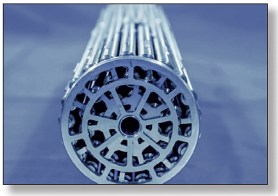
Radioactive Waste Management and Decommissioning
2020

Storage of Radioactive Waste and Spent Fuel



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Radioactive Waste Management and Decommissioning

Storage of Radioactive Waste and Spent Fuel

NEA No. 7406

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Cover photo: Spent nuclear fuel storage pool at La Hague, Cherbourg, France (Areva/Jean-Marie Taillat); Prototype fuel bundle (CNL).

Foreword

There is general consensus worldwide that geological repositories provide the necessary safety for the long-term disposal of radioactive waste, and that these depositories are feasible to construct using current technologies. Until final disposal facilities become available, however, existing radioactive waste must be managed in both a safe and secure way so that the risks posed to human health and to the environment over the long timescales involved in radioactive waste management are minimised.

In 2006, the NEA Radioactive Waste Management Committee (RWMC) issued a report on *The Roles of Storage in the Management of Long-Lived Radioactive Waste*. While interim storage remains a crucial component of the radioactive waste management strategies in many NEA member countries, in 2015 the RWMC noted gradual progress made in the development of disposal solutions for radioactive waste and decided to examine the current situation of how radioactive waste management programmes are dealing with waste in the predisposal phase (i.e. storage).

The report summarises the latest strategies and best practices in managing radioactive waste prior to final disposal. It is primarily directed at decision makers with a technical knowledge of the subject.

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List of abbreviations and acronyms

CNSC	Canadian Nuclear Safety Commission
DGR	Deep geological repository
HLW	High-level waste
IAEA	International Atomic Energy Agency
ILW	Intermediate-level waste
LLW	Low-level waste
NEA	Nuclear Energy Agency
NPP	Nuclear power plant
NRC	Nuclear Regulatory Commission (United States)
NWMO	Nuclear Waste Management Organization (Canada)
OECD	Organisation for Economic Co-operation and Development
SF	Spent fuel
SSCs	Structures, systems and components
RW	Radioactive waste
RWMC	Radioactive Waste Management Committee (NEA)
WAC	Waste acceptance criteria

Chapter 1. Background

Radioactive waste is produced from various industrial, medical radioisotope and research uses of radioactive materials. Like other hazardous waste, radioactive waste (RW) must be properly managed in order to protect humans and the environment, which means isolating or containing RW so that harmful radionuclides do not escape into the biosphere. In 2006, the NEA Radioactive Waste Management Committee (RWMC) published a report on *The Roles of Storage in the Management of Long-Lived Radioactive Waste*. In 2014, noting the absence or slow progress in the development of final geological repositories in many countries, the RWMC approved the creation of an expert group – the NEA Expert Group on Predisposal Management of Radioactive Waste (EGPMRW) to re-evaluate the current situation of predisposal RW management (NEA, 2014). The expert group focused on examining the storage and transport aspects of three types of conditioned RW generated at commercial nuclear power plants (NPPs), namely high-level waste (HLW), intermediate-level waste (ILW) and low-level waste (LLW), as well as spent fuel (SF) currently in or ready for storage.

In carrying out its work, the EGPMRW had the following aims:

- to evaluate the current challenges associated with storage of conditioned waste and SF for a few decades in view of subsequent disposal, particularly noting the potential ageing issues in relation to stored SF;
- to explore future transport requirements for stored waste (and waste packages) from storage to disposal facilities;
- to assess potential ageing issues related to SF, waste packages, storage structures and components.

The EGPMRW launched an initial survey in July 2015 to gather information on current storage RW practices and challenges of RWMC members. Fifteen responses were received and analysed by the expert group. The current report summarises the analysis results of the 2015 survey and identifies best practices for interim storage, as well as potential transport needs for future transfers of RW from storage to disposal. The report covers the current storage practices/ management strategies for HLW, ILW and LLW generated from NPPs, along with SF that may or may not be reprocessed. This radioactive waste is either in storage or will be placed in storage. Radioactive waste generated from research reactors, historic waste and medical radioisotope applications are not covered in this report, but may be considered in future publications.

The objectives of this report are:

- to summarise the national management strategies and approaches used in the long-term management of RW in NEA member countries;
- to examine the roles of storage in long-term management of RW;
- to examine the existing regulatory framework for RW storage in the NEA community;
- to evaluate the various technical aspects of storage and the potential implications of extended storage of RW;
- to summarise key, outstanding issues that require further consideration, for example in relation to storage of RW, including any foreseeable challenges of RW transport;
- to reveal societal issues that may impact the long-term management of RW.

For clarification purposes, long-term management of RW refers to the safe containment and management of RW in storage for 50 years (or longer) until final disposal. The following definitions aim to clearly define the types of RW covered in this report. Management practices for different types of waste are discussed in more detail in Chapter 3 and in Table 2.1.

Spent fuel

The spent fuel of NPPs consists of irradiated fuel bundles removed from commercial nuclear reactors. This SF is associated with penetrating radiation, which requires shielding. It contains significant quantities of long-lived radionuclides and requires long-term isolation. In this report, spent fuel includes fuel generated from NPPs, such as:

- SF that is declared as waste;
- SF that is in storage and is to be reprocessed;
- SF that is placed in storage and is awaiting a management decision.

High-level waste

High-level waste (HLW) is defined as:

- spent reactor fuel foreseen for disposal;
- waste that contains both long-lived and heat-emitting radionuclides.

Intermediate-level waste

Intermediate-level waste (ILW) contains quantities of long-lived radionuclides, but does not have self-heating properties. ILW typically exhibits sufficient levels of penetrating radiation to warrant shielding during handling and storage. Certain ILW may have heat generation implications in the short term because of its total radioactivity level.

Low-level waste

Low-level waste (LLW) is defined as waste that contains radionuclide content above clearance levels or exempted quantities. Despite its low radioactivity, LLW requires isolation and containment for periods of up to a few hundred years.

Chapter 2. Safety assurance for radioactive waste

Safety remains paramount in the management of radioactive waste (RW) and spent fuel (SF) resulting from the generation of nuclear energy. Safely managing SF and RW requires the containment of radionuclides for long time frames in order not to adversely impact human or environmental health. Most fission products remain radioactive for less than a thousand years, while radioactive decay for actinides (e.g. plutonium and neptunium) takes much longer to decay (up to millions of years). More than five decades of experience have shown that surface storage facilities can provide safe and secure containment as long as the storage facilities are appropriately designed, constructed and maintained to ensure containment integrity. Maintenance and control of storage facilities by responsible institutions for periods anticipated to be up to a century is a common practice in some countries. There are no technical reasons why such facilities could not be maintained or rebuilt, provided adequate financial resources are made available, technical expertise is maintained, conformity of the RW packages is guaranteed and the quantities of RW remain manageable in terms of size. For long-term storage (i.e. 50 years or more), therefore, the uncertainties lie in whether commitment of the necessary resources and public acceptance of RW storage can be maintained by society in the future. Ultimately, developing an acceptable RW disposal plan is the responsibility of national decision makers.

National radioactive waste management policies, strategies and regulatory framework

The 15 countries that responded to the NEA survey vary significantly in terms of their RW management policies and strategies. There is considerable variation in the definition of radioactive materials in the different countries, which is, to a large degree, a reflection of the specific type of nuclear fuel cycle in place nationally. Countries such as Canada, Sweden and the United States have adopted a "once-through" fuel cycle in which SF is disposed of without reprocessing. The United Kingdom and France have built and are still operating SF reprocessing facilities, although the United Kingdom government has decided that SF reprocessing will cease by 2020. Japan has its own reprocessing plant and has also sent SF to France and the United Kingdom for reprocessing; Russia is reprocessing some of its SF, and lastly, Belgium, Germany, the Netherlands and Switzerland have reprocessing contracts with France and the United Kingdom. The storage practices of these countries also vary; some have built independent centralised storage facilities (e.g. Sweden, Switzerland) for RW and SF, while others use on-site storage (e.g. Canada, United States, etc.); (the United States has currently halted work on a repository at the Yucca Mountain site); in some countries, both forms of storage facilities exist or are envisaged (e.g. Belgium, Korea and Spain). What is common among the national programmes of these countries is that each one of them is developing effective methods for addressing safe and responsible management of RW. Some countries such as Canada have adopted a phased approach – an approach that is based on adaptive decision making supported by public engagement and continuous learning (NWMO, 2015), while others have suspended their repository programmes until a later date, hoping advancements in knowledge will allow more informed decisions to be made. In Germany, a new site selection procedure for a disposal facility for high-level waste (HLW) was set up in 2017. Spain has also halted its repository siting programme, and similarly, in the Netherlands, all disposal projects have been formally suspended and interim storage for 100 years has been selected instead. Since repository programmes have not proceeded as they were expected to, these countries must continue their active management of RW either at centralised storage facilities or at a number of different locations (e.g. at nuclear power plants [NPPs]).

International frameworks have been established to provide safe RW management guidance to countries. The International Atomic Energy Agency (IAEA) Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, which came into force in June 2001, requires that safety is ensured in relation to the storage of nuclear waste, including transport, location, design and operation of storage facilities, through the enhancement of national measures and international co-operation. The European Council Directive 2011/70 EURATOM stipulates that responsible and safe management of SF and RW must be practised in the member states of the European Union without imposing undue burden on future generations. Specifically, Article 4 of Directive 2011/70 requires EU member states to establish and maintain national policies and strategies to achieve the defined goals and requirements.

An RW management policy is essential as it provides the basis for preparing or revising the related legislation. Management policies are generally established by the government and incorporated in the national legislative systems. RW management policies adopted by countries typically include:

- a clear definition of safety and security objectives;
- the roles and responsibilities of the involved stakeholders in the management process;
- a specification of resources provided for SF and RW management;
- the management methods of SF and RW (e.g. reprocessed SF or direct disposal);
- provisions for public information and participation.

The implementation of a policy requires a strategy that sets out the means for achieving the specified goals and requirements stated in the policy. An RW management strategy translates the declared goals and requirements into practical and operational parameters. An RW management plan is generally used to clearly specify how the national policy will be implemented. The ultimate purpose of an

RW management plan is to describe the organisational arrangements and responsibilities for the control, storage and transfer of RW from generation to RW management facilities. National RW policies should cover all waste types and different waste life cycle phases (i.e. from cradle to grave), and address public concerns during the implementation process. An RW management strategy can be established by the waste owner, the facility operator, or by a governmental organisation or a national waste management agency.

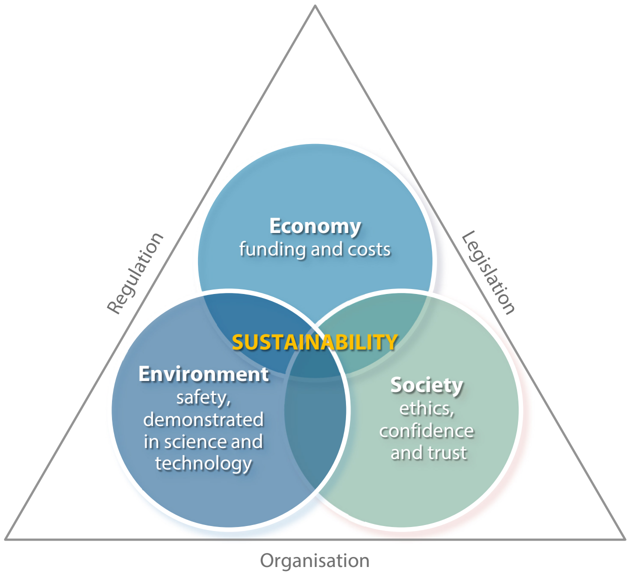
A national RW management plan in general serves the following purposes:

- to demonstrate compliance with regulatory requirements, national RW management policies and strategies;
- to show consistency with applicable national and international standards of RW management;
- to illustrate the interdependencies of all steps in the RW management cycle.

