<tr><td>Brazil

[A–8]</td><td>Uses the IAEA classification system (see below).</td></tr>
<tr><td>Bulgaria

[A–9]</td><td>Category 1 –Transitional waste, that contain small concentrations of safety significant radionuclides so that it does not require provisions for radiation protection or does not need a high level of containment and isolation; this category of waste is additionally sub-divided in:

    Category 1a – Exempt Waste

    Category 1b – Very Short Lived Waste,

    Category 1c – Very Low Level Waste

Category 2 – Low and Intermediate Level Waste (LILW). Because of its radionuclide content, LILW requires robust isolation and containment but no special measures for heat removal during its storage and disposal; this category of waste is additionally sub-divided in:

    Category 2a – low and intermediate level waste containing mainly short-lived radionuclides (with a half-life no longer then Cesium-137 half-life) as well as long-lived</td></tr>
</table>

COUNTRY [REFERENCE]	CLASSIFICATION SYSTEM
	radionuclides at significantly lower levels of activity, limited for the long-lived alpha emitters under 4.10^6 Bq/kg for each individual package and a maximum average for all packages in the respective facility of 4.10^5 Bq/kg, for such RAW, reliable isolation and containment is required for a period of up to several hundred years, *Category 2b* – low and intermediate level waste containing long-lived radionuclides at activity levels of long-lived alpha emitters, exceeding the limits for category 2a. *Category 3* – high level waste: with concentration of radionuclides at which heat removal must to be considered in its storage and disposal; a higher level of isolation and containment compared to low and intermediate level waste is needed through disposal in deep, stable geological formations.
Canada [A–10]	*Uranium mine and mill waste* - waste rock and mill tailings are a specific type of radioactive waste generated during the mining and milling of uranium ore and the production of uranium concentrate. In addition to tailings, mining activities typically produce large quantities of mineralized and clean waste rock excavated to access the ore body. The tailings and mineralized waste rock contain significant concentrations of long-lived radioactive elements, namely thorium-230 and radium-226. *Low-level radioactive waste (LLW)* - contains material with radionuclide content above established clearance levels and exemption quantities, and generally limited amounts of long-lived activity. LLW requires isolation and containment for up to a few hundred years. LLW generally does not require significant shielding during handling and interim storage. LLW has two subcategories described below: *Very-short-lived low-level radioactive waste (VSLLW)* - can be stored for decay for up to a few years and subsequently cleared for release. This classification includes radioactive waste containing only short half-life radionuclides of the kind typically used for research and biomedical purposes. Examples of VSLLW are iridium-192 and technetium-99m sources, as well as industrial and medical radioactive waste that contains similar short half-life radionuclides. Generally, the main criterion for VSLLW is the half-life of the predominant radionuclides. In practice, the management of VSLLW should be applied only to radionuclides with a half-life of 100 days or less. *Very-low-level radioactive waste (VLLW*) - has a low hazard potential but is nevertheless above the criteria for exemption. Long-term waste management facilities for VLLW do not usually need a high degree of containment or isolation. A near-surface repository with limited regulatory control is generally suitable. Typically, VLLW includes bulk material such as low-activity soil and rubble, decommissioning wastes and some uranium-contaminated wastes. *Intermediate-level radioactive waste (ILW)* - waste that typically exhibits sufficient levels of penetrating radiation to warrant shielding during handling and interim storage. This type of radioactive waste generally requires little or no provision for heat dissipation during its handling, transportation and long-term management. However, some ILW may have heat generation implications in the short term (e.g., refurbishment waste) because of its total radioactivity level. *High-level radioactive waste (HLW)* – is used (irradiated) nuclear fuel that has been declared radioactive waste or waste that generates significant heat (typically more than two kilowatts per cubic metre) via radioactive decay. In Canada, "irradiated nuclear fuel" or "used nuclear fuel" are more accurate terms for spent fuel because discharged fuel is considered a waste material even when it is not fully spent. Despite the name difference, in this report the term "spent fuel" is used to be consistent with the terminology found in the Joint Convention. Spent fuel is associated with penetrating radiation, which requires shielding. Furthermore, spent fuel contains significant quantities of long-lived radionuclides, meaning that long-term isolation is also required. Waste forms derived from spent fuel (e.g., nuclear fuel reprocessing wastes) can exhibit similar characteristics and may be considered HLW. Placement in deep, stable geological formations is considered the preferred option for the long-term management of HLW.

COUNTRY [REFERENCE]	CLASSIFICATION SYSTEM
Chile [A-11]	*Category 1:* Alpha emitting radioisotopes, whatever their activity. *Category 2:* Radioisotopes with beta and gamma emitters whose half-life is greater than 100 days. *Category 3:* Radioisotopes with beta and gamma emitters whose half-life is less than 100 days.
China [A–12]	Uses the IAEA classification system (see below).
Croatia [A–13]	*Exempt and cleared radioactive waste* – radioactive waste that fulfils the requirements for the release from regulatory control *Very short lived radioactive waste* – radioactive waste containing radionuclides with half-life shorter than 100 days *Low level radioactive waste* – radioactive waste containing radionuclides with half-life less than 30 years with a restricted alpha long-lived radionuclide concentration (limitation of long lived alpha emitting radionuclides to 4000 Bq/g in individual waste packages and to an overall average of 400 Bq/g in the total waste volume). The generation of thermal power in this waste is lower than 2 kW/m^3 *Intermediate level radioactive waste* – radioactive waste with activity concentrations exceeding the limits for low level radioactive waste *High level radioactive waste* – radioactive waste thermal power above 2 kW/m^3
Cuba [A-14]	*Low and intermediate level and very short lived waste* – radioactive waste containing radionuclides with a short half-life (less than 100 days) which, after a period of interim storage will decay to clearance levels *Low level and intermediate level and short lived waste* – Radioactive waste containing radionuclides with activity levels above the clearance levels established by the regulatory body, with half-life higher than 100 days and less than 30 years which does not generate residual heat above 2 kW/m^3 *Low and intermediate level and long lived waste* – Radioactive waste containing radionuclides with activity levels above the clearance levels established by the regulatory body, with half-life higher than 30 years which does not generate residual heat above 2 kW/m^3
Cyprus [A–15]	Uses the IAEA classification system (see below).
Czech Republic [A–16]	*Temporary radioactive waste* - which after storage for at most 5 years exceeds radioactivity lower than clearance levels. *Very low-level waste* - with radioactivity higher than that of temporary radioactive waste, but which does not require any special measures during disposal. *Low-level waste* - with radioactivity higher than that of temporary radioactive waste, but which at the same time contains limited amounts of long-lived radionuclides. *Intermediate-level waste* **-** contains a significant amount of long-lived radionuclides, and therefore it requires a higher degree of isolation from the surrounding environment than the low-level waste. *High-level waste* - during storage and disposal, it is necessary to take into account heat generated by decay of the contained radionuclides; the waste is processed and treated to meet the acceptance criteria and it must to be disposed in deep geological repositories several hundred meters under the ground.

COUNTRY [REFERENCE]	CLASSIFICATION SYSTEM
Estonia [A–17]	*Exempt waste* – waste arising from radiation practices, for which the activity and activity concentration or activity concentration on the surface is lower that the clearance levels established *NORM waste* – radioactive waste produced as a result of handling raw materials containing substances that contain natural radionuclides (Th-232 and U-238 and radionuclides belonging to their decay series), the specific activity of which is grater than the clearance levels established *Short-lived waste* - radioactive waste containing radionuclides with less than a 100-day half-life that will decay below the clearance levels established within up to 5 years *Low and intermediate activity short-lived waste* – radioactive waste that contains beta and gamma sources with a half-life less than 30 years and a limited amount of long-lived alpha sources (no more than 4000 Bq/g for one waste package and no more than 400 Bq/g averaged over the total waste package amounts) *Low and intermediate activity long-lived waste* – radioactive waste containing radionuclides with half-life higher than 30 years with the activity concentration higher than that for low and intermediate activity short-lived waste and which will generate less than 2 kW/m^3 heat energy by radioactive decay *High level waste* – radioactive waste, which generates more than 2 kW/m^3 heat energy by radioactive decay
Finland [A–18]	The classification system for the purpose of the predisposal management of LILW from nuclear facilities, including NPPs, is based on activity concentrations, Solid and liquid waste arising from the controlled area of an NPP contain almost exclusively short-lived beta and gamma emitters and are grouped into the following activity categories: *Very low-level waste (VLLW)* - refers to waste whose average activity concentration of significant radionuclides does not exceed the value of 100 kBq/kg and the total activity does not exceed 1 TBq, α-activity < 10 GBq. *Low level waste (LLW)* - contains so little radioactivity that it can be treated without any special radiation protection arrangements. The activity concentration in the waste must not be more than 1 MBq/kg. *Intermediate level waste (ILW)* - contains radioactivity to the extent that effective radiation protection arrangements are needed when the waste is processed. As a rule, the activity concentration in the waste is from 1 MBq/kg to 10 GBq/kg. *HLW level waste (HLW)* – Spent fuel is regarded as HLW. The classification for disposal distinguishes short-lived and long-lived waste accordingly: *Short-lived waste* - refers to nuclear waste of which the activity concentration after 500 years will be below the level of 100 MBq/kg in each disposed waste package and below an average value of 10 MBq/kg of waste in one emplacement room. *Long-lived waste* - refers to nuclear waste, of which the activity concentration after 500 years will be above the level of 100 MBq/kg in a disposed waste package, or above an average value of 10 MBq/kg of waste in one emplacement room.
France [A–19]	*Very short lived* - waste comes mainly from the medical and non-nuclear power generating research. *Very low level waste* – mainly comes from the decommissioning of the NPPs, the fuel cycle facilities and research centres and, to a lesser extent, from the operation and maintenance of this type of nuclear installations. The activity level of this waste is generally lower than 100 Bq/g. *Low-level and intermediate-level short-lived waste* - waste results mainly from the operation, maintenance and decommissioning of nuclear power plants, fuel cycle facilities, research

