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The Safety of Long-Term Interim Storage Facilities in NEA Member Countries

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Organisation de Coopération et de Développement Économiques
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**NUCLEAR ENERGY AGENCY
COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS**

The Safety of Long-Term Interim Storage Facilities in NEA Member Countries

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FOREWORD

Working under the mandate of the Committee on the Safety of Nuclear Installations (CSNI), the objective of the OECD Nuclear Energy Agency (NEA) Working Group on Fuel Cycle Safety (WGFCs) is to advance the understanding by regulators, technical support organisations and operators of relevant aspects of nuclear fuel cycle safety in NEA member countries.

Interim storage of spent fuel (SF) and high-level waste (HLW) before final disposal is being performed internationally using different storage concepts. Given the generalised delays in the final repository site selection and licensing processes (with a few exceptions), the temporary storage solutions that were originally envisaged to last for a few decades are faced with the need for an extension of their service life beyond their intended design life. This extension entails potential challenges to storage safety, and defines the need for additional technical knowledge on the ageing of storage facilities and on SF and HLW long term behaviour under storage conditions.

On 21-23 May 2013, the WGFCs organised a workshop on the Safety of Long-Term Interim Storage Facilities hosted by GRS (Germany). The workshop brought together about 90 participants representing 14 NEA member countries and 2 International Organisations. As part of the workshop conclusions, the representatives of member countries at the WGFCs decided to continue working on this matter, and to prepare a dedicated paper on the issue.

The WGFCs considered of interest to prepare a questionnaire to obtain additional information specific to each country represented in the working group. This document builds on the conclusions of the long-term interim storage (LTIS) workshop, complemented by the information obtained in response to the questionnaire.

ACKNOWLEDGEMENTS

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The NEA also wishes to thank the eleven member countries that responded to the questionnaire, enabling the WGFCS to complete this report. Further, Véronique Lhomme (IRSN) and Olli Nevander (NEA), secretariat of the WGFCS, gave valuable input to various chapters of the paper and contributed significantly to the final editing work.

LIST OF ABBREVIATIONS AND ACRONYMS

AECL	Atomic Energy of Canada Ltd. (Canada)
AGR	Advanced gas-cooled reactor
AMP	Ageing management programme
ASN	Autorité de sûreté Nucléaire (France)
ATC	Almacén Temporal Centralizado (Centralised Interim Storage, Spain)
AVM	Atelier de vitrification de Marcoule (Vitrification Workshop, France)
AVR	Abeitsgemeinschaft Versuchsreaktor – Pebble-bed reactor (Germany)
BAM	Federal Institute for Materials Research and Testing (Germany)
BEFAST	BEhaviour of spent Fuel Assemblies in Storage (IAEA project)
BMU	Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (Germany)
BMUMB	Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (Germany)
BNFL	British Nuclear Fuel Ltd. (United Kingdom)
BWR	Boiling water reactor
CANDU	CANada Deuterium Uranium (Canadian-developed, pressurised heavy water reactor)
CEA	Commissariat à l'énergie atomique et aux énergies alternatives (France)
CFR	Code of Federal Regulations (United States)
CLAB	Central Interim Storage Facility for Spent Nuclear Fuel (Sweden)
CNL	Canadian Nuclear Laboratories (Canada)
CNRS	Centre national de recherche scientifique (France)
CNSC	Canadian Nuclear Safety Commission (Canada)
COVRA	Centrale Organisatie Voor Radioactief Afval – Nuclear waste processing and storage company (Netherlands)
CRL	Chalk River Laboratories (Canada)
CSA	Canadian Standards Association (Canada)
CSN	Consejo de Seguridad Nuclear (Spain)
DBTT	Ductile to brittle transition temperature
DCF	Dalton Cumbrian Facility (United Kingdom)
DEMO	DEMONstration Power Station – IAEA project
DOE	Department of Energy (United States)

DRP	Direct research portfolio
EA	Environmental assessment
ECN	Energieonderzoek Centrum Nederland – Energy research centre (Netherlands)
EDF	Électricité de France (France)
EIA	Environmental impact analysis
ENSREG	European Nuclear Safety Regulators Group
ENRESA	Empresa Nacional de Residuos Radiactivos (Agency for the management of nuclear wastes, Spain)
ENUSA	Industrias Avanzadas (Spain)
EPRI	Electric Power Research Institute (United States)
ERU	Enriched reprocessed uranium
ESCP	Extended Storage Collaboration Program (DOE-EPRI, United States)
ESK	Entsorgungskommission (Nuclear Waste Management Commission, Germany)
EST	Extended storage and transportation
FCF	Fuel cycle facility
FNR	Fast-neutron reactor
GOJ	Government of Japan
GRS	Gesellschaft für Anlagen und Reaktorsicherheit (Germany)
HABOG	High-Level Waste Processing and Storage Building (Netherlands)
HAL	High activity liquid
HAW	High activity waste
HBF	High-burnup fuel
HLW	High-level waste
HSS	Human and social sciences
IAEA	International Atomic Energy Agency
ILW	Intermediate-level waste
IRSN	Institut de radioprotection et de sûreté nucléaire (France)
ISF	Interim storage facility
ISFSI	Independent spent fuel storage installation
JAEA	Japan Atomic Energy Agency (Japan)
JNFL	Japan Nuclear Fuel Ltd (Japan)
LILW	Low- and intermediate-level waste
LTIS	Long-term interim storage
LWR	Light water reactor
MCC	Mining and chemical combine

MOX	Mixed oxide fuel
MPA	Mayak Production Association (Russia)
NDA	Nuclear Decommissioning Authority (United Kingdom)
NEA	Nuclear Energy Agency
NEPA	National Environmental Policy Act (United States)
NORM	Naturally occurring radioactive materials
NPD	Nuclear power demonstration (reactor)
NPP	Nuclear power plant
NRA	Nuclear Regulation Authority (Japan)
NRC	Nuclear Regulatory Commission (United States)
NSCA	Nuclear Safety and Control Act (Canada)
NWMO	Nuclear Waste Management Office (Canada)
OECD	Organisation for Economic Co-operation and Development
ONR	Office for Nuclear Regulation (United Kingdom)
PNNL	Pacific Northwest National Laboratory (United States)
PRA	Probabilistic risk analysis
PSA	Probabilistic safety assessment
PSR	Periodic safety review
PWR	Pressurised water reactor
R&D	Research and development
RB	Regulatory body
RIS	Radiation induced sensitisation
RW	Radioactive waste
SAP	Safety assessment principles
SFP	Spent fuel pool
SF	Spent fuel
SKB	Nuclear Fuel and Waste Management Company (Sweden)
SNF	Spent nuclear fuel
SPAR	Spent Fuel Performance Assessment and Research (IAEA project)
SR	Safety report
SSM	Strålsäkerhetsmyndigheten (Radiation Safety Authority, Sweden)
STUK	Radiation and Nuclear Safety Authority (Finland)
TAST	Technical assessment guidance
TEPCO	Tokyo Electric Power Company Holdings, Inc.
TLAA	Time-limited ageing analysis

THORP	Thermal oxide reprocessing plant (United Kingdom)
TSN Act	Transparency and Safety in Nuclear Act (France)
UOx	Uranium oxide
USNRC	United States Nuclear Regulatory Commission (United States)
WGFCs	Working Group on Fuel Cycle Safety
WGFS	Working Group on Fuel Safety
WOC	Working Organising Committee
WWER	Water-Water Energetic Reactor (Russia)
ZLN	Zwischenlager Nord (Germany)

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EXECUTIVE SUMMARY

Management of spent fuel (SF) and high-level waste (HLW) is fundamental to the fuel cycle safety. The original management strategies were established on the basis of limited interim storage periods of 50-60 years, with different national approaches based on the main storage concepts: wet storage in pools and dry storage in casks or vaults.

To date, no final repository for SF or HLW is in operation, and many Nuclear Energy Agency (NEA) member countries have expressed their intention/need to plan for long-term interim storage (LTIS), and much longer interim storage periods are being considered. This situation brings additional regulatory and operational issues into focus.

With the aim of providing a discussion forum to address these arising issues, the Working Group on Fuel Cycle Safety (WGFCS) in co-operation with the Working Group on Fuel Safety (WGFS) organised the NEA workshop on the “Safety of Long-term Interim Storage (LTIS) Facilities”, held in Munich (May 2013). National activities and regulatory approaches, practices and current developments for the safety of LTIS facilities were shared and discussed among safety authorities, TSO, fuel cycle facilities (FCF) operating organisations and international organisations representatives.

As a result of the Workshop Organising Committee (WOC) conclusions and recommendations, included in the proceedings of the workshop published by the NEA (2013) ([NEA/CSNI/R\(2013\)/10](#)), and driven also by the CSNI, the WGFCS decided to develop this report. The report is based on the information presented in the workshop together with additional information supplied by the WGFCS members on LTIS requirements, research and development (R&D) needs and ongoing programmes, operational practices and experience, recording the different approaches and solutions and extracting relevant conclusions to help NEA members to learn from current experience and make informed decisions on LTIS issues in their own countries.

The collection of information has been managed through the Questionnaire included in Annex 1, developed by the WGFCS as a tool to systematically collect the necessary information to achieve a comprehensive overview of LTIS current status for preparation of the report. Through WGFCS country representatives, the Questionnaire has been covered by experts from eleven countries: Canada, Finland, France, Germany, Japan, the Netherlands, Russia, Spain, Sweden, the United Kingdom and the United States, and the raw responses provided have been included in Annex 2 of the document.

The main topics addressed in this report are as follows:

- LTIS national approaches: current practices and expectations for LTIS, including the SF/HLW updated inventory, the storage systems and strategies being in use or considered in each country, as well as the funding principles are reviewed. In general terms, all countries are faced with the need for LTIS although fostered by different scenarios.
- LTIS national regulatory framework: policy and regulations, main limits and requirements are analysed, showing that specific regulations for LTIS are not fully developed in most countries,

and high-level safety rules and principles for storage are considered applicable to LTIS. Ongoing efforts to establish more detailed regulations specific to LTIS have been reported by several countries, with the focus on renewal applications and ageing management as a key factor.

- LTIS facilities licensing process: safety analysis to support LTIS safety cases, licence timeframe and renewal processes are discussed. Licensing processes are generally based on short-term certificates, and as a response to the need for longer storage periods, several countries have extended the licence validity period for storage casks. New regulatory processes are applied for both storage casks and facilities licence renewal, based on the results of the periodic safety review (PSR) that is usually performed every 10 years. Ageing management and SF behaviour are key factors to demonstrate the safe operation for the next licensing term. Compliance with the safety case applicable in the subsequent transportation step is also addressed, though there is little agreement.
- LTIS technical gaps and challenges are reviewed, and national programmes developed to address them, as well as research and development (R&D) needs. Main issues are related to demonstrating performance in the long term: integrity of SF, especially for high-burnup fuel, and ageing management of storage system associated components.
- LTIS considerations resulting from the Fukushima lessons learnt: the assessment of the potential impact of the Fukushima Daiichi accident on LTIS facilities is surveyed, and in general terms a limited effect is reported. Some changes to the facility design and recommendations for improvement in specific areas have been identified.
- LTIS cross-cutting issues: knowledge management, preservation of records, continued facility surveillance, public confidence, political commitment and financial resources are identified as relevant issues for LTIS.

The updated information provided by eleven NEA member countries in the LTIS questionnaire reflects major differences in the importance of the long-term process and various ways to address it. The LTIS characteristics and their relevance are strongly dependent on the framework established by the different national strategies developed for the management of the fuel cycle backend. The three main options identified are as follows:

- Direct disposal of spent fuel and high-level waste: Some countries have a disposal facility already designed and undergoing licensing, and therefore the interim storage period is planned to be limited.
- Long-term (more than 50 years) storage before transfer to a future final disposal facility: In this case, the design of the facility is still in the conceptual phase, and the licensing process is not started.
- Reprocessing option: After a limited cooling time, the SF will be transported to the reprocessing facility.

The different national strategies in NEA member countries are combining the three options, often based on political and legislative decisions far from technical argumentations. The different boundary conditions in each country, lead to a variety of strategies and timeframes, and therefore LTIS facilities have different roles in the fuel cycle, although in one way or another LTIS is always necessary.

However, the following issues for future co-operation in the international level are necessary:

- Co-operation for establishing more detailed and LTIS specific rules and regulations with the focus on ageing management of LTIS components.
- Gathering and assessment of the information on the SF behaviour for demonstrating the safe operation in LTIS and subsequent transportation conditions.
- Research and development work in order to close the common technical gaps identified.

1. INTRODUCTION

When the nuclear fuel is removed from the reactor after irradiation, it is initially stored under water in the nuclear power plant (NPP) pools. The spent fuel (SF) pools were not designed to store all of the SF produced over the complete lifetime of operation of the NPP. Most reactors have addressed this issue by changing the racks in the SF pools, using rack designs with a reduced distance between the fuel assemblies to increase the storage capacity. However, this reracking process again does not provide the storage capacity needed for the entire lifetime of operation, and it is necessary to unload SF from the pool in order to continue operating the plant. In case the facilities for the backend steps of the fuel cycle are not available (repository, centralised storage facility, or reprocessing facility), the only option is to build additional on-site storage, either wet or dry.

As a result, interim storage of SF and high-level waste (HLW) before final disposal or fuel reprocessing is being considered or performed internationally using different storage concepts. Given the generalised delays in the final repository site selection and the associated licensing processes (with a few exceptions), the temporary storage solutions that were originally envisaged to last for a few decades are faced with the need for an extension of their service life beyond their intended design life. The duration of this extension may be well over one hundred years, and entails potential challenges to storage safety. Consequently, there is a need for additional technical knowledge on the ageing of storage facilities and on SF and HLW long-term behaviour under storage conditions.

Whatever the fuel cycle option adopted, the SF and HLW would need to be transported after the extended period of storage. There is concern that the potential ageing and degradation processes during storage may change the condition of SF and HLW, and can hence have an impact on the capability of the waste package to fulfil the transportation safety functions.

The extended duration of SF and HLW management schemes that include long-term storage gives rise to additional needs that can be quoted as non-technical, and include preservation of knowledge and information, social implications, and other.

The purpose of this paper is to review the status of these issues in Nuclear Energy Agency (NEA) member countries, and to give an overview of how the associated challenges are being faced. The paper is based on the conclusions of the NEA Workshop on Long-term Interim Storage (LTIS) that was held in Munich in 2013 (NEA, 2013), complemented with the information provided by 11 member countries of the Working Group on Fuel Cycle Safety (WGFCs) (Canada, Finland, France, Germany, Japan, the Netherlands, Russia, Spain, Sweden, the United Kingdom and the United States) in response to a questionnaire that covered all the issues mentioned. The text of the questionnaire is included as Annex I of this paper, and a compilation of the responses is in Annex II.

2. NATIONAL APPROACHES

Generally speaking, the options available for the backend of the fuel cycle can be arbitrarily termed as follows:

- Direct disposal: after a limited cooling time at the nuclear power plant (NPP) wet storage, the spent fuel (SF) and high-level waste (HLW) is transported to a centralised storage facility (either dry or wet) that serves as the buffer for the disposal installation.
- Storage and disposal: in this case the disposal facility is not available yet, dictating the need to store the SF and HLW for periods of time of a duration dependent on the country situation. This need is covered by the construction of additional storage installations at the NPP and/or centralised storage facilities, in order to accommodate the excess inventory that gradually accumulates.
- Reprocessing: after a limited cooling time at the NPP wet storage, the SF is transported to a centralised storage facility (either dry or wet) that serves as the buffer for the reprocessing facility.

The need for long-term interim storage (LTIS) depends on the approach followed in each country, but also on the complete adherence of the real SF and HLW management to the approved concept plans and schedules. The following paragraphs provide information on the SF and HLW under storage in some countries, and review the status of the three strategies described above in representative countries.

2.1 Inventory of stored fuel and high-level waste

The current inventory of SF and HLW stored in the different countries, based on the information provided, is included in Table 1. Although the survey is limited to a total of 11 countries, it should be noted that all the strategies that can possibly be used for SF and HLW management are represented. As a result, some relevant observations can be made, even if the information from some important countries is missing.

Most countries have already transferred fuel to dry storage, either in casks or in centralised facilities such as vaults or silos. The exceptions are those countries in which SF reprocessing is (or has been) the preferred option, as well as those countries aiming to direct disposal of the fuel. The inventory of SF in dry storage is already rather high, and increasing. Absolute total numbers of the stored inventory are difficult to obtain, the data being given in different units (i.e. CANDU fuel bundles, light water reactor (LWR) fuel assemblies, number of loaded casks or mass of heavy metal).

As a result of this increasing inventory, independent on-site interim dry-storage facilities have been built in at least 5 of the countries surveyed, and on-site wet interim storage facilities are also in operation in Russia. The number of dry-storage facilities currently licensed is close to 100 in those 5 countries only, and the corresponding number of LWR SF casks loaded amounts to thousands of casks.

Centralised SF storage facilities have been built in many countries. Wet storage is the preferred approach in countries reprocessing SF or aiming for direct disposal, while dry storage is used in the rest. Russia is currently operating both wet and dry SF centralised storage facilities.

Regarding HLW, the inventory is obviously very high, and continuously increasing, in the countries reprocessing SF. Generally, the HLW is vitrified and converted into pellets that are loaded in welded canisters. The canisters are stored in dry facilities of different designs or, in the case of Germany, in dry-storage casks similar to those used for SF. The final option chosen in all cases is disposal, meaning that a long storage time of the HLW canisters can be expected.

It is noted by some countries, notably Russia the big amount of accumulated high activity liquid (in the range of tens of thousands of cubic metres) that would need to be conditioned for disposal.

2.2 Direct disposal

Direct disposal of SF and HLW can only happen in those countries that have an approved final repository installation or have a solid perspective of obtaining an approval for the facility in the short term. Among the countries surveyed, only Finland and Sweden are in this situation. The Finnish government granted the construction licence for the final repository in November 2015, and a similar approval by the Swedish government is expected in the short term.

Availability of a final repository reduces the SF storage period duration to less than 50 years, hence avoiding the potential concerns raised by long-term storage before SF transportation. Wet storage at the NPP is performed in both countries, without SF transfer to dry-storage casks. Accumulated experience is available that demonstrates the feasibility of safe wet storage of SF for periods up to 50 years (IAEA, 1999).

In the case of Sweden, the fuel is later transported in dry casks to a centralised wet storage facility (CLAB) where it will complete the cooling time required before being loaded in the repository canisters (currently 30 years). As a result, the SF is subject to two drying processes (one for loading in the dry cask used for transportation to CLAB and a second during loading in the repository canisters) and an intermediate quenching process when unloaded from the transportation cask and stored under water in the CLAB.

2.3 Storage and disposal

Countries following this strategy aimed originally for direct disposal. This approach is in fact the result of the difficulties found in many countries to designate and licence a repository site, as well as to prepare the logistics and infrastructure needed to operate it, notably transportation of SF and HLW to the site. The outcome of these difficulties is a delay in the SF management process, which has to be solved by extending the duration of the SF storage period after irradiation. As a result, the SF management systems may need to be operated for longer than originally envisaged, maybe exceeding their original design life.