International guidance and directives for developing an RW management plan are available (e.g. IAEA NW-G1.1 and EC Council Directive 2011/70 EURATOM). The maintenance of an up-to-date management plan is especially important as waste processing and/or storage arrangements may change as a result of new regulatory requirements and relevant standards. The plan should therefore be a living document and subject to review when new information arises. In practice, this requires that changes in design, equipment, storage conditions, RW or SF characteristics, quality assurance, record management and any overall management arrangements should be assessed to ensure the modification will not adversely impact the operability or safety of the associated RW management facilities. In addition, in developing the national plan, all involved RW parties and organisations should analyse the available management options and provide the reasons for the selected management methods. RW management plans now tend to be produced in a proportionate way (sometimes referred to as the "graded approach") in which the management method is selected or designed based on the magnitude of the hazard posed by the RW and/or the complexity of the operations involved. To verify that they are complete and address all relevant aspects, many RW management plans undergo appropriate peer reviews and independent assessment to confirm that the management methods and data used are "fit for purpose". Periodically, the national plan should be subject to a sensitivity check.

Many RW management programmes are now using a holistic, sustainable approach to ensure their RW management activities are planned and carried out in a systematic manner. The concept of sustainable development, as depicted in Figure 2.1, essentially comprises three constituents: i) environment, wherein RW management should demonstrate safety through science and technology; ii) economics, in which sufficient funding and cost optimisation should be ensured; and iii) society, where ethical aspects as well as social trust and confidence are built into all activities of waste management. It is a concept that goes beyond environmental protection. By applying a holistic, sustainable management approach, RW management options are not measured only against the technical criteria, but also the predominant values held by society, as well as the financial health of managing RW.

Figure 2.1. **A concept of sustainable development**



Source: Based on three pillars of sustainable development from Table 3 in *Prototype Global Sustainable Development Report* (United Nations, 2014).

Changes in national policies and strategies since 2006

Table 2.1 shows the different policies and strategies adopted in NEA member countries for the management of SF and RW considered in this report. Despite the differences in national policies and strategies, common RW management principles and goals set the stage for managing RW in a safe, comprehensive, environmentally sound and cost-effective manner through institutional and financial arrangements. The ways in which a country develops its national RW management strategies and policies often depend upon the safety requirements, the cost effectiveness in managing national liabilities and resources, and societal influences. In determining the acceptable level of safety requirements, many countries have followed the fundamental safety principles as those stipulated in the IAEA Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management. Ultimately, any chosen strategy has to be economically viable to achieve an acceptable level of safety and to adequately address the relevant ethical issues. In NEA member countries, it is a common practice that governments are responsible for developing policy and regulating and overseeing RW producers and owners so that they meet their operational and funding responsibilities in accordance with approved long-term RW management plans, whereas waste owners are responsible for funding (in accordance with the "polluter pays" principle), organising, managing and operating long-term RW management facilities.

Table 2.1. **National policies and strategies for SF and RW management in selected NEA member countries**

Country	National policies	Storage situation	Strategy change since 2006
Australia	· Reprocess SF from research reactors, except the US origin fuel. SF to be returned to supplier. · Near-surface disposal for low-level waste (LLW), short-lived intermediate-level waste (ILW). · Above-ground storage for long-lived ILW (i.e. waste arising from the reprocessing of the non-US SF).	· Storage facilities for SF and operational waste available. · Spent fuel at the Open Pool Australian Lightwater (OPAL) research reactor is in wet storage pending overseas reprocessing. · Reprocessed spent fuel from the obsolete High Flux Australian Reactor (HIFAR) is in above-ground interim storage. · Short-lived ILW and LLW is stored at the point of generation or in central stores within each state jurisdiction. · Western Australia LLW disposal at state near-surface disposal facility.	· N/A
Belgium	· Direct disposal of SF (reprocessing earlier). · Near surface for LLW. · DGR for ILW, HLW and SF.	· LLW/ILW stored at Dessel. · SF stored on-site at NPP. · Vitrified HLW stored at Dessel.	· N/A
Canada	· National policy – Waste owners responsible for the funding, organisation, management and operation of facilities to safely manage their waste over the short and long term. (*Radioactive Waste Policy Framework,* 1996) · SF – Direct disposal and national approach for the long-term management of SF. Nuclear Waste Fuel Act outlines process and implementation. The Nuclear Waste Management Organization (NWMO) implementing the adaptive phased management approach – a DGR for long-term management of Canada's SF. · Ontario Power Generation planning a DGR for long-term management of its LLW and ILW. · Canadian Nuclear Laboratories proposing to construct a near-surface disposal facility at Chalk River Laboratories for Atomic Energy of Canada Limited's LLW.	Spent fuel: Interim management: · SF held in interim storage in wet or dry storage facilities located at the waste owners' site. · SF from research reactors is either returned to the fuel supplier or transferred to Canadian Nuclear Laboratories Chalk River Laboratories for storage. · Interim dry storage facilities are constructed as needed. Radioactive Waste: interim management: · Managed by licensee (on-site or at a dedicated waste management facility). · Managed in situ/above-ground mounds. · Managed in near-surface facilities adjacent to the mines and mills. · Waste from small generators transferred to licensed waste management facilities for management.	· Canadian Nuclear Laboratories' proposal for a near-surface disposal facility.

Table 2.1. **National policies and strategies for SF and RW management in selected NEA member countries** *(cont'd)*

Country	National policies	Storage situation	Strategy change since 2006
Czech Republic	· Direct disposal of SF. · DGR for SF/HLW. · Intermediate depth disposal for LLW and ILW (Dukovany, Richard, Bratrstvi).	· SF stored at NPP and at Dukovany. · SF from research reactor stored at Rez.	· N/A
Finland	· Direct disposal of SF. · Near-surface disposal for LLW and ILW (Olkiluoto and Loviisa). · DGR for SF and HLW (Olkiluoto).	· SF from NPP in ~20-40 year wet storage (Loviisa and Olkiluoto). · SF from research reactors to be returned to the United States.	· New SF needs a longer cooling period.
France	· Reprocessing HLW and long-lived-ILW to be disposed of in DGR after storage: Cigéo Project. · Surface disposal under operation for short-lived ILW (Aube/Manche previously). · Siting activities and conceptual design studies of shallow disposal for long-lived LLW.	· Commercial SF stored in NPP pools, and later in La Hague pools pending reprocessing. · ILW and HLW stored in surface centralised facilities at production sites. · Research and defence SF stored in CASCAD dry facility (Cadarache).	· New storage facilities are being planned to ensure the provision of all necessary resources is in place complementary to disposal.
Germany	· Vitrified HLW from reprocessed SF in the past (in United Kingdom and France) is stored in surface facilities at Gorleben and Ahaus. · DGR for LLW and ILW (Konrad) and HLW (site to be determined).	· SF interim storage at NPP.	· New siting procedure for HLW disposal facility.
Hungary	· Undecided on reprocessing of SF. · DGR for short-lived LLW and ILW (Bátaapáti, Püspökszilágy). · DGR for long-lived LLW and ILW, HLW from NPP, SF/long-lived LLW and ILW/HLW from research reactors.	· SF interim storage (Paks).	· No significant changes for storage since 2006.
Italy	· Reprocess SF (in France and United Kingdom).	· NPP RW stored on-site. · Institutional RW stored at national collection centre. · SF from research reactor in wet storage (ITREC), to be dry stored in future. · Vitrified HLW to be stored in a LT (unlimited duration) centralised storage facility which requires regular update of safety case and surveillance programme to address ageing issues.	· Extended storage due to delayed operations of a DGR. · Also implemented a 50-year storage requirement for storage packages.

Table 2.1. **National policies and strategies for SF and RW management in selected NEA member countries** *(cont'd)*

Country	National policies	Storage situation	Strategy change since 2006
Japan	· Reprocess SF. · DGR for HLW and transuranic waste; subsurface disposal for L-1 LLW, near-surface disposal for L-2 LLW (pits), L-3 LLW (trenches). Note: L1, L2 and L3 LLW are defined as "relatively HLW", "relatively LLW", and "very LLW", respectively.	· On-site interim storage for SF and L-2 LLW at NPPs. · Off-site interim storage for SF (Mutsu, Aomori). · Vitrified HLW storage at Rokkasho-Mura and Tokai-Mura.	· N/A
Netherlands	· Reprocess SF (in France and United Kingdom). · Deferred decision on waste management.	· Central 100-year storage, LLW and ILW (Borssele), HLW (Habog).	· N/A
Poland	· Near-surface disposal for LLW and ILW from research reactors (Rozan).		· Adopted a national SF and RW plan in 2014 – initiated studies on DGR for SF.
Russia	· Reprocess SF. · DGR for HLW and ILW. · Near-surface disposal for LLW and very LLW. · Liquid LLW and ILW disposed in deep wells (Mining and Chemical Combine [MCC], Siberian Chemical Combine (SCC), Research Institute of Atomic Reactors [NIIAR]).	· SF stored at NPPs and research centres (FEI, NIIAR, others); at the centralised storage facility (MCC). · Solid RW stored in different types of storage facilities (NPP, system of radon facilities, etc.). · Liquid HLW stored in tanks at the Federal State Unitary Enterprise "Mayak Production Association" (FSUE PO Mayak). · Liquid ILW and LLW stored in separate open pools (FSUE PO Mayak, SCC, MCC).	· Reconsidering the management strategies for different SF.
Slovenia	· Direct disposal SF or reprocessing abroad.	· On-site storage for SF in SF pool at Krško NPP, then dry storage of SF on the site ready by 2021. · On-site storage for LILW at Krško NPP. · Storage for institutional waste at the Central Storage Facility.	· Adopted a national strategy on RW and SF for 2016-2025.
Spain	· Reprocessed SF abroad previously (until 1983). · Now direct disposal. · DGR for HLW and SF. · Near-surface disposal for LLW and ILW (Córdoba).	· 60-year central SF and HLW storage (Cuenca), facility under licensing.	· Potentially delayed operational period of a DGR in 2068.

Table 2.1. **National policies and strategies for SF and RW management in selected NEA member countries** *(cont'd)*

Country	National policies	Storage situation	Strategy change since 2006
Sweden	· Direct disposal of SF. · Intermediate depth disposal for LLW, short-lived ILW (SFR, Forsmark). · DGR for SF (Östhammar).	· SF stored at NPP (1 year), then at wet storage at the Central Interim Storage Facility for Spent Nuclear Fuel (CLAB) (40-50 years) followed by final disposal (Östhammar).	· N/A
Switzerland	· DGR for all RW. · Reprocessing of SF was suspended in 2006.	· NPP sites have on-site installations for RW conditioning and stored their own operational waste. · The central storage facility Zwilag stored SF and other RW with on-site incineration of LLW. · Zwibez at Beznau NPP stored low-level operational waste and stored SF (dry). · Also a wet SF storage at Gosgen NPP.	· Delayed operations of a low- and intermediate-level waste DGR (2050) and a HLW and SF DGR (2060).
United Kingdom	· Reprocess SF. · Near-surface disposal for LLW (Cumbria). · DGR disposal for higher activity radioactive waste (HLW, ILW, and some parts of LLW).	· ILW, vitrified HLW stored at Sellafield, SF at Sizewell B (50-year storage). · SF from new built will not be reprocessed, but stored at NPPs. · Repository near Drigg stored LLW.	· New storage facilities are planned because of a longer than expected siting process which adopted a strategy of volunteerism.
United States	· DGR disposal for defence-related transuranic waste (Waste Isolation Pilot Plant). · Surface/near-surface disposal for LLW (various sites). · DGR disposal for SF.	· Most commercial SF stored on reactor site in pools. · SF also stored in dry cask storage systems at independent SF storage facilities (ISFSIs) both at and away from reactor site. US Nuclear Regulatory Commission (NRC) reviewing licence application for consolidated interim SF storage facility.	· Extended storage cask renewal period to 40 years. · The US Department of Energy (DOE) has issued a draft consent-based siting process for consolidated storage and disposal facilities for SF and HLW. · The DOE, requested funding to resume licensing of the proposed repository at Yucca Mountain, and would not be pursuing consent-based siting, as the Yucca Mountain site is already sited.

Among the existing national frameworks reviewed, regulatory policies for RW and SF, in general, adhere to the following key principles which govern the regulation of SF and RW management (as it is articulated in the articles of the IAEA Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management) – INFCIRC/546: Specifically Article 4 outlines general safety requirements for SF, and Article 11 outlines general safety requirements for RW.

- ensure that criticality and removal of residual heat generated during SF management are adequately addressed;
- ensure that the generation of RW associated with SF management is kept to the minimum practicable, consistent with the type of fuel cycle policy adopted;
- take into account interdependencies among the different steps in SF management;
- provide for effective protection of individuals, society and the environment, by applying, at the national level, suitable protective methods as approved by the regulatory body, in the framework of its national legislation which has due regard to internationally endorsed criteria and standards;
- take into account the biological, chemical and other hazards that may be associated with SF management;
- strive to avoid actions that impose reasonably predictable impacts on future generations greater than those permitted for the current generation;
- aim to avoid imposing undue burdens on future generations.