COUNTRY [REFERENCE]	CLASSIFICATION SYSTEM
	centres and, to a far lesser extent, from medical research activities. The level of this waste is between a few hundred and a million Becquerels per gram. *Low-level long-lived waste* - mainly graphite waste and radium bearing waste. Graphite waste comes primarily from the old gas-cooled reactor technology. Graphite waste primarily contains long-lived beta radionuclides such as carbon-14 and chlorine-36. Their activity level is about ten thousand to a to a hundred thousand of Becquerels per gram. Radium-bearing waste, mostly from non-nuclear power generating activities mainly contains long-lived alpha emitting radionuclides and their activity level is between a few tens to a few thousand Becquerels per gram contains long lived alpha emitting radionuclides and their activity lies between a few tens to a few thousands of. *Intermediate level, long-lived waste* – mainly comes from spent fuels after reprocessing and activities involved in the operation and maintenance of fuel reprocessing plants. The activity level of this waste is about one million to one billion Becquerels per gram. The heat given off is slight or negligible. *High level waste* - waste consists mainly of vitrified waste packages from spent fuels after reprocessing. The activity level of vitrified waste lies in the order of several billions of Becquerels per gram and it generates significant heat. *Spent fuel* - is not generally considered to be a waste and is normally reprocessed and recycled. However, some limited amounts of spent fuel that are not compatible with the reprocessing facilities may be directly disposed as a waste.
Georgia [A–20]	Uses the IAEA classification system (see below).
Germany [A–21]	*Negligible heat generating radioactive wastes* are radioactive waste with an average heat output of less than about 200 W/m^3 of waste (corresponding to a 3 degree K increase in temperature at the wall of the disposal chamber of the Konrad repository caused by decay heat from the radionuclides contained in the waste packages). *Heat generating radioactive wastes* are characterized by high activity concentrations and therefore by high decay heat output. This category includes reprocessing residues and spent fuel.
Ghana [A–22]	Uses the IAEA classification system (see below).
Greece [A–23]	Uses the IAEA classification system (see below).
Hungary [A–24]	Radioactive waste producing significant amount of heat is classified as high-level waste. Heat generation is significant if it needs to be considered during the design of storage and disposal and during operation. The rest of the radioactive wastes are low- and intermediate-level wastes which are to be classified considering the following aspects: a) the low- and intermediate level radioactive waste, in which the half-life of the radionuclides is 30 years or less, and which contains long-lived alpha emitter radionuclides only in limited concentration is considered short-lived; b) the low- and intermediate level radioactive waste, in which the half-life of the radionuclides and/or the concentration of the alpha emitter radionuclides exceed the limits of short-lived radioactive waste, is considered long-lived. The classification of the radioactive waste into low and intermediate level classes shall be performed based on the activity-concentration and exemption activity-concentration of the given radioisotope.

COUNTRY [REFERENCE]	CLASSIFICATION SYSTEM
Indonesia [A-25]	Solid Low level waste: • Very short half-life • Very low level • Relative low level Intermediate level waste: • DSRS with half-life less than 15 years • DSRS with half-life between 15 and 30 years • DSRS with half-life more than 30 years • Other than DSRS High level waste – spent nuclear fuel Liquid • Low active – activities 37 kBq/m^3 to 0.37 GBq/m^3 • Intermediate active – activities of 0.37 GBq/m^3 to 3700 GBq/m^3
International Waste Classification System [A-26]	*Exempt Waste (EW):* Activity levels at or below clearance levels, which are based on an annual dose to members of the public of less than 0.01 mSv. *Very Short-lived Waste (VSLW):* Waste that can be stored for decay over a limited period of up to a few years and subsequently cleared from regulatory control according to arrangements approved by the regulatory body, for uncontrolled disposal, use or discharge. This class includes waste containing primarily radionuclides with very short half lives often used for research and medical purposes. *Very Low Level Waste (VLLW):* Radioactive waste considered suitable by the regulatory body for authorized disposal, subject to specified conditions, with ordinary waste in facilities not specifically designed for radioactive waste disposal. *Low and Intermediate Level Waste (LILW):* activity levels above EW and thermal power ~< $2kW/m^3$ LILW is subdivided into: • Short lived Low and Intermediate Level Waste (LILW-SL), short-lived waste with long lived alpha nuclides of less than 400 Bq/g average or 4000 Bq/g for individual packages • Long lived Low and Intermediate Level Waste (LILW-LL), long lived concentrations above LILW-SL *High Level Waste (HLW):* thermal power > 2 kW/m^3 and long lived radionuclide concentrations above LILW-SL. This category includes spent fuel where it has been declared a waste.
Italy [A-27]	*Very short lived waste* - Radioactive waste containing radionuclides with very short half-life, of less than 100 days, requiring up to 5 years to reach activity concentrations lower than values specified in legislation. *Very low level waste* - Radioactive waste with activity concentration that doesn't meet the criteria set out for exempt waste, but though lower than 100 Bq/g with a maximum alpha contribute of 10 Bq/g for alpha-emitting long-lived radionuclides. *Low Level Waste* - Radioactive waste that doesn't meet the criteria established for exempt waste and that requires containment and isolation periods of up to a few hundred years in order to be disposed of. This category includes radioactive waste characterized by levels of activity concentration of up to 5 MBq/g for short-lived radionuclides, of up to 40 kBq/g for the long lived isotopes of Nickel and of up to 400 Bq/g for long lived radionuclides. *Intermediate level waste* - Radioactive waste with activity concentrations exceeding the values set out for low level waste, though not requiring provisions for heat dissipation during

COUNTRY [REFERENCE]	CLASSIFICATION SYSTEM
	its storage and disposal. This category includes waste containing long lived radionuclides that mostly requires a degree of isolation higher than that provided by near surface disposal facilities with engineered barriers, therefore requiring disposal in geological formations. This category includes also waste characterized by levels of activity concentrations of up to 400 Bq/g for alpha-emitting radionuclides and mainly containing radionuclides beta/gamma emitters even long lived, with such an activity concentrations that they can be disposed of in near surface facilities with engineered barriers, provided that the level of activity concentration complies with the objectives of radiation protection established for the abovementioned surface disposal facility, such as, for instance, the waste containing activation products arising from the decommissioning of some parts of the nuclear facilities. *High level waste* - Radioactive waste with high activity concentrations, such as to generate a significant amount of heat or with high concentrations of long-lived radionuclides, or both of these characteristics, which require a degree of isolation and containment for a time period of thousands of years and over. This waste requires disposal in geological formations.
Japan [A-28]	Two basic solid waste categories: *Category 1:* Final disposal by a method on the burial of radioactive waste in the excess of criteria defined by legislation as they have potential significant risks to human health *Category 2:* all other radioactive waste, subdivided into several categories based on their disposal paths: *Intermediate Depth Disposal* is burial of radioactive waste at a depth of 70 m and up from ground and not exceeding criteria defined by legislation *Pit Disposal* is by a method on the burial of radioactive waste above ground or less than 70m from ground, and not exceeding criteria defined by the legislation. *Trench Disposal* is by a method on the burial of radioactive waste above ground or less than 70 m from ground, and not exceeding criteria defined by legislation.
Jordan [A-29]	Uses the IAEA classification system (see below).
Kazakhstan [A-30]	By the activity level radioactive waste is classified as follows: *Low level waste* – a waste with specific activity (kilo Becquerel per kilogram): less than one thousand – for beta-emitting nuclides, less than one hundred – for alpha emitting nuclides (excluding transuranium), less than ten – for transuranium nuclides; *Intermediate waste* – a waste with specific activity (kilo Becquerel per kilogram): from one thousand to ten million – for beta-emitting nuclides, from one hundred to one million – for alpha emitting nuclides (excluding transuranium), for ten to one hundred thousand – for transuranium nuclides; *High level waste* – a waste with specific activity (kilo Becquerel per kilogram): more than ten million – for beta-emitting nuclides, more than one million – for alpha emitting nuclides (excluding transuranium), more than one hundred thousand – for transuranium nuclides
Latvia [A-31]	Uses the IAEA classification system (see below).
Lithuania [A-32]	*Very Low Level Waste (VLLW).* Radioactive waste with radiological characteristic values exceeding clearance levels, however, lower than the characteristics for low level waste. VLLW will be disposed in licensed landfills. *Low and Intermediate Level Waste (LILW).* Radioactive waste with radiological characteristics between those of very low level waste and high level waste. These may be long-lived waste (LILW-LL) or short-lived waste (LILW-SL). LILW-SL will be disposed of in Near Surface Repository (NSR) at the site