In addition, the extension of the SF storage period increases the inventory of fuel that needs to be stored. The NPP wet storage capacity is usually not sufficient, and the SF may need to be transferred to dry or wet storage systems (casks) that are initially stored on-site. Eventually, transport to a centralised interim storage facility (ISF) is performed in some countries.

Table 1 show that this is the situation in countries such as Canada, Germany, Spain and the United States. The duration of the storage period needed is difficult to determine, again due to the uncertainty in the date of availability of the final repository. The licenses of the storage systems, initially valid for a range

of 20 to 50 years depending on the country, would need to be extended, and have in fact been extended already in some countries such as the United States and Germany.

Together with licence renewals, some countries have designed centralised storage facilities. The design life of this type of facilities is of 100 years in the Netherlands and Spain. Before reaching the centralised facility, the SF has already been stored under wet and/or dry conditions for a period that may have lasted several decades. As a result, when the SF is finally unloaded from the centralised facility, the total storage time of the SF after irradiation might have reached 150 years or more.

The perspective of the backend of the fuel cycle can change drastically if this type of facilities with very long design lives is available. These facilities provide a solution for waste storage for the next 100 years or more, and then a long period of time becomes available to make the necessary decisions towards a final solution. Furthermore, the long SF and HLW cooling times involved reduce the design requirements of the final management solution, i.e. heat removal capability and shielding needed.

This is the approach being used by the Netherlands. The HABOG centralised storage facility has a design life of 100 years, and no decision about a final solution will be taken at this point in time. Research on the different options will be performed, and new technologies or management approaches that will surely arise in the next 100 years will be considered. This work will be the basis for the decision to be taken in due course, one of the options being the extension of the facility design life for an additional 100 year period.

2.4 Reprocessing, storage and disposal

Theoretically, countries that reprocess SF do not have the need to store the SF for long storage periods. The best example is France, where SF is cooled for 1-2 years at the NPP wet storage. Then, it is transported in dry casks to a centralised wet storage at the reprocessing facility (La Hague), where it remains for around 7 years (minimum 5) until reprocessed. From this perspective, this approach is very similar to that of direct disposal, in the sense that the wet storage period of SF would be limited to a few decades at most. However, the HLW arising from the reprocessing operations would remain in dry storage for as long as needed pending final disposal.

Likewise, Russia pursues complete reprocessing of all fuel types, and is building facilities additional to those already in operation. In a process similar to that followed in France, the SF is cooled for a few years at the NPP wet storage, and then is transported to centralised storage facilities (dry or wet) located by the reprocessing installations.

However, not all the SF is recycled in countries that have the capability to reprocess, due to different reasons. Again in the case of France, part of the SF inventory from research reactors is not reprocessed and is dry stored until final disposal. Also, irradiated enriched reprocessed uranium (ERU) and mixed oxide fuel (MOX) fuel is currently not reprocessed due to different reasons, and remains stored at wet storage facilities, with the perspective of reprocessing in the future for re-use in Generation IV fast reactors. The wet storage capability of the reprocessing facility (La Hague) cannot be used as storage facility awaiting disposal. In case reprocessing finally does not happen, the much higher heat generation rate of MOX compared with uranium oxide (UO_x) SF for long cooling times may impose additional requirements for the disposal facility.

Other countries are using a mixed approach, in which not all the fuel inventory, or maybe not all the fuel types, is reprocessed. In the case of the United Kingdom, reprocessing has been the preferred strategy for a long time, and is still so for the complete inventory of Magnox fuel. However, advanced gas-cooled reactor (AGR) and light water reactor (LWR) fuel can be reprocessed until the year 2018 only, in which

the THORP facility will stop operations. From that time, both AGR and LWR SF will be stored in ponds waiting for disposal. Availability of the disposal facility is planned for 2075.

Japan has reprocessed some quantities of SF at foreign facilities (United Kingdom, France), and is currently building a reprocessing facility. As a result, the approach includes extensive wet storage (including independent SF storage pools) and a small fraction of dry storage during a limited period of time.

3. REGULATORY FRAMEWORK

Based on the information provided in prior paragraphs, it becomes clear that countries that are not able to follow the path of direct disposal can sooner or later be faced with the need for long-term interim storage (LTIS). This is undeniably the case of countries storing spent fuel (SF) and high-level waste (HLW) while the disposal facility becomes available, but can also happen in countries reprocessing the SF due to different reasons, at least with a part of the SF inventory.

SF and HLW storage is performed in dry conditions in most cases. The exceptions are again the countries aiming for direct disposal or those reprocessing the SF, which generally use centralised wet storage facilities for a limited storage period (few decades at most). Regulations for this type of facilities are similar to those applied to on-site SF storage pools, and there is well established operating experience for the storage time range foreseen and for the current fuel designs and materials. Hence, the focus of this chapter will be on the regulatory framework for LTIS in dry conditions, for which less operating experience exists.

3.1 Regulation of long-term interim storage

Dry storage of SF is usually made using storage casks of different designs. For HLW, both casks and dry vault storage can be used. The casks are in its turn stored in a dedicated installation, either a concrete pad in the open or inside a building, that can be located at the NPP site or elsewhere. In some cases, a centralised facility exists in which the SF and HLW is unloaded from the casks and stored again under controlled conditions. Hence, there are two licensing actions involved, the first for the regulatory approval of the storage cask design and the second for the approval of the facility design.

The regulations rely on the defense-in-depth approach based on multiple layers of protection to guarantee compliance with the storage safety functions. These functions include subcriticality, confinement, and radiation shielding and heat removal. In some countries, such as Spain or the United States among others, capability to retrieve¹ the SF and HLW from the storage system at any time is also a regulatory requirement, recognising that the waste may need to be further processed in the future before disposal. However, the precise definition of this safety function may vary depending on the specific management concept and design of the storage and disposal facilities in operation or foreseen in each country. Some approaches would need to guarantee the retrievability of individual SF assemblies, while others may only require that the complete cask or canister can be retrieved and processed (USNRC, 2015). Likewise, the design of the SF management facilities may require retrievability after storage, but not after transportation, or at least not after a transportation accident.

As shown in Table 2, the survey performed indicates that LTIS is not specifically addressed in the national regulations, the only exception being Canada. In this case, the regulations define some high-level

1. Usually, retrievability of individual fuel assemblies is defined as the capability to unload and manage the fuel using the normal handling tools and procedures.

principles for the long-term management of SF and HLW. In Germany, the general regulations are applicable for LTIS, and a discussion paper on long-term storage has recently been published (ESK, 2015).

However, the existing high-level regulatory framework could be applicable to LTIS, complemented with some detail requirements, as is the case in the United States. The Canadian regulator Canadian Nuclear Safety Commission (CNSC) has recently presented a discussion paper (CNSC, 2016) to seek early feedback from stakeholders on the opportunities presented to improve the CNSC regulatory framework for waste and decommissioning. This includes potentially consolidating and updating the requirements for the waste management programme, which encompasses the LTIS of high-level waste.

In 2010, the USNRC established a programme named “EST Regulatory Program” to examine potential issues related to EST of SF. The main goal of the EST Program is the identification of changes in the Nuclear Regulatory Commission’s (NRC) regulatory framework that might be needed to support EST of SF. Achieving this goal requires assessment of both technical and potential regulatory issues. The conclusion obtained is that there are no regulatory gaps.

In addition, some regulatory bodies (notably the USNRC, 2012) are considering the advantages of risk-informed, performance-based approaches to address the long-term storage of SF. Given the potential uncertainties associated with the possibility of multiple licence extensions, risk-informed and performance-based approaches may provide additional alternatives for ensuring safety within or beyond the long term, providing a better understanding of the probability and consequence of specific ageing degradation failures.

Regulations for the storage facility design are country specific. The main difference lies on whether the storage facility is considered as a nuclear installation with the same regulatory regime that NPPs or either there exist specific national regulations for storage facilities. Countries such as France, the Netherlands or Spain (among others) would consider SF and HLW storage facilities in the same regulatory group than NPPs, while others i.e. the United States have established separate regulations for NPPs and storage facilities.

When the regulations for a storage facility are the same than for the NPPs, a complete body of high-level rules already exists for the facility, and potential regulatory concerns such as definition of the safety case, configuration control (changes to the facility), and consideration of risk insights or facility ageing, are already addressed in the regulations. One of the requirements that will be applied to storage facilities is the need for performing a periodic safety review (PSR) and submitting it for review. It has been found that, whatever the regulatory approach used, the regulations in all the countries surveyed require PSR for storage facilities, usually every ten years. This requirement is in agreement with the contents of the applicable IAEA Safety Standards (IAEA, 2014), and is an important step for the licensing process, as will be shown in Section 3.2.

The scope and objectives of a PSR are very similar in the different countries. Taking France as an example, the PSR consists of two parts:

- An examination of the facility’s compliance with its safety documentation: this aims to ensure that any changes to the facility or to operating conditions, primarily due to modifications, obsolescence or ageing of equipment or buildings, together with any changes to the environment, are bounded by the safety case of the facility.
- A safety reassessment of the facility in light of operating feedback and, if applicable, of the currently available knowledge and the latest regulations and practices relative to safety and radiation protection.

The complete PSR contents should demonstrate that structures, systems and components important to safety will continue to perform their intended function for the next licence period up to the time when the next PSR will be performed. Ageing considerations need to be included in the analysis.

An additional potential source of regulatory requirements for LTIS facilities is the regulatory review of the consequences and implications of the Fukushima Daiichi accident for nuclear facilities. The technical aspects of this issue are covered more in depth in Section 4.5. No changes in the regulations or additional requirements derived from the Fukushima Daiichi accident have been identified in the responses to the questionnaire.

The dose limits applicable for this type of facilities are very similar in most countries, and are generally based on the recommendations of ICRP 1990. The information gathered is shown in Table 2. Most countries apply a limit of 1 mSv/year for the dose in normal operation conditions and 50 mSv in accident conditions.

Limit values for the public provided by Finland and the Netherlands are more limiting than the rest, both in normal operation and accident conditions. Both countries apply a limit of 0.1 mSv/year for normal operation. The Finnish limit is a site-specific limit for all nuclear facilities in the same site. In accident conditions, Finland applies gradual limits depending on the accident severity Class. For the most limiting case (Design Extension Conditions), the limit is 20 mSv, well below the 50 mSv limit commonly used in other countries. A similar approach is used in the Netherlands. In this case, the effective dose limits for accidental conditions are dependent on the estimated frequency of the event, ranging from 1 mSv in case of frequency between 10^{-1} and 10^{-2} per year up to 100 mSv for event frequencies below 10^{-4} . These limits are reduced for individuals below 16 years of age.

In addition, some countries apply dose restriction limit values that are below those recommended by ICRP 1990. This is the case of Spain, where the dose limit for normal operation of the centralised storage facility has been reduced to 250 μ Sv/year from the general regulatory value of 1 mSv/year.

Regarding dose limits for exposed workers during normal operation of the facility, the limits are quite homogeneous among countries (50 mSv/year and not more than 100 mSv in 5 years). France applies a much lower limit of 20 mSv in 12 consecutive months. In the case of dose limits for workers in an emergency situation, there are visible differences among countries.

3.2 Licensing

As stated before, there are potentially two separate licensing processes involved in LTIS: the licensing of the storage casks and that of the storage facility. In the cases where the fuel remains loaded in storage casks at the storage installation (i.e. the fuel is not unloaded from the cask at the storage facility), then coherence of both licensing processes in terms of licence duration and conditions is clearly needed.

In the past, dry storage casks were generally licensed for a period of 20 years, with a one-time license renewal for an additional 20-year period allowed by the regulations. Given the need to extend the storage time for an undefined period, regulations in some countries now include licences for a period of 40 years (the United States) that can be extended for additional periods of 40 years also. In the case of the United States, independent SF storage installation (ISFSI) licences and storage system Certificates of Compliance (COC) were initially issued for 20 years, consistent with 10 CFR Part 72 requirements that were in place when these licences and certificates were issued. 10 CFR 72.42 was subsequently modified in 2011 to allow both initial and renewed licences for dry storage to be issued for periods up to 40 years each. In Germany the initial licences were granted for storage up to 40 years. An extension is possible if the

licensing requirements at the time of extension are met. Furthermore the Bundestag has to be participated if a longer storage duration at a site is necessary.

The system of a limited duration licence and subsequent periodic renewals, in combination with PSR, provides a mean to periodically reassess the safety basis of storage facilities and ageing management programmes, and, if the need arises, to enhance the regulatory frameworks with new approaches to address uncertainties during extended storage.

Regarding storage facilities, the design life ranges between 40 and 100 years. The operation licence in most countries, however, has duration of 10 years that can be shorter as in the case of Canada (5 years in some cases). At the end of the licensed period, a periodic safety review of the facility has to be submitted to the regulatory authority and the review and evaluation of the PSR is the basis for the license renewal for an additional term. This licensing process allows for due consideration of the impact of ageing phenomena on the facility and on the stored SF and HLW. In some cases, additional management programmes and safety assessments are needed to demonstrate compliance with the required safety functions for an additional 10-year period.

3.3 Transportation of SF and HLW

There are a number of dry casks concepts and designs for SF and HLW. The most basic classification that can be made separates casks that can be used only for storage from those that are designed for both storage and transportation, usually called dual purpose casks. SF stored in storage-only casks would in principle need repackaging before being transferred to a centralised storage or repository, while dual purpose casks can directly be transported without additional handling of the SF. Nowadays, most casks used are dual purpose, but this has not been so in the past in some countries. In the case of Germany, the regulations require that dry storage of SF is performed in dual purpose casks.

Dual purpose casks must comply with both the storage and transportation regulations. Hence, the SF and the cask should demonstrate compliance with the general requirements for transportation included in IAEA regulations, and with the country-specific regulations for storage. Depending on the cask design and on the country regulations for storage, regulatory conditions for transportation can be more demanding than those of storage. As a result, the SF must fulfil general requirements for transportation that are additional to those usually applicable for storage in each country, and can be more restrictive.

The question arises if the transportation requirements need to be met at the time of loading the SF in the dual purpose cask for storage, or whether they only need to be fulfilled at the time in the future when transportation takes place. Countries pursuing direct disposal or reprocessing (Finland, France, Japan, Russia, Sweden) are unaffected by this question, because SF is usually transported from the NPP fuel pool to a centralised storage soon after the end of irradiation, and transportation requirements have to be met at the time of cask loading.

The situation varies in the rest of countries. The regulations in some countries do require compliance with the requirements both for storage and transportation at the time of loading the cask and transportability has to be guaranteed even after long-term storage of SF. This has also been the usual licensing practice in Spain, but there is no explicit regulatory requirement behind that decision. On the contrary, the United States does not require the cask to have a transportation certificate, and only the storage requirements and limitations have to be considered at the time of loading.

4. TECHNICAL ISSUES

Widespread initiatives have been taken during the last years to identify and address the technical issues and challenges associated with long-term interim storage (LTIS) of spent fuel (SF). Many of them have been the result of collaborative efforts among the different stakeholders. As an example, Canada's waste owners are in the process of developing a radioactive waste management industry forum for the purpose of identifying challenges among the industry and sharing best practices. Further examples of collaboration are given later.

The technical issues of SF and HLW LTIS requiring resolution have been the subject of different studies addressing the knowledge gaps (gap analysis) in LTIS and subsequent transportation. These very detailed technical studies express the views of different organisations with responsibilities in SF management. Some relevant examples are the following:

- The EST Programme of the United States Nuclear Regulatory Commission (NRC) already mentioned in Section 3.1, although focused on the identification of changes in the regulatory framework that might be needed to support EST of SF, includes also an assessment of technical issues. A list of technical information needs was published in a May 2014 in the report known as EST-TIN (USNRC, 2014), which provides a prioritised list of research needs for EST.
- Gap analysis report for long-term storage published by the USDOE (USDOE, 2012a).
- In the framework of the Extended Storage Collaboration Programme (ESCP) co-ordinated by EPRI, an international gap analysis report has been prepared (EPRI, 2012) with the contribution of organisations from several countries.
- Gaps are either specific to one or more storage systems, or considered “cross-cutting”. IAEA (2016) provides a list of specific and cross-cutting data gaps that have been identified as important by several countries.

These reports provide a comprehensive overview of the importance and priority of issues affecting SF and storage facilities. In the following, only the more relevant aspects identified in the responses to the questionnaire are covered, and the reader is directed to the referenced reports for more detailed analyses.

4.1 Fuel behaviour

Extended storage periods entail potential challenges for the SF integrity during storage, as well as during the subsequent transportation, and define the need for additional technical knowledge on SF long-term behaviour under storage conditions. In addition, whatever the fuel cycle option adopted, the SF will need to be transported after the extended period of storage. There is concern that the potential ageing and degradation processes during storage may change the condition of SF and high-level waste (HLW), and can hence have an impact on the capability of the waste package to fulfil the transportation safety functions.

Some of the more relevant issues that may affect fuel integrity during storage have been identified in the survey, and are briefly described below.

4.1.1 Hydrogen effects

As the high-temperature reactor coolant water reacts with the cladding, zirconium based cladding materials undergo outer surface corrosion during in-reactor operation, producing a zirconium oxide layer. A number of factors, notably the alloy composition, influence the rate of oxide layer formation. The hydrogen released during this chemical reaction is partially absorbed by the cladding material (hydrogen pickup). When the concentration of hydrogen exceeds the solubility limit, zirconium hydrides form. Depending on the size, distribution, and orientation, these hydrides can embrittle the cladding and reduce ductility. Furthermore, the presence of hydrides can facilitate propagation of cracks if the hydrides are aligned radially, perpendicular to the tensile stress field.

Although comprehensive experimental and modelling programmes have been performed both with fresh (pre-hydrided) and irradiated cladding, the issue is far from being resolved. The results obtained in limiting conditions of cladding temperature and hoop stress indicate that hydride re-orientation to the radial direction and cladding embrittlement may still be an issue, but when more realistic conditions are examined it appears that the associated risks may be less than previously thought. As a result, more research work is necessary to close this knowledge gap.

Hydrides precipitate preferentially near the outer surface of cladding, which is at a lower temperature than the rest of the cladding material. The hydrogen precipitation near the surface can be enhanced if there is a thermal gradient created by oxide spallation. In this case, the spalled area becomes a cold spot in the cladding, enhancing hydrogen migration to that zone and hydride precipitation. In some instances, a hydride blister containing high concentration of hydrides can be created in the outer cladding surface. These blisters are essentially brittle, and may jeopardise the capability of the cladding to withstand the loads associated to drying, storage and transportation.

4.1.2 Fuel drying

Once the cask is loaded and sealed in the SF pool, the cask cavity needs to be drained and dried. Fuel drying is a key process for potential hydrogen induced fuel failures. Cladding hydrides are typically observed to be oriented in the circumferential direction but can reorient to the radial direction, depending on the stress condition of the cladding; when it is cooled from a higher temperature, such as will occur during storage following the drying process. The United States and Japan regulations limit the peak cladding temperature during the drying process to help reduce the potential for radial hydride formation causing embrittlement and loss of ductility.