Safety requirements and regulatory frameworks

Many national legal and governmental frameworks regulate RW management facilities based on international safety principles, such as the IAEA Fundamental Safety Principles (GSR Part 1) and the IAEA Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management. These international standards aim to assist countries to maintain safety by setting international benchmarks to which countries subscribe; i.e. provide measures for reducing radiation risks, emergency situations and monitoring of the environment, and disposal. Despite the fact that licensing regimes vary from country to country, the main aim of any regulatory framework should be to provide licensees a clear and transparent regulatory process involving early dialogue between the regulators, the operators of the RW and SF facilities and other stakeholders.

Most regulatory authorities of NEA member countries have recognised the importance of a flexible yet efficient regulatory process. A clear, auditable document trail of regulatory decisions is considered a key component in the licensing process. Communication, particularly early interaction between licensees and regulators is worthwhile for efficiently regulating RW management activities. Especially in countries with multiple regulatory authorities with various levels of jurisdictions, clear communications between the applicant and regulators have avoided miscommunications (NEA, 2012). In a 2012 NEA workshop, the RWMC Regulator's

Forum[1] assessed the effectiveness of different legislation settings in making RW management decisions. The workshop concluded that a single regulatory body to lead or co-ordinate the licensing process would allow a simplified process and would avoid potential conflicts or irreconcilable requirements. In reviewing license applications, many regulators recognised the importance of maintaining their independence and open communications with the involved and interested parties. To ensure license requirements are appropriately defined and enforced, regulatory organisations should maintain adequate technical and managerial competence and ensure that the required human and financial resources are available. Considering each country has its own experience and resources, it is not uncommon to see the involvement of independent technical support organisations (TSOs) in supporting regulating and implementing agencies in technical evaluations, legal advice and regulatory decisions or even in training of staff and project management. In that context, it is important that all involved organisations follow the two basic principles of independence and transparency. With regards to independence, a TSO must be able to develop and express its technical assessment independently of any external interests or influences, be they political or economic. It should be clear that the sole responsibility for making decisions on legal matters lies with the regulator and TSOs can assist by providing the necessary facts and technical assessments. Services provided to a licensee must be carried out in a fully transparent manner while excluding conflicts of interest. It is with these principles that a trustful relationship can be formed and values can be shared.

With the wide variety of potential hazards of RW and SF, many regulators also use a graded regulatory approach to assign resources according to the level of hazards in order to efficiently utilise the available resources. There are international frameworks (e.g. the Western European Nuclear Regulators Association [WENRA]) where regulators jointly develop a common approach and knowledge to achieve nuclear safety while maintaining independent regulatory capability in their own countries. Radioactive waste management facilities may require both a construction licence and an operation licence, and a common approach used by the regulators is to specify detailed safety requirements related to activities in different phases in the licences. Some regulators also impose hold points for inspection during the construction phase to ensure regulatory compliance while others may specify mandatory documentation and to substantiate requirements in demonstrating safety.

The following points summarise the common requirements requested in licences:

- design requirement on the strong preference for passive safety relevant features (safety-significant structures, systems and components [SSCs]);
- design requirement on ageing resistance during the design lifetime of safety-significant SSCs;
- operational requirement on establishing, performing and evaluating appropriate ageing management programmes on safety-significant SSCs;

[1] The RWMC Regulator's Forum was renamed as "Regulator's Forum" in 2019 to support both the RWMC and the Committee on Decommissioning of Nuclear Installations and Legacy Management (CDLM)."

- corresponding operational requirement on monitoring the properties of the stored RW;
- organisational requirement on establishing acceptance criteria for incoming RW and their verification as part of the facilities integrated management system;
- organisational requirement on the information management on the properties of stored RW (preservation on data files, historical records, etc.).

Licensing experience of RW and SF storage facilities already exists in NEA member countries. In most cases, storage activities are stringently regulated in which safe operations of facilities are demonstrated in safety cases. Periodic safety reviews supported by specific licensing documentation as required by most regulatory frameworks during the licensing process have been effective in providing continual improvements to RW and SF storage.

During the decades-long waste management process, some countries foresee that the ownership of the SF and RW may change. Such potential change, in addition to adding complexity to the multiple interfaces of the responsible personnel, also reinforces the need for clear responsibility during transitions, for record keeping, and to ensure sustainable financing of waste management operations. As some of these issues indeed go beyond the scope of the nuclear regulators, they are challenges that national policymakers need to discuss and address.

With regards to licence conditions and compliance verification, there are a wide variety of safety requirements and measures used by nuclear regulators to verify compliance status of their licensees. Many safety requirements are based on dose constraint and follow the *International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources* (IAEA, 1996). Measures to verify compliance of RW storage typically include inspections, reviews, audits and assessments. Many regulators also conduct regulatory inspections to verify whether a licensed programme, process or practice complies with the requirements as stated in a licence. Visits to facilities are performed by trained and qualified inspectors to review documentation, collect objective evidence and make expert judgement based on knowledge of best practices. Other regulators may establish and maintain a compliance verification programme based upon the risk level that the RW or activity presents to human health and the environment. In evaluating the safety performance of a facility, the Canadian regulator (Canadian Nuclear Safety Commission, CNSC) for example, encourages licensees to perform analysis of safety-significant events. The objective of the analysis is to ensure licensees have adequate processes in place to perform corrective actions when needed and to integrate lessons learnt from past events into day-to-day operations.

Financial issues

All NEA member countries apply the polluter pays principle, by which waste owners are financially responsible for the management of their RW, and funding mechanisms are already in place. Provisions for ensuring that financial resources are available for the RW and SF management programme are often stated in legislation and/or in national plans. Financial support is either provided from centralised funds set up by governments or through the payment of fees by the waste owners. The funding mechanisms do not generally take account of an extension in storage period; however, financial resources are part of the periodic reviews of the national plan, which are carried out at the national level, and the mechanisms for funding may be modified according to the changes included in the plans. Unlike RW disposal, the shorter operating period of an RW facility allows financial assurances to be managed via institutional control. In designing funding measures, the financing mechanism should be tailored to particular national circumstances as there is no ideal funding scheme. A crucial aspect in determining the requirements of financing mechanisms is the production of a baseline plan or programme. Risk assessment should also be appropriately managed by assessing the risk and sensitivities associated with each cost. The programme plan should be revisited on a regular basis to test the assumptions and reduce uncertainties. The funding mechanisms and financial arrangement of some NEA member countries are illustrated in Table 2.2.

Table 2.2. **Financial arrangements in selected countries**

Belgium	The Royal Decree of 25 April 2014, which amends the Royal Decree of 30 March 1981, determines the guiding principles that are the basis for establishing the fees for contributing to the long-term fund. Six guiding principles are established in the royal decree on the methods of calculation of the fees for waste transfer from the waste producer to the Belgian National Agency for Radioactive Waste and enriched Fissile Material (ONDRAF/NIRAS) and on the alimentation of the long-term fund (i.e. the fund created for financing waste storage and disposal by ONDRAF/NIRAS). These principles will be applied by adapting the contractual clauses and consequently by signing new contracts/amendments with the main waste producers (or the approval of notes for the management of liabilities). The royal decree requires the contracts with the waste producers to be adapted as soon as possible and by 31 December 2018 at the latest.
Canada	Waste owners are responsible for the funding, organisation, management and operation of waste management facilities for their waste. CNSC licensees are financially responsible and required to provide a financial guarantee (FG) for the decommissioning, interim storage and long-term management of RW, including SF – CNSC, G-206, *Financial Guarantees for the Decommissioning of Licensed Activities*. Major nuclear facilities are required to keep decommissioning plans and FG up to date throughout the life cycle of a licensed activity, CNSC, G-219, *Decommissioning Planning for Licensed Activities*. These are reviewed on a five-year cycle by the licensee and the CNSC. In regards to the long-term management of SF, owners of SF make annual contributions to trust funds under the Nuclear Fuel Waste Act (NFWA), according to the funding formula approved by the Minister of Natural Resources. The funding formula for the management of SF allows funds to be collected over the life cycle of the nuclear reactors producing the SF bundles, with unforeseen events, contingencies provided in the cost estimates. To harmonise requirements under the Nuclear Safety and Control Act and the NFWA, the funds set aside by SF owners in their NFWA Trust Funds are considered part of the licensee's total FG required by the CNSC.

Table 2.2. **Financial arrangements in selected countries** *(cont'd)*

Finland	The operators of nuclear facilities are responsible for financing the management of the waste that they generate. To ensure that the financial liability is covered, costs estimates for managing the existing waste and future arising from decommissioning of NPPs are estimated and annual contribution to the State Nuclear Waste Management Fund must be made. Extended storage is not considered in the current national strategy, however, the current financing system is capable of adjusting to the inclusion of extended storage should it be required.
Hungary	In Hungary, the Central Nuclear Financial Fund (CNFF) was established to finance all management activities related to RW and SF such as disposal of RW, storage of SF, closure of the nuclear fuel cycle and decommissioning of nuclear facilities. The payment of fees from the Paks NPP to the CNFF is determined by the government in order to cover all the costs elements associated with the national programme.
Italy	The long-term management fund for managing SF and decommissioning, set up by the national electricity company ENEL (Ente nazionale per l'energia elettrica), is now managed by the RW managing organisation Sogin (Società Gestione Impianti Nucleari). Since the separation of Sogin from ENEL, additional costs incurred as a result of increased management costs and change of decommissioning plan are covered through national taxation.
Russia	Funding mechanism has not been set up for managing the funding of the possible extension of storage. The federal law on RW management issued on 11 July 2011 (Federal Law No. 190) established the principles that financial responsibility for the RW produced before the law ("legacy") is with the state, while the financial responsibility for the new generated RW including its disposal is with the operator.
Slovenia	The Slovenia national programme foresees general timelines and financing for activities related to the management of RW and SF for ten years and the current financing scheme includes an option for a financing mechanism for the storage of RW beyond the operating lifetime of the waste producer. However, the financial public service operates on a one-year programme of work and funding that causes difficulties in securing financing for current operations and future investment. In addition, compensations for local communities increase the operating costs of storage facilities for RW.
Spain	Waste producers are liable for financing the long-term management of RW. Extended storage is included in the 2006 General Plan for Radioactive Waste Management (GPRWM), which is used to legally establish the contributions of waste producers to the nuclear waste fund. There are no plans to modify the existing financial scheme for RW management and decommissioning of nuclear facilities as it is showing to be a reliable and robust one. The current arrangements are considered appropriate as the GPRWM can be revised and updated by the government as appropriate, including the financial arrangements for the plan.
Sweden	A dedicated system for setting money aside in segregated funds for future costs was established in the early 1980s. These cost estimates are reviewed every three years for reliability/accuracy. In doing so, any changes to previous assumptions should be considered and reflected in the collection of money to the fund. There is, in addition, a system for addressing contingencies, (e.g. cost increase) by means of requirements on licensees to provide for insurances to cover such situations.

Table 2.2. **Financial arrangements in selected countries** *(cont'd)*

Switzerland	The costs for the management of SF and RW (i.e. conditioning and storage) as well as for the preparations for later disposal are paid by the waste producers as part of their operational budget. The financial contributions of each waste producer to the waste management and the decommissioning fund are determined by an independent funds commission following the review of the national waste management programme every five years. The contributions are based on the updated technical basis provided by the waste producers and the RW manager (National Cooperative for the Disposal of Radioactive Waste [Nagra]) and confirmed by the regulator.
United Kingdom	The wide ranging nature of its historical nuclear programme has resulted in inadequate financial provision having been made at the time when the waste was generated. Although it has been recommended that financial provision from the UK government should be provided on a long-term basis through separate funding allocations, this recommendation has not been taken up and therefore the funding of waste recovery, conditioning and storage provision is subject to the standard UK government three-year cycle of spending reviews. Asset management plans for both stores and packages are either in place or being developed to ensure that the costs of pursuing different waste management strategies – for example, extended storage versus geological disposal – can be assessed. These plans ensure that there is flexibility in the strategies, as evidenced by the different policies currently being pursued in Scotland and England/Wales.
United States	The Nuclear Waste Policy Act specifies that the cost of both interim storage and permanent disposal is the responsibility of the generators and owners of the waste. Because of delays in the siting and licensing of a repository, the US government bears an increasing financial responsibility for SF storage costs, and it may become responsible for paying all the costs associated with SF storage at some time in the future.