COUNTRY [REFERENCE]	CLASSIFICATION SYSTEM
	High Level Waste (HLW). Spent fuel which shall be placed in deep geological repository due to its significant emitting capacity of a heat generated during radioactive decay or due to the contained amount of long-lived radionuclides.
Madagascar [A-33]	*exempt waste:* It is the wastes whose very low level of activity allows their elimination by conventional techniques, without any particular consideration for their radioactive properties. *low and medium-level waste:* Short-lived low-level and intermediate-level waste must be divided into three categories according to their radioactive period: • Type 1 waste, which contains only radionuclides with a period of less than 6 days; • Type 2 waste, which contains radionuclides with a period of between 6 and 71 days; • Type 3 waste, which contains radionuclides with a period of more than 71 days. *Long-lived waste:* This refers to wastes whose average activity in long-lived alpha emitters exceeds that set for short-lived waste. *High Activity Waste:* It is waste with a thermal capacity of more than 2 kW per cubic meter and a concentration of long-life emitters exceeding that set for short-lived waste.
Malawi [A-34]	Uses the IAEA classification system (see above).
Mauritius [A-35]	Uses the IAEA classification system (see above).
Mexico [A-36]	*Low-level waste* • *Class A.* Radioactive waste that within a period of 100 years constitute a level of risk that is acceptable for population and environment. • *Class B.* Radioactive waste that within a period of 300 years constitute a level of risk that is acceptable for population and environment. • *Class C.* Radioactive waste that within a period of 500 years constitute a level of risk that is acceptable for population and environment. *Intermediate-level waste.* Radioactive waste whose risk remains above acceptable levels for more than 500 years. *High-level waste.* Radioactive wastes arising from reprocessing of spent nuclear fuel and spent nuclear fuel itself, once the Government declares it as waste. *Mixed waste.* Radioactive waste mixed with other hazardous materials. *Uranium and thorium tailings.* Radioactive waste arising from ore processing in a mill to extract metal content.
Montenegro [A-37]	Uses the IAEA classification system (see below).
Morocco [A-38]	Uses the IAEA classification system (see below).
Netherlands [A-39]	*Exempt waste* *Short-lived waste* *low-level and intermediate-level radioactive waste LILW* (including NORM waste) • Category A: alpha bearing waste • Category B: Beta/gamma contaminated waste from nuclear power plants

COUNTRY [REFERENCE]	CLASSIFICATION SYSTEM
	• Category C: Beta/gamma contaminated waste from generators other than nuclear power plants with a half-life longer than 15 years • Category D: Beta/gamma contaminated waste from generators other than nuclear power plants with a half-life shorter than 15 years *high-level radioactive waste* (HLW, non-heat generating and heat generating) • Heat generating, consists of the vitrified waste from reprocessing of spent fuel from the two nuclear power reactors in the Netherlands (Borssele and Dodewaard), the spent fuel of the two research reactors (Petten and Delft) and the spent uranium targets of the molybdenum production. Non heat generating, is mainly formed by the reprocessing waste other than the vitrified residues. It also includes waste from research on reactor fuel and some decommissioning waste.
Nigeria [A-40]	*Category I:* Low level radioactive waste (less than 10 MBq), containing short lived radionuclides only (less than 50 days) that will decay to clearance levels within one year after the time of its generation *Category II:* Low and intermediate level radioactive waste, containing the radionuclides with half-life less than 30 years and restricted long-lived radionuclide concentrations and that is not expected to decay to clearance levels within one year from the time of its generation (limitation of longer lived alpha emitting radionuclides to 400 Bq/g individual waste packages and to an overall average of 400 Bq/g per waste packages) *Category III:* Low and intermediate level radioactive waste, containing the radionuclides with half-life over 30 years and concentration of alpha emitters exceeding the limitations for Category II. This waste needs to be disposed of in deep geological facilities only. *Category IV:* High level radioactive waste with thermal power above 2kW/m^3 and concentration of alpha emitters exceeding the limitations for Category III (e.g. spent fuel from research reactors). This waste needs to be disposed of in deep geological facilities only.
North Macedonia [A-41]	*Cleared waste;* *Radioactive waste with radionuclides with a very short half-life* – radioactive waste that may be stored over a limited period of time of a few years and be subsequently released from control; this class includes radionuclides used for research and medical purposes; *Very low activity radioactive waste;* *Low activity radioactive waste* – radioactive waste that is above release levels, but with limited amounts of long-lived radionuclides; such radioactive waste requires robust isolation and containment for periods of up to a few hundred years and is suitable for disposal in engineered near surface facilities; low activity radioactive waste may include short-lived radionuclides at higher levels of activity concentration and long-lived radionuclides, but only at relatively low levels of activity concentration; *Intermediate activity radioactive waste* – radioactive waste that, because of its content, particularly of long-lived radionuclides, requires a greater degree of containment and isolation than that provided by near surface disposal; such waste needs only limited provision for heat dissipation during its storage and disposal; it may contain long-lived radionuclides, in particular alpha emitters, that will not decay to a level of activity concentration acceptable for near surface disposal; such radioactive waste requires disposal at greater depths, in the order of tens of metres to a few hundred metres; and *High activity radioactive waste* – such radioactive waste requires disposal in stable geological formations several hundred metres below the surface.
Paraguay [A-42]	*Very shorth half-life waste* – waste that must to be stored for decay for a limited period of up to a few years, to be subsequently released from regular control in accordance with the provisions approved by the regulator and managed by not controlled disposal, use, or download.

COUNTRY [REFERENCE]	CLASSIFICATION SYSTEM
	Very low activity waste - radioactive waste that, even when exceeding the dispensing levels, does not require a high level of isolation and containment, so it can be disposed of in landfill-type surface disposal facilities with a reduced regulatory control, in which other hazardous wastes could also be placed. *Low Activity Wastes* – waste containing limited amounts of long half-life radionuclides. The wastes require a high level of isolation and containment for periods of up to several hundred years and are suitable for final disposal in surface facilities. *Intermediate activity waste* - wastes that due to their content of radionuclides, particularly those with a long half-life, require a higher degree of isolation and containment, than what a surface disposal facility can provide. However, these wastes do not require, or may require in a very limited way, that measures be taken during their storage and final disposal to control the release of the heat they generate. *High level waste* – waste with activity concentrations high enough to generate significant amounts of heat due to radioactive decay processes, or waste contaminated with large amounts of long half-life radionuclides, such that they need to be considered in the design of the facility planned for its disposal.
Poland [A-43]	Radioactive waste is classified into three categories with respect to the concentration of radioactive isotopes contained in the waste: low, medium and high level radioactive waste. These categories are further subdivided into subcategories according to the half live of radioactive isotopes and the concentration of radioactive isotopes contained in the waste. Liquid waste is additionally classified according to its activity concentration. Spent nuclear fuel intended for disposal is classified as a high level radioactive waste. The low, intermediate and high level waste is subsequently classified into subcategories: - Transitional waste which will decay within the period of three years below the value defined in the legislation, - Short-lived waste – waste containing radionuclides of half-life < 30 years with the restricted long lived radionuclides concentration to 4000 kBq/kg in individual waste packages and to an overall average of 400 kBq/kg in the total waste volume, - Long lived waste: waste whose long lived radionuclides activity exceeds 400 kBq/kg.
Portugal [A-44]	Uses the IAEA classification system (see above).
Republic of Korea [A-45]	*High Level Waste* – radioactive waste which radioactive concentration and the heat generation rate are higher than levels prescribed by the Regulatory Body: • Radioactivity concentration higher than 4000 Bq/g for alpha emitting radionuclide having a half-life longer than 20 years • Heat generation rate higher than $2kW/m^3$ *Low and Intermediate Level Waste* – waste other than HLW. There are three sub-categories: • Very low level radioactive waste • Low level radioactive waste and • Intermediate level radioactive waste. *Very Low Level Waste*
Romania [A-46]	*Excluded radioactive waste* (EW) is waste containing radionuclides with an activity concentration so small that the waste can be released from regulatory control (conditionally or unconditionally). *Transitional radioactive waste* (TW) is waste having activity concentration above clearance levels, but which decays below clearance levels within a reasonable storage period (not more than 5 years). *Very low level radioactive waste* (VLLW) is short-lived waste in which the activity concentration is above the clearance levels, but with a radioactive content below levels