In addition, the water remaining in the cask cavity after the drying process may lead to additional cladding oxidation during storage, and hence is also a key factor to avoid fuel degradation in long-term storage. Currently available information on this matter is reduced, and further research is needed to address the issue.

The availability of water in the cask cavity may lead to the generation of Hydrogen by radiolysis. The potential for creating an explosive atmosphere inside the cask in the longer term needs to be clarified, and again deserves additional research work.

4.1.3 High-burnup fuel

SF is conventionally considered to be high-burnup fuel (HBF) if the assembly average burnup is higher than 45 GwD/MtU. High-burnup cladding is characterised by a thicker cladding corrosion layer, a dense

hydride rim and a radiation-hardened zirconium-alloy matrix. The increased hydrogen contents in high-burnup SF cladding may challenge its integrity.

HBF has also higher decay heat and higher rod internal pressure. Both factors together with higher hydrogen content make the cladding more susceptible to radial hydride formation. These potential differences in the behaviour of low and HBF have been reflected in the applicable regulations.

Furthermore, the fuel cooling over the storage period will promote hydride precipitation under stress, and if the peak temperature during drying and the cladding stress during cooling are high enough, hydride precipitation will occur in the radial direction. If the fuel cladding temperature during storage drops below a certain value, and if the total hydride content is high enough or sufficient radial hydrides have formed, the cladding behaviour will be brittle, and its capability to withstand the mechanical loads associated to normal operation and postulated accidents after extended storage may be limited.

The limit temperature for which cladding embrittlement may occur due to radial hydrides is usually termed ductile to brittle transition temperature (DBTT), and depends on many factors. Determination of DBTT for the different cladding materials is hence a difficult process that requires an extended research effort. However, an issue of concern in this issue is that only Argonne National Laboratory is performing experimental research on this phenomenon, and the knowledge of DBTT behaviour is scarce.

4.1.4 *Transport implications*

The mechanical properties of the irradiated cladding material after a long storage period are degraded by different mechanisms, mostly related to hydrogen effects, what could be particularly worse for HBF. It is important to note that even for brittle material, a large enough load must be applied to reach the failure. The above-mentioned radial hydrides issue becomes more critical, and accurate determination of DBTT values for the different cladding materials is crucial to address this potential issue. The mechanical loads associated with normal transportation conditions (i.e. vibration and shock impacts); need to be precisely determined through tests and analysis, in order to verify the fuel integrity in those conditions. Research activities have been carried out in the past to determine the real loads on the cladding during normal conditions of transport, and new experimental projects are being launched. Also Canada has reported the durability of irradiated CANDU fuel bundles under transportation conditions has been investigated performing drop tests and vibration test in Canadian Nuclear Laboratories' (CNL) hot-cell facilities.

The hypothetical accident conditions (regulatory cask drop accidents) are the most limiting scenarios for irradiated fuel from this perspective. An accurate representation of the SF condition during transport, as well as the development of advanced analysis methodologies to model the dynamic SF assembly and rod behaviour is needed to show compliance with the rod integrity requirements.

4.2 Facility design and monitoring

As required in the specific country regulations, the facilities for LTIS of SF and HLW are being designed based on existing industry codes and standards technically sound and widely accepted. However, the extended validity of this body of technical requirements and guidelines over hundreds of years can be questioned. Among other countries, this concern has been explicitly noted by France, where the validity of the industry codes and standards is considered to be limited to 50 years.

As a result, monitoring and surveillance of the facilities and of the stored materials becomes a key issue, in order to assure a continued safe operation of the facility. The monitoring information obtained is also one the inputs needed to perform the PSR already mentioned in prior paragraphs.

Leaving aside the necessary environmental surveillance of the facility during the storage period, the monitoring process should include both the facility and the materials stored. Monitoring of items such as concrete degradation, outer corrosion of storage canisters or casks, and cask seal integrity can readily be performed using standard techniques. However, monitoring of the stored material can only be performed if the stored packages can be accessed (linked to the retrievability safety function) and the means to carry the inspection of the material are available (i.e. adequate hot cell and other equipment). Given these conditions are fulfilled; a monitoring plan can be put in place to periodically retrieve selected packages for inspection of their contents.

The means to unload the storage packages and monitor the contents are not available in many cases. Also, the process could be costly in terms of radiation doses to the operating personnel, as well as challenging in many different aspects. As a result, items like the status of the fuel matrix and cladding of SF are not monitored in storage facilities. There is a need to develop techniques to monitor evolution of fuel in storage and to qualify fuel for subsequent activities. In order to minimise human intervention and waste generation, non-destructive monitoring methods should be developed.

Requirements for monitoring vary in the different countries. Canada has reported that the Canadian regulatory system is migrating towards standard licence conditions for all licensees. As part of this, licensees are required to have a waste management programme in place. Components of the waste management programme that relate to LTIS include monitoring among other characteristics, and the performance of interim storage containers and structures is monitored through normal ageing management activities.

On the other hand, Germany indicates that neither inspection nor monitoring of the stored inventory and the inside of the casks is performed.

4.3 Ageing of facilities

Understanding the phenomena involved in ageing processes of the LTIS facility structures, systems and components, as well as those affecting the stored packaged and their contents, is a key factor in LTIS sustainability. Ageing processes are always present, and should be taken into account in the facility design to the extent possible.

Sufficient knowledge of the potential degradation phenomena is needed to reliably predict the behaviour of the LTIS facility in the long term, what is essential in order to define acceptable criteria and safety margins during the storage lifetime. Predictions of ageing effects are also needed to substantiate the safety case presented in the PSR. Continued monitoring of the facility as described in Section 4.2 provides the necessary feedback for improvement of the predictions. Nevertheless, the need for research projects addressing ageing issues has been identified in the questionnaire by several countries.

The importance of the ageing issue is recognised by all the countries, which have reported numerous activities in this field. Some of them are described below.

In the United States of America, within the EST regulatory programme already mentioned in prior paragraphs, the USNRC approach is to consider the ageing of systems and components as occurring on a continuum that extends from initial licensing and renewal through longer periods of extended storage. In this regard, in evaluating component and system ageing, the NRC has considered a period of up to 300 years of dry storage. Licence renewal applications for additional 40 year terms must include evaluation of ageing effects and a description of the ageing management programme.

Two projects related to safety aspects of long-term storage of SF and heat-generating waste have been funded by the administration in Germany. In the currently funded project, basic information and data on

national and international experience is being compiled, in order to assess at an early stage the safety issues related to the long-term storage of fuel assemblies and to be able to make competent assessments of corresponding concepts and strategies for their future storage. The project has focused on the topics of ageing management during storage, the long-term behaviour of casks and cask inventories, and the exchange of experience at national and international level.

In addition, the experience gained from the pilot phase in the Gorleben site has led to the finalisation and publication of the “ESK guidelines for the performance of PSR and on technical ageing management for storage facilities for SF and heat-generating radioactive waste”, in March 2014, by the Nuclear Waste Management Commission (ESK).

In 2010, the French national agency for radioactive waste management (Andra) launched the “Memory” project, which addresses different issues related to LTIS. One of them is the performance of scientific studies concerning materials ageing.

As stated in Section 4.2, the storage containers and structures are monitored in Canada through normal ageing management activities. The ageing management programme established in Canada for SF dry-storage concrete canisters includes periodic condition survey; non-destructive tests and laboratory testing of extracted concrete cores.

4.4 R&D activities

Long-term interim storage has been the subject of an extensive R&D activity in many countries during the last years. A substantial amount of international collaboration has taken place in this field, in many instances through bilateral co-operation agreements, but also through multinational projects. The IAEA has contributed to this effort since many years now, by proposing co-ordinated research projects (CRP) such as BEFAST (IAEA, 1981-1986; 1986-1991; 1991-1996), SPAR and DEMO (IAEA, 2016). The three phases of BEFAST and the four phases of SPAR (including the phase currently ongoing) have been running consecutively from 1981, and are devoted to research on the behaviour of SF during extended storage under both wet and dry-storage conditions. The DEMO project (which official name is “Demonstrating Performance of Spent Fuel and Related Storage System Components during Very Long-Term Storage”) promotes research to gather experimental data and advance computational methods to substantiate very long-term SF performance. HBF is one of the specific issues addressed. A second phase of this CRP is currently being prepared.

A significant number of experimental studies have been conducted to determine the expected behaviour of dry-storage systems over extended storage times. Usually these tests are made under conditions that are small scale (e.g. laboratory tests), and accelerate the expected degradation phenomena that might affect the overall behaviour of the system. Based on these tests, models are developed to extrapolate the results to longer time frames. An alternative to this approach is to perform a demonstration project of significant duration, in which the complete system is tested under realistic conditions, including the system evolution with time.

Several storage demonstration projects have been performed in the past. IAEA (2016) provides a complete perspective of the demonstration work already performed. Although these past projects have been very useful, the conditions addressed in some of them do not represent the current needs regarding the fuel and system designs tested, the fuel burnup and other characteristics. Other projects have been focused on specific issues, i.e. they are not integral demonstrations.

At least two integral demonstration projects of SF long-term storage are ongoing. The USDOE has planned a demonstration project EPRI (2014), co-ordinated by EPRI, using a commercial storage cask that

will be loaded with 32 HBF assemblies, containing) a variety of cladding materials. The cask will be opened at the end of the storage period and some fuel rods will be unloaded for inspection. Sister rods of those that will be extracted have already been obtained and shipped to hot cells, to serve as reference.

In Japan, to ensure safety of transportation after the storage, some of the Japanese electric companies are conducting a long-term storage test for pressurised water reactor (PWR) SF assemblies, in the similar environment of actual casks and to confirm maintenance of the SF integrity. A two-assembly cask is used for the project. Gas samples will be taken from inside the container every 5 years for maximum 60 years to determine if any of the fuel rods have begun leaking, and confirm the fuel cladding integrity. The first of the two assemblies (a PWR with a burnup of 42GWd/MTU) was inserted in 2016 and the testing begun. The second assembly (burnup of 55 GWd/MTU) will be loaded in 2026.

The “Used Fuel Disposition Campaign” launched by the USDOE is one of the most comprehensive research programmes in place (USDOE, 2012b). Based on the knowledge gap analyses mentioned in Section 4.1, the programme objective is addressing all the relevant aspects identified that may affect long-term SF storage and subsequent transportation. The technical work in the programme is co-ordinated by Pacific Northwest National Laboratory (PNNL), and all the national laboratories in the United States are involved.

The specific R&D needs identified in the questionnaire can naturally be derived from the technical issues listed in the prior paragraphs, and in some cases have already been mentioned there. Additional R&D activities identified in the answers to the questionnaire are included in this paragraph.

The objectives and the amount of research activities varies greatly among the different countries, due to differences in the SF management programmes, in the fuel types and in the storage facility design. In some cases, such as the Netherlands, the research interest lies exclusively in the SF disposal, without any research need identified for LTIS. In other cases, like that of Russia, it is deemed that sufficient information and knowledge exists to support SF storage for periods up to 50 years, so that research would be needed only for longer storage terms.

The CNL is currently evaluating the need for an R&D programme to investigate the current conditions of the stored fuel. The goal of the investigation would be to obtain information required to support the long-term SF management strategy. Broad objectives could include providing the basis for potential life extension of the existing storage systems, for improving dry-storage technology, and for preparing the stored fuel for repository disposition in a safe and most cost-effective way.

Germany focuses the R&D efforts in the possible long-term material degradation effects due to the extended exposure to radiation, heat and mechanical loads. These apply to fuel claddings, as well as to safety related cask components, like metal gaskets or the polymer neutron shielding components.

Based on the responses to the questionnaire, research activities regarding HLW are limited. In the case of Japan, it is deemed that additional research on HLW is not needed. The United Kingdom is making research focused around durability studies of containers associated with eventual geological disposal of HLW. In Russia, the main issue to be solved is processing the accumulated inventory of liquid HLW from reprocessing. Research activities to develop new techniques are being carried out.

An example of a country-specific issue needing R&D activities is provided by the United Kingdom. From 2018 onwards, SF from the United Kingdom’s second fleet of nuclear power stations, the advanced gas-cooled reactor (AGR), will be stored in ponds awaiting geological disposal. This follows the planned closure of reprocessing facilities at Sellafield. During wet storage, however, the fuel’s cladding can be susceptible to corrosion due to radiation exposure during reactor operation. This phenomenon, known as

radiation induced sensitisation (RIS), has seen significant research over the last decades. Understanding has increased in recent years, following improvements in corrosion modelling and material characterisation, alongside. Availability of irradiation facilities such as the Dalton Cumbrian Facility (DCF), with a particular focus on whether RIS will limit long-term (i.e. more than 25 years) wet storage of AGR fuel, is key. The DCF will be used to irradiate small samples of cladding materials to induce RIS, hence reducing the level of experimental work required on actual spent AGR fuel.

The United Kingdom has also setup a Direct Research Portfolio (DRP) to address general issues in areas of strategy, technology innovation and skills. The project base is the work performed at universities, and includes waste management issues and the management of SF and nuclear materials.

In addition to the demonstration project described above, Japan is performing research activities on the design and operation of concrete storage systems and on stress corrosion cracking of canisters for concrete cask storage system.

4.5 Impact of the Fukushima Daiichi accident

The earthquake off the eastern coast of Japan on 11 March 2011 and the resulting flooding by a tsunami triggered a nuclear disaster at the Fukushima site. All the nuclear installations, including SF and HLW storage facilities have undergone risk and safety assessments ("stress tests") aimed to check whether the safety standards used when the facilities got their licences were sufficient to cover unexpected extreme events, beyond the design basis of the facility. Specifically, the tests measured the ability of nuclear facilities to withstand damage from hazards such as earthquakes, flooding, terrorist attacks or aircraft collisions. A report has been prepared by each country containing the results of the tests, and the measures taken and design changes performed in view of the results obtained. The country reports can be found at the NEA website.

The scope and criteria for the "stress tests" process were originally defined for application to NPPs. Adaptation of the process to other nuclear facilities in the fuel cycle has not been uniform, so that some small differences in the approach can be found among the different countries. Nevertheless, these differences do not affect the correct compliance with the process objectives.

This issue has been highlighted by the United Kingdom, noting the significant differences between NPPs and the Sellafield site which is instead centred around two reprocessing facilities (Magnox and THORP), with a supporting infrastructure of waste processing and storage facilities, coupled with a legacy of high hazard older facilities. To support the requirement to analyse beyond-design-basis events and the subsequent loss of safety critical utilities (as experienced at Fukushima), Sellafield Ltd. has developed two further processes, Severe Accident Analysis and Resilience Evaluation, to enable a more developed understanding of both potential fault states and the required responses. These processes use the very developed understanding already in place because of a comprehensive programme of safety cases.

Regarding storage installations, some of the countries surveyed have focused on the potential impact on wet storage facilities only. This is the case of i.e. Canada, Finland and Sweden, and the issues addressed include preservation of the fuel pool integrity and generation of hydrogen among other issues. The results of the tests have led to improvements in the seismic design, ultimate heat sink, fuel pool cooling systems and instrumentation.

Russia has developed geodynamic, seismic and geotechnical systems to monitor the sites and the buildings at the Mining and Chemical Combine (MCC) complex, and has performed analysis of beyond-design-basis accident scenarios. The analysis has led to the identification of relevant measures ensuring effective management of such accidents, including seismic reinforcements.

Finally, at least three countries (Germany, the Netherlands and the United States) have reported that the revision process has not identified any vulnerabilities leading to relevant changes or to additional safety measures.

5. OTHER ISSUES

The extension of the storage periods up to 100 years and more gives rise to additional issues of a non-technical nature, which may either facilitate or obstruct the deployment of long-term interim storage (LTIS) facilities, e.g. legal, institutional, industrial, economic and social factors.

To this respect, the questionnaire focused in questions such as knowledge management, preservation of records and social memory, in order to preserve information for future generations while maintaining technical and societal oversight of the facilities for as long as necessary. While these three aspects are important components of today's safety culture, it has to be recognised that it has not been so in the past, and that maintaining this safety culture in the long term is more problematic.

The work performed in this area so far has generally been related to geological repositories, but the vast majority of the approaches and conclusions obtained are applicable to many long-term projects running across generations and in particular to LTIS. The Radioactive Waste Management Committee of the NEA published in 2014 a Collective Statement on these issues for the post-closure phase of a repository (NEA, 2014). Many of the principles and advices in that paper are applicable to LTIS in a rather straightforward manner. One of the forefront conclusions of the Statement is that the planning for future records, knowledge and memory preservation is best addressed while waste management plans are designed and implemented and funding is available.

5.1 Knowledge management

The problem of knowledge management has been identified as very important by many countries, and related activities have already been launched in some of them. In the case of Germany, the issue of knowledge or personnel management (as well as record keeping) is already addressed in the current "Guidelines for dry cask storage of SF and heat-generating waste" (ESK, 2013).

The experience of the Swedish Radiation Safety Authority (SSM) in trying to maintain review competence during the very long timescales associated with a repository programme can be of interest. Although SSM has been preparing for the licensing of a SF repository for decades, it has not been possible to fully take advantage of these preparations due to staff turnover. SSM has compensated for this problem by procuring international experts in the review process. Nevertheless, knowledge management and systematic transfer of staff experience to newly employed staff are identified by Sweden as an area for improvement.

The same problem of ensuring the availability of qualified staff through the years is reported by the Netherlands, aggravated by the fact that the countries' nuclear programme is small, and the available group of experts is correspondingly reduced. The organisation in the Netherlands licensed to manage and store high-level waste (HLW) and spent fuel (SF) will have to preserve at least a minimum of qualified staff for the foreseen storage period of 100 years. To mitigate the problem, the same solution of obtaining additional expertise from the international arena already used by Sweden is proposed.

5.2 Preservation of records

As stated in (NEA, 2014), preservation of waste material and facility records is essential to enable future members of society to make informed decisions, and is part of responsible, ethically sound, sustainable radioactive waste management, and is in line with a prudent approach regarding safety. While this issue has been identified as very relevant by most countries, only three of them have reported activities in this field.

In the framework of the “Memory” project already mentioned in Section 4.3, the French national agency Andra is performing work aimed to continue to create and improve the memory of and records about the disposal facilities, as well as to address issues specific to human and social sciences. In addition, in 2011, Andra set up a multidisciplinary steering committee to create a consortium of laboratories for cross-cutting human and social sciences. The committee includes researchers from different research and university institutions, and the general central research topic for the consortium is “transmission between generations and understanding of long time scales”.

The practical solution adopted by the Netherlands ensures the preservation of information on the stored waste and its history by technical means: all data are preserved in a double archive, using both digital as well as conventional paper data storage. A distinction is made between the short-term archives (<15 years) and the long-term archives (>15 years). For the long-term archive, additional measures are taken. The digital information is stored in two different buildings and a procedure exists to update this information at regular intervals. Paper information carriers are printed on certified durable paper and ink and stored in a conditioned room.

Finally, one of the components of the waste management programme required to all licensees that relate to LTIS (see Section 4.2) is record keeping, as well as staff training.

5.3 Facility surveillance

Facility surveillance during its complete operational life is a key issue from many perspectives. In the case of France, surveillance of the facility and of the stored material is identified as a specific safety function for the facility, at the same level than maintenance or ageing management.