Chapter 3. Storage of radioactive waste and spent fuel

Different types of radioactive waste (RW) have different storage needs. Detailed design and operation of spent fuel (SF) and RW storage are described in the IAEA Safety Guides SSG-15 *Storage of Spent Nuclear Fuel* (IAEA, 2012) and WS-G-6.1 *Storage of Radioactive Waste* (IAEA, 2006) and will not be repeated in this report. The following sections give an overview of the current storage situations in NEA member countries and best practices in storage of RW and SF.

Safety and management practices for spent fuel

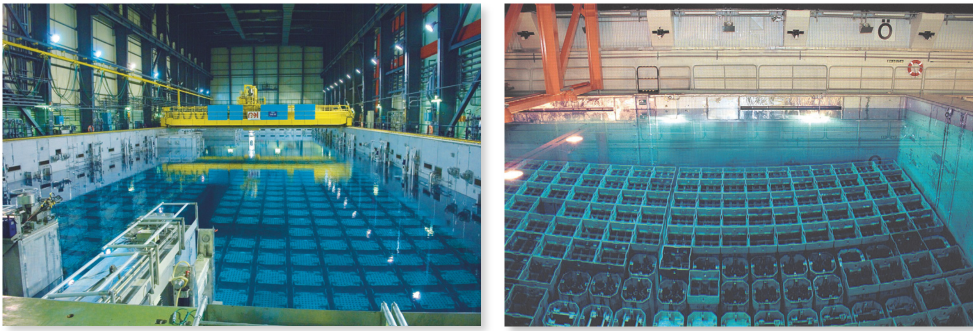
Until the 1970s, many countries considered reprocessing SF to extract and recover unused plutonium and uranium. Reprocessing SF also reduces the disposal volume and the radioactivity level in the resulting high-level waste (HLW). In part out of concerns about the proliferation of nuclear weapon materials, some nations, such as Sweden and Finland, subsequently adopted a nuclear fuel cycle that was "once-through" in which SF removed from reactors would be placed in interim storage and then disposed of in a deep geological repository.

Whether it is to be reprocessed or not, SF removed from a nuclear power plant (NPP) is stored initially in wet storage bays. A number of designs are used for SF wet storage (Figure 3.1). One common design is to equip the wet bays with cooling and purification systems to provide containment and cooling of the SF. Water provides the necessary shielding to protect the workers whereas the bay structure and other structural elements (e.g. fuel containers and stacking frames) provide mechanical protection of the stored SF. In all cases, the water purity in the wet bays needs to be controlled within design limits. A purification system often includes ion exchange resin columns and filters that are chemically controlled by instrumentation at sample points. Proper control of the water chemistry will:

- minimise metal corrosion, thus containing radioactivity and reducing radiation in the bay area;
- maintain clarity of the bay water for ease of operation.

SF can become damaged inside the reactor or during handling. Despite the low defect rate, damaged SF is generally placed in a sealed container and stored in a designated part of the wet bay, out-of-reactor zone. With extended operating lifetimes and continual exposure to radiation, the wet bay and its components (e.g. bay liner) could deteriorate and regular maintenance is essential. Techniques have been developed to locate and repair deteriorations or leaks underwater. After a few years of storage in the wet bays, the SF will have reduced heat and radioactivity and can be transferred to dry storage.

Figure 3.1. **Spent fuel wet storage in France and Sweden**



Source: AREVA/Jean-Marie Taillat, France.

Source: SKB, Sweden.

There are two different types of dry storage: vault-type storage and container-type storage. SF, in dry storage, is typically placed in a sealed metal cylinder with a concrete outer shell to provide radiation shielding (Figure 3.2). While dry storage containers can come in different designs and dimensions, these canisters in general serve the same purpose of containing radiation, allowing heat to dissipate and preventing nuclear criticality. Another option would be to use dual-purpose canisters. These canisters can be used for transporting, storing and eventual disposal of SF. In designing the storage facility for SF, all credible hazards must be adequately analysed and properly addressed in the safety case. Analyses must demonstrate that the storage and handling of the stored SF is safe and an inadvertent criticality will not occur under normal or credible abnormal conditions. To ensure safety, many countries carry out research and development programmes to examine specific issues such as the integrity of the SF, durability of storage structures and components, monitoring techniques and the long-term performance of SF.

Figure 3.2. **Spent fuel dry storage in casks stored outdoors in the United States**

Source: Sandia National Laboratories.

Safe storage of SF around the world has been established through effective regulatory control, and the use of robust storage containers and proven SF handling mechanisms in suitably engineered structures to minimise escapes of radionuclides into the environment. Current operating experience gained at existing wet and dry storage facilities around the world has provided a high level of confidence that SF can be safely stored, without undue risk to workers, the public and the environment. Many RW experts also consider that the interim storage of SF can be technologically advantageous by providing time for SF to cool thermally through radioactive decay, and societally advantageous, by allowing more time for deliberative decision making.

Safety and management practices for low- and intermediate-level waste

Low- and intermediate-level waste (LLW and ILW) resulting from NPP operations include materials such as protective clothing, contaminated equipment, radioactive sludge and others. They are stored in a variety of structures located in waste management facilities at NPP sites or away from NPPs (Figure 3.3). LLW makes up the largest physical volume of RW, and is often volume reduced by incineration, compaction or shredding prior to storage. To ensure safe processing of LLW, some countries develop derived release limits to monitor airborne and effluent radioactive releases from the processing site. Ultimately, whenever possible, LLW and ILW are processed to produce a structurally stable waste form, i.e. liquid waste or sludge is converted to solid, the converted waste is enclosed in containers and/or over packed if required. LLW and ILW are mostly stored in metal containers, in above-ground storage buildings or in shallow near-surface storage structures. RW facility operators generally use a combination of engineering design features, operating procedures and monitoring programmes to achieve safe handling, processing and storage of LLW and ILW. Safety provisions focusing on radiation protection, occupational health and safety, environmental protection and monitoring for individual areas, as well as the overall facility, are common practices at RW storage facilities.

Figure 3.3. **LLW/ILW storage in Germany** (left)**, and LLW/ILW storage buildings and in-ground storage in Canada** (right)

Source: GNS/Kloth.

Source: OPG/John Flesher.

Important aspects of interim storage and best practices

Interim storage is a temporary measure that enables RW and SF to be safely managed until final disposal. According to the 1999 NEA report on geological disposal: "In virtually all countries, some period of interim surface storage to allow decay of radiation and heat generation has always been recognised to be necessary or valuable" (NEA, 1999). Interim storage allows continual radioactive decay (decay storage) in which the radioactivity levels will be reduced. Decay storage is an effective practice for the clearance of RW containing short-lived radionuclides (e.g. <100 days) as the RW can be removed from regulatory control when its radioactivity is below the clearance level.

In designing an interim storage facility, the following factors should be considered:

- passive safety;
- multiple barrier containment;
- robust storage facilities with adequate storage capacity;
- appropriately established waste acceptance criteria for storage;
- effective storage facility maintenance, inspection and retrieval;
- record management.

Passive safety and stability of waste

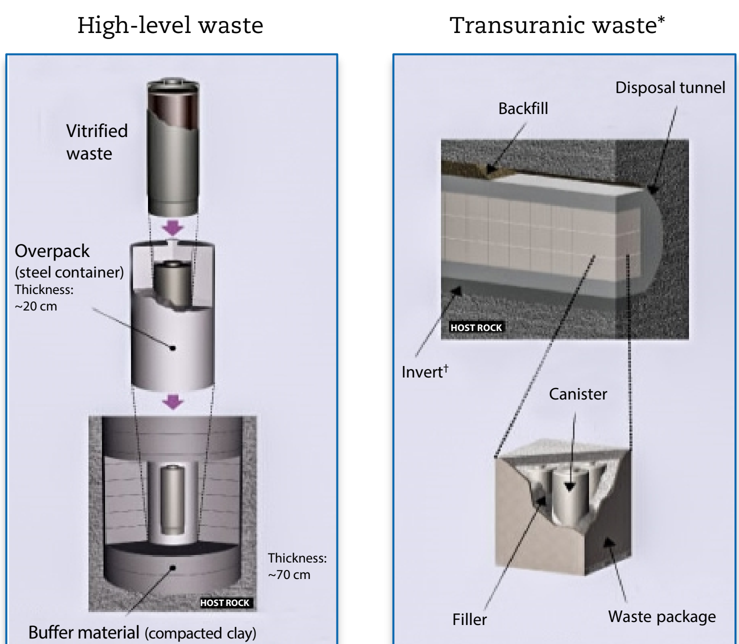
Radioactive waste is stored in physically and chemically stable form to achieve passive safety that minimises the need for active safety control systems. This form exhibits good resistance to leaching, corrosion, as well as predictable behaviours during the intended storage period, which are important to retain radionuclides and hazardous waste constituents under normal and accident conditions. For example, a storage environment with low air humidity and proper temperature setting will also preserve the longevity of the waste packages. To prevent criticality, heat removal or ventilation systems may be necessary to keep the temperature of the SF and HLW below the design temperature. In designing the heat removal system, the heat load and heat transfer characteristics of the stored HLW and SF, the container and the heat capacity of the system must be considered. On the other hand, in cases where liquid waste is stored, heating may be required to prevent freezing in cold weather.

For interim storage lasting more than a few decades (e.g. >50 years), some active systems may be necessary although it is generally preferred that the use of active systems be minimised. In cases where active systems are used, the reliability of the system and the requirements for redundancy and system diversity need to be considered. Active systems should also be designed for minimum maintenance, and, in the event of failure, immediate repair or replacement should not be necessary in order to ensure continuing safety of the facility and its contents. The extent to which active systems are implemented will need to be determined by considering a balance between safety, characteristics of RW and SF, relevant good practice, protection of the RW, cost and sustainability.

Multiple barrier containment

In aiming to achieve passive safety, the typical physical barriers include the waste form itself, any material that may be used for encapsulation, the waste container, and the storage building or structure, each of which should be designed to provide effective containment, prevent leakage of radioactive material and provide adequate shielding of operators and the public against the radiation hazard from the radioactivity in the waste (Figure 3.4). Barriers should be provided to an extent proportionate to the hazards presented to safety and the environment by the stored RW and SF, to limit the consequences of any postulated events and to mitigate accident sequences. If the long-term storage of RW involves the discharge of radioactivity to the environment, provisions should be made to mitigate the release of radioactivity from the facility, taking account of normal operation, anticipated operational occurrences and design basis accidents. For example, if gaseous discharges may occur via ventilation systems that are designed to maintain dry and clean conditions in the facility, then such discharges shall use the proper filtration or isolation means.

Figure 3.4. **Design of the engineered barrier system in Japan**



* Example of hulls and ends.

† The invert is the base of the tunnel and is composed of concrete or a similar material.

Source: NUMO website, www.numo.or.jp/en/jigyou/geological.html.

Integrity of spent fuel and cladding

Preserving the integrity of SF enables the containment of radionuclides during storage and later during transport to the encapsulation and/or disposal facility. Extensive research has been performed to evaluate the effects of thermal profiles, residual moisture and material (cladding) degradation on the overall integrity of SF with time (NEA, 2011). The fuel cladding is important (i.e. metal tubes containing fuel in a used fuel assembly) because it provides an initial barrier for radioactivity release during storage (Figure 3.5). The integrity of this cladding is an important consideration in the long-term storage and is of concern irrespective of the type of fuel or the type of storage. Cladding degradation mechanisms include oxidation, corrosion, stress corrosion cracking, hydrogen effects and mechanical degradation mechanisms. Many of the degradation phenomena important for fuel and cladding integrity are correlated to the condition that SF has been exposed to during reactor irradiation. To minimise the potential for fuel degradation during storage, SF is stored in inert gas-filled storage casks. Helium provides an inert environment to deter corrosion of the cladding, the storage cask and the metal internals. During the decades-long dry storage period, degradation mechanisms also act on the outside of storage casks, as well as on other storage components (e.g. storage concrete pads). The effect of these degradation mechanisms depends on the environmental storage conditions such as temperature variations, and the presence of contaminants and moisture in the air.

Figure 3.5. **CANDU fuel bundle**

Source: Canadian Nuclear Laboratories.