COUNTRY [REFERENCE]	CLASSIFICATION SYSTEM
	established by CNCAN for defining the low level waste. The disposal of very low level waste requires less complex arrangements than the disposal of short-lived low level waste. *Low and intermediate level radioactive waste* (LILW) is radioactive waste in which the activity concentration is above the levels established by CNCAN for the definition of very low level waste, but with a radioactive content and thermal power below those of high level waste. Low level waste does not require shielding during handling or transportation. Intermediate level waste generally requires shielding during handling, but needs little or no provision for heat dissipation during handling or transportation. - *Long lived radioactive waste* is a waste containing radionuclides with half-life above 30 years in quantities and/or concentrations of activity above the values established by CNCAN, for which isolation from biosphere is necessary for more time than the institutional control duration. - *Short-lived radioactive waste* is a radioactive waste that is not long lived. *High level radioactive waste* (HLW) is: (a) liquid radioactive waste containing the most part of fission products and actinides existing initially in the spent fuel and forming the residues of the first extraction cycle of reprocessing; (b) the solidified radioactive waste of (a) and spent fuel; and (c) any other radioactive waste with activity concentration range similar to the waste mentioned above.
Russia [A-47]	*Class 1* - solid high-level RW that shall be disposed of in deep disposal facilities after being stored to reduce the decay heat *Class 2* - solid high level radioactive waste and intermediate-level long-lived radioactive waste containing radionuclides with half-lives grater than 31 years that shall be disposed of in deep disposal facilities without prior storage to reduce the decay heat *Class 3* – solid intermediate level radioactive waste and low level long-lived radioactive waste containing radionuclides with half-lives greater that 31 years that shall be disposed of in near-surface disposal facilities at a depth of up to 100 metres. *Class 4* – solid low-level radioactive waste and very low-level radioactive waste that shall be disposed of in near-surface disposal facilities located at the ground level. *Class 5* – liquid intermediate-level and low-level radioactive waste that shall be disposed in deep well injection disposal facilities. *Class 6* – radioactive waste generated from mining and processing of uranium ores or during operations that are not associated with atomic energy use, namely, mining and processing of mineral and organic raw materials with an increased concentrations of naturally occurring radionuclides that shall be disposed of in near-surface disposal facilities.
Serbia [A-48]	Uses the IAEA classification system (see above).
Slovakia [A-49]	Uses the IAEA classification system (see above).
Slovenia [A-50]	*Transitional radioactive waste* - the activity of which decreases during storage below the limit value enabling their release into environment; *Very low level radioactive waste*, for which the competent regulatory body for nuclear and radiation safety may approve conditional clearance; *Low and intermediate level radioactive waste* (LILW), with insignificant heat generation, which is classified into two groups: a) *Short-lived LILW*, containing radionuclides with a half-life shorter than 30 years and specific activity of alpha emitters equal to or lower than 4,000 Bq/g for an individual package, but on average not higher than 400 Bq/g in the overall amount of LILW;

<table>
<tr><th>COUNTRY
[REFERENCE]</th><th>CLASSIFICATION SYSTEM</th></tr>
<tr><td></td><td>b) Long lived LILW, where specific activity of alpha emitters exceeds the limitations for short-lived LILW;

High level radioactive waste (HLW), which contains radionuclides whose decay generates such an amount of heat that it has to be considered in its management;

NORM -Radioactive waste containing naturally occurring radionuclides that are generated in processing of nuclear mineral materials or other industrial processes and are not sealed sources of radiation in accordance with the regulations on the use of radioactive sources and radiation practices.</td></tr>
<tr><td>South Africa

[A-51]</td><td>High Level Wastes (HLW): Heat generating radioactive waste with high, long and short-lived radionuclide concentrations

• with thermal power > 2 kW/m^3 or
• Long lived alpha, beta and gamma emitting radionuclides at activity concentration levels > levels specified for LILW-LL or
Long lived alpha, beta and gamma emitting radionuclides at activity concentration levels that could result in inherent intrusion dose (the intrusion dose assuming the radioactive waste is spread on the surface) above 100 mSv per annum

Low and Intermediate Level Wastes- Long Lived LILW-LL: Radioactive waste with low or intermediate short-lived radionuclide and intermediate long lived radionuclide concentrations.

• Thermal power (mainly due to short-lived radio nuclides (T ½ < 31 y) <2 kW/m^3) AND
• Long lived alpha radio nuclides (T ½ > 31 y) concentrations:
o Alpha: < 4000 Bq/g
o Beta and gamma: <40000 Bq/g
• OR Long lived alpha, beta and gamma emitting radionuclides at activity concentration levels that could result in inherent intrusion dose (the intrusion dose assuming the radioactive waste is spread on the surface) between 10 and 100 mSv per annum.
Low and Intermediate Level Wastes- Short-lived (LILW-SL): Radioactive waste with low or intermediate short/lived radionuclide and/or low long lived radionuclide concentrations

- Thermal power (mainly due to short-lived radio nuclides (T ½ < 31 y) <2 kW/m^3) AND
- Long lived alpha radio nuclides (T ½ > 31 y) concentrations:
o Alpha: < 400 Bq/g
o Beta and gamma: <4000 Bq/g
- OR Long lived alpha, beta and gamma emitting radionuclides at activity concentration levels that could result in inherent intrusion dose (the intrusion dose assuming the radioactive waste is spread on the surface) below 10 mSv per annum.
Very Low Level Waste (VLLW): Radioactive waste containing very low concentration of radioactivity.

Naturally Occurring Radioactive Materials - low activity (NORM-L): Potential Radioactive waste containing low concentrations of NORM. Long lived radio nuclide concentration < 100 Bq/g.

Naturally Occurring Radioactive Materials - enhanced activity (NORM-E): Radioactive waste containing enhanced concentrations of NORM. Long lived radio nuclide concentration > 100 Bq/g.</td></tr>
<tr><td>Spain

[A-52]</td><td>Low and Intermediate Level Wastes (LILW), which include those whose activity is due mainly to the presence of beta or gamma-emit ting radionuclides with short or intermediate half-lives (less than 30 years), and whose content of long lived radionuclides is very low and limited. This group includes the sub-category of Very Low Level Wastes (VLLW).

Special Waste (SW), in accordance with Nuclear Safety Council Instruction IS-29 on safety criteria in temporary storage facilities for spent fuel and high level radioactive waste, includes the following: nuclear fuel attachments; neutron sources; used in-core instrumentation or substituted components deriving from the reactor vessel system and</td></tr>
</table>

COUNTRY [REFERENCE]	CLASSIFICATION SYSTEM
	reactor internals, generally metallic and presenting a high level of radiation through neutron activation; and other waste which, because of its radiological characteristics, is not eligible for management in the existing near surface level definitive disposal facility for LILW in Spain. Its management is connected to that of High Level Waste. *High Level Wastes* (HLW) are those that contain long lived alpha emitters with half lives of more than 30 years in appreciable concentrations and that may generate heat as a result of radioactive decay, due to their high specific activity. This category includes spent fuel. Also included, for the purposes of integral management, are those other Intermediate Level wastes (ILW) that in view of their characteristics are not eligible for definitive management under the conditions established for 'El Cabril' and that require specific installations for this purpose.
Sweden [A-53]	There is no legally defined waste classification system in Sweden for nuclear or radioactive waste. There are, however, established waste acceptance criteria for different disposal routes of nuclear and radioactive waste. Waste classification scheme used by the Swedish nuclear industry: Cleared material – material with so small amounts of radioactive nuclides that it has been released from regulatory control Very low level waste short-lived (VLLW-SL) – Contains small amounts of short-lived nuclides with a half-life less than 31 years, dose rate on waste package is less than 0.5 mSv/h. Long-lived nuclides with a half-life greater than 31 years can be present in restricted quantities. Low level waste short-lived (LLW-SL) – Contains small amounts of short-lived nuclides with a half-life less than 31 years, dose rate on waste package (and unshielded waste) is less than 2 mSv/h. Long-lived nuclides with a half-life greater than 31 years can be present in restricted quantities. Intermediate level waste short-lived (ILW-SL) – Contains significant amounts of short-lived nuclides with a half-life less than 31 years; dose rate on waste package is less than 500 mSv/h. Long-lived nuclides with a half-life greater than 31 years can be present in restricted quantities Low and intermediate long-lived waste (LILW-LL) – Contains significant amounts of long-lived nuclides with a half-life greater than 31 years, exceeding the restricted quantities for short-lived waste. High level waste (HLW) – (Nuclear fuel) Typical decay heat > 2 kW/m^3 and contains significant amounts of long-lived nuclides with a half-life greater than 31 years, exceeding the restricted quantities for short-lived waste.
Switzerland [A–54]	*High level waste* (HLW): Vitrified fission product waste from the reprocessing of spent fuel, or spent fuel if declared as waste. *Alpha-toxic waste* (ATA): Waste with a concentration of alpha-emitters exceeding 20,000 Bq/g of conditioned waste. *Low and intermediate level waste* (L/ILW): All other radioactive waste.
Syria [A–55]	Uses the IAEA classification system (see above).
Türkiye	Very short lived rad-waste - Their activities are above exemption levels and after a storage period of a few years at most they will be thus appropriate for clearance. No need to dispose, decay storage is the preferred option Very low level rad-waste - They are not classified as very short lived wastes and they have activity concentrations below approximately a hundred times of the clearance limits. Surface disposal is the preferred option for this class of waste.