Storage facilities with a design life in the order of centuries imply that there would need to be a permanent institutional control of the facility by the public powers during that extended period, and that the regulatory activities will also be maintained. Experience shows that societal changes in just 100 years are remarkable, so that it is difficult to be confident that surveillance and maintenance of the facility will be performed indefinitely. This line of reasoning makes the use of passive controls at the LTIS facility, which do not rely on energy supply or human actions, to be the preferred choice for maintaining safety, because of their higher reliability, lower operating costs and reduced reliance on institutional controls.

Moreover, as indicated by France, the concept of “long-term duration” should also lead to question about the sustainability of the facility management by an operator, over a period of time when a decline or disappearance of nuclear industrial activity could be possible.

5.4 Public confidence

The public confidence on the role of LTIS within the management solution of SF and HLW is perhaps the main problem that needs to be faced. LTIS means in fact that the main decisions as to the final solution of radioactive waste are postponed in time, passing the burden of that solution to new generations. Postponements are being repeated for decades in most cases, even though no framework for extending storage beyond the long-term exists in many cases.

Transparency and communication are an integrated part of the operations of the HLW and SF management organisation in the Netherlands (COVRA). Because of the long-term activities, COVRA can only function effectively when it has a good, open and transparent relationship with the public and particularly with the local population. When COVRA in 1992 constructed its facilities at a new site, it took it as a challenge to build a good relationship with the local population. From the beginning attention was paid to psychological and emotional factors in the design of the technical facilities. All the installations have been designed so that visitors can have a look at the work as it is done. Creating a good working atmosphere open to visitors was aimed at. The idea was not to create just a visitors centre at the site, but to make the site and all of its facilities the visitor's centre.

5.5 Financing

The issue of allocating sufficient financial resources for ultimate waste management is paramount, especially when the option of LTIS is chosen. In all of the countries surveyed financial support for SF and HLW storage is the responsibility of the waste generators ("polluter-pays principle"), and it is enforced by law. The system to obtain the funds is usually based in collecting a periodic fee while the facilities are in operation. The amount of the fee can be either fixed by the Government (case of Spain and Sweden), or else the operators calculate the total cost of waste management and reserve the necessary funds. In both cases, the amount of funds needed is updated periodically, and the fees are updated accordingly.

However, although the principle of the operator being responsible for the financial resources needed for radioactive waste management is generally applied, there are exceptions in some countries in which mixed approaches including public financing are in place. It is for instance the case of Russia, where the establishment of centralised SF storage facilities is funded by the federal budget, whereas the costs associated with SF storage and reprocessing are covered by operating organisations and through the federal budget.

Taking France as an example, an arrangement to ring-fence secure financing of long-term nuclear costs, instituted by the Waste Act and codified in the Environment Code, provides for the creation of a portfolio of dedicated assets by the nuclear licensees during the period of operation. To do this, the licensees are required to make a prudent evaluation of the long-term costs, including the cost of decommissioning and the costs linked to management of the spent nuclear fuel (SNF) and radioactive waste (owners pay for processing), create the relevant provisions and ring-fence the necessary assets for coverage of these provisions. The law comprises monitoring measures and sanctions. The licensees are required to issue a report every three years.

However, although the principle of the operator being responsible for the financial resources for waste management is generally applied, there are exceptions in some countries in which mixed approaches including public financing are in place. It is for instance the case of Russia, where the establishment of centralised SF storage facilities is funded by the federal budget, whereas the costs associated with SF storage and reprocessing are covered by operating organisations and through the federal budget.

Adoption of the LTIS strategy may pose a challenge on the radioactive waste management financing. LTIS implies higher expenditures, because more funds are consumed to finance additional steps in SF management for an extended period. That period will surely be longer than the operational life of the nuclear facilities, and hence probably beyond the end of the fee collection. In addition, costs are increased due to the need to build additional storage facilities that need to be maintained, surveilled and where ageing should be managed.

Financial and economic factors have an impact on the issues covered in this chapter. The lack of adequate budget would jeopardise the capability to preserve records and maintain data archives, because systematic documentation and its maintenance require human and financial resources. It has been found in

(NEA, 2014) that much information on waste disposal sites has been lost due to missing budgets for record making and keeping. In the survey performed in that reference, this problem shows up in nearly all the cases investigated.

Table 1: Overview of SF and HLW management: policy, inventory and facilities by country

Country (Year of information)	Policy	Inventory		ISFSIs	Centralised facilities
		SF	HLW		
Canada (End 2013)	Storage and disposal	<ul style="list-style-type: none"> ▪ 1 503 068 fuel bundles (wet storage) ▪ 975 189 fuel bundles (dry storage) 		<ul style="list-style-type: none"> ▪ 5 at NPP ▪ 3 at research centres 	
Finland (2013)	Direct disposal	1 934 tHM in wet storage			
France (End 2013)	<ul style="list-style-type: none"> ▪ Reprocessing of SF ▪ LTIS of HLW awaiting disposal 	Wet storage: <ul style="list-style-type: none"> ▪ 12 000 tHM of UOx SF ▪ 420 tHM of ERU fuel ▪ 1 540 tHM of MOX fuel 	<ul style="list-style-type: none"> ▪ ~16 000 vitrified HLW containers at La Hague ▪ ~3 500 vitrified HLW containers at Marcoule 	Dry storage (Cascad facility) for SF from research reactors	Interim wet storage of SF at La Hague prior to reprocessing and dry storage of HLW
Germany (End 2014)	Storage and disposal	907 dry casks	113 dry casks	<ul style="list-style-type: none"> ▪ 12 at NPP ▪ 1 at research centre 	3 dry storage
Japan	Storage and reprocessing	16 869 tonnes	<ul style="list-style-type: none"> ▪ 2 035 HLW containers ▪ 415 m³ HAL ▪ > 400 000 containers of wastes from fabrication and research 		
Netherlands (End 2013)	Long-term above-ground storage	<ul style="list-style-type: none"> ▪ 85.6 m³ of SF and HLW, dry storage ▪ 5.4 m³ of waste from research centres 			Dry storage
Russia (End 2013)	Reprocessing and centralised storage of SF Conditioning and disposal of HLW	21 350 tonnes (60% RBMK fuel, 38% WWER fuel, 2% others)	> 30 000 m ³ of HAL	Wet storage ISFSIs at NPP	<ul style="list-style-type: none"> ▪ Dry storage (MCC, RBMK fuel) ▪ Wet storage (MCC, WWER fuel) ▪ Dry storage (MCC, RBMK and WWER fuel)
Spain (July 2015)	Storage and disposal	<ul style="list-style-type: none"> ▪ 13 000 fuel assemblies in wet storage ▪ 1 200 fuel assemblies in dry storage 	< 15 m ³ of vitrified HLW	3 in operation at NPP, 1 under construction, 2 more projected	Dry storage
Sweden (End 2013)	Direct disposal	6 250 tonnes in wet storage (550 at NPP)			Wet storage (CLAB)
United Kingdom	Reprocessing in the past. Storage and disposal	<ul style="list-style-type: none"> ▪ 6 500 tonnes of AGR fuel, wet storage ▪ 30 tonnes of LWR fuel, wet storage 	<ul style="list-style-type: none"> ▪ 6 000 HLW containers ▪ 7 000 tonnes of U equivalent HAL 		
United States (May 2015)	Storage and disposal	82 000 fuel assemblies and HLW in dry storage		<ul style="list-style-type: none"> ▪ 63 at NPP ▪ 3 for research waste 	Dry storage (projected)

Table 2: Overview on LTIS regulatory framework by country

Country	Specific LTIS regulation	Design life ³ (years)	Operating licence duration (years)	Licence renewal (years)	Dose limits		
					Workers (mSv)	Public	
						Normal operation (mSv/year)	Accidents (mSv)
Canada	Yes	50	5-10	Possible	50 per year 100 in 5 years	1	
Finland	No	--				0.1	1-20 ¹
France	No	50		Yes	20 in 12 months	1	50
Germany	Yes	40	40	Possible	20 in 12 months	1	50
Japan	No				50 per year 100 in 5 years	1	-
Netherlands	No	100		Yes		0.1	1-100 ²
Russia ⁴	No	50	10	10	50 per year 100 in 5 years	0.1	100
Spain	No	100	10	Undefined	50 per year 100 in 5 years	0.250	50
Sweden	No				50 per year 100 in 5 years	1	
United Kingdom	Facility dependent ³	Facility dependent	10			1	Note ²
United States	No	40		40			

1. Limits are established based on the frequency of the events: 1 and 5 mSv for Class 1 and 2 accidents, 20 mSv for design extension conditions.
2. Effective dose limits depend on event frequency: 100 mSv is for event frequency less than 10^{-4} .
3. Generally, the operating licence for interim storage facilities is valid for a period of about 10 years, and needs to be renewed based on PSR until the design life is reached.
4. Since there are no special LTIS exposure regulation the given values are related to sources of ionising radiation in general.

6. CONCLUSIONS

The capacity for wet storage of spent fuel (SF) at the nuclear power plant (NPPs) is not sufficient to accommodate all the fuel used throughout the entire operational life. Hence, it is necessary to unload SF from the pool in order to continue operating the plant. The discharged fuel is usually loaded in dry storage systems, although some examples of centralised wet storage facilities have been provided by some countries.

Due to the generalised delays in the final repository site selection in most countries, the temporary storage solutions that were originally envisaged to last for a few decades are faced with the need for an extension of their service life beyond their intended design life, leading in many cases to building of additional facilities. The duration this extension may have is not known, but may be well over one hundred years.

It is noted that long-term interim storage (LTIS) is not a deliberate decision in most cases, but the result of a need stemming from unexpected factors such as delays and repository siting difficulties, including societal aspects. As a result, there is a general need of planning for LTIS that addresses the regulatory and technical challenges needing resolution.

In general terms, the survey performed shows that all the countries are faced with the need for long-term storage of SF and high-level waste (HLW), due to different reasons:

- In countries where the repository availability has been delayed, the need is obvious. Some countries are planning centralised interim storage facilities for dry storage of SF and HLW, usually based on dry storage. The design life of those facilities is 100 years or over.
- Countries reprocessing SF and without a repository site are also affected, because not all the SF types can be recycled with the current technologies (for example, multiple recycles of mixed oxide fuel (MOX) fuel or fuel from test and material reactors).
- The few countries having a reliable repository planning (i.e. Finland, Sweden) do not need extended SF dry storage periods, and are the only exception. However, the SF is kept for decades in wet centralised storage facilities, as it is also in countries recycling the fuel.

Long-term SF and HLW dry storage entails potential challenges to storage safety. There is a need for additional operating experience and technical knowledge on the ageing of storage facilities and on SF and HLW long-term behaviour under storage conditions. As all the SF and HLW will need to be transported after storage, the potential changes in the condition of SF and HLW during storage may also affect its capability to fulfil the transportation safety functions.

Specific regulations for LTIS are not fully developed in most countries, but high-level safety rules and principles for storage are considered applicable to LTIS. Ongoing efforts to establish more detailed regulations specific to LTIS have been reported by several countries.

The licensing process for LTIS facilities is generally based in limited duration licences. As a response to the need for longer storage periods, several countries have extended the licence validity period for storage casks. A licence renewal regulatory process is applied for both storage casks and facilities, based on the results of the periodic safety review (PSR) that is usually performed every 10 years. The PSR is a review of the operating experience of the facility and a demonstration of the safe operation for the next licensing term, and is applied and graded according to the safety relevance of the different structures, systems and components.

Conditions for SF transport can be in some cases more demanding than those of storage for both the cask and the contents, and demonstration of compliance with the transportation safety functions may be more difficult in that case. This is especially true if the SF has been stored for an extended period before transportation. Some countries require the transportation requirements to be met at the time of loading the SF in the cask for storage, while others do not.

SF technical issues that need solution are deserving generalised R&D efforts. The main issue is demonstrating SF integrity in the long term. Among other factors, SF cladding integrity can be challenged by hydrogen effects, fuel drying consequences on the SF, and hydride precipitation and re-orientation. Transportation after storage is of concern, especially for HBF.

Ageing of the facilities is also a key factor in LTIS safety demonstration. Sufficient knowledge of the potential degradation phenomena is needed to reliably predict the behaviour of the LTIS facility in the long term, what is essential in order to define acceptable criteria and safety margins during the storage lifetime. Predictions of ageing effects are also needed to support the safety case presented in the PSR.

Monitoring and surveillance of the facilities and of the stored materials is necessary in order to assure continued safe operation. The monitoring information obtained is also one of the inputs needed to perform the PSR assessment, and contributes to understand ageing effects.

A compilation of the extensive research activities being performed has been included in this report, based on the R&D needs identified in the survey. It is noted that some issues have been identified as important for which no research activities have been reported.

The assessment of the potential impact of the Fukushima Daiichi accident on LTIS facilities has generally been reported to have had a limited effect on LTIS facilities. Some changes to the facility design and recommendations for improvement in specific areas have been identified though.

Non-technical issues of LTIS such as knowledge management, preservation of records, continued facility surveillance, public confidence and financial aspects have been addressed in the questionnaire.

The problem of knowledge management has been identified as very important by many countries, and related activities have already been launched in some of them. The need to maintain qualified staff for storage periods of 100 years or more may be solved gathering additional expertise from the international arena, especially in countries with a limited nuclear programme.

Preservation of waste material and facility records is essential to enable future adoption of informed decisions, and is part of a responsible, ethically sound, sustainable radioactive waste management, and is a safety related need. Several countries have reported activities in this field.

Storage facilities with a design life in the order of centuries will require a permanent institutional control of the facility by the public powers during that extended period, and the regulatory activities will also need to be maintained. The facility design may help to reduce the control needs by using passive

systems. An additional problem that should be addressed is the facility management by an operator, over a period of time when a decline or disappearance of nuclear industrial activity could be possible.

The issue of allocating sufficient financial resources for ultimate waste management is paramount, especially when the option of LTIS is chosen. LTIS implies higher expenditures, because more funds are consumed to finance additional steps in SF management for an extended period. That period will surely be longer than the operational life of the nuclear facilities, and hence probably beyond the end of the fee collection. In addition, costs are increased due to the need to build additional storage facilities that need to be maintained, surveilled and where ageing should be managed.

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**ANNEX I:
QUESTIONNAIRE FOR THE TECHNICAL OPINION PAPER ON THE SAFETY
OF LONG-TERM STORAGE FACILITIES**

AI.1. INTRODUCTION TO THE LONG-TERM INTERIM STORAGE (LTIS) QUESTIONNAIRE

The NEA Workshop on the “Safety of Long-Term Interim Storage Facilities” held in Munich (May 2013), organised by the Working Group on Fuel Cycle Safety (WGFCS) in co-operation with the Working Group on Fuel Safety (WGFS) and which proceedings have been already published by NEA, identified differences in the approaches and requirements for the long-term interim storage (LTIS) of spent nuclear fuel (SF) and high-level waste (HLW) in a number of participant NEA member countries.

As a follow-on to the recommendations stemming from the workshop, as well as in compliance with recommendations from NEA’s Committee on the Safety of Nuclear Installations (CSNI), a proposal was developed by the WGFCS to prepare a technical report to better understand the situation and requirements for LTIS in NEA member countries.

LTIS management is fundamental to the safety of nuclear installations and “state-of-the-art” information collated would be of high interest to both regulators and operators. The approach to LTIS in NEA member countries may be different and the aim of the proposal is to record these different approaches and to hopefully learn from this exchange of information and extract relevant conclusions. The review of the requirements which should be taken into account when preparing for the LTIS of SF and HLW in different member countries, will foster the exchange of information, so that differences and similarities can be identified, enabling NEA members to learn from current experience and make informed decisions on LTIS issues in their own countries.

As stated above, this information should comply with the report objective collecting the current experience, identifying challenges and determining and communicating the safety research needs associated to LTIS of nuclear fuel and high-level waste. To fully cover the report scope, the LTIS workshop information and conclusions will/should be complemented by the information supplied by the WGFCS members to get a picture as complete as possible of the current status of the issue in NEA member countries.

The following questionnaire has been developed as a mean to systematically collect the necessary information for a successful report, which scope should provide a comprehensive overview of LTIS current national activities, regulatory approaches and requirements, technical needs and R&D programmes to overcome them.

You are kindly requested to cover the questionnaire gathering the information from the responsible organisations in your country.

AI.2. QUESTIONNAIRE

1. Describe the national approach, including used or planned funding principles, and expectations for long-term interim storage (LTIS) management of spent nuclear fuel and high-level waste (HLW) in your country.
2. Describe qualitatively and if possible quantitatively also the SF/HLW inventory as well as the storage systems used.
3. Describe the LTIS strategies being in use or considered.
4. Describe the regulatory framework for LTIS: policy and regulations: <ul style="list-style-type: none"> ✓ Main limits and acceptance criteria for the environmental effects and public exposures for normal operation and accidents. ✓ Main safety design and radiation protection requirements.
5. Describe the licensing process of the storage application in your country with focus on: <ul style="list-style-type: none"> ✓ Supporting safety assessment: base case and specific requirements for LTIS e.g. ✓ Timeframe and renewal process. ✓ Transportation considerations, if any, at the time of storage.
6. Describe the main identified gaps and challenges for LTIS, as well as the national programmes developed to address them. Please include considerations on how cross-cutting issues (knowledge management, records keeping, etc.) as well as non-technical aspects (e.g. public confidence and political commitment) are addressed.
7. Describe the needs for R&D identified for LTIS.
8. Describe the considerations on LTIS resulting from the Fukushima lessons learnt.

**ANNEX II.
COMPILATION OF ANSWERS TO THE QUESTIONNAIRE**

1. Describe the national approach, including used or planned funding principles, and expectations for long-term interim storage (LTIS) management of spent nuclear fuel and high-level waste (HLW) in your country

CANADA

- SF is stored in wet and dry states at the locations where it is produced. After seven to 10 years, depending on-site specific needs and organisational administrative controls and when the associated heat generation has diminished, the spent fuel (SF) can be transferred to an on-site interim dry-storage facility.
- Each licensee managing the LTIS of SF or radioactive waste (RW) must provide guarantees that adequate financial resources are available for decommissioning of these facilities and managing the resulting RW, including SF, as per paragraph 3(1)(l) of the General Nuclear Safety and Control Regulations.
- The 1996 Government of Canada Policy Framework for Radioactive Waste states “waste owners are responsible, in accordance with the “polluter-pays” principle, for funding, organising, managing and operating long-term waste management facilities and other facilities required for their waste”.
- CNSC regulatory policy, P-290, Managing RW, describes the philosophy that underlies the CNSC’s approach to regulating the management of radioactive waste and the principles that are taken into account when making a regulatory decision.
- The Canadian Standards Association (CSA) Group has developed a standard consisting of best practices for the safe site preparation (siting), design, construction, commissioning, operation and decommissioning of facilities and associated equipment for the dry storage of SF, known as CSA N292.2-13, Interim dry storage of irradiated fuel.
- CSA standard N292.0-14, General principles for the management of RW and irradiated fuel, outlines the requirements for the management of RW and SF from generation to storage or disposal.
- The CNSC is migrating towards standard licence conditions for all licensees. As part of this, licensees are required to have a waste management programme in place. Components of a typical waste management programme that relate to LTIS include monitoring, auditing, record keeping, staff training and continuous programme review.