Many countries have put in place research programmes to investigate used fuel integrity in the long term in wet and dry environments. Advanced concepts suitable for long-term storage are also being researched as new generations of nuclear fuel are developed (e.g. higher burn-up fuels and mixed-oxide fuels). For longer-term storage, such as for 50 to 300 years, the additional technical requirements are still in the development stage in many countries. These relate to fuel integrity, structural durability, handling of SF after long-term storage, encapsulation and packaging of SF for disposal, monitoring technologies and techniques and new cladding materials. Table 3.1 provides some examples of international programmes related to long-term storage aspects.

Table 3.1. **Examples of national research and development programmes for long-term storage of spent fuel**

Country	Research and development programmes
Canada	Storage parameters have been monitored for dry storage containers; conceptual studies of centralised long-term storage have been performed. Extensive fuel integrity research work was carried out in support of storage and disposal programmes (OPG 2000: "Nuclear Waste Management, Managing OPG's Nuclear Waste Safely and Responsibly", Information Brochure).
France	In accordance with the French 2006 waste law, a research programme on RW storage was performed to improve the complementarities between storage and deep disposal. Particular attention was given to extended storage duration up to 100 years, storage modularity and versatility with regard to variations in waste volumes and characteristics. Research has also been performed on the integrity of SF during storage.
Germany	Germany carried out various studies and prototype facilities for the conditioning of SF for extended storage and disposal.
Japan	Studied a centralised away-from-reactor storage facility, as well as a number of programmes to determine the long-term integrity of SF in dry storage conditions.
Russia	Research has been conducted to determine the maximum storage times for dry stored fuel. Developments of dual-purpose metal and concrete casks have been made.
Sweden	Established an encapsulation plant (Central Interim Storage Facility for Spent Nuclear Fuel, CLAB) for containerisation of SF for long-term storage and disposal.
United States	The US Department of Energy, with industry co-operation, has initiated a High Burnup Dry Storage Cask Research and Development Project. This project will provide measured temperature data from inside an SF cask to help validate thermal models for dry cask storage.

Similar to SF storage, provisions are also to be made during RW storage to preserve the containment capacity of waste forms with regard to the safety of storage itself and of later transport and disposal. For instance, vitrified HLW are to be stored in conditions that avoid a risk of recrystallisation and limit internal mechanical stressing. This may require keeping the temperature within the glass block below an acceptable limit (such as 500 °C). Potential interactions between co-stored SF and/or RW packages are to be considered over the storage period. For example RW packages stored in the vicinity of highly irradiated or exothermic sources might be damaged by radiolysis or temperature rise. Sufficient separation to avoid unwanted interactions needs to be provided in such a case. By doing so, the risk of container deterioration by internal corrosion or change of the physical-chemical characteristics of the waste form is avoided. For instance, an excessive temperature can lead to a macroscopic inhomogeneity of bituminised sludge by sedimentation modifying their behaviour under irradiation, and later weakening their leaching resistance.

Radioactive waste or spent fuel containers

Among the various engineered barriers, the containers designed for interim storage of RW and SF are one of the most important barriers in achieving safe storage during the planned storage period. Their designs and material selections must ensure SF and RW are adequately contained and isolated from humans and the environment during normal, abnormal and accidental conditions (Figure 3.6). Specifically, structural integrity must be maintained over the design life of the containers with no loss of any safety function i.e. shielding, criticality, heat dissipation, retrievability and containment.

Figure 3.6. **Spent fuel dry storage containers in Canada**

Source: NWMO.

Steel is often used to manufacture waste containers as well as storage structures and is typically surrounded by additional steel, concrete or other material to provide radiation protection. Even in unfavourable local weather conditions, a low value of air moisture can be obtained inside the storage facility provided that ventilation air is heated sufficiently. The stacking arrangement of the waste packages should be taken into account when designing the ventilation system. Where exothermic HLW or SF is stored, the produced heat can be used. A part of the warm air flow at the ventilation outlet can be reintroduced upstream to avoid any condensation on the metallic surfaces in the entire storage facility.

Corrosion studies have long noted that the initial state of the outer surface of metallic components affects the speed of corrosion (ASTM, 1993). The kinetics of corrosion of polished and cleaned steel is much slower than pre-corroded or micro cracked steel. The stainless steel components that have sustained significant deformation may exhibit weaker resistance to corrosion, except if they have been previously treated, for example by annealing or grit blasting. To control corrosion, many countries use leak tight SF containers and leak tightness is monitored during the entire storage period. Some containers are even equipped with specific features to monitor their evolving performance. Dual-purpose casks are continuously monitored with pressure transducers. For instance, the Canadian SF dry storage container is equipped with a surveillance system to monitor ageing effects. Leak tightness is verified through helium leak testing before containers are placed in storage, followed by continuous maintenance activities to ensure that the container condition and weld integrity are maintained. To ensure the stored RW and SF will maintain their safety function during the planned storage period, it is also an emerging regulatory trend for regulators to assess the appropriateness/effectiveness of the ageing management plan or programme of a storage facility.

Storage structures

SF and RW storage structures are designed to ensure that radiation exposures to people and radioactive emissions to the environment are kept as low as reasonably achievable under normal, off-normal and accidental conditions (Figure 3.7). Especially for SF and RW with high heat-contents, the storage structures of these materials must be designed to ensure nuclear criticality safety when significant quantities of fissionable materials are stored or handled. Criticality safety analysis must clearly demonstrate that the storage and handling meets regulatory safety requirements, and that an inadvertent criticality cannot occur under normal or credible, abnormal conditions while conforming to national security and safeguard requirements. Equally important are the thermal and shielding analyses that must be carried out for design and safety assessment purposes. The heat of the SF and RW must be able to dissipate through the containers, so that the cladding temperature does not exceed its maximum design temperature, and must have enough shielding to control the dose rates. Metals and cement-based components are common elements for constructing safe structures, systems and components (SSCs) and their long-term behaviours when exposed to average atmospheric environment are well understood.

Figure 3.7. **Dry storage facility for spent fuel in the United States**

Source: US Nuclear Regulatory Commission.

Robust storage facilities with adequate storage capacity

Passive safety of storage conditions for RW and SF can be achieved using good engineering practices. Safety features such as the provisions of containment to limit and confine contaminations, temperature control or other measures to prevent inadvertent criticality (for SF and fissile materials), and shielding to provide radiation protection are often used in facility designs. Facility robustness can also be enhanced by periodic inspection and monitoring of the stored waste as well as maintenance and repair of storage components when required. Essentially, a defence-in-depth approach is often used in designing storage facilities which generally include three elements:

- conservative design and high quality in construction and operation;
- control, limiting and protection systems and other surveillance features;
- engineered safety features and accident procedures.

In determining storage capacity, the facility owner or the operator should – to the extent possible – anticipate the amount of RW or SF that will need to be stored, taking into account the need of additional storage capacity to accommodate potential waste which may arise in abnormal situations. Noting that many facility licences limit the amount of SF or RW that can be stored and/or specify boundary dose limits, the provision of reserve storage capacity will enable a facility to accommodate additional waste arising at times when system modifications or refurbishments are being undertaken.

Overall, in designing RW and SF storage facilities, the optimal radiological protection of operating personnel, the public and the environment via the use of appropriate shielding and control of potential releases must be considered. Storage facilities must be designed and operated to prevent a criticality accident, considering the criticality relevant parameters during normal operation and accident conditions. Means for removing residual heat during normal operation and design basis accidents should be provided where necessary as identified in the safety case. If the proposed storage facility is to be located on the site of a nuclear power plant or other licensed facility, the potential interactions between the storage facility and such other facility – including shared common utilities and services – must be evaluated. Storage buildings – if utilised – should provide sufficient protection to the stored RW and SF to maximise the waste package life and to facilitate safe transfer to final disposal or to a further storage site. This may require control and monitoring of the storage environment (e.g. temperature, relative humidity and particulates in the air) in order to minimise package deteriorations caused by corrosion. This may be particularly important for storage facilities that are located in areas where chloride levels in the atmosphere are high.

Storage facilities should therefore be designed with provision for routine inspection and the ability to retrieve waste packages. Resistance to external hazards should be considered in the facility design; for example, seismic events and flooding. Facilities should be designed to require minimal need for prompt remedial action following any off-normal operations. Any effects which would cause deterioration of the waste form, container or storage structure over the storage period should be taken into account in the safety case. As storage structures and components will deteriorate over time, it is also a good practice to design a storage facility that facilitates inspection and to allow for access with equipment should repair or maintenance be required.

Waste acceptance criteria for storage

Waste acceptance criteria (WAC) for storage are specific requirements defined to ensure waste consigned to a specific storage facility complies with applicable regulatory requirements. They are parameters often specified in terms of the required physical form of the waste and the waste packages, maximum levels of radioactivity, dose rate, packaging requirements, etc., in order to provide reasonable assurance that the emplaced waste can be stored and retrieved safely at a storage facility within the planned time frame.

Some NEA member countries have developed their storage WAC based on the foreseeable conditions as identified in the facility safety case (e.g. the United Kingdom), some also with the future disposal requirements or management strategies taken into account (e.g. Sweden). In planning the storage conditions, compatibility with handling, transport and storage requirements (including suitability for retrieval and transport following the anticipated storage period) are often considered. To ensure that waste packages meet the defined acceptance criteria upon receipt, most countries implement processes and procedures such as auditing, inspection and conformance verification. Taking the United Kingdom as an example, the UK Radioactive Waste Management (RWM) defines conditions for acceptance (CfA, equivalent to WAC) for all stored waste, which are underpinned by a safety case, and confirms acceptance through disposability assessment. Only when the waste is rendered passively safe and meets the defined waste specifications will RWM issue a letter of compliance. RWM also undertakes technical audits of their waste packaging and storage operations to confirm their continual consistency with their future disposable waste packages. Unlike the United Kingdom, some countries have defined WAC in their regulations or regulators are involved in drafting WAC. In these countries, WAC need approvals from the regulators or specific requirements for waste conditioning, waste forms and packages may be defined in the facility licensing documents (e.g. Finland, Poland and Sweden). In Russia, WAC are not separately specified for storage, but for the entire RW management process (i.e. storage included). Their series of RW management requirements, namely NP-058-14; NP-019-15; NP-020-15 and NP-035-02, require the nuclear facilities to have the necessary organisational and technical measures to ensure safe RW storage.

Overall, it may be concluded that WAC are facility specific, often developed by facility operators and waste management agencies, with inputs from the facility designers to ensure that waste can be safely stored using robust storage technologies and under the planned storage conditions. To ensure waste packages maintain their design functions and meet the WAC upon arrival at a storage site, transport requirements, potential storage conditions as described in the safety case are often taken into consideration in developing WAC. Such an approach not only enables consistency with regards to implementation of safety requirements, but also facilitates the periodic revision process, thus, revisions of the WAC are triggered when safety assessments are revisited.

RW and SF should be appropriately characterised in terms of its radiological, physical and chemical properties. RW and SF will evolve or degrade over time; characterisation information might be used to inform decisions about their subsequent management step(s). The overall purpose of RW and SF characterisation for storage should be to support later stages in the RW lifetime. It should be noted that characterisation activities in the various stages of the life cycle may have significant effects on the cost and efficiency of waste management. In general, characterisation is easier and less expensive in the earlier stages of the life cycle when properties of RW can be easily measured in the raw waste stage whereas detailed characterisation may be problematic following waste conditioning and non-destructive techniques may be of limited utility. RW characterisation should be carried out as soon as a lack of information is identified or when there is potential impairment to the safety case as a result of changes in the RW/SF properties, from generation to disposal.

Compliance with waste acceptance criteria before and during interim storage

Compliance of the waste with the WAC is checked prior to the actual shipment of the packages to the interim storage facility. The compliance is documented in "inspection reports". Depending on the country-specific situation, the inspection reports are elaborated by the nuclear operator following its "quality assurance programme", the waste management agency or the nuclear regulator.

After acceptance of the waste, some storage facility operators conduct compliance monitoring by means of visual inspection on the waste and the package conditions or by performing technical audits on the interim storage conditions.