COUNTRY [REFERENCE]	CLASSIFICATION SYSTEM
	Low and intermediate level rad-waste: • After conditioning, alpha emitting radionuclide concentrations are below 400 Bq/g for the average of whole package and below 4000 Bq/g for an individual waste package. Near surface disposal is the preferred final solution for this class of waste. • After conditioning, alpha emitting radionuclide concentrations are above 400 Bq/g for the average of whole package and above 4000 Bq/g for an individual waste package. Intermediate depth disposal is the preferred final solution for this class of waste. High level waste - They are spent fuels declared as radioactive waste, radioactive wastes which are products of reprocessing and may include fission products and actinides, and other radioactive wastes with comparable activity levels with those above. Deep geological disposal is final solution for this class of waste.
United Arab Emirates [A-56]	Uses the IAEA classification system (see above).
United Kingdom [A-57]	**High-level waste** High-level waste (HLW) is typically the Highly Active Liquor (HAL) by-product from the reprocessing of spent fuel, is sufficiently radioactive that it generates a significant amount of heat (typically thermal power above about 2kW/m^3) which has to be taken into account for its storage and disposal. waste in which temperature may rise significantly as a result of its radioactivity, so that this factor has to be taken into account in designing storage or disposal facilities. **Intermediate-level waste** Intermediate-level waste (ILW) is waste with radioactivity levels exceeding the upper boundaries for low-level waste (LLW), but which does not require heating to be taken into account in the design of storage or disposal facilities. **Low-level waste** radioactive waste having a radioactive content not exceeding 4 (GBq/te of alpha and/or 12GBq/te of beta/gamma activity. **Very-low-level waste** Very Low Level Waste (VLLW), a sub-category of LLW is defined as: which can be safely disposed of alongside municipal, commercial or industrial waste, or at permitted landfill facilities, subject to defined limits on radioactivity content (defined in the specific waste acceptance criteria for each landfill facility).
United States of America [A-58]	The United States of America has two waste classification systems: one for 'civilian' wastes and the other for DOE (defense related) wastes. For civilian wastes, the categories are based on suitability for near surface disposal: *Low Level Waste* (LLW) is defined in regulation based on suitability for near surface disposal through consideration of concentrations of long and short-lived radionuclides. See 10 CFR 61 [USNRC 1982] for full definitions. It is subdivided into: *Class A low level waste* is determined by characteristics listed in 10 CFR 61.55 and physical form requirements in 10 CFR 61.56. (The US does not have a minimum threshold for Class A waste). *Class B low level waste* is waste that must meet more rigorous requirements on waste form than Class A waste to ensure stability. *Class C low level waste* is waste that not only must meet more rigorous requirements on waste form than Class B waste to ensure stability but also requires additional measures at the disposal facility to protect against inadvertent intrusion.

COUNTRY [REFERENCE]	CLASSIFICATION SYSTEM
	Greater than Class C waste (GTCC) is waste that exceeds the limits for Class C waste and is not generally acceptable for near surface disposal. *High level waste* (HLW): The highly radioactive material resulting from reprocessing of spent fuel, including liquid waste generated directly in reprocessing and any solid material derived from such liquid waste containing fission products in sufficient concentrations and other highly radioactive material that the NRC, consistent with existing law, determines by rule requires permanent isolation. *Spent fuel* (SF) is fuel that has been withdrawn from a nuclear reactor following irradiation, the constituent elements of which have not been separated by reprocessing. For civilian applications, this is considered to be a waste. *Byproduct material* (uranium mill tailings), tailings or wastes generated by the extraction or concentration of uranium or thorium from any ore processed primarily for its source material content. (Also referred to as AEA 11(e)2 waste.) The DOE classifies wastes as: *Low level waste (LLW)*:radioactive waste other than HLW, TRU and byproduct material. *High level waste* (HLW): (similar to civilian definition). *Transuranic waste* (TRU): US DOE owned waste (mostly defense related) contaminated with man made radioisotopes beyond or 'heavier' than uranium on the periodic table of the elements (long lived alpha emitting waste with concentrations greater than 3700 Bq/g [100 nCi/g]). Subdivided into: a) *Contact handled* TRU (CH): TRU waste with a surface dose rate of less than 200 millirem per hour b) *Remote handled* TRU (RH): TRU waste with a surface dose rate of 200 millirem per hour or greater *Byproduct material:* (similar to civilian definition). *Spent fuel*: The DOE does not consider spent fuel to be a waste.
Ukraine [A-59]	*Low-level waste* – material with the special activities between 10 kBq/kg and 10 MBq/kg *Intermediate-level waste* - material with the special activities between 10 MBq/kg and 100 GBq/kg *High-level waste* – materials with the special activities over 100 GBq/kg
Uzbekistan [A-60]	Uses the IAEA classification system (see below).
Viet Nam [A-61]	*Low level waste, very short-lived (LLW-VSL)* – waste contains only very short-lived radionuclides (their half-life is shorter than 100 days) and can decay to the level lower than clearance levels within 5 years from generation *Low and intermediate level waste, short-lived (LILW-SL)* – radioactive waste can not decay to the level lower than clearance levels within 5 years from generation and contains radionuclides emitting beta/gamma with half-life from 100 days to 30 years or contains radionuclides emitting alpha with average activity concentration equal to or lower than 400 Bq/g *Low and intermediate level waste, long lived (LILW-LL)* – radioactive waste contains radionuclides having half-life longer than 30 years or contains radionuclides emitting alpha with average activity concentration higher that 400 Bq/g but activity concentration equal to or lower than 10^4 TBq/m^3 *High level waste (HLW)* – radioactive waste contains radionuclides with activity concentration higher than 10^4 TBq/m^3

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ANNEX 2. STATUS OF NATIONAL LONG TERM MANAGEMENT POLICIES

Country	Non-Nuclear Fuel Cycle Waste	Disused Sealed Sources	Nuclear Fuel Cycle Waste	SF
Albania	Storage	Return to supplier or storage.	N/A	N/A
Argentina	Disposal in existing and planned LLW disposal facilities. ILW is planned to be disposed in DGR	Storage awaiting disposal	Disposal in existing and planned LLW disposal facilities. ILW stored and will be disposed in planned DGR	Reprocessing decision deferred, a tentative schedule for disposal with be established together with strategic plan
Armenia	Planned disposal of VLLW and LLW is near surface disposal facility and for ILW and HLW DGR	Storage.	Planned disposal of VLLW and LLW is near surface disposal facility and for ILW and HLW DGR	Dry storage
Australia	Planned disposal for facilities for LLW and ILW	Return to supplier where possible or storage awaiting disposal.	N/A	RR sent for reprocessing, the resulting ILW stored awaiting disposal.
Austria	Storage awaiting disposal	Return to supplier or storage	N/A	Return of RR fuel to country of origin.
Belarus	Long term storage and then disposal in planned disposal facility for VLLW, LLW	Return to supplier or long-term storage	For VLLW and LLW the same management as for Application Waste. For ILW and HLW disposal in deep geological formations after long term storage	Return to Russian Federation for processing
Belgium	Currently stored. LLW is planned to be disposed in near surface facility	Return to supplier or storage.	Currently stored at central facility. Near surface disposal planned for LLW in Dessel and geological dispslal still to be confirmed.	Long term policy still to be defined – disposal of waste from reprocessing or direct disposal
Bosnia and Herzegovina	Storage	Return to the supplier	N/A	N/A
Botswana	Storage	Return to the supplier.	N/A	N/A

Country	Non-Nuclear Fuel Cycle Waste	Disused Sealed Sources	Nuclear Fuel Cycle Waste	SF
Brazil	Storage awaiting disposal	Return to supplier or storage.	Not defined	No decision. Current policy is storage at reactor site pending for decision.
Bulgaria	Disposal. Near surface disposal facility for LLW in construction. For ILW and HLW the long term storage.	Returning to the supplier or disposal.	Disposal. Near surface disposal facility for LLW in construction. For ILW and HLW the long term storage.	Reprocessing abroad
Canada	Storage. Disposal facility for VLLW/LLW is in process	Return to supplier, reuse or storage.	Existing storage by each major waste owner. Disposal facility for VLLW/LLW is in process	Planned deep disposal at a volunteer host site in either crystalline or sedimentary rock.
Chile	Storage	Return to supplier or storage	N/A	Long term dry storage for SF from RR
China	Storage and disposal according to waste category	Return to supplier or storage.	Planned geological disposal for HLW and disposal of LLW in near surface disposal facilities (existing and planned)	Reprocessing of NPP SF, direct disposal of certain types of SF is not ruled out. Research reactor SF, planned deep disposal colocated with HLW.
Croatia	Long term storage followed by disposal	Return to supplier or storage	Long term storage followed by near surface disposal	Dry storage followed by disposal
Cuba	Storage	Return to supplier or storage	N/A	N/A
Cyprus	Decay storage	Return to the supplier	N/A	N/A
Czech Republic	Disposal in operating disposal facilities and in planned DGR.	Disused sealed sources are disposed in operating disposal facilities and in planned DGR or returned to the country of origin.	Existing surface disposal (at Dukovany power plant site) Disposal in operating disposal facilities and in planned DGR.	Direct disposal in DGR is preferred option, but other options are not excluded.
Denmark	Storage awaiting disposal	Return to supplier or storage	N/A	Dual track – either disposal in Denmark or international solution
Estonia	Storage awaiting disposal	Return to supplier or storage awaiting disposal.	N/A	N/A