FINLAND

- The Finnish long-term management option for SF is disposal in the Finnish bedrock. Until disposal, SF is stored in interim storage facilities at NPP sites.
- NPP’s are fully responsible for interim storage including financing. Interim storage time for SF is expected to be 30-50 years.
- The construction license application for the final repository was submitted in 2012, and the government granted the construction license for the repository in November 2015.
- Costs for the treatment and disposal of SF and RW from NPPs are funded directly by waste producers. Waste producers, NPP licensees, are also required to pay fees to a secured waste

management fund that licensees have paid based on evaluated waste management and disposal costs. SF disposal is scheduled to start in early 2020's.

FRANCE

- In France, there is no national approach for LTIS of SF or HLW.
- Spent nuclear fuel (SNF) from NPPs, as it contains recoverable materials, is not considered as final waste according to the French regulation and, as such, is not disposed of. France has opted for a policy of processing and recycling: uranium and plutonium are therefore extracted from the SNF to be recycled in fresh fuel assemblies, and only the fission products and minor actinides, considered as ultimate waste forms, are vitrified for future disposal; the reprocessing operation packages the waste from the SNF in the form of vitrified waste packages (HLW).
- The selected strategy for managing the SF generated by civil research reactors or military activities is developed in relation to the characteristics of the fuel and involves either processing/recycling or direct disposal. However, most of the SF is sent for processing to the La Hague plant and only a minor quantity of SF is intended for direct disposal.
- The management of HLW (and ILW-LLW) is studied in three complementary directions, identified in the Act of 30 December 1991 on research into high-level, long-lived waste, and then incorporated into the Planning Act 2006-739 of 28 June 2006 on sustainable management of radioactive waste, called the “Waste Act”:
 - Reversible disposal in a deep geological layer. The Waste Act requires commissioning of a reversible deep geological disposal facility in 2025. The underground installations in the planned repository is called Cigéo (French acronym for industrial centre for geological disposal).
 - Long-term packaging and storage. The HLW waste packages are stored in facilities on the sites of the producers; this storage allows the safe management of waste pending the opening of the long-term disposal facility. In this framework, new storage installations are created or existing ones are modified in order to meet the needs (in terms of capacity, lifetime, etc.).
 - Separation and transmutation of long-lived radionuclides, the purpose of which is to remove the minor actinides from the ultimate waste as they are the main contributors to its long-term radiotoxicity and to the residual thermal load after the decay period.
- An arrangement to ring-fence secure financing of long-term nuclear costs, instituted by the Waste Act and codified in the Environment Code, provides for the creation of a portfolio of dedicated assets by the nuclear licensees during the period of operation. To do this, the licensees are required to make a prudent evaluation of the long-term costs, including the cost of decommissioning and the costs linked to management of the SNF and radioactive waste (owners pay for processing), create the relevant provisions and ring-fence the necessary assets for coverage of these provisions. The law comprises monitoring measures and sanctions. The licensees are required to issue a report every three years.

GERMANY

- Long-lasting dispute on the suitability of the Gorleben site to host a deep geological repository was the most serious obstacle to find a final solution.

- The German government initiated a new consensus-based site selection process for a HLW repository. In July 2013, the Act on the Search for selection of a site for a repository (Site Selection Act) entered into force.
- The storage licences for the storage of SF and heat-generating waste are limited to 40 years. A possibly necessary prolongation of this period depends on how long it will take until a repository will be available.
- The polluter-pays principle also generally applies to the financing of all activities related to the management of SF and RW.

JAPAN

- The GOJ will reinforce measures towards final disposal of high-level RW and take the initiative in solving this problem. However, the process will take a long time.
- In the meantime, it is necessary to expand the capacity for storing the SFs and is urgently important to broaden the range of choices for managing the SFs while ensuring safety.
- While studying a wide range of locations as possible sites, regardless of whether they are inside or outside the premises of a power plant, GOJ will strengthen its effort for facilitating construction and utilisation of new intermediate storage facilities and dry-storage facilities.

NETHERLANDS

- Dutch Policy: Long-term above-ground storage of SF and HLW.
- All hazardous and radioactive waste must be isolated, controlled and monitored. In principle, this can be achieved by storage in buildings and institutional control. It can also be achieved by landfill and near-surface disposal and maintenance of a system of long-term institutional control, or by deep geological disposal, for which institutional control is likely to be discontinued at some moment. For the options mentioned, the degree of required institutional control is the highest for storage in buildings and the lowest for geological disposal. When containment is required over periods of time longer than the existence of present society can be foreseen, doubt may be raised on the capacity of society to fulfil the control requirement.
- The cumulative waste volume (HLW, LILW and NORM) that is actually in storage (about 30 000 m³) is not economically feasible to construct a geological disposal facility. The waste volume anticipated to be collected in a period of 100 years was judged as large enough to make viable a disposal facility in the future. It is intended to dispose of all types of RW in the disposal facility since this is the only way to make the national geological disposal facility economically feasible. Storage in buildings is required. This creates at least five positive effects:
 - There is a period of 100 years available to allow the capital growth fund to grow to the desired level. This brings the financial burden for today's waste, that the generator has to pay, to an acceptable level.
 - In the period of 100 years the heat-generating HLW will cool down to a situation where cooling is no longer required.
 - A substantial volume of the waste will decay to a non-radioactive level in 100 years and has not to be stored in a deep geological disposal.

- In the meantime research into the best long-term solution can be done without pressure of time. And in 100 years from now new techniques or management options can become available.
- During the next 100 years, an international or regional solution may become available. For most countries, the total volume of RW is small. Co-operation creates financial benefits, and could result in a higher safety standard and a more reliable control.
- Consequently, it was concluded that a suitable solution is to store all radioactive waste at one place, to take over by the government the responsibility for the waste in return of a sufficient payment by the producer in order to keep control over all the RW generated. The government decided to build at one location buildings specially designed for the storage of RW for a period of at least 100 years and to prepare financially, technically and socially a deep geological disposal during this period in such a way, that it can really be implemented during the interim storage period. Of course, after these 100 years society will have the freedom to choose between continuations of the storage for another 100 years, to realise the final disposal, or to use new techniques or management options that may become available during the period of interim storage. The reasoning is that future developments and/or innovations may necessitate such an extension. The design of the above-ground facilities can accommodate such flexibility.
- The Netherlands applies the polluter-pays principle, requiring that all costs associated with RW management is borne by the generators. The utilities and the operators of research reactors agreed to build a facility (HABOG) for treatment and long-term storage of SF and HLW at the COVRA site. Both the construction and operating costs are borne. In the frame of transfer of ownership of COVRA from the utilities and ECN to the State, the utilities decided to discharge themselves from any further responsibility for management of the RW. They made a down payment to COVRA covering the discounted costs for operation and maintenance of the HABOG during the envisaged operational period (~100 years). The other customers of the HABOG pay their share of operational costs by annual instalments.

RUSSIA

- Reprocessing of all SF types is the core principle of the National Policy of the Russian Federation in the field of SF management.
- After at-reactor pool storage, SF from RBMK-1000 reactor units is transferred to wet storage facilities located in the vicinity of NPPs. Since 2012, SF is shipped from NPP sites to a centralised “dry” storage facility (first unit) at Mining and Chemical Combine (MCC).
- After at-reactor pool storage, SF from WWER-440 and BN-600 is shipped for reprocessing to PA “Mayak”. SF from nuclear submarines, some types of SF from research reactors and transportation ship nuclear facilities is also reprocessed at PA “Mayak”. Reprocessing of “damaged” SF from RBMK-1000 reactor units has been started.
- WWER-1000 SF from at-reactor cooling pools is routinely shipped to a centralised “wet” storage facility at MCC. In 2015, the second unit of the “dry” storage facility designed for WWER-1000 and RBMK-1000 SF will be completed. Thereafter, WWER-1000 SF will be transferred from the “wet” storage facility to the “dry” storage facility. WWER-1000 SF reprocessing at the Pilot-Demonstration Centre, currently being constructed at MCC, is scheduled to start after 2020.
- SF from EGP-6 reactor units is stored in-reactor pools at Bilibino NPP.

- The establishment of centralised SF storage facilities is funded by the federal budget, whereas the costs associated with SF storage and reprocessing are covered by operating organisations and through the federal budget.
- The biggest amount of HLW in Russia accounts for the PA “Mayak” facilities. These wastes generated from SF reprocessing are vitrified.
- The costs associated with HLW storage and its subsequent transfer to the national operator for disposal is covered by relevant operating organisations. It should be noted that RW disposal funds are collected into a special reserve fund of the State Corporation “Rosatom”. The fee that each organisation has to pay to the fund is determined based on the amount of RW generation and the disposal tariff established by regulatory authority. Costs associated with management and disposal of federally owned RW are covered through the funds of federal target programmes.

SPAIN

- All operating nuclear reactors (8 units at 6 sites) are storing SF at on-site pools. As of 1 July 2015, there are 3 ISFSIs operating at-reactor sites and 1 additional ISFSI in the licensing process. All ISFSIs are licensed as a design modification of the NPP, and the operating licence is granted for a period of 20 years.
- It is foreseen to have ISFSIs licensed for all the Spanish NPP. It is also expected that the license duration would need to be extended at least once for an additional 20-year period.
- The Spanish General Radioactive Waste Plan establishes that HLW and SF management priority is the interim storage at a Centralised Storage Facility (acronym in Spanish ATC). The conceptual design of the facility was approved by CSN, and the Villar de Cañas site was approved by the Government. The facility is currently under construction, and the design capacity will cover the needs for SF storage even if the operating life of all the plants is extended.
- The basic concept of the ATC operation is to unload the SF and HLW from the transport casks received at the facility and load it in specific ATC welded canisters, which are then stored in the ATC wells. The facility design life is 100 years, meaning that, if the prior SF storage time in casks is added, the total storage period can reach 140 years or even more. Therefore, the expectation for LTIS is very clear.
- Funds for SF and HLW management are provided by the utilities and companies having nuclear assets. A yearly fee, which is revised every year by the Government, is paid to a public company (ENRESA) that takes de waste management responsibility and follows the mandate in the General Waste Plan approved by the Parliament. For the NPP, the fee is based on the energy produced by the plant during the natural year.

SWEDEN

- The national strategy for spent nuclear fuel is direct disposal without reprocessing, i.e. SF is managed as waste and not as a resource in the Swedish programme.
- After cooling in the reactor site, the SF is transported by sea in a dedicated ship to the central ISF, Clab, located next to the Oskarshamn power plant. It is an underground storage consisting of two caverns with a rock cover of 25-30 m, each containing five storage pools with a storage capacity of approximately 8 000 tonnes of SF. The SF will be stored for at least 30 years before encapsulation and transport, also by sea, to the repository.

- On 16 March 2011, SKB submitted an application for final disposal of spent nuclear fuel in the Forsmark site. The facility is expected to be in operation in 2030.
- Costs for the treatment and disposal of SF and radioactive waste from nuclear activities are covered by fees that licensees are required to pay.

UNITED KINGDOM

- The NDA is the single body responsible for civil public nuclear liabilities, and for developing and implementing an estate-wide strategy and plans to deal with them.
- Plans for decommissioning the sites rely upon the availability of a final disposal solution for waste. For HAW, the chosen solution is for deep geological disposal and the availability of a repository is the key. Historically the United Kingdom's approach has been to reprocess SF, but the facilities for this are ageing or, in some cases, shut down.
- The majority of the NDA's direct income comes from the provision of SF management services including a number of contractual commitments to reprocess utility customers' SF.
- United Kingdom Government policy states that SF management is a matter for the commercial judgement of its owners, subject to meeting the necessary regulatory requirements.
- The strategy is to secure and subsequently implement the most appropriate management approach for Magnox and oxide fuels and, where possible, take advantage of these approaches to manage exotic fuels. Any remaining fuels will continue to be managed on a case-specific basis in a safe and secure manner pending subsequent disposition.
- All fuels are managed through the sequential lifecycle phases and decision points to secure the optimal management route. The most cost-effective solutions for Magnox and oxide fuels will include continued and extensive use of existing reprocessing and storage facilities. NDA intend to continue using the oxide, Magnox and, where appropriate, exotic fuels management routes in an integrated way to optimise utilisation of facilities at Sellafield and across the NDA estate.
- Magnox Fuel – planned to reprocess the entire inventory of spent fuel. A contingency of cold vacuum drying and storage in welded canisters has been developed to demonstrate feasibility.
- AGR fuel – the plan is to store the remaining fuel inventory when THORP reprocessing ceases in late 2018 in an existing modern pond storage facility potentially until a geological disposal facility is available (planned from 2075).
- LWR fuel – remaining LWR fuel at the end of reprocessing will be pond stored alongside AGR fuel.
- HLW – stored as vitrified product in stainless steel canisters within a modular vault dry store.

UNITED STATES

- Currently, all US operating NPPs are storing spent fuel in NRC-licensed on-site spent fuel pools (SFP) and a majority also have spent fuel in dry storage in NRC-licensed ISFSIs located on-site. Commercial HLW remains stored at the operating nuclear power reactors. In January 2013, the US DOE published the *Strategy for the Management and Disposal of Used Nuclear Fuel and*

High-Level Radioactive Waste. The Administration currently plans to implement a programme over the next 10 years that:

- sites, designs and licences, constructs and begins operations of a pilot ISF by 2021 with an initial focus on accepting used nuclear fuel from shut-down reactor sites;
 - advances towards the siting and licensing of a larger ISF to be available by 2025 that will have sufficient capacity to provide flexibility in the waste management system and allows for acceptance of enough SF to reduce expected government liabilities; and
 - makes demonstrable progress on the siting and characterisation of repository sites to facilitate the availability of a geologic repository by 2048.
- As noted in the 2013 Strategy, full implementation of the strategy will require legislation which should include requirements for consent-based siting; a reformed funding approach to provide sufficient and timely resources; and consideration of a new organisational structure for implementation of the programme.

2. Describe qualitatively and if possible quantitatively also the SF/HLW inventory as well as the storage systems used

CANADA

- Inventory (as of 31 December 2013):
 - number of SF bundles in wet storage: 1 503 068;
 - number of SF bundles in interim dry storage: 975 189.
- Storage systems:
 - Wet storage – This is the immediate type of interim storage utilised following the discharge of fuel from the reactor. The irradiated fuel bays, together with the cooling and purification systems, provide containment, shielding and sufficient heat transfer. The walls and floors of CANDU reactor water pools are constructed of carbon steel reinforced concrete that is approximately two metres thick. Inner walls and floors are lined with a watertight liner. The bay structure is seismically qualified.
 - Dry storage – There are currently three basic designs for the interim dry storage of SF in Canada. All container types provide sufficient shielding that no additional barriers are required:
 - AECL concrete canister – Cylindrical in design with a reinforced concrete shell and internal liner. 54-, 38- and 60-bundle storage capacity. These containers are stored outdoors.
 - Modular Air-Cooled Storage (MACSTOR) system or CANSTOR (CANDU Storage) modules – The original design was reinforced concrete structure holding 20 vertical steel cylinders, each of which holds 10 sealed baskets of 60 SF bundles, or 12 000 bundles. These structures are stored outdoors.

- OPG dry-storage container – transportable containers that are rectangular, with walls of reinforced, high-density concrete sandwiched between interior and exterior shells made of carbon steel. Each container holds 384 fuel bundles. These containers are stored indoors as an additional contingency measure in fitness-for-service.

FINLAND

- The two storages in Finnish NPP sites are pool type storages. All SF generated in Olkiluoto NPP is stored at Olkiluoto interim storage (1 374 tHM, year 2013). Loviisa NPP SF was exported to Soviet Union and Russia until 1996. The rest of Loviisa SF is stored in NPP interim storage (560 tHM, year 2013).

FRANCE

- Regarding the inventory of nuclear fuel stored in France pending processing/recycling, or direct disposal in some cases, solutions, at the end of 2013 the situation was as follows:
 - Spent UOX fuel: 12 000 tHM in total, with 3 700 tHM on the sites of the 19 PWR NPPs, and about 8 200 tHM at the La Hague processing plant. 30 tHM of fuel from outside France were also stored on the site at La Hague.
 - Spent ERU fuel: 110 tHM on the site of the NPP in Cruas, together with about 310 tHM at La Hague.
 - Spent mixed oxide (MOX) fuel: 340 tHM on the sites of the 6 PWR NPPs authorised to use this type of fuel, together with 1 200 tHM at La Hague.
 - Spent fast-neutron reactor (FNR) fuel: 105 tHM of fuel from the Superphénix reactor on the site at Creys-Malville, 38 tHM of fuel from the Phénix reactor at the reactor's site, at Marcoule, and at La Hague.
 - Spent oxide fuel from civil research reactors: 57 tHM on the CEA sites and 5 tHM on the site at La Hague.
 - Spent metal fuel from the experimental CEA reactors and gas-cooled reactors: 15 tHM on CEA sites and 4 tHM on the site at La Hague.
 - Spent nuclear fuel from nuclear propulsion: about 156 tonnes.
 - Fresh FNR fuel (fuel that has not been irradiated in the *Superphénix* reactor because the reactor was shut down permanently in 1998): 72 tHM on the site at Creys-Malville.
- The storage system used for SNF is mainly wet storage. Facilities exist:
 - At each NPPs sites. After being unloaded from the reactor core, SF assemblies are stored in a cooling ponds adjacent to the reactor building (the pool is also used for loading operations), in borated steel racks. The length of this initial storage period is between 12 and 18 months, to allow the radioactivity to decay sufficiently and enable enough heat to be released for the fuel to be transported to the reprocessing plant, at La Hague.
 - At the La Hague processing plant. Fuel assemblies that are to be reprocessed are stored in baskets, in four large pools (total capacity authorised by decree corresponding to a total of

17 600 metric tonnes). The fuel is cooled in these pools for a minimum of five years. Fuel currently spends on average eight years in these pools in practice. After this cooling period, the fuel is processed to recover the uranium and plutonium it contains, and the residue is conditioned as vitrified waste (HLW). Spent ERU fuel and MOX fuel, which are not reprocessed as they are produced, are also grouped and stored in these pools; EDF plans to treat this fuel later so that the separated materials can be reused in 4th generation fast neutron reactors.