In many NEA member countries, a waste package monitoring programme has been found useful throughout the storage phase, as it confirms the integrity of waste packages, their safe storage, retrieval and final disposal within the limits specified in the safety case and/or storage WAC. Such a programme typically considers the effects of the potential degradation and the perceived risk to the container's integrity, which often includes applicable internal and external corrosion of waste packages, loss of mechanical strength, lifting feature degradation and gas generation as the waste evolves. Waste packages of conditioned waste are inspected regularly, either randomly or on selected packages to examine the conformity with the relevant WAC. The results of those periodical physical inspections are recorded in specific reports and can include pictures of the waste packages in order to visually evaluate their evolution. Submitting random packages of conditioned waste to repeated tests like gamma spectrometry and surface contamination and H_2-production rate are also common practices in some countries.

Licensees should have remedial plans to deal with waste packages that show signs of loss of integrity (e.g. overflow of bitumen) and degradation (e.g. corrosion). Beside the remedial plans, the necessary analyses have to be performed on the possible causes of the non-conformity and the potential effect on other waste packages. Depending on the observations, the monitoring programme can be extended to other waste packages or even all waste packages from the same production campaign. It is important that the licensees, waste management organisations and regulators exchange the results of these observations and lessons learnt throughout with other international partners.

Waste characterisation

Waste characterisation should yield sufficiently accurate and precise information on the following:

- the radioactivity and isotopic content of the RW in order to meet the waste acceptance criteria (WAC) for storage and other requirements such as preliminary criteria for final disposal;
- the package dose rate to demonstrate compliance with the facility licensing conditions;
- the amount of any surface contamination to meet safety case requirements;
- waste package fissile contents, if applicable, to enable assessment of the criticality hazard and to facilitate nuclear safeguards arrangements;
- the bulk composition and chemical properties of the RW (e.g. organic, reactive components, explosive, flammable, corrosive and pyrophoric materials) to understand the extent of any potential chemical hazards;
- the bulk physical properties of the RW (e.g. dimensions, weight of the RW, physical form, mechanical properties) to evaluate any risks posed and to ensure compliance with all related safety case limits.

For difficult to measure radionuclides, scaling factors may be an effective means to simplify the WAC procedures. Nevertheless, operational experience of RW storage facilities has concluded that WAC should be concise, measurable and allow for flexibility.

Effective maintenance, inspection and retrieval

Maintenance, monitoring and periodic inspection should be undertaken to ensure that the storage facilities, SSCs are functioning in accordance with the design intent and safety requirements. Detailed procedures for maintenance, testing and inspection of systems are essential for safe storage of RW and SF. A vast amount of facility maintenance and monitoring experience has been developed in many NEA member countries and good technologies for detecting any unsafe condition, the degradation of SSCs, as well as effective decontamination procedures are available.

A typical monitoring programme for an SF dry storage facility may include radiation monitoring, container monitoring for leaks and tightness verification, airborne and liquid effluent emissions and environmental monitoring of water quality, soil and other biota parameters. Where degradation has been identified, appropriate actions to remedy the situation must be clearly identified and documented. Equipment necessary for maintenance, retrieval, periodic testing and inspection should be designed to take account of radiation protection aspects. They should be easy to maintain, continue to function under foreseeable accidents and their proper use should be controlled. The frequency of maintenance, monitoring and inspection should allow time for preventative action to be put in place or be in accordance with the facility safety case. Results should be recorded, assessed and lessons learnt should be incorporated.

Procedures for managing and operating the storage facility under normal conditions and in credible incidents are particularly important in preparing for emergency situations. Clear responsibilities and actions for the designated responsible person can assist emergency personnel to perform the necessary actions in a timely manner. Operating procedures should be periodically reviewed, taking into account operational experience and lessons learnt. In revising operational documentation, the impact of any modifications on the safety of the stored waste, operational limits and relevant licence conditions should be considered.

Measures and/or design provisions for easy retrieval will ensure the safety of handling of the stored SF and RW for transfer to its final disposal destination. In planning for RW or SF retrieval, a detailed waste retrieval plan including selection of the technology and subsequent management is necessary. In particular, the condition of the waste packages, the status of the radiological hazard, the adverse impact on human safety, security of waste or protection of the environment during the retrieval process, as well as supporting facilities required once waste is retrieved must be assessed.

To maintain the safety interim storage over the long storage period, many countries implement an ageing management programme for the critical, safety-credited SSCs, as well as an inspection regime on the stored RW.

Ageing management programmes

Ageing management is the set of engineering, operational, inspection and maintenance actions that control, within acceptable limits, the effects of physical ageing and obsolescence of systems, structures and components that occur over time or with use. Understanding the ageing mechanisms of the key storage SSCs not only improves the designs of the storage systems, it also enables appropriate inspection and maintenance routines to be performed for maintaining integrity of SSCs throughout their design life. Many ageing management programmes in NEA member countries are implemented to quantify the factors affecting the ageing of the facilities, with specific focus placed on the critical, safety-credited SSCs. Ongoing inspection and maintenance are carried out to ensure the SSCs maintain their safety functions and necessary integrity throughout their design life. Some storage operators have also developed surveillance tools to control ageing of the confining barriers including waste package, metallic and concrete structure, ventilation shafts, etc. For instance, metallic and concrete samples are emplaced in packages stored in near-surface storage structures at the La Hague facility (France), which provide physical evidence for studying the ageing phenomena.

Extended storage

In most NEA member countries, RW and SF have been managed by their producers with a nominal storage life of 50 years. Countries such as Belgium, Finland, Sweden and Switzerland explicitly stated that extended storage is not considered in their national strategies. In countries, such as the Netherlands, Spain and the United Kingdom, longer storage periods (as long as 100 years) have been implemented in centralised storage facilities where RW and SF are gathered from different production sites. Extended storage can be considered when the initial licensed or foreseen storage period of waste packages will have to be extended for a substantially longer period. In most cases, the extended storage period is related to the absence of a final surface or geological disposal facility, but even in countries where a geological disposal project is in progress, an extension of the storage duration is often considered. To maintain RW or SF packages in safe conditions, the first option is to prolong the operation of the existing storage facilities provided that surveillance, ageing management programmes and if necessary, refurbishment are implemented. The capacity to extend operation of the storage facility over its initial design lifetime is assessed during a relicensing process or comparable procedures (e.g. periodic safety review). The second option is to construct new storage facilities with design lifetimes largely longer than those of the previous facilities.

The aim is to manage the increased number of waste packages pending disposal or to transfer the RW or SF packages from obsolete facilities to new facilities which meet current safety requirements. For this option, reconditioning of the RW or SF packages may be needed prior to transfer.

In France, the suitability of the storage facilities in La Hague for vitrified HLW packages and compacted hulls and ends long-lived ILW packages for long-term management up to 100 years has been appraised (Devezeaux, 2006). The new storage vaults recently built or planned to complement the storage capacity of the current facilities meet more stringent requirements concerning durability so that their lifetime could eventually be extended for another 75 years. When the final disposal facility is unavailable at the end of the intended storage period, a new or relicensed storage facility becomes necessary. More countries accept extended storage as unavoidable because of delays in implementing final RW and SF disposal solutions. Some countries also have experience in extending storage duration and demonstrating the safety of old interim storage facilities to support relicensing (e.g. Canada). To be able to extend storage beyond the original design lifetime, it is necessary to verify the integrity of the stored waste and structure components (i.e. the SF, the storage casks, RW and containers). Licence renewal or amendment will also require the original documentation, facility performance, compliance history and associated risks be revisited. All in all, the objective is to prove that safety of storage will continue to meet environmental targets over the facility's extended operating lifetimes. More effective or longer-term surveillance, ageing management programme with refurbishment may be required. The continued operation of existing RW management facilities must be conducted in accordance with its associated regulations and the renewed licence conditions. The capacity to extend the operation of a storage facility over its initial design lifetime must also be assessed in the relicensing process or comparable procedures.

In circumstances where new storage facilities with long-term design lifetimes (e.g. 100 years) are to be implemented, new design, construction, commissioning, operation and decommissioning of facilities and new construction and operation licences will be required. For a new licence, most countries now require applicants to submit comprehensive information on RW management policies and programmes. In addition to the design and components of the proposed facility, details as specific as the manner in which the facility is expected to operate (i.e. facility operating manuals), plans for SF and RW transfer from the old facility, any potential impacts on the site or surrounding environment during the transfer, and decommissioning plans would be required. The aim is to ensure the new facility has assessed its performance under normal operating and abnormal conditions, that the potential consequences of any failures are mitigated to tolerable levels with proper engineering measures established.

During the (re)licensing process, many countries are now including public consultations in the environmental assessment process in which the range of stakeholders to be consulted is often determined by a criteria-based approach, i.e. based on the interests of the involved and/or interested public. Public participation in the licensing process allows all involved stakeholders an opportunity to comment on matters before a decision is made. To allow stakeholders enough time to review an application and its associated documentation, public consultations may take place in multiple phases in which major decisions are made after a thorough public review process. For applications with minor amendments or changes of low safety significance, or when the amendments are more administrative in nature where there is less public interest in the matter being requested, a full public consultation or hearing may not be necessary and regulators may select to manage the application via an abridged hearing. Abridged hearings typically involve shortened notification requirements, reduced time periods and/or limited participation and may be held in a closed or public forum. However, it is a good practice for regulators to publicly publish the records of proceedings including detailed reasons for each decision following the hearing. There are also periodic licence renewals that enable regulators to have a regular update of the status of the facility.

It is never the intention to use extended storage, but due to the lack of political will, it is the de facto situation. The users of extended storage have stressed that interim storage experience has indicated no environmental problem in the last 50 years of operation and argued that extended storage can protect public and environmental health for several centuries.[2] Others have argued that extended storage only delays the decision on geological disposal, increases the risk and creates the impression that no final disposal solution exists. Public resistance to developing RW facilities has already been witnessed in some countries. In many cases, public and political opposition to storage is not necessarily less than that to geological disposition. If extended storage is intended as a long-term management alternative, national decision makers must also address the effectiveness of controls to restrict site access and ensure containment integrity, and the degree of confidence that can be placed in these controls.

Operational experience and challenges in interim storage and extended storage

SF and RW have been stored safely and securely in many countries for decades. As confirmed in the 2015 survey, most respondents consider their current storage technologies safe. Yet, operators continue to face challenges in maintaining good

2. IAEA (1999) defines 300 years as a period to cover “extended storage”.

quality storage in these countries. Challenges may be broadly categorised into technical, societal and organisational challenges.

Technical challenges

The technical challenges that many countries are facing include:

- the management of historic and legacy waste and in particular of non-conforming stored packages and existing storage facilities;
- the ageing behaviour of SF, HLW and long-lived LLW and ILW during long storage periods;
- the continual ageing storage components and structures;
- the changing of regulations over the storage time.

While the management of historic and legacy waste is not addressed in this report, aged packages that do not meet current national standards are a valid challenge in many RW management programmes. To solve these technical challenges, most countries assessed various storage facilities and concepts taking into account the durability of materials, and the design of structures and installations. Extensive research examining the long-term performance of waste packages and storage components has been conducted while studies to investigate corrosion and other degradation mechanisms, long-term stability of storage structures and effects of high burn-up SF remain ongoing in many research programmes. The ultimate goal of this ongoing research is to obtain more data to support the continued certification of the existing storage systems.

To maintain storage safety, countries often rely on the following means:

- continuous monitoring programmes and procedures, e.g. monitoring of the containment and the surrounding environment, ageing management programmes to monitor degradations of storage structures and components;
- regulatory oversight with stringent requirements in licence, e.g. imposition of rigorous reporting requirements on the waste managers, verification of compliance through inspections and audits;
- periodic safety assessments, execution of remediation projects if necessary;
- continual research and development work to address safety and degradation of storage facilities and components, particularly to determine how long storage may be technically feasible.

In cases where storage of RW or SF is envisaged beyond the originally planned lifetime, the hazard status of the stored waste, the structural integrity of all storage components taking into account of stress and degradations in material properties, and shielding requirements must be reassessed in the safety assessment of the facility. Certain repackaging and/or renewal or construction of new storage buildings may be required. The exposure of workers and environmental implications of these activities need to be carefully considered in determining the extension of long-term storage.

Specific challenges to regulators – regulating ageing storage facilities

In regulating RW management activities, the role of a regulator is first to decide the requirements for demonstrating safety and compliance that a licensee must obey; then it is up to the regulator to demonstrate the credibility and adequacy of these requirements to the other stakeholders (e.g. the public), and finally followed by verifying the compliance status of the licensee. These roles require high-level technical competencies and resources to review and to decide if the science behind the safety assessment is valid. The regulatory process also relies on having sufficient resources to communicate the requirements with licensees and credible decisions with other stakeholders.