Country	Non-Nuclear Fuel Cycle Waste	Disused Sealed Sources	Nuclear Fuel Cycle Waste	SF
Finland	Disposal in silos	Return to supplier or disposal	Disposal in intermediate depth bedrock, existing underground cavern disposal (at each reactor site)	Disposal in bedrock. Construction of the encapsulation plant and the disposal facility started in 2016.
France	Existing disposal options for VLLW and LLW	Return to supplier. Disposal or recycling routes being implemented.	Existing disposal options for VLLW and LLW. Storage for the other waste	Reprocessing then disposal of resulting waste
Georgia	Storage awaiting disposal	Storage awaiting disposal	N/A	N/A
Germany	Storage awaiting disposal	Return to supplier or storage awaiting disposal .	Storage with the objective of disposal in deep geological formations	Planned deep disposal for NPP SF, site not yet decided For research reactor fuels, return to country of origin, or manage with NPP fuel.
Ghana	Return to supplier or storage at Centralized Waste Processing Facility	Return to supplier or storage.	N/A	N/A
Greece	Stored in RW Interim Storage and Management Facility until final management solution	Return to supplier	N/A	N/A
Hungary	Disposal in existing near surface repository at Püspökszilágy or Deep Geological disposal facility	Disposal	Disposal at the National Radioactive Waste Repository in Bátaapáti, or deep geological disposal	Deep geological disposal for SF from NPP. For RR SF repatriation to the manufacturer's country
Iceland	Return to supplier	Return to supplier	N/A	N/A
Indonesia	Returned to supplier of managed by Radioactive Waste Technology Centre	Return to supplier or storage.	Stored until possible disposal	Return of RR fuel to the country of origin
Iran, Islamic Republic of	Treatment and storage	Storage and reuse	Storage until possible disposal	N/A

Country	Non-Nuclear Fuel Cycle Waste	Disused Sealed Sources	Nuclear Fuel Cycle Waste	SF
Ireland	Storage	Return to supplier or overseas for recycling/reuse.	N/A	N/A
Italy	Central storage. Planned national LLW and ILW near surface disposal facility	Return to supplier or storage	Planned VLLW/LLW near surface disposal facility and storage facility for ILW/HLW	Reprocessing abroad, long term storage of remaining SF
Japan	Near surface disposal	Return to supplier or storage.	Planned geological disposal, intermediate depth disposal and near surface disposal. There are existing LLW disposal facilities.	Reprocessing.
Jordan	Long term storage until disposal in near surface LILW disposal site	Return to the supplier if possible or storage.	Long term storage	Return to country of origin
Kazakhstan	Long term storage	Storage	Long term storage	Long term storage
Korea, Republic of	Engineered shallow land disposal facility is under review	Storage or disposal	Engineered shallow land disposal facility is under review	On site storage until operation of an interim storage facility and development of HLW disposal facility
Latvia	Disposal of LLW and storage of ILW	Return to supplier or storage pending disposal.	N/A	N/A
Lithuania	Storage awaiting disposal.	Return to supplier or storage.	Storage awaiting disposal.	Stored for 50 years. Disposal in planned in deep geology
Luxembourg	Export to Belgium	Return to supplier or export to Belgium	N/A	N/A
Madagascar	Storage	Storage	N/A	N/A
Malta	Export when possible or storage	Return to supplier or storage	N/A	N/A
Mexico	Storage awaiting disposal	Return to supplier or storage	Storage awaiting disposal	Disposal in planned DGR for both NPP and RR SF

Country	Non-Nuclear Fuel Cycle Waste	Disused Sealed Sources	Nuclear Fuel Cycle Waste	SF
Montenegro	Storage	Return to supplier or storage	N/A	N/A
Morocco	Storage	Return to supplier or storage	N/A	Wet storage
Netherlands	Storage (at COVRA) followed by future free release or disposal	Return to supplier or storage	Existing 100 year storage (at COVRA), followed by planned deep disposal for all waste types in a single facility	Reprocessing Existing 100 year storage (at COVRA), followed by planned deep disposal for all waste types in a single facility.
Nigeria	Storage	Return to supplier or storage.	Planned front end activities	Return of SF from RR to supplier or storage
North Macedonia		Return to supplier or storage	N/A	N/A
Norway	Disposal of LLW at KLDRA Himdalen	Return to supplier or disposal	Disposal of LLW at KLDRA Himdalen. New facility needed for higher activity waste	RR is currently stored and ongoing assessment for management options
Oman	Storage	Return to supplier	N/A	N/A
Peru	Storage	Return to supplier or storage	Stored until possible to send to the Radioactive Waste Management Plant	Storage in spent fuel pool at RR site until repatriation to the supplier is possible
Poland	Disposal in Rozan Repository or in planned near surface repository.	Return to supplier or disposal	Disposal in planned near surface repository and in planned DGR	RR spent fuel is transported to the country of origin
Portugal	Storage	Return to supplier or storage	N/A	RR SF returned to USA
Republic of Moldova	Storage until possible disposal	Return to supplier or storage pending disposal.	N/A	N/A
Romania	Near surface disposal for short lived waste in construction. Long lived waste will be disposed in DGR.	Return to supplier or storage	Near surface disposal for short lived waste in construction. Long lived waste will be disposed in DGR.	Storage and then disposal in planned DGR. Return to the supplier in case of SF of RR.

Country	Non-Nuclear Fuel Cycle Waste	Disused Sealed Sources	Nuclear Fuel Cycle Waste	SF
Russian Federation	Processing and storage awaiting disposal	Treatment and disposal	Processing and transfer for disposal. There are near surface facilities for LLW and ILW	Storage and reprocessing
Saudi Arabia	Site is chosen for central waste management facility	Return to supplier or storage	N/A	N/A
Senegal	Storage	Return to supplier	N/A	N/A
Serbia	Storage awaiting disposal	Return to supplier or storage	N/A	N/A
Slovakia	Disposal in existing (Mochovce site) and planned disposal facility	Return to supplier or storage	Existing surface disposal at Mochovce.	Long term wet and dry storage. Looking at geological repository or multinational solution.
Slovenia	Central Storage and then disposal	Return to supplier or storage	Planned near surface and deep geological disposal facilities	Geological disposal is reference scenario; however the multinational option is kept open.
South Africa	Existing near surface disposal at Vaalputs. Possible medium depth disposal facility for long lived waste	Return to supplier or storage	Existing near surface disposal at Vaalputs. Possible medium depth disposal facility for long lived waste	Long term storage with possible reprocessing or disposal in DGR.
Spain	Existing surface disposal (at El Cabril) for VLLW and LLW	Return to supplier or storage	Existing surface disposal (at El Cabril) for VLLW and LLW. Waste from SF reprocessing will be disposed together with SF.	Storage for 60 years at Centralized Storage or upgraded storage facilities until DGR is available.
Sweden	Disposal in Nuclear Fuel Cycle facilities when appropriate	Return to supplier or stored/disposed	Existing LLW disposal facility, planned long lived waste disposal facility, as well as geological disposal.	Planned DGR at Forsmark site.
Switzerland	Disposal in planned deep geological repository for L/ILW	Recycling if possible, otherwise management as radioactive waste	Planned deep disposal in DGR, colocated repository for long lived wastes and HLW.	Deep geological disposal in planned DGR. Ban on reprocessing.