- At the civil research reactors in operation (CEA’s reactors and Laue-Langevin Institute’s reactor). SF assemblies are stored in cooling ponds before being transported to the reprocessing plant, at La Hague.
- At a dedicated workshop (*Atelier pour l’évacuation du combustible* – APEC) located on the Creys-Malville site. Irradiated FNR fuel from Superphénix (currently under decommissioning), which was removed from the reactor between 1999 and 2002, and washed, is stored, in racks, in the facility’s pool as well as the above-mentioned fresh FNR fuel. The operating decree of the facility, issued in 2006, authorise its operation till 2035.
- Dry-storage facilities also exist for SF in France. The main one is the Cascad facility, a dry-storage bunker, at the CEA site of Cadarache, used mainly to store fuel from research reactors, fuel from R&D studies conducted by the CEA or “military” fuel from nuclear propulsion, until a further management decision is made concerning this fuel. The facility has been in operation since 1990 and was designed to store irradiated nuclear fuel conditioned in steel containers for 50 years. Besides its technical facilities for reception, checking and conditioning, the facility has a storage unit consisting of 319 sealed wells placed in a concrete structure and cooled externally by a transverse air flow by natural convection. In June 2014 about 80% of the storage wells were occupied. Through a resolution of July 2014, the ASN authorised storage for a further ten years of the SFs that have been present in the facility for more than fifteen years. This resolution is without prejudice to the conclusions of the next PSR of the installation, planned for 2017.
- The storage system used for HLW, pending disposal in the Cigéo repository, is dry storage (in pits with evacuation of the heat generated by natural or forced convection):
 - The waste produced in the SF reprocessing plants at La Hague (including standard packages of vitrified waste CSD-V) are placed in the warehouses adjoining the facilities (R7 and T7 units of the UP2-800 and UP3 plants) and then in the Glass storage Extension – South-East (EEV-SE), once their thermal power drops below 2 000 watts. The R7 and T7 units entered service in 1989 and 1992 respectively, for an anticipated operating lifetime of 50 years; the E-EV-SE storage facility has been operational since 1996, for an anticipated operating lifetime of 70 years. The three storage facilities (R7, T7 and E-EV-SE) have a combined capacity of 12 420 packages, which are now saturated. In 2006, AREVA undertook the study and construction of an extension to the E-EV-SE (called E-EV-LH) for which partial service entry was in 2013, with a capacity to store about 4 199 packages. A new extensions are being envisaged to store the annual production of vitrified waste packages (about 800 packages in 2015 and 1 180 packages expected in 2030 with the start of reprocessing of MOX fuel) which will last until vitrification of the rinsing effluents generated after final closure of the UP2-800 and UP3 units, planned for 2040.
 - The vitrified waste produced in the “Atelier de vitrification de Marcoule” (AVM) are stacked in the workshop warehouse, built in 1978, on ten levels in 380 vertical wells; the heat from the package is evacuated by a mechanical ventilation. About 3 500 packages, especially from

the reprocessing of SNF from natural uranium graphite gas reactors, are currently stored. Provided that the facility can be used at least until 2035, the sufficiency of the total capacity of the facility (3 800 packages) to allow the storage of the existing and additional waste until their shipment to Cigéo for disposal must be confirmed.

GERMANY

- Thick-walled dual purpose casks are being used for the dry storage of SF/HLW. Each cask is equipped with a double barrier lid system with permanent monitoring of its leak-tightness. The casks are placed in interim storage facilities, which are cooled by passive air convection.
- At present, there are 12 on-site storage facilities and 3 centralised storage facilities for SF/HLW in Germany. Another storage facility is located in Jülich, where the SF from the high-temperature pebble-bed reactor AVR is stored.
- At the end of 2014, the total amount of casks stored in Germany was 1020, 113 of those casks contain vitrified HLW from reprocessing.

JAPAN

- The current inventory of stored SF is 16 869 tonnes, including both UOX and MOX fuel.
- Vitrified HLW inventory is 2 035 containers, with a capacity ranging from 120 litres up to 170, the majority of the canisters being from the latter size. In addition, 415 m³ of high-level liquid RW are stored.
- Over 100 000 drums containing long half-life, low heat-generating waste from reprocessing operations are stored.
- Uranium waste coming from enrichment and fuel fabrication processes amounts to 50 963 drums (200 l each).
- The research facilities are also storing their RW, which currently amounts to more than 250 000 drums (200 l) of solid waste and close to 80 m³ of liquid waste. This waste includes long-life low heat-generating waste and uranium waste.

NETHERLANDS

- The HLW at COVRA consists partly of heat-generating waste (vitrified waste from reprocessed SF from the NPPs in Borssele and Dodewaard, conditioned SF from the research reactors and spent uranium targets from molybdenum production) and partly of non-heat-generating waste (such as hulls and ends from fuel assemblies and waste from nuclear research and radio-isotope production).
- Because of the long-term storage requirement, the design of the HLW treatment and storage building (HABOG) includes as many passive safety features as possible. In addition, precautions are taken to prevent degradation of the waste packages.
- The SF is stored in an inert noble gas atmosphere and cooled by natural convection. The non-heat-generating waste is, remotely controlled, stacked in well-shielded storage areas. The heat-generating waste such as the vitrified residues is put into vertical storage wells cooled by natural ventilation.

- The HABOG storage facility is in full operation since 2003. At the end of 2013, a total of 85.6 m³ HLW and SF was kept in storage. SF of the research reactors amounts to 5.4 m³ SF. Uranium targets amount to 1 m³. In 2130 the volume is expected to be 70 000 m³, of which about 400 m³ HLW.
- The SF of the research reactors are delivered to COVRA in a cask containing a basket with circa 33 elements. Inside COVRA the basket is removed from the cask and placed in a steel canister, which is welded tight and filled with an inert gas (helium). These sealed canisters are placed in wells, in the same way as the vitrified residues. The wells are filled with another inert gas (argon) to prevent corrosion of canisters with SF or vitrified waste.

RUSSIA

- The total amount of SF (uranium dioxide) accumulated to date in the Russian Federation amounts to more than 21 000 tonnes: 60% accounts for RBMK SF and 35% for WWER-1000 SF. SF is either stored in at-reactor cooling pools (normally for 3 years), detached storage facilities or centralised storage facilities.
- NPPs with RBMK-1000 reactor units, Novovoronezh NPP and research centres are fitted with detached SF storage facilities.
- Centralised SF storage facility is operated at MCC. “Wet” storage facility for WWER-1 000 SF has been operational since 1985. The “dry” storage facility first unit became operational in 2012 (RBMK-1000 SF). The “dry” storage facility second unit designed for WWER-1000 and RBMK-1000 SF is currently under construction.
- HLW inventory and HLW storage facilities
 - Operational HLW. Some 4 000 m³ of liquid HLW with a total activity of 1.5·10¹⁸ Bq and 360 tonnes of solid HLW with a total activity of 3.9·10¹⁸ Bq are generated annually in Russia.
 - Vitrified HLW arising from SF reprocessing are placed in storage facilities at PA “Mayak” and will be disposed of in a geological disposal facility in the future. The new HLW vitrification electric furnace EP-500/5 at PA “Mayak” will enable to vitrify up to 3·10¹⁸ Bq of RW per year, thus, requiring to increase the capacity of a vitrified RW storage facility.
 - Solid RW are placed in purpose built long-term storage facilities.
 - Accumulated inventory. The inventory liquid HLW accumulated to date at PA “Mayak” and resulting from past radiochemical processing (before 1987) amounts to more than 30 000 m³. These wastes having a total activity of 10¹⁹ Bq are held in storage tanks housed in structures isolated from the environment.

SPAIN

- There are three ISFSIs in operation and two coexisting cask concepts:
 - dual purpose metallic casks (Ensa DPT);
 - multipurpose metallic canisters (Holtec design).

- In all cases, the storage and transportation authorisations have to be obtained before any SF assembly can be loaded in the cask or canister.
- As of 1 July 2015, over 1 100 SF assemblies are dry stored in the 3 licensed ISFSIs in Spain:

ISFSI	1 st loading	Fuel type	Cask system	Licensed capacity casks/FAs	Stored casks/FAs
Trillo NPP	2002	PWR 16x16	DPT (Ensa)	80/1680	28/588
José Cabrera NPP	2009	PWR 14x14	HI STORM 100Z (Holtec)	12/384	12/377
Asco NPP	2013	PWR 17x17	HI STORM 100 (Holtec)	32/1024	7/224

- The inventory of SF wet stored in the on-site pools is over 13 000 FAs, with less than 20% empty SF storage capacity available in all pools.
- Less than 15 m³ of HLW coming from SF reprocessing will be dry stored at the ATC.

SWEDEN

- The storage of SF generated in Sweden is pool type, cooling time at the reactor pool and transport to the Clab centralised storage, also consisting of a number of underground pools. At the end of 2013, approximately 5 700 tonnes were stored in the Clab, plus about 550 tonnes stored at the NPPs.

UNITED KINGDOM

- AGR fuel: ~6 500 teU to be stored in high density flooded storage racks.
- LWR fuel: ~30 teU to be stored in multi element bottles alongside AGR fuel storage racks.
- Liquid HLW: Less than 7 000 te (U equivalent) stored in cooled stainless steel tanks prior to vitrification.
- Vitrified HLW: Approximately 6 000 vitrified product containers currently in storage within a passively ventilated shielded facility, this will rise to approximately 7 400.

UNITED STATES

- As of May 2015, over 82 000 SF assemblies and HLW have been loaded into over 1 700 spent fuel storage casks in the United States. SF and HLW are not co-mingled, but may be stored in very similar cask designs co-located at an NRC-licensed ISFSI.
- There are a number of unique dry cask storage systems licensed in the United States. A listing of SF storage systems approved for general use is provided on the NRC's public website (<http://www.nrc.gov/waste/spent-fuel-storage/designs.html>).

4. Describe the LTIS strategies being in use or considered

CANADA

- In Canada, all SF is stored at the site where it was produced, with the following exceptions:
 - Small quantities that are transported to research facilities for experimental or examination purposes, and which are stored at those facilities.
 - The fuel from the Nuclear Power Demonstration (NPD) reactor, which is stored at the nearby AECL Chalk River Laboratories (CRL) site.
- All Canadian NPP were constructed with on-site irradiated fuel bays. SF is stored in either wet storage or dry-storage facilities at the location where it was produced.
- Since 1990, dry-storage technology has been chosen for additional on-site interim storage. In addition, the SF from the earlier decommissioned prototype reactors is stored on-site in dry-storage facilities. The spent research reactor fuel rods are stored in dry-storage facilities in tile holes and in silos at the CRL and the Whiteshell Laboratories waste management facilities.
- The engineered dry-storage structures were originally designed for a 50-year lifetime. The actual life of the structures could be much longer. These structures are vigorously monitored; in the event of a structure failure, the SF can be retrieved and transferred to a new structure.
- Dry-storage facilities are licensed for a limited period. Licences issued by the CNSC are generally valid for a five- to 10-year period. At the time of licence renewal, the CNSC examines the operational performance of the dry-storage facility to determine whether it can continue to operate safely for another licensing term – again, typically for a five- to 10-year period. This situation may continue until a long-term management facility becomes available.
- Reprocessing of SF is currently not a consideration in Canada.

FINLAND

- Finland's SF strategy is interim storage until disposal in Finnish bedrock. The expected interim storage time of SF is 30-50 years. Finland does not define this type of interim storage as LTIS.

FRANCE

- The French nuclear safety authority (ASN) considers that the long-term storage cannot be a permanent solution for managing radioactive waste of high-level long life because it “presupposes maintaining a control on the part of society and their recovery by future generations, which seems difficult to guarantee over periods of several hundreds of years”.
- However, even if there is no LTIS strategy in France up to now, it is assumed that storage and deep geological disposal of HLW complement to optimise the waste management regarding impact on humans and the environment, safety and costs of investment and operation, and ensure the reversibility of disposal.
- In this framework, storage offers a degree of flexibility for the construction and operation of the Cigéo facility, as uncertainties subsist with regard to the schedule for commissioning the facility, the delivery time frames for packages that will be adopted, and the acceptability of certain waste

packages. In addition, the retrievability of the emplaced packages is a key component of the reversibility of the repository, which entails guarantees concerning the feasibility of possible storage of any package removed from the repository.

- In France, the regulatory documents do not define the long-term duration for storage. However, it must be mentioned that, before being put into disposal, some HLW need to be stored for a certain period of time to allow a reduction in the heat it gives off. A storage time minimum of 60 years for existing package, and 70 years for future productions, is required. For the record, a longer storage time, up to a hundred years, would save disposal resources.

GERMANY

- The “Site Selection Act” entered into force on 27 July 2013. According to this act, a site selection process for a disposal facility is foreseen to be finished by 2031. The site selection process will be followed by the licensing procedure and construction of the repository. Since this will take at least another 20 years, a disposal facility will not be available before 2050, followed by an operational phase of about 30 years to dispose of all waste packages.
- For the interim storage, it was confirmed in the licensing procedure that the casks are suitable for a storage period of at least 40 years. The first storage facility operation licence will expire in 2034, the last one in 2047. Thus, an extended storage will be needed to bridge the gap until the disposal facility is available. The strategy of dry SF storage in dual purpose casks will be continued if it is demonstrated that the safety requirements will be fulfilled during an extended storage period.
- In order to sustain a continuous high safety level over the whole period of storage, the procedure of PSR was implemented into the regulatory system for interim storage. The experience gained from the pilot phase in Gorleben led to the finalisation and publication of the “ESK guidelines for the performance of PSR and on technical ageing management for storage facilities for SF and heat-generating radioactive waste” in March 2014 by the Nuclear Waste Management Commission (ESK).

JAPAN

- For SF:
 - Recycle-Fuel Storage company has constructed a dry-storage facility (Max capacity: 3000 tonnes) for SF in Mutsu.
 - The Japan Atomic Power Company has constructed a dry-storage facility (Max capacity: about 250 tonnes) for SF in Tokai.
 - CHUBU Electric Power will construct a dry-storage facility (Max capacity: 400 tonnes) for SF in Hamaoka.
- For HLW:
 - Japan Nuclear Fuel Limited (JNFL) has constructed a storage facility (Max capacity: 2 880 canisters) for HLW received from overseas in Rokkasho.
 - And the JNFL has constructed a storage facility (Max capacity: 3 195 canisters) for HLW receiving from JNFL reprocessing plants in Rokkasho.

- In addition, JNFL will construct a storage facility (Max capacity: 5 040 canisters) for JNFL reprocessing plants in Rokkasho.
- Japan Atomic Energy Agency (JAEA) has constructed a storage facility (Max capacity: 420 canisters) for HLW receiving from JAEA reprocessing plants in Tokai.

NETHERLANDS

- See Q1/Q2.

RUSSIA

- See answer to Q1. Considering the diversity of technical options for SF and HLW storage and reprocessing, the long-term SF management strategy involves its storage in centralised facilities and reprocessing, whereas HLW management strategy provides for HLW conditioning and disposal.
- In 2011, the Federal Law №190-FZ “On the Management of Radioactive Waste” was enacted providing that all HLW generated before 15 July 2011 are qualified as federal property, HLW generated thereafter are owned by relevant operating organisations. This law also requires that all HLW shall be processed (conditioned in accordance with waste acceptance criteria for disposal) and disposed of in deep geological disposal facilities. The rate of waste reprocessing (RW conditioning in accordance with waste acceptance criteria) shall exceed the rate of RW generation.

SPAIN

- All NPPs are storing spent fuel at on-site SF pools and there are ISFSIs licensed to dry store SF at 3 reactor sites, licensed for an initial period of 20 years renewable up to 40.
- A centralised interim storage facility (ATC) is under construction, which operation is expected in 2017 (facility design life 100 years) but it will not prevent the need for renewal of ISFSIs licences. The ATC will allow the storage of the total SF inventory in Spanish NPPs.
- There is no defined time frame for final disposal availability. This fact, together with the ATC design life and the extended duration of the previous cask storage period, makes LTIS a need that will be difficult to avoid.

SWEDEN

- Sweden SF national strategy is interim storage in pools, on-site or centralised facilities, until disposal in Swedish bedrock.
- The expected interim storage time in the Clab is defined by the cooling time required for subsequent operations, currently a minimum of 30 years before encapsulation and transport to the repository. No LTIS strategy is required.

UNITED KINGDOM

- Reprocessing of Magnox SF has taken place for over 50 years. Over 90% of the lifetime arising of Magnox fuel has already been reprocessed following United Kingdom Government policy.

- In the event of an irrecoverable failure it will be necessary to manage the remaining un-reprocessed fuel. Depending on the circumstances leading to failure, possible options include extending the period of fuel storage in nuclear reactor cores and in ponds at Magnox stations and Sellafield. Fuel under water in ponds is susceptible to corrosion, so NDA will invest in dry-storage technologies and continue to explore options to dispose of any spent Magnox fuel not reprocessed. In parallel, will continue to progress R&D that will improve our knowledge of the feasibility and practicality of interim wet storage of Magnox fuel. By pursuing a variety of interim wet and dry-storage approaches for Magnox SF it is the intention to have a diverse range of strategic options to call upon should reprocessing capacity be unavailable.
- Oxide fuel is used in AGR and in LWR. Oxide fuel is reprocessed in the THORP at Sellafield, which started operation in the 1990s. When the NDA took over the United Kingdom's nuclear liabilities, it inherited from BNFL a range of SF management contracts with domestic and overseas customers.
- NDA are contractually committed to receive and manage all SF arising from the seven AGR power stations in England and Scotland. About half of this fuel is under contract for reprocessing, while it is the NDA's decision to reprocess or directly dispose of the remainder. We are also contracted to reprocess overseas LWR fuel that has been received and is being stored at Sellafield, returning products and any associated wastes to customers, in line with contractual commitments.
- The LTIS is wet storage of spent the United Kingdom origin fuel pending the availability of a geological disposal facility – planned for 2075.
- The LTIS is dry storage of United Kingdom origin HLW within a modular vault dry store pending the availability of a geological disposal facility. Fresh waste from reprocessing is being blended with existing stored waste and vitrified to a programme which manages overall waste stock levels within specified levels against an overall HAL inventory reduction targets. HAL is incorporated into borosilicate glass, using a vitrification process. This is then poured into stainless steel canisters, which hold approximately 150 litres, and a stainless steel lid is welded on.
- Vitrified United Kingdom HAL is stored at Sellafield while overseas vitrified residue is returned to the country of origin. Returning this waste to overseas customers fulfils contractual obligations and also the United Kingdom government policy.

UNITED STATES

- Currently, all US operating nuclear power reactors are storing SF in on-site SFP and a majority also has SF in dry storage in ISFSIs located on-site. Commercial HLW remains stored at the operating nuclear power reactors.
- Initial storage licences were issued for 20 year terms, but in 2011, regulations were changed to allow initial licence and renewals for up to 40 years.
- In the absence of a permanent repository, ISFSI storage at-reactor sites is expected to continue for an extended period. As noted in Q1, the Administration has defined a strategy to develop one or more consolidated interim storage facilities to move SF and HLW to a centralised storage location. The earliest that an ISF would be available is 2025.

- It is anticipated that existing ISFSIs will need at least one licence renewal period before all fuel could be moved to an ISF. To ensure the safety of continued storage at the ISFSI, the NRC's regulations require applications for ISFSI license renewals to include:
 - TLAAAs that demonstrate that structures, systems, and components important to safety will continue to perform their intended function for the requested period of extended operation; and
 - A description of the AMP for management of issues associated with ageing that could adversely affect structures, systems, and components important to safety.