In case of extended storage, regulators also have to determine how to manage risks associated with the ageing storage SSCs, transport and financial security. Some of these issues or uncertainties are not resolvable at present, and therefore many regulators select to improve present co-ordination with the licensees, in terms of setting out clear requirements and to strengthen the implementation of crucial improvement initiatives. In this context, the Canadian Nuclear Safety Commission (CNSC) issued REGDOC 2.6.3, *Aging Management*, in March 2014 that specifies operational, inspection and maintenance actions that control the effects of physical ageing and obsolescence of SSCs that occur over time. To ensure the RW management structures remain fit for duty, the CNSC uses a rigorous, risk-informed, compliance verification programme which includes routine inspections at nuclear facilities. To improve the regulatory framework, the CNSC developed the *Harmonized Plan* which identifies, prioritises and manages improvement opportunities. NUREG-1927, *Standard Review Plan for Renewal of Specific Licenses and Certificates of Compliance for Dry Storage of Spent Nuclear Fuel* provides guidance to the US Nuclear Regulatory Commission (NRC) staff on how to assess a licensee's proposed ageing management activities. The *Managing Aging Processes in Storage (MAPS) Report*, which was issued in July 2019 (US NRC, 2019), provides expanded guidance for NRC staff regarding potential ageing mechanisms in the context of renewals of licences and certificates of compliance for the storage of SF.

Societal challenges

More countries are now realising that although interested and affected communities may lack technical expertise, they do have strong and legitimate views regarding how RW should be managed. The major limiting factor to the slow progress of national RW management programmes made to date has been the lack of public support and confidence. Many social issues are linked to a lack of public trust in the nuclear industry and governments, the accountability of nuclear organisations, obligations to future generations and the fairness of decision making. Societal resistance and distrust have been witnessed in a number of countries (e.g. France, Japan and the United States) particularly in siting RW facility and planning RW transport on public roads. To face these challenges, deeper understanding of past difficulties encountered in public interaction and new ways of managing these social issues must be sought.

Public and stakeholder involvement

The benefits of engaging local communities in the development of plans for the disposal of RW have long been recognised. Despite some NEA member countries having experienced difficulties with public stakeholder engagement, most partnerships have been found to provide useful forums for exchanging information. In Belgium, the partnership with the local communities of Mol and Dessel developed for the integrated surface disposal project provides a communication platform which is also beneficial for storage activities. In the United States, the final report of the Blue Ribbon Commission on America's Nuclear Future (BRC), published in 2009 after the Obama Administration's decision to halt work on a repository at Yucca Mountain, recommended a consent-based approach to siting storage or disposal facilities. The US Department of Energy (DOE) is therefore planning to engage tribes, states, stakeholders and the general public to discuss the development of a phased, adaptive consent-based siting process. The NRC has made a significant effort over the last few years to increase its interactions with members of the public and to increase the resources to be spent for this purpose. The NRC has made it a priority to communicate to stakeholders the roles and responsibilities of the organisation, and its mission to protect public health and safety. In addition, the NRC provides many opportunities for stakeholders to comment on NRC activities.

In Canada, the Nuclear Waste Management Organization (NWMO), which is responsible for the long-term management of SF, engages with local communities as well as with regional government, and elected representatives at both the federal and provincial levels. The NWMO explores topics of common interest (e.g. transport) with interested stakeholders through shared learning and planning while fulfilling the duty to consult aboriginal people in evaluating potential access to public land. The NWMO is developing its adaptive phased management (APM) project with Canadian citizens to reflect its values, priorities and objectives. The APM is to be implemented in steps, with review and reflection of continuous learning to adapt plans in response to evolving societal expectations and values, as well as changes in public policies. The APM is expected to be implemented in a collaborative manner with the people who would be affected to make sure that the project, and its advancement, continues to be aligned with societal expectations. The approach used in the selection of a site, for example, was to develop the siting process collaboratively with a cross-section of Canadians to make sure it reflected citizen values, objectives and priorities. This collaborative approach is intended to bring people together in an area to learn about the project and reflect on whether it is a good fit with the area.

One of the main societal issues that have emerged from the programmes set up by different countries for the safe long-term management of RW has been the willingness of local communities and the general population of the country to accept stakeholder involvement for the solutions proposed by national governments for the management of RW and SF. In Spain, the main challenge encountered by the national programme relates to the willingness of the population to accept the siting of storage facilities, particularly the centralised temporary storage facility (ATC); finding the best ways to make effective the public participation in the licensing process has also proven to be a challenging task. Italy and Poland, countries which do not have operating disposal facilities, have faced similar opposition from society and local communities. In Poland, the selection of a site of the repository for low- and intermediate-level waste has been opposed by a local community and the Polish general public, and further investigation for an alternative location is taking place. The opposition in Italy relates to the uncertainty on whether a national repository for the disposal of RW will ever be constructed and therefore concerns were raised over the extended period RW would be stored on-site.

In some countries opposition from the local community where a storage facility is to be built is to the transfer of waste from other nuclear facilities to that facility. In the United Kingdom, the programme of waste consolidation has allowed the number of storage facilities to be reduced, but there has been some societal resistance to the transfer of waste between sites. In France, public acceptance for storage of RW is easier to obtain if the facility is implemented within an existing nuclear site rather than at a new site. The main concerns raised by local communities is that large amounts of RW or material from different sites should not be moved to a facility and that the storage operation should not be extended over an undefined period of time, turning storage into an undeclared disposal of the waste. For example, local representatives and population in the Meuse/Haute-Marne district have agreed to the implementation of the Cigéo deep geological disposal facility, but have turned down the proposal to create any significant storage capacity within the surface facility for intermediate- and high-level waste (ILW and HLW), since they have considered only temporary storage as acceptable. Similar objections were put forward for the CEDRA facility at CEA Cadarache site and the ICEDA facility at EDF Bugey site.

Continued political and societal commitments to maintain the safety of storage

Countries that are managing their SF and RW ensure that their commitment continues by making sure that there is political, economic and societal stability in the country and by establishing a clear and comprehensive institutional and regulatory framework. In general, governments are responsible for developing policy and the general national strategy and for producing relevant regulations, while a regulatory authority has the responsibility to oversee RW producers and owners so that they meet their responsibilities and commitments in accordance with national long-term waste management plans. In Spain, for example, the 2006 General Plan for Radioactive Waste Management (GPRWM) identifies the responsibilities allocated to each of the institutional actors: the government sets the policy and strategy, the Consejo de Seguridad Nuclear (CSN) has the responsibility to stablishes the principles, criteria and regulations governing nuclear safety and the Empresa Nacional de Residuos Radioactivos SA (Enresa) has the responsibility for managing the facilities for storage.

Canada's *Policy Framework for Radioactive Waste*, released in 1996, sets the basis for institutional and financial arrangements to manage RW in a safe, comprehensive, environmentally sound, integrated and cost-effective manner. It provides the foundation for the structure of policies, legislation and responsible organisations that are in place to safely manage low-level and intermediate-level waste and SF, both in the short and long term.

In the United Kingdom, reliance is given to the regulatory system in place to ensure that a competent licensee exists with responsibility for predisposal management of raw and packaged waste. This means that site licensees can be assumed to be enduring organisations, with transfer of undertakings being appropriately managed under regulatory oversight. These undertakings include the responsibility for producing and maintaining disposable packages, together with all the associated lifetime records, safety documentation and other records for meeting any conditions and ongoing requirements, and for making provision to address any caveats imposed by the UK authority, Radioactive Waste Management.

Waste arising in the United Kingdom cover a period of over 60 years, during which time there has been a number of changes in ownership of the waste. This introduces challenges in maintaining historical records and ensuring that they are transferred and preserved in a suitable form for future use. The existence of the UK Nuclear Decommissioning Authority (NDA) is both confirmation of this and an indication of the present commitment of policymakers and government to address the legacy and new waste arising.

In Belgium, the Royal Decree of 25 April 2014, which amends the Royal Decree of 30 March 1981, determines the missions and sets out the operating modes of the National Agency for Radioactive Waste and Enriched Fissile Material.

In the United States, the NRC provides reasonable assurance of the safety and security of SF storage through its licensing and oversight programmes. NRC's current opinion, as documented in its 2014 *Generic Environmental Impact Statement for the Continued Storage of Spent Nuclear Fuel* (NUREG-2157, Volume 1), is that highly visible, hazardous material facilities are unlikely to be left abandoned or forgotten. As a result, it is reasonable that any government would, in the interest of its citizenry, ensure that appropriate oversight (e.g. monitoring, maintenance and replacement of facilities as needed) remains in place, consistent with radiation protection principles and regulatory restrictions, until final disposition of the SF occurs.

National RW management programmes now realise that social and ethical considerations must be considered in the decision-making process. Many countries are promoting a collaborative decision process that is open and transparent, with public participation. Sufficient time must be allotted to engage the affected and/or interested citizens. A flexible and adaptive management approach, with capability to adjust to corrections and that is effective in interacting with the concerned public has the greatest chance of success.

Organisational challenges

Safe management of SF and RW requires effective management of knowledge and records associated with the stored RW and SF. It is also equally essential to ensure that expertise and knowledge can be transferred, over potentially long timescales and through changes in the organisations responsible for the RW. In particular, two organisational challenges have been identified in the 2015 survey:

- record management and more specifically effective means to maintaining historical records and preserving them in a suitable form for future use;
- maintenance of competencies of experts.

Record management

Storage of RW and SF in passive safety form may last for many decades. Consequently, RW generators and long-term custodians of the RW need to be equipped with the knowledge and records they need to manage RW. Comprehensive information and records need to be assembled and preserved. Records need to be securely retained and to be accessible when required. Information should be appropriately managed so that it can persist over long timescales and through potential changes in organisations responsible for the waste.

There is an inherent threat that information contained in some records may become inaccessible over time. This may be as a result of damage to or loss of the record, or changes in technology, terminology and language. The risks associated with some of these threats may be considered low today, but they will inevitably increase with time. A risk management strategy relating to information and records would be a good practice to reduce the risk of loss. In particular, a risk register may be considered which identifies the threats over time, their likelihood of occurring and the potential consequences. The risk register, if created, should be reviewed on a regular basis and action taken, as necessary, to reduce risks to an acceptable level within the restraints of time and cost.

A common means to reduce the risk of record loss is to set up a backup recording medium. Increased assurance can be provided if information backup is performed on a frequent basis and if the recording medium used is different from that of the primary record. As in the case of most procedures, the procedures for backing up information should be documented and regularly reviewed for effectiveness. The type and amount of records handling to which a record is subjected will have a significant effect on its life expectancy. A storage regime should be established that minimises handling. Licensees or waste management organisations may choose to transfer records to an off-site archive operated by a third party. When this approach is used, licensees should ensure that the records are managed to a standard appropriate for their long-term preservation and accessibility. The case for using an off-site archive should include an assessment of the ability of the archive to meet the minimum requirements set out. Similarly, the information and communication technology (ICT) security arrangements should satisfy minimum requirements for the information stored. These arrangements should be regularly checked and assessed. The nature of the information, recording medium, storage conditions and handling will be factors in determining the review period, which should be defined in the information management strategy. Licensees or waste management organisations should remain responsible for the records relating to waste for which they are responsible (even if the records are physically located with a third party) until such time that they transfer the wastes and associated information and records to another custodian (e.g. to disposal).

The following sections describe some of the requirements to help RW generators and regulators to collect and appropriately manage the information necessary for safely managing the RW during storage. For long-term records management, the NEA Preservation of Records, Knowledge and Memory (RK&M) across Generations initiative has developed an integrated record management system to maintain awareness of geological repositories.

- Need for information management

An information management system could meet the demands likely to be inherent in the next generation of waste custodians (i.e. those who will assume responsibility for the records over the next 40-50 years). Measures could be built in the information management system to ensure the future transfer of knowledge and records. The processes applied to manage and store records may vary depending on usage and long-term value. Some records may be used in the short term up to the point when they are archived and again when RW and SF are sent for disposal. It is important that these records are managed for the longer term and can be accessed at any time. A procedure for periodic review of the records is recommended. The procedure for such review could take into account the continuing relevance of the information and the records, the suitability of the medium on which the information is stored and the needs and expectations of stakeholders.

Resources and training could be provided to ensure that record management duties can be performed efficiently by staff. These components could be considered as an integral part of the organisation's records management.