Country	Non-Nuclear Fuel Cycle Waste	Disused Sealed Sources	Nuclear Fuel Cycle Waste	SF
Syria	Storage awaiting disposal	Return to supplier or storage	N/A	N/A
Thailand	Storage	Return to supplier or storage	N/A	Return of RR SF to country of origin
Türkiye	Storage	Return to supplier or storage	Storage and disposal	Long term storage at NPP site
Ukraine	Storage and Disposal in Vektor site	Return to supplier or storage	Storage and Disposal in Vektor site	Awaiting decision, centralized storage
United Arab Emirates	Storage	Return to the supplier	Disposal in planned near surface repository for LLW or geological disposal facility for ILW and HLW	Reference scenario is disposal in DGR, other options are still under review.
United Kingdom	Existing surface disposal (at LLWR&Dounreay) Conventional surface land fill facilities for management of VLLW. Other facilities may be developed if required .	Return to supplier or storage	Existing surface disposal (at LLWR&Dounreay) Other facilities may be developed if required.	Disposal of the SF in DGR.
United States of America	For LLW near surface disposal. For ILW the disposal path to be determined	Return to supplier. Disposal, reuse or recycle.	For HLW disposal in geological repository. For LLW near surface disposal.	Disposal in geological repository after storage in wet or dry storages.
Uruguay	Return to the producer or storage	Return to supplier or storage	N/A	N/A
Uzbekistan	Storage	Return to supplier or storage	Storage	Return of SF from RR to supplier
Viet Nam	Central Storage awaiting disposal	Return to supplier or storage	Central storage awaiting disposal	Return of SF from RR to supplier
Zimbabwe	Storage	Return to the supplier	N/A	N/A

ANNEX 3. NATURE AND ROLE OF THE WASTE MANAGEMENT ORGANIZATION (AS OF 31 DECEMBER 2019)

Country	Waste Management Organisation (WMO)	Responsibilities	Ownership
Albania	Institute of Applied Nuclear Physics	Management and storage of and radioactive waste	State
Argentina	National Radioactive Waste Management Program - Argentine Atomic Energy Commission (PNGRR - CNEA)	Management of radioactive waste and surveillance of spent fuel	State
Armenia	No specified WMO		
Australia	Australian Radioactive Waste Agency (ARWA)	Management of radioactive waste	State
Austria	Nuclear Engineering Seibersdorf GmBH (NES)	Predisposal management of radioactive waste	State
Azerbaijan	Specialized Enterprise 'Isotope'	Management of radioactive waste	State
Belarus	Specialized Enterprise UE Ekores	Management of radioactive waste	State
Belgium	ONDRAF/NIRAS	Development and operation of disposal facilities for all types of radioactive waste and spent fuel.	State
Bolivia	Bolivian Nuclear Energy Agency (ABEN)	Management of radioactive waste	State
Bosnia and Herzegovina	No specified WMO		
Bulgaria	State Enterprise Radioactive Wastes (SE RAW)	Management of radioactive waste	State
Canada	Nuclear Waste Management Organization (NWMO)	Development and operation of disposal facility for spent fuel	Utility
	Low Level Radioactive Waste Management Office (LLRWMO)	Cleanup and management of Canada's historic waste.	State/Private
	(other waste owners)	Management and disposal of their own wastes	Utility/State/Private
Chile	Chilean Nuclear Energy Commission	Management of radioactive waste	State

Country	Waste Management Organisation (WMO)	Responsibilities	Ownership
China	No specified WMO		
Croatia	Fund for the Financing of the Decommissioning and Disposal of Radioactive Waste and Spent Nuclear Fuel from the Krško Nuclear Power Plant	Management of radioactive waste	State
Cuba	Centre for Radiation Protection and Hygiene (CPHR).	Management of radioactive waste	State
Cyprus	No specified WMO		
Czech Republic	SÚRAO	Development and operation of radioactive waste and spent fuel storage and disposal facilities	State
Denmark	Danish Decommissioning	Management of all radioactive waste	State
Estonia	A.L.A.R.A. Ltd.	Management of all radioactive waste	State
Finland	Posiva Oy	Development and operation of disposal facility for spent fuel. Low level waste disposal is the direct responsibility of the NPPs.	Utilities
France	ANDRA	Development and operation of disposal facilities for all types of radioactive waste.	State
Georgia	Department for Radioactive Waste Management	Management of radioactive waste	State
Germany	BGZ	Predisposal management of radioactive waste	State
	BGE	Disposal of radioactive waste	State
Ghana	Radioactive Waste Management Centre (RWMC)	Management of radioactive waste	State
Greece	National Centre of Scientific Research 'Demokritos"	Management of radioactive waste	State
Hungary	PURAM	Development and operation of storage and disposal facilities for all types of radioactive waste and spent fuel and decommissioning of nuclear facilities.	State
Iceland	No specified WMO		

Country	Waste Management Organisation (WMO)	Responsibilities	Ownership
Indonesia	National Nuclear Energy Agency (BATAN)	Management of spent fuel and radioactive waste	State
Iran, Islamic Republic of	Iran Radioactive Waste Management Company (IRWA)	Management of radioactive waste	State
Ireland	No specified WMO		
Italy	SOGIN	Decommissioning of nuclear facilities and management of radioactive waste	State
Japan	Nuclear Waste Management Organization (NUMO)	Development and operation of disposal facility for HLW	State
Jordan	Jordan Atomic Energy Commission (JAEC)	Management of spent fuel and radioactive waste	State
Korea, Republic of	Korea Radioactive Waste Management Corporation (KORAD)	Development and operation of storage and disposal facilities for all types of radioactive waste and spent fuel, and management of radioactive waste management fund	State
Latvia	State Ltd 'Latvian Environment, Geology and Meteorology Centre'	Management of all radioactive waste	State
Lithuania	Ignalina NPP	Management of radioactive waste and spent fuel	State
Luxembourg	No specified WMO		
Malaysia	Nuclear Malaysia	Management of radioactive waste	State
Mexico	National Institute of Nuclear Research (ININ)	Management of radioactive waste	State
	Laguna Verde NPP	Management of radioactive waste and spent fuel	State
Moldova	Radioactive Waste Storage Facility (RWSF)	Storage of radioactive waste	State
Morocco	National Centre for Nuclear Energy, Science and Technology (CNESTEN)	Management of radioactive waste	State
Netherlands	COVRA	Management of radioactive waste	State
North Macedonia	No specified WMO		
Norway	Norwegian Nuclear Decommissioning (NND)	Decommissioning and management of radioactive waste	State

Country	Waste Management Organisation (WMO)	Responsibilities	Ownership
Paraguay	No specified WMO		
Peru	RASCO Nuclear Centre	Management of radioactive waste	State
Poland	Radioactive Waste Management Plant (ZUOP)	Management of radioactive waste and spent fuel	State
Portugal	School of Engineering of the University of Lisbon (IST)	Management of radioactive waste	State
Romania	Nuclear and Radioactive Waste Agency (ANDR)	Development and operation of disposal facilities for all types of radioactive waste and spent fuel.	State
Russian Federation	Federal State Unitary Enterprise National Operator for Radioactive Waste Management (NO RAO)	Development and operation of disposal facilities all types of radioactive waste. Predisposal management is distributed among several organisations as FSUE RosRAO, Moscow Radon, etc.)	State
Saudi Arabia	King Abdullah City for Atomic and Renewable Energy	Management of radioactive waste	State
Serbia	Public Company Nuclear Facilities of Serbia	Management of radioactive waste	State
Slovakia	Nuclear Decommissioning Company (JAVYS)	Development and operation of storage and disposal facilities for all types of radioactive waste and spent fuel, operation of centralised waste processing facilities, and decommissioning of nuclear facilities.	State
Slovenia	Agency for Radwaste Management (ARAO)	Development and operation of storage and disposal facilities for all types of radioactive waste and spent fuel.	State
South Africa	National Radioactive Waste Disposal Institute (NRWDI)	Management of radioactive waste and spent fuel.	State
Spain	ENRESA	Development and operation of storage and disposal facilities for all types of radioactive waste and spent fuel. Decommissioning of reactors.	State
Sweden	SKB	Development and operation of storage and disposal facilities for all types of radioactive waste and spent fuel.	Utilities
Türkiye	TENMAK	Management of radioactive waste	State
Ukraine	SA Radon	Management of radioactive waste	State

Country	Waste Management Organisation (WMO)	Responsibilities	Ownership
United Kingdom	NDA	Overseeing strategic management of radioactive waste and spent fuel including waste from historic operations	State
United States of America	DOE	Development and operation of disposal facilities for all spent fuel, certain ILW (greater than class C LLW), and DOE owned or generated radioactive waste.	State
	States/Compacts	Responsible for disposal of LLW (disposal occurs at commercially operated facilities)	
Viet Nam	No specified WMO		