5. Describe the regulatory framework for LTIS: policy and regulations

- a) **Main limits and acceptance criteria for the environmental effects and public exposures for normal operation and accidents**
- b) **Main safety design and radiation protection requirements**

CANADA

- CNSC regulatory policy, P-290, Managing Radioactive Waste, outlines the philosophy and six principles that govern the CNSC's regulation of RW. P-290 identifies the need for long-term management of radioactive and hazardous waste arising from licensed activities.
- The policy statement in P-290 defines RW as any form of waste material containing a nuclear substance as defined in the NSCA. This definition is sufficiently comprehensive to include SF without any other special consideration. The policy indicates that, when making regulatory decisions about the management of RW, the CNSC will seek to achieve its objectives by considering certain key principles in the context of the facts and circumstances of each case, as follows:
 - The generation of RW is minimised to the extent practicable.
 - The management of RW is commensurate with its radiological, chemical and biological hazard to the health and safety of persons, to the environment and to national security.
 - The assessment of future impacts of RW on the health and safety of persons and the environment encompasses the period of time when the maximum impact is predicted to occur.
 - The predicted impacts on the health and safety of persons and the environment from the management of RW are no greater than the impacts that are permissible in Canada at the time of the regulatory decision.
 - The measures needed to prevent unreasonable risk to present and future generations from the hazards of RW are developed, funded and implemented as soon as reasonably practicable.
 - The transborder effects on the health and safety of persons and the environment, which could result from the management of RW in Canada, are not greater than the effects experienced in Canada.

FINLAND

- SF fuel interim storage requirements are described in STUK safety regulation YVL D.3.
- In the handling and storage of nuclear fuel at a nuclear power plant, the limit for the annual dose of an individual in the population, arising from the normal operation of the entire NPP, is 0.1 mSv (Government Decree 717/2013, Section 8). Other situations:
 - 0.1 mSv as a result of an anticipated operational occurrence;
 - 1 mSv in the event of a Class 1 postulated accident;
 - 5 mSv in the event of a Class 2 postulated accident; and
 - 20 mSv as a result of a design extension condition
- The interim storage design shall follow structural and functional defense-in-depth principle. Main safety features are practical elimination of loss of water pool structures. Other main safety principles are ensuring subcriticality, SF cooling and containment of radioactive substances.

FRANCE

- Regarding the main limits and acceptance criteria for the environmental effects and public exposures for normal operation and accidents:
 - For the protection of workers exposed to ionising radiation during the course of their professional activities, the Labour Code stipulates that the annual dose limit is 20 mSv for 12 consecutive months, except if a waiver is granted, in order to take into account any exceptional exposure that has been justified beforehand or any emergency occupational exposure;
 - The regulatory exposure limits set by the Labour Code do not apply to emergency workers. On the basis of the optimisation principle, “reference levels” are defined by the regulations (Public Health Code). Two groups of emergency workers are thus defined:
 - The first group comprises the personnel making up the special technical or medical response teams set up to deal with a radiological emergency. These personnel benefit from radiological surveillance, a medical aptitude check-up, special training and equipment appropriate to the nature of the radiological risk.
 - The second group comprises personnel who are not members of the special response teams but who are called in on the basis of their expertise. They are given appropriate information.
 - The reference individual exposure levels for the participants, expressed in terms of effective dose, should be set as follows:
 - The effective dose which may be received by personnel in group 1 is 100 mSv. It is set at 300 mSv when the intervention measure is aimed at protecting other people.

- The effective dose which may be received by personnel in group 2 is 10 mSv. In exceptional circumstances, volunteers informed of the risks involved in their acts may exceed the reference levels, in order to save human life.
- For a member of the public, the annual effective dose limit from any nuclear activity must not exceed 1 mSv in accordance with the Public Health Code, while equivalent dose limits for crystalline lenses and the skin are set at 15 and 50 mSv/year (average value for any skin area of 1 cm²), respectively.
- The aim of the strategy for protecting the public in the event of a threat or actual radioactive release is to limit the public's exposure level as low as reasonably achievable. During the emergency phase, this strategy is based on three key measures:
 - an evacuation is ordered if public-exposure predictions exceed a whole-body effective dose of 50 mSv;
 - shelter-in-place is ordered if public-exposure predictions exceed a whole body effective dose of 10 mSv;
 - stable-iodine prophylaxis is ordered if thyroid-exposure predictions exceed an equivalent dose to the thyroid of 50 mSv.
- If existing in France, LTIS for SF and HLW would be considered as a basic nuclear installation (BNI) and subject to specific regulatory arrangements as defined by the TSN Act of 13 June 2006.
- In particular, Article 3.4 of Title III of Order dated 7 February 2012, laying down the General rules for basic nuclear installations defines the fundamental safety functions for nuclear facilities:
 - control of the nuclear chain reaction;
 - control of the thermal power due to radioactive material and reactions;
 - radioactive material containment;
 - radiation protection of the workers, the public and the environment.
- In addition, some specific safety functions could be defined for storage facilities:
 - surveillance, maintenance of the facility and of the stored objects;
 - management of the stored objects (traceability, radiological inventory, storage mapping, etc.);
 - retrieval at any time, under conditions planned, of stored radioactive objects (packages).
- The safety provisions for a storage facility should be justified as for any nuclear facility, in accordance with the defense-in-depth principle. All the internal and external hazards taken into account in the nuclear facility safety case have to be studied for LTIS facilities.

- From the lessons learnt of the feedback of existing dry-storage facilities implemented in France and in other countries, IRSN estimates that the following specific recommendations could be taken into account in the design of future dry-storage facilities:
 - modular organisation;
 - two static independent containment barriers, fuel cladding is not considered as a barrier;
 - the first barrier isolates one or a limited number of SF assemblies or vitrified containers;
 - the SF assemblies or waste packages and containers (or tubes) are dried and inert atmosphere is present in the containers (or tubes), the volume of oxidant gases and water vapour are drastically limited;
 - the second barrier (shaft, canister, container, well...) is filled with dried air or inert gas of a different nature;
 - integrity of the two barriers is controlled during storage;
 - cooling with natural convection outside the second barrier is favoured;
 - the storage itself is inside a concrete building or a transport cask that may participate to the shielding.
- In addition, the storage facility and the stored radioactive objects should be designed to allow some adaptability to the safety rules in force in the coming decades. On this point, the experience feedback from the last twenty years highlights the significant evolution of safety practices. This shows that it is not possible for such a facility as for any basic nuclear installation to define a long lifetime a priori at the design stage.
- Also, given the long storage lifetime and the interest of limiting the interventions, it should be sought as far as possible a design combining simplicity and robustness, incorporating sufficient margins to take account of technical or regulatory uncertainties related to the time scale referred.
- Natural environmental evolution is difficult to forecast for a long period of time. The same applies to human activities in the site area (transport evolution, industrial activities...).
- Moreover, the notion of “long-term duration” should also lead to question about the sustainability of the facility management by an operator and its control by the nuclear regulatory safety authority, over a period of time when a decline or disappearance of nuclear industrial activity could be possible.
- By the nature of long-term storage facility, the fundamental safety parameter to be considered is facility ageing. Indeed, any industrial facility is subject over time to a number of defects of the components of mechanical, thermal or chemical type.
- These defects can have effects on the components by changes in material properties because of ageing embrittlement by irradiation, and/or the propagation of pre-existing defects at the manufacturing of the components.

- Thus, lifetime of a storage facility or radioactive objects to be stored is affected by normal wear of components which depends on one hand on their age, and on the other hand on surveillance, inspections (expertise) and maintenance activities.
- In order to avoid as much as possible significant ageing of components, the designer should take into account this phenomenon both in the design and the realisation of its facility as well as of the packages that will be stored. If the ageing phenomenon cannot be avoided, the designer should attempt to predict its magnitude, in order to ensure acceptable safety margins during the design lifetime. The programmes of facility surveillance and expertise of radioactive object set up by the operator for the facility lifetime are expected to ensure that the objectives remain in the envelope of the requirements.
- IRSN estimates that it is not necessary to set a lifetime for a long-term storage facility. In fact, the safety principles governing the long-term storage are similar to any storage facility; extension of operation duration remains subjected to PSRs. These safety reviews will have to permanently show that the safety requirements, particularly the margin requirements, are met.
- In this case, the scenarios of loss of control of the installation for limited periods may be considered, provided that such accidents are taken into account in the design of the facility. These scenarios can be compared to degraded operation as for any basic nuclear installation. But this is not obvious in the design of the facility.
- In addition, the scenario of final forgotten of the storage (hypothetical scenario) should be analysed by the designer or the operator. Given the high activities and/or the long period of radionuclides of radioactive objects stored, this scenario cannot be accepted, insofar as the radiological consequences would be definitely unacceptable.

GERMANY

- For SF management in Germany, the concept of dry interim storage in dual purpose casks before direct disposal is being pursued. According to an amendment of the Atomic Energy Act (AtG) in April 2002, SF from power reactors, which has not been reprocessed until 30 June 2005, has to be stored at the NPP sites in dry storage and transport casks. Beginning in 2002, dry cask storage facilities were commissioned and started operation stepwise at twelve NPP sites. In addition, the earlier commissioned centralised storage facilities at Ahaus and Gorleben are used for the interim storage of SF from different types of reactors and vitrified HLW returned from reprocessing abroad. The ISF “*Zwischenlager Nord*” (ZLN) is used for the storage of SF from the Greifswald and Rheinsberg NPP of Soviet design.
- In order to sustain a continuous high safety level over the whole period of storage, and also to be in line with international requirements and practices, the procedure of PSR was included into the regulatory system for interim storage facilities. In November 2010, the ESK handed the BMU a recommendation of guidelines for the implementation of a PSR for interim storage facilities. The PSR for SF/HLW storage facilities was established in 2014. It also includes the assessment of ageing management actions and provisions. Till 2017, all storage facilities should have finished their first PSR. The PSR has to be repeated every ten years. The result of the PSR should demonstrate the fulfilment of the basic protection goals for the remaining licensed operation time.

- Detailed safety requirements for dry interim storage are written down in “Guidelines for dry interim storage of SF and heat-generating high active waste in casks” originally issued in 2001 and now available in the revised and amended version of 2012.
 - It is a general rule for all nuclear facilities and installations that an effective dose of no more than 1 mSv per calendar year may result for individual members of the general public due to their operation. On-site storage facilities for SF do not generate any discharges of RW water, since any contaminated waste water, e.g. from maintenance work on the containers which exceeds the maximum permitted activity concentrations specified in radiation protection ordinance, is transferred to sewage treatment facilities for disposal. Discharges into the air by releases from the storage casks are not anticipated, although release values have been applied for in order to allow for possible contamination of the cask surfaces, for example. In practice, however, discharges to the air are negligible, due to the leak-tightness criteria for storage casks and the existing rules for surface contamination on the outside of the casks. Radiation exposure due to direct irradiation by gamma and neutron radiation occurs in the immediate vicinity of the storage facilities. In such cases, the aforementioned radiation exposure limits for personnel and the general public must be taken into account.
 - For the design of on-site storage facilities for SF it is required that, during accident conditions, a maximum effective dose of 50 mSv due to the release of radioactive substances into the environment (calculated across all exposure paths with 50-year committed doses) must not be exceeded.
 - For extended storage periods, all relevant safety demonstrations have to be in line with the intended extension time and the current state of technology. Basic safety issues of the German approach are:
 - The main safety goals, in particular safe enclosure of the radioactive inventory, subcriticality, radiation shielding and decay heat removal, are provided by the casks. The storage building ensures additional shielding and weather protection. The casks are monitored for leakage of the double lid system. Safety-related installations of the storage facility are subject to in-service inspections whose frequency is to be stipulated in accordance with the safety significance of the components to be tested. Neither inspection nor monitoring of the stored inventory and the inside of the casks are performed. Transportability of the casks and manageability of the fuel elements must be assured at the end of storage period.

JAPAN

- Main limits and acceptance criteria for the environmental effects and public exposures for normal operation and accidents:
 - 1 mSv/y (normal operation).
- Main radiation protection requirements are included in laws such as Reactor Regulation Act. Standards comply with ICRP 1990 recommendations.
- Regulatory requirements are prescribed in the NRA Ordinance, and include control of exposure of facility workers and monitoring of radioactive material releases. Occupational dose limits for radiation workers are included in the Table below.

	Dose limits
A. Radiation workers	
(1) Effective dose limit	100 mSv/5 years and 50 mSv/year
(2) Female workers	As prescribed in (1), plus 5 mSv/3 months
(3) Pregnant workers	As prescribed in (1), plus 1 mSv/user for internal exposure from the time the pregnancy is recognised until childbirth.
(4) Equivalent dose limit for the lens of the eye	150 mSv/year
(5) Equivalent dose limit for the skin	500 mSv/year
(6) Equivalent dose limit for the abdominal surface in pregnant workers	2 mSv/user from the time the pregnancy is recognised until childbirth.
B. Radiation workers involved in emergency work	
(1) Effective dose limit	100 mSv
(2) Equivalent dose limit for the lens of the eye	300 mSv
(3) Equivalent dose limit for the skin	1 Sv

- In addition, the dose limit at the boundary of the controlled area has been set at 1.3 mSv per three months, based on the special limit for the public of 5 mSv per year.
- Exhaust gas and effluent concentration limits are prescribed for the facilities of disposal businesses pursuant to the Radiation Hazards Prevention Act, ensuring that the dose at the boundary of the business establishment does not exceed 250 micro Sv/3 months.
- To ensure that release levels are below the legal limits outside the Surrounding Monitored Area, licensees prescribe release control targets equal to the annual release quantity stipulated at the time they received their installation permit. In their Operational Safety Programmes, they guarantee that they will not exceed those levels and the NRA checks the status of compliance when conducting Operational Safety Inspections.
- To evaluate the impact of radioactive materials released from nuclear facilities on the surrounding environment, licensees monitor air radiation dose rates at the monitoring station and measure radioactivities in environmental samples so that facility is well managed. To protect the health and safety of the public in nearby communities, local governments in prefectures where reactor facilities are located also conduct local radiation monitoring.
- The above-mentioned rules prescribe that the three-month-averaged concentration of radioactive materials in air outside the Surrounding Monitored Area shall not exceed the concentration limits for discharge of gaseous radioactive waste, that the three-month-averaged concentration of radioactive materials in water outside the boundary of the Surrounding Monitored Area shall not exceed the concentration limits for discharge of liquid radioactive waste by a discharge facility, and that doses due to liquid discharge of radioactive waste from reprocessing facilities monitored at the outlet to the ocean shall not exceed the dose limit for three months.
- Licensees stipulate in their Operational Safety Programmes the measures to be taken in the event of an emergency; these include the steps to be taken in the event of an unplanned or uncontrolled

release of radioactive materials into the environment, to control the release and mitigate its effects.

- If an unplanned or an uncontrolled release of radioactive materials from a nuclear facility triggers a specific event prescribed in the Nuclear Emergency Act, emergency activities will be initiated according to the procedure stipulated in accordance with the Nuclear Emergency Act. If the accident is serious enough, a Declaration of Nuclear Emergency is issued and emergency measures such as evacuation will be taken.

For details, see *National Report of JAPAN for the Fifth Review Meeting, Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management*, Government of Japan, October 2014, pp. 38-40.

NETHERLANDS

- The basic legislation governing nuclear activities is contained in the Nuclear Energy Act ('*Kernenergiewet*' or Kew). It is a framework law, which sets out the basic rules on the application of nuclear technology and materials, makes provision for radiation protection, designates the competent authorities and outlines their responsibilities. Under the Nuclear Energy Act, a number of Decrees exist containing additional more detailed regulations related to radiation protection and the use of nuclear technology and materials. These continue to be updated in the light of ongoing developments. The Nuclear Energy Act also provides the basis for a system of more detailed safety regulations concerning the design, operation and quality assurance of NPPs. These are referred to as the Nuclear Safety Rules ('*Nucleaire VeiligheidsRegels*', NVRs). NVRs mostly are amended IAEA Safety Guides. Due to the small, but diverse nuclear programme to allow maximum flexibility, detailed requirements are listed in the licence requirements, tailored to the characteristics of the installations, rather than in general ordinances. In the licenses, the NVRs can be referenced as well as other nuclear codes and standards.
- Environmental Protection Act (describing o.a. EIA requirements) and General Administration Act are also to be followed.
- Limits and criteria:
 - For a single source (for instance a waste management facility), the maximum individual dose has been set at 0.1 mSv per year (normal operation). The Decree on nuclear technology and materials specifies that the risks due to accidents for which protection is included in the design of the facility, i.e. the design base accidents, should be lower than the values given in Table below.

Set of safety criteria related to postulated Design Base Accidents for nuclear facilities *Frequency of occurrence (F) Maximum permissible effective dose (E, 50 years)*

	Persons of age ≥ 16	Persons of age < 16
$F \geq 10^{-1}$	0.1 mSv	0.04 mSv
$10^{-1} > F \geq 10^{-2}$	1 mSv	0.4 mSv
$10^{-2} > F \geq 10^{-4}$	10 mSv	4 mSv
$F < 10^{-4}$	100 mSv	40 mSv

- An additional limit of 500 mSv thyroid dose (Hth) must be observed in all cases. Non-compliance with the values in the Table is a reason for refusing a licence. The same decree specifies probabilistic acceptance criteria for individual mortality risk and societal risk. The maximum permissible level for the individual mortality risk (i.e. acute and/or late death) has been set at 10⁻⁵ per annum for all sources together and 10⁻⁶ per annum for any single source.
- External events from category 4 (<10⁻⁶) which have been considered in the consequence analysis are the following:
 - flooding of the buildings;
 - earthquakes;
 - hurricanes;
 - gas cloud explosions;
 - release of toxic and/or corrosive substances;
 - crashing aircraft (military aircraft);
 - external fire;
 - severe external accidents have been looked at, but the risk of a fatal radiation injury is smaller than 10⁻⁸.

RUSSIA

- The federal laws governing safety in the field of SF and RW management include: the Federal Law № 170-FZ “On the Use of Atomic Energy”, № 190-FZ “On the Management of Radioactive Waste”, №317-FZ “On the State Atomic Energy Corporation – Rosatom”, № 68-FZ “On Protection of Population and Territories from Natural and Man-Induced Emergencies”; № 3-FZ “On Radiation Safety of Population”, № 174-FZ “On Environmental Assessment”; № 74-FZ “The Water Code of the Russian Federation”, № 52-FZ “On Sanitary and Epidemiological Welfare of Population”, № 7-FZ “On the Environmental Protection”.
- SF and HLW management facilities are designed in keeping with a number of federal norms and rules (NP-050-03, NP-064-05, NP-035-02, NP-058-04, NP-071-06).
- Requirements for the safety and protection of personnel and population during normal operation of nuclear fuel cycle facilities and in case of emergencies are listed in following regulations:
 - regulation of the Russian Federation for Preparedness and Response on Emergencies;
 - federal norms and rules setting up general safety requirements for nuclear facilities (NP-001-97, NP-033-11, NP-022-2000, NP-016-05, NP-038-11);
 - federal norms and rules establishing the requirements regarding the contents of emergency action plans for personnel protection and emergency preparedness (NP-075-06, NP-015-2000, NP-077-06, NP-078-06, NP-015-12);
 - federal norms and rules establishing the procedure for declaring emergency preparedness status, emergency situation and real-time data transmission in case of radiation hazardous situations at nuclear facilities (NP-005-98, NP-078-06);

- requirements on planning and ensuring prompt efforts on eliminating the consequences of transportation accidents involving nuclear materials and radioactive substances (NP-074-06);
- sanitary norms and rules (NRB-99/2009, OSPORB-99/2010, SPORO-2002, SP AS-03).

SPAIN

- The waste management policy is defined by the National Parliament in the General Radioactive Waste Plan. Currently the concept is to initially have the SF and HLW stored in dry casks that will later be transported to an interim storage facility, where dry storage will continue for an extended period in facility-specific welded canisters.
- There is no regulatory framework specific to LTIS facilities. Leaving aside the high-level laws, the national regulations for nuclear and radioactive facilities is the “Reglamento sobre instalaciones nucleares y radiactivas”. The current version was approved in 2008, and it contains no specific provisions for LTIS. More detailed requirements are enforced in specific Safety Instructions prepared by the CSN, which are mandatory. The limits and criteria applicable to temporary storage installations are included in Safety Instruction no. 29, and the content applies to LTIS.
- The general safety objective is to protect the people and the environment from the effects of ionising radiation. To reach this objective, the following conditions must be met:
 - exposure of people to radiation and RW releases to the environment should be minimised and controlled;
 - the probability of events leading to loss of control of any radiation source should be limited;
 - in case those events occur, their consequences should be mitigated;
 - the amount of RW produced should be minimised.
- The following Safety Functions must be met: subcriticality, confinement, heat removal, radiation protection and retrievability.
- The Defense-in-depth principle is applied. In addition, compliance with the Safety Functions would preferably be achieved using passive systems.
- During normal operation of temporary storage facilities, as well as during anticipated operational occurrences, the total effective dose to a member of the public located outside the controlled zone of the facility may not exceed 250 μ Sv.
- In addition, to guarantee that the dose to the public is kept as low as reasonably possible, operational restrictions on the maximum dose due to both facility effluents and external irradiation are applied.
- During a design basis accident, the dose to a member of the public located outside the controlled zone of the facility cannot exceed:
 - an effective dose of 50 mSv;
 - an equivalent dose to the skin of 500 mSv;
 - an equivalent dose to crystalline lens of 150 mSv.

SWEDEN

- The dose limit for a worker regarding effective dose is 50 mSv in a calendar year, with the additional constraint that the integrated effective dose over five consecutive years must not exceed 100 mSv. The equivalent dose limit to the lens of the eye and to skin, hands and feet is 150 mSv and 500 mSv in a year, respectively. Lower limits apply for apprentices and special rights for rearrangements at work apply to breastfeeding and pregnant women. Additional requirements ensure that the dose to a foetus does not exceed 1 mSv for the remaining period of a pregnancy. Data on intakes and individual radiation doses is kept in the national dose register. Dose records are saved until a person has reached the age of 75, and at least until 30 years after work with ionising radiation has ceased.
- The effective dose limit for members of the public is 1 mSv per year. A dose constraint for the discharges of radioactive substances to water and air (authorised releases) is set to 0.1 mSv per year and site including all nuclear facilities located at that site. The dose constraint is subject to comparison with the calculated dose to the most exposed individual (critical group). The dose models used are approved by SSM.
- The 0.1 mSv dose constraint is compared with the sum of: a) the effective dose from the annual external exposure; and b) the committed effective dose resulting from a yearly discharge. A 50-year integration period is used for the committed effective dose. If the calculated sum dose exceeds 0.01 mSv per year, realistic calculations of the individual radiation doses, using measured dispersion data, food habits, etc., shall be made for the most affected area.

UNITED KINGDOM

- In line with a goal setting framework, Sellafield Ltd as licensee has to make and implement adequate arrangements in line with its Nuclear Site License. The adequacy of the arrangements is evaluated by the Office for Nuclear Regulation and is set out in the ONR Safety Assessments Principles (SAPs) and in more detailed technical assessment guidance (TASTs). The fundamental principles set out in detail the main limits and acceptance criteria for the environmental effects and public exposures for normal operation and accidents and also the main safety design and radiation protection requirements.
- Fundamental principles are given below:
 - FP.1 Responsibility for safety: The prime responsibility for safety must rest with the person or organisation responsible for the facilities and activities that give rise to radiation risks.
 - FP.2 Leadership and management for safety: Effective leadership and management for safety must be established and sustained in organisations concerned with, and facilities and activities that give rise to, radiation risks.
 - FP.3 Optimisation of protection: Protection must be optimised to provide the highest level of safety that is reasonably practicable.
 - FP.4 Safety assessment: Duty holders must demonstrate effective understanding and control of the hazards posed by a site or facility through a comprehensive and systematic process of safety assessment. (In addition, the regulatory assessment of safety cases is covered in detail in the SAPs including expectations for the nature and content of safety cases).

- FP.5 Limitation of risks to individuals: Measures for controlling radiation risks must ensure that no individual bears an unacceptable risk of harm.
- FP.6 Prevention of accidents: All reasonably practicable steps must be taken to prevent and mitigate nuclear or radiation accidents.
- FP.7 Emergency preparedness and response: Arrangements must be made for emergency preparedness and response in case of nuclear or radiation incidents.
- FP.8 Protection of present and future generations: People, present and future, must be adequately protected against radiation risks.

UNITED STATES

- The regulatory framework for any potential LTIS of spent nuclear fuel in the United States is established in US NRC regulations in the CFR, Title 10, Part 72 (10 CFR Part 72). The provisions of 10 CFR Part 72 establish two different types of licences for the storage of spent nuclear fuel: a site-specific licence or a general licence. Although there can be significant differences in the pre-requisites and processes followed to obtain either type of licence, in general, the main limits and acceptance criteria for ensuring occupational and public health and safety, as well as the requirements for protection of the environment, remain the same regardless of the type of licence issued. Current regulations limit the licence term to a period not to exceed 40 years from the date of issuance. Initial licences for existing interim storage facilities were issued for an initial term of 20 years. Licence renewal applications for additional 40 year terms must include evaluation of ageing effects and a description of the ageing management programme.
- Before issuing a licence for a proposed ISF, the NRC must ensure that the applicant has properly described the proposed facility, including the site and the proposed storage system's design, and that the applicant has evaluated these against specific regulatory requirements. NRC must verify that the facility meets specific design criteria, that it has been properly evaluated for the effects of natural and man-induced events, and that it has an acceptable physical protection and emergency plan, and an approved quality assurance programme. The NRC must also verify that the applicant has the required training, operating procedures, and qualifications programmes necessary to safely operate the proposed facility.
- Subpart E of 10 CFR Part 72, "Siting Evaluation Factors", specifies the required evaluations needed to assess the suitability of a site for construction of an ISF. These factors require an evaluation of design basis external natural events, design basis external man-induced events, potential effects of an ISF of the ISFSI on the region, geological and seismological considerations, and the limits for radioactive materials in effluents and direct radiation. The limits for radioactive materials in effluents and direct radiation from the ISFSI from normal operations and anticipated occurrences are contained in 10 CFR 72.104. These limits specify that, for normal operations and anticipated occurrences, doses to any individual beyond the controlled area of the ISFSIs may not exceed 25 mrem. Limits on radiation and effluents from the ISFSI resulting from design bases accidents are specified in 10 CFR 72.106. These limits specify that doses to any individual from design basis accidents must not exceed 5 rem.
- Subpart F of 10 CFR Part 72 establish the minimum design criteria for the design of the storage system and the storage facility. In summary, these design criteria specify that the storage structures, systems, and components deemed important to safety must meet specific requirements

for radiation shielding, confinement, heat removal, and criticality control. These storage systems must be designed to store SF for the term proposed in the application, must be compatible with wet or dry SF loading and unloading facilities, and must be designed to facilitate decontamination to the extent practicable. In addition, they must also demonstrate that the storage system will reasonably maintain confinement of radioactive material under normal, off-normal, and credible accident conditions.

6. Describe the licensing process of the storage application in your country with focus on:

- a) Supporting safety assessment: base case and specific requirements for LTIS e.g.**
- b) Timeframe and renewal process**
- c) Transportation considerations, if any, at the time of storage**

CANADA

- The management of SF and RW is regulated through the entire lifecycle, from site preparation, construction and operation to decommissioning and, finally, abandonment. Each phase of the lifecycle requires a separate licence, although a combined licence of site preparation and construction may be requested.
- The CNSC maintains the philosophy that a licensee is responsible for the safe operation of its own facilities. Licensees make safety-related decisions routinely; therefore, they must have a robust set of programmes and processes in place to ensure adequate protection of the environment and the health and safety of workers and the public. The CNSC performs regulatory oversight and verifies that licensees and operators comply with the NSCA and its regulations.
- Early communication with the CNSC can help applicants develop a good understanding of the licensing process, regulatory requirements for LTIS facilities and information to be submitted in support of a licence. Early communication also enables the CNSC to develop a regulatory review, which ensures that qualified staff is available to carry out the application review.
- In order for an applicant to receive a licence under the NSCA, they must first submit an application. The applicant must meet general performance criteria, provide information and develop programmes in accordance with the NSCA and regulations to be considered. An application for a CNSC licence may be subject to other legislation and regulations. For example, an environmental assessment (EA) under the Canadian Environmental Assessment Act, 2012, may be required for a designated project regulated under the NSCA. Only after a positive decision is made on the EA (if one is required) may the Commission proceed with a licensing decision. The CNSC comprises of the Commission, which makes licensing decisions, and the CNSC's staff organisation, which prepares recommendations to the Commission, exercises delegated licensing and authorisation powers, and assesses licensee compliance with the NSCA and its associated regulations and licence conditions. The Commission holds public hearings to consider licence applications for major facilities. Public hearings give organisations and interested members of the public a reasonable opportunity to comment on matters before the Commission.
- Typical licence periods for waste management facilities vary from five to ten years. Applications for licence renewals require the CNSC to revisit the original documentation and assessment in light of licensee performance and compliance history. LTIS facilities are subject to the CNSC public hearing process, where the Commission reviews and makes a decision on the application.

- The transport of SF is jointly regulated between the CNSC and Transport Canada; however, the prime responsibility for ensuring the safety of SF during transport rests with the consignor who is preparing the shipment.

FINLAND

- Storage facilities are licensed as part of NPP's and they follow the same principles as all nuclear facilities of Finland:
 - Safety analysis report has to be supported by deterministic safety analysis and PRA.
 - Interim storage safety is reviewed in NPP periodic safety reviews and as part on renewal on operating license. PSR needs to be performed at least every 10 years.
 - SF from Loviisa interim storage needs to be transported to Olkiluoto for disposal.

FRANCE

- Licensing process for a LTIS should be the same than for any other nuclear facility (e.g. see ASN's report on the state of nuclear safety and radiation protection in France for 2014, p. 122 – http://www.asn.fr/annual_report/2014gb/#122).
- See also Q4.
- About the renewal process, the TSN Act of 2006 provides that "the licensee of a BNI will perform regular safety reviews of the facility while taking the best international practices into account... The periodic safety reviews will take place every ten years. However, the licence may set a different frequency where this is justified by the nature of the installation." The PSR file has two main parts:
 - An examination of the facility's compliance with its safety documentation: this aims to ensure that any changes to the facility or to operating conditions, primarily due to modifications, obsolescence or ageing of equipment or buildings, together with any changes to the environment, comply with the safety demonstration set out in the design and operating documents;
 - A reassessment of safety at the facility in light of operating feedback and, if applicable, available knowledge and the latest regulations and practices brought into effect relative to safety and radiation protection.

GERMANY

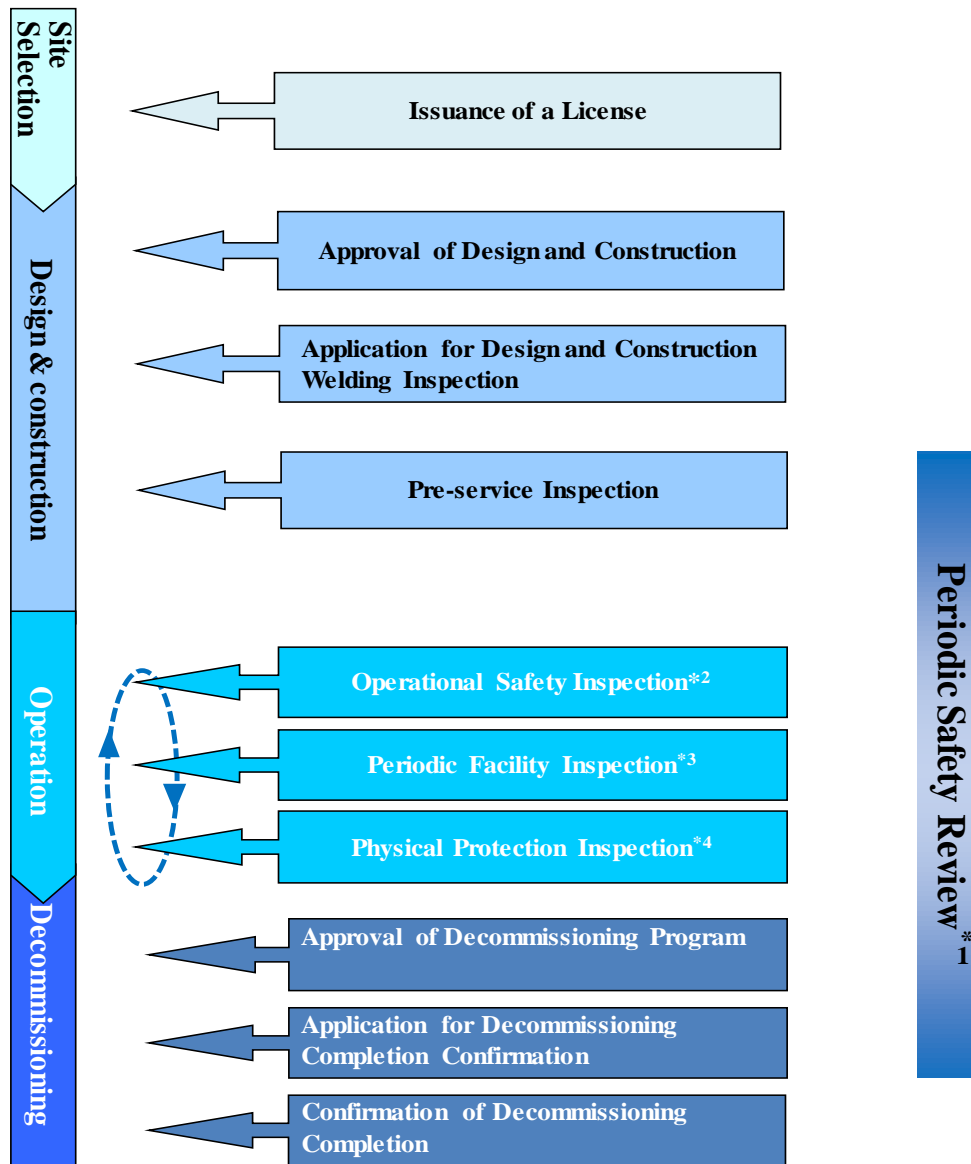
- All interim storage facilities for SF have been licensed under atomic law and are designed as dry-storage facilities in which transport and storage casks loaded with SF are emplaced. The licences are granted for a period of 40 years, beginning with the emplacement of the first cask.
- In order to sustain a continuous high safety level over the whole period of storage and also to be in line with international requirements and practices, the procedure of periodic safety review was included into the regulatory system for interim storage facilities. In November 2010, the ESK handed the BMU a recommendation of guidelines for the implementation of a PSR for interim storage facilities. The PSR for SF/HLW storage facilities was established in 2014. It also includes the assessment of ageing management actions and provisions. Till 2017, all storage facilities

should have finished their first PSR. The PSR has to be repeated every ten years. The result of the PSR should demonstrate the fulfilment of the basic protection goals for the remaining licensed operation time.

- Detailed safety requirements for dry interim storage are written down in “Guidelines for dry interim storage of SF and heat-generating HAW in casks” originally issued in 2001 and now available in the revised and amended version of 2012.
- The radiological protection objectives safe enclosure, avoidance of unnecessary radiation exposure, subcriticality and decay heat removal will have to be met also during LTIS. Further appropriate safety assessments, concerning e.g. the long-term behaviour of fuel assemblies and cask components, have to be provided in extended storage scenarios (>40 years). Within due time, as a rule six years before the licence for storage will expire, the licensee has to provide evidence for further disposal of the stored nuclear fuel. If necessary, an extension of the storage period has to be applied for.
- All casks require a Type B package design approval based on the national regulations for the safe transport of dangerous goods with respect to the IAEA regulations and must maintain their transportability during storage. According to current practice, the approval of type B(U) for public transport of the casks must remain valid for the whole storage period, license partially takes credit of the approval. The transportability has to be ensured in compliance with the transport regulations even after long-term storage.

JAPAN

Figure G-1 Regulatory Flow for Spent Fuel Storage



*1: (1) Assessment of the implementation status of operational safety activities and assessment of the application of the latest technical knowledge in operational safety activities: Every 10 years or less from the date of commencing business
 (2) Technical assessment concerning aging degradation: Within 20 years of the date of commencing business and every 10 years or less thereafter
 *2: Operational safety program compliance inspection: Conducted quarterly (4 times a year)
 *3: Inspection to confirm that facility capabilities comply with the technical requirements: Conducted annually
 *4: Physical protection program compliance inspection: Conducted regularly

NETHERLANDS

- A licence for a SF management facility is only granted if the applicant complies with the national requirements and, more in general, with international (IAEA) established safety goals, codes and guides, as well with the international state of the art. The applicable parts of the IAEA Safety Standards (Safety Fundamentals, Safety Requirements and Safety Guides) must be covered or incorporated in the Safety Report (SR), which is submitted to the RB.
- A typical example is compliance with the requirements addressing the site-specific external hazards, such as military aircraft crashes, external flooding, seismic events and gas cloud explosions. After obtaining the licence but before construction the LH drafts and submits to the RB the safety analysis report (SAR) and supporting topical reports. In these reports detailed descriptions of the facility are presented as well as an in-depth analysis of the way in which the facility meets the requirements and the international state of the art. After construction and commissioning of the SF management facility the LH submits the SAR with a description of the as-built facility and the results of the commissioning to the RB for approval before start of the routine operation. Since full compliance is expected with the SR, no formal update of the safety assessment or EA is foreseen and there will be no need for revision of the SR, which is the basis of the licence. However, all the results of the commissioning programme are incorporated in a full update of the detailed SAR.
- As IAEA regulations are fairly general and hence lack technical detail, the licensing basis for the HABOG building was based on the French state of the art for SF/HLW storage. As an independent assessment tool for the SAR the United States ANS/ANSI standard 57-9-1992 was incorporated. Selected items or documents in the SAR are studied in more depth, often using assessment by independent organisations. These key documents are submitted to the RB for approval. Other documents are submitted for information only. The final EIA of the first HABOG building was in 1995 and after that it took until 2003 before the facility started first operation. The licensing process for the extension of the building was much easier because of the modular approach. The license of COVRA contains a condition of periodic operational safety review every 5 years and comprehensive safety review every 10 years.

RUSSIA

- Licensing activities are governed by the following regulations:
 - On Licensing Activities in the Field of Atomic Energy Use, № 280 of 29 March 2013.
 - On Licensing Particular Types of Activities, № 99-FZ of