The licensee could keep records showing the receipt, inventory (including location), disposal, acquisition and transfer of all SF and RW containing significant quantities of uranium and plutonium. The records could include as a minimum the name of the shipper of the material to the storage facility, the estimated quantity of radioactive material per item, item identification and seal number, storage location, on-site movements of each fuel assembly or storage canister, and ultimate disposal. These records for SF and RW at a storage facility could be retained for as long as the material is stored and for a period, as specified by the regulatory authority, after the material is disposed of or transferred out of the storage facility. Regulators could provide guidance on the required records over which the RW and SF management organisations must exercise control.

The licensee could also conduct a periodic physical inventory of all SF and high-level RW per national requirements, which may include special or more rigorous requirements for significant quantities of plutonium and uranium enriched above 0.7%.

Each licensee could establish, maintain, and follow written material control and accounting procedures that are sufficient to enable the licensee to account for material in storage. The licensee could retain a copy of the current material control and accounting procedures until the regulatory body terminates the licence.

Given the long RW and SF management life cycle, the transfer of RW and/or SF from one licensee to another is highly probable. The current licensee could transfer its records to the new licensee and the new licensee could be responsible for maintaining these records until the licence is terminated or transferred again. The two licensees could work closely together to ensure that suitable knowledge and records are transferred, and that the handover is properly controlled and recorded. Each licensee could make available to the regulatory body for inspection, upon reasonable notice, records kept by the licensee pertaining to its receipt, possession, packaging, or transfer of SF or high-level RW. Each licensee could also periodically prepare and provide its financial report to the regulatory body. Regulators could ensure sufficient data and information on waste packages are properly recorded so that future safety assessments, access and/or retrieval can be carried out when required.

Records of SF and high-level RW could be kept in duplicate. The duplicate set of records could be kept at a separate location sufficiently remote from the original records that a single event would not destroy both sets of records. Records of SF transferred out of a storage facility could be preserved for a period of time established by the regulatory body after the date of transfer.

- Recording medium

There is no optimum recording medium and therefore the use of different media, such as paper, digital and microform records should be considered. Many records linked to the management of RW and SF are likely to be required for more than 100 years and will ultimately be transferred to a public archive to be maintained indefinitely. Licensees should consider the short- and long-term roles of records under their control and discuss the requirements of the next waste custodian and other stakeholders, in order to select the most appropriate recording medium and method of storage. Measures should be implemented to ensure that information is accessible, particularly where digital media are used. Records with different characteristics require different management approaches. A sustainable and effective record can be regarded as a combination of the following elements, which are interrelated:

- the recording medium – the selected medium should be readily available at reasonable cost and not require sophisticated preservation techniques that rely on unusual technologies or challenging storage environments;
- the primary data – this should be documented using a format that is "fit for purpose" and of appropriate quality, and can be recovered, shared and understood by contemporary and future users;
- the metadata – it is essential for the long-term preservation and access requirements that metadata comply with international and/or regulatory standards;
- information providing context – explicit links to other sources of information to aid interpretation and consistency should be added.

- Security of sensitive information and records

Information relating to RW and SF may contain sensitive information and need to be protected accordingly. Licensees should be aware of potential sensitivities and ensure appropriate security arrangements are implemented and followed. Sensitive information which relates to activities carried out on or in relation to nuclear sites or other nuclear premises may need to be protected in the interest of national security.

Maintaining competent personnel

Many countries with mature nuclear programmes are now facing challenges in recruiting experienced staff to replace an ageing workforce. The issue of long-term sustainability of the workforce is not unique to the RW management community, but also common in the nuclear sector. Both nuclear regulators and waste owners or operators have recognised the importance and urgency in maintaining competent personnel in this field, noting that adequate human resources must be in place to carry out all necessary activities without undue stress or delay. To ensure their ability to effectively respond to changing requirements in the RW management industry, many RW management organisations are increasing their efforts in their human resource and talent management practices. For workforce planning, organisations are examining the capabilities and competencies that will be required in the next decade, identifying potential risk areas and developing strategies to address the issues. To maintain a competent and engaged workforce, many employers look to new graduate recruitment for organisational renewal. Their goal is to ensure a sustainable supply of qualified nuclear engineers and scientists that can meet the current and future needs of the national nuclear sector. Many nuclear power utilities, research and regulatory agencies are supporting nuclear education in universities by providing funding and supporting education and research in nuclear science and engineering. To assist young professionals in developing the competencies required, core skills training is provided. Specifically with regard to management and leadership development, career maps and learning plans are being developed to ensure that employees are prepared for future careers while building the skills required for their current roles. Nevertheless, the lack of career opportunities still makes it an unattractive sector for young people and some member countries.

Staffing demand in the nuclear sector and in the RW management community will fluctuate, depending mostly upon attrition from retirements. Adequate succession planning and staff development in both social and technical areas are therefore essential in order to meet the staffing requirements for both the short and long term.

Chapter 4. Transport of radioactive waste and spent fuel, and related technical issues

Although in a few cases it may be possible to site the storage and the disposal facilities in such a way that transport through public areas by road, rail or ship can be avoided, such transport will be unavoidable in the majority of countries. For decades, nuclear shipments have taken place worldwide largely without serious radiological incident and often unnoticed by the general public. "The US government and the nuclear industry have been transporting nuclear materials, including a modest amount of commercial SF, for decades, without incident" (Smith, 2006).

Existing national transport regulations and legal requirements

As early as 1959, the United Nations Economic and Social Council charged the International Atomic Energy Agency (IAEA) with establishing recommendations on the transport of radioactive material. For radioactive material, i.e. for class 7 goods according to the dangerous goods classification for transport, the respective normative guidelines are issued by the IAEA. They are continuously kept up to date by a well-established procedure every two years. These recommendations can be used for the development of national requirements for the domestic transport of dangerous goods, and by international organisations such as the International Maritime Organization (IMO), the International Civil Aviation Organization (ICAO) and the Economic Commission for Europe as the basis for regulations and international/regional agreements or conventions governing the international transport of dangerous goods by sea, air, road, rail and inland waterways. Many NEA member countries are involved in the application of the above-mentioned recommendations. National variations in the implementation of these recommendations tend to be of minor importance and have been significantly reduced in the past years.

Currently, storage of radioactive waste (RW) and spent fuel (SF) and the subsequent disposal is understood as a national, rather than regional, task. For this reason, the final transport from storage sites to the national repository will in most cases be a national consideration.

The principal means for achieving transport safety is the strong reliance on the properties of the packaging for shielding and containment of the radioactive material. When transporting low-hazard material, the package must withstand normal transport conditions and operational occurrences. Package designs are specified, tested and qualified as per their applicable regulatory requirements. Package designs for high-level waste (HLW) and SF are subject to a certification process. Certificates are issued by the national competent authority on the basis of a safety analysis report giving evidence that the package design can withstand severe transport accidents while maintaining all safety functions. The validity of these certificates is limited to five years at maximum and must be renewed thereafter. Typically carriers need a general licence issued by a national or federal regulator. Most such carriers are specialised in the specific issues connected to class 7 material and are generally well known to the national regulator. In some countries, local bodies may specify certain additional transport conditions, such as prohibited or specially recommended routes.

Operational experience in radioactive waste transport

The transport frequency of class 7 dangerous goods is very low compared to the total number of transports of all nine classes of dangerous goods. Additionally, the transport of RW and SF contributes only a very minor amount to the total of number of shipments of radioactive material as they are dominated by shipments of sources for medical and industrial applications such as radiopharmaceuticals or sources for non-destructive tests. In general, national transport regulations and requirements in NEA member countries are compliant with the IAEA recommendations to a very high degree.

Foreseeable challenges and risks associated with the transport of radioactive waste

With very few exceptions, countries rely on cladding integrity for transport prior to disposal of SF. The fuel rod and its cladding can be damaged inside the reactor, during SF handling or while in storage. Analytical tests have shown that cladding embrittlement can be induced by hydride reorientation during dry storage. One of the challenges in planning for safe transport of SF is characterising the mechanical properties of the irradiated cladding, which may change due to the thermal transients during the cask drying process and the cooling of stored SF. While analytical and numerical models have been developed to predict SF behaviour, good knowledge of the characteristics and behaviour of materials during storage conditions remains essential and the potential rupture risks of SF must be properly analysed with allowable safety margins in order to ensure safe SF transport. The IAEA techniques for detecting and assessing fuel characteristics may be considered in planning for SF transport after long-term storage (IAEA, 2009).

Apart from the technological risks, the constant revision process of transport regulations, as described in Chapter 4, poses an administrative risk to the continuing transportability of any loaded and stored packages. Results of various recent activities inside the IAEA, initiated by its Transport Safety Standards Committee (TRANSSC), led to modifications in the 2018 edition of Regulations for the Safe Transport of Radioactive Material (IAEA, 2018). The major issue will be the mandatory incorporation of an appropriate ageing management programme for the design lifetime of a package ranging from the design stage until the end of usage.

After the application of ageing management procedures with positive results it should be possible to ensure safe transport of loaded dual-purpose casks or storage canisters even after several decades of storage.

In many countries, the public perception is that a large transport campaign of SF may eventually result in an accident that releases radioactivity. Potential accidental releases of radioactivity are likely to remain an explicit public concern. This may lead to strong opposition regarding potential transport routes of radioactive material to the disposal site. Governments may need to develop a communication plan and consider ways in which the safety and robustness of transport packages can be demonstrated to the general public.

Chapter 5. **Conclusions**

As proven by more than 50 years of operation, the storage of spent fuel and radioactive waste can be both safe and secure. Storage fulfils the ethical goal of keeping future radioactive waste management options open, provided that facilities are continuously monitored and maintained. For countries that are new to civil nuclear power generation, developing a programme for storage of radioactive waste and spent fuel must ensure passive safety, multiple barrier containment, robustness with adequate storage capacity and effective storage facility maintenance. Appropriately established waste acceptance criteria (WAC) for storage are the basis to verify the compliance of waste packages with a storage licence. Maintenance, monitoring and periodic inspection of the installation and the waste packages should be undertaken to ensure that the storage facilities, and the stored radioactive waste and spent fuel, are in accordance with the storage licence.

Many countries now consider storage a de facto management option for spent fuel and radioactive waste until a disposal solution is adopted. Because of the experience gained in safe storage, there appears to be no immediate urgency to implement a disposal solution. However, the long-term radioactive waste and spent fuel storage option has societal challenges and uncertainties: efforts in siting new storage facilities have encountered public resistance, while existing storage facilities require a continuing commitment of resources to achieve safety. Maintaining the safety and security of storage facilities over decades or centuries is subject to additional uncertainties. One major uncertainty is whether future generations will have the political or societal stability to maintain the institutional controls needed to guarantee safety and security. Surface or near-surface storage facilities may undergo weathering deteriorations that could eventually breach the structures and protective barriers. In addition, it should be taken into account that human access to a surface facility is much easier than access to a geological repository. All countries with nuclear programmes, including those that are planning to phase out nuclear energy, have to deal with increasing radioactive waste and spent fuel inventories. The issue of the risks posed by radioactive waste and spent fuel cannot be considered as resolved until the challenge of how to safely manage radioactive waste has been addressed in a satisfactory manner.

Interim storage is necessary in all countries with nuclear programmes, even those that are implementing geological repositories. The availability, safety and security of interim storage facilities must be ensured for as long as these facilities are needed. Since the safety of interim storage requires continuous institutional controls, it is important that geological disposal programms continue to be developed as the only currently foreseeable option for a permanent, passively safe, disposal method. Until final disposal becomes available, adequately trained staff, management support and resources for maintaining the safety of interim storage must be ensured, and means to transfer knowledge and information to future generations must be established. A continuing dialogue between the technical community and the public is essential in supporting the decision-making process and can help increase public involvement.

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Storage of Radioactive Waste and Spent Fuel

Safety remains the most important factor in managing radioactive waste and spent fuel resulting from the generation of nuclear energy. General consensus has emerged worldwide that deep geological repositories are the safest option for long-lived radioactive waste, and that constructing repositories is feasible using current technologies. However, until repositories become available, radioactive waste must be managed safely and securely so that the risks posed to human health and to the environment over the long timescales involved are minimised.

This report examines the predisposal phase of radioactive waste management programmes in NEA member countries for all types of waste from high-level to intermediate- and low-level waste, and spent fuel. It reviews regulations, policies, strategies and financial issues in member countries, as well as best practices both in terms of storage and transport. The report is primarily directed at decision makers with a technical knowledge of the subject.

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