ANNEX 4. FINANCING SCHEMES AND FUNDING MECHANISMS FOR SPENT FUEL AND RADIOACTIVE WASTE

Country	Funding of RWM	Funding of SF and HLW management	Funding of decommissioning
Albania	Producers pay for RWM	N/A	N/A
Argentina	Producers pay for RWM. Governmental funding if produced in the State owned facility.	Governmental funding	Governmental funding when the facility is state-owned, otherwise the Owner of facility.
Armenia	Producers pay for RWM in case of waste from NPP, governmental funding for other institutional waste	Facility funding	Decommissioning fund
Australia	Governmental funding	Governmental funding	Governmental funding
Austria	Producers pay for RWM and Governmental funding	Governmental funding	Governmental funding
Belarus	Operator’s financial assets or state budget	Operator’s financial assets	Operator’s financial assets or state budget
Belgium	Producer pays, contribution to ONDRAF/NIRAS long-term fund.	NPP operators contribute to the fund	NPP operators contribute to the fund; various funds for historical liabilities fed by state;
Bosnia and Herzegovina	Producer pays or Governmental funding	N/A	Licensee funding
Botswana	Producer pays or Governmental funding	N/A	N/A
Brazil	Operator or Governmental funding	Operator (Governmental) funding	Operator (Governmental) funding
Bulgaria	Payments to Radioactive Waste Fund	Operators payments to Radioactive Waste Fund and international contributors	Operators payments to Nuclear Facilities Decommissioning Fund and international contributors
Canada	Producers pay for RWM	Each licensee has to create its fund	Each licensee has to create its fund
Chile	Producers pay for RWM	Governmental funding	Governmental funding
China	Producers pay for RWM	Collection of the funds into a dedicated account based the electricity production.	Provided by the generator and the related government
Croatia	Producers pay for RWM	The ‘Fund for Financing the Decommissioning of the Krsko Nuclear Power Plant and the Disposal of	The ‘Fund for Financing the Decommissioning of the Krsko Nuclear Power Plant and the Disposal of

Country	Funding of RWM	Funding of SF and HLW management	Funding of decommissioning
		Radioactive Waste and Spent Nuclear Fuel’	Radioactive Waste and Spent Nuclear Fuel’
Cuba	Producers pay for RWM	N/A	Producers responsibility
Cyprus	Producers pay for RWM	N/A	N/A
Czech Republic	Producers pay for RWM to specific fund by Government	Specific fund by licence holders held by Government	Decommissioning fund
Denmark	Producers pay for RWM	Governmental funding	Governmental funding
Estonia	Producers pay for RWM	The state carries the financial liability	Governmental funding
Finland	Producers pay for RWM	Nuclear Waste Management Fund	Nuclear Waste Management Fund
France	Producers pay for RWM.	The licensee finances and dedicated assets are required.	The licensee finances and dedicated assets are required.
Georgia	Producers pay for RWM. In case of legacy waste founded by state.	N/A	Governmental funding
Germany	Producers pay for RWM: Private facilities setting aside provisions. State owned facilities financed by public funds. Small waste producers pay fees to the Land collecting facilities.	Private facilities setting aside provisions. State owned facilities financed by public funds.	Private facilities setting aside provisions. State owned facilities financed by public funds.
Ghana	Producers pay for RWM	Governmental funding	Producers responsibility
Greece	Producers pay for RWM	N/A	Licensee, Governmental funding
Hungary	Central Nuclear Financial Fund	Central Nuclear Financial Fund	Central Nuclear Financial Fund
Iceland	Producers pay for RWM	N/A	N/A
Indonesia	Producers pay for RWM	Producers responsibility	Producers responsibility
Ireland	Producers pay for RWM	N/A	N/A
Italy	Producers pay for RWM	Partly funds set aside by NPP, but due to early shut down, these are insufficient. Additionally, levy on electricity	Governmental funding
Japan	Producers pay for RWM	Licensees pay into the Reserve fund	Licensees pay into the Reserve fund

Country	Funding of RWM	Funding of SF and HLW management	Funding of decommissioning
Jordan	Producers pay for RWM	The state carries the financial liability	Governmental funding
Kazakhstan	Producers pay for RWM	Governmental funding and international donors	Governmental funding and international donors
Korea, Republic of	Producers pay for RWM	Radioactive Waste Management Fund operated by Government (KORAD)	Decommissioning cost of NPPs is accumulated by Korea Hydro & Nuclear Power Co. and for research reactors by the government.
Latvia	Producers pay for RW predisposal management, State pays for disposal	N/A	Governmental funding
Lithuania	Producers pay for RWM	Funds provided by NPP, State and international contributors	Funds provided by NPP, State and international contributors
Lesotho	Producers pay for RWM	N/A	N/A
Luxembourg	Producers pay for RWM	N/A	N/A
Madagascar	N/A	N/A	N/A
Malaysia	Producers pay for RWM	Producers responsibility	Producers responsibility
Malta	Producers pay for RWM	N/A	N/A
Mexico	Producers pay for RWM, governmental funding	Producers responsibility, Governmental funding	Producers responsibility
Morocco	Producers pay for RWM	N/A	Governmental funding
Netherlands	Producers pay for RWM	Producers fund the processing and long term management	Producers responsibility
Nigeria	Producers pay for RWM	Producers responsibility	Producers responsibility
North Macedonia	Producers pay for RWM	N/A	N/A
Norway	Producers pay for RWM	Producers responsibility	Producers pay, partly governmental funding
Oman	Producers pay for RWM	N/A	Producers pay
Peru	Producers pay for RWM	Producer (state or private) responsibility	Producers pay
Poland	Producers pay for RWM	Decommissioning fund or State budget (in case of the research reactor)	Decommissioning fund or State budget (in case of the research reactor)

Country	Funding of RWM	Funding of SF and HLW management	Funding of decommissioning
Portugal	Producers pay for RWM, partly covered by governmental funds	Governmental funds	Governmental funds
Republic of Moldova	Producers pay for RWM	N/A	Governmental funds
Romania	Producers pay for RWM	Producer has to pay fee to Radioactive Waste Management Funds	Producer has to pay fee to Decommissioning Fund or State Budget (in case of the research reactor)
Russian Federation	Producers pay for RWM	Fund contributed to by operators and government	Fund contributed to by operators and government
Saudi Arabia	Producers pay for RWM	N/A	National fund
Senegal	Producers pay for RWM	Producers responsibility	Producers responsibility
Serbia	Producers pay for RWM or Governmental funding	Governmental funding	Governmental funding
Slovakia	Producers pay for RWM	Producers responsibility, National Nuclear Fund	National Nuclear Fund paid into by operators and State; in case of NPP V-1 contributes also EU.
Slovenia	Producers pay for RWM	Fund raised by NPP – Decommissioning Fund	Fund raised by NPP – Decommissioning Fund
South Africa	Producers pay for RWM	Producers responsibility	Owners/Waste producers pay
Spain	Producers pay for RWM	Fund from NPP operators and payments for waste management services	Fund from NPP operators and payments for waste management services
Sweden	Producers pay for RWM	Nuclear Waste Fund —collected as a fee on nuclear power production	Nuclear Waste Fund included in the fee for SF and decommissioning
Switzerland	Producers pay for RWM	Liability is with the NPP-owners, after NPP shutdown Waste Management Fund	Liability is with the NPP-owners, after NPP shutdown Decommissioning Fund
Syria	Producers pay for RWM	N/A	N/A
Thailand	Producers pay for RWM	Governmental funding	Producers responsibility
Türkiye	Producers pay for RWM	Producers have to pay fee to Radioactive Waste Management Account	Operators have to pay fee to Decommissioning Account
Ukraine	Producers pay for RWM, National RW Management Fund	National RW Management Fund	Decommissioning Fund, Governmental funding for Chernobyl NPP

Country	Funding of RWM	Funding of SF and HLW management	Funding of decommissioning
United Arab Emirates	Producers pay for RWM	Fund for NPP operators - Decommissioning Trust Fund	Fund for NPP operators - Decommissioning Trust Fund
United Kingdom	Producers pay for RWM	Producers responsibility, Governmental funding, Nuclear Liabilities Fund.	Governmental funding for Decommissioning costs for the NDA estate. Decommissioning costs for the currently existing AGR and PWR reactors will be met through the Nuclear Liabilities Fund.
United States of America	Producers pay for RWM	Private operators of facilities need to demonstrate capability to fund operational waste management. Public facilities obtain government funding. For spent fuel and HLW disposal operators have paid into a Nuclear Waste Fund (currently suspended)	For NPPs have decommissioning funds, in case of non-legacy sites producer pays.
Uruguay	Producers pay for RWM	N/A	N/A
Uzbekistan	Producers pay for RWM	Governmental funding	Governmental funding
Viet Nam	Producers pay for RWM	Producers contribute to National Radioactive Waste Management Fund to be established	Decommissioning Fund from fee on the nuclear energy

ABBREVIATIONS

DSRS	disused sealed radioactive source
Euratom	European Atomic Energy Community
EC	European Commission
EW	exempt waste
HLW	high level waste
ILW	intermediate level waste
LLW	low level waste
MOX	mixed oxide
tHM	tonnes of heavy metal
NORM	naturally occurring radioactive material
NPP	nuclear power plant
OECD/NEA	OECD Nuclear Energy Agency
OECD	Organisation for Economic Co-operation and Development
SRIS	Spent Fuel and Radioactive Waste Information System
UMM	uranium mining and milling
VLLW	very low level waste
VSLW	very short lived waste
WMO	waste management organization
WNA	World Nuclear Association

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Technical Meetings

Virtual: 21–25 February 2022

Vienna, Austria: 14–16 February 2023

Consultants Meetings

Virtual: 20–23 October 2020, 12 January–30 June 2021, 1 September-29 October 2021, 23-25 November 2021

Vienna: 22-25 February 2022, 01-03 November 2022, 14-16 February 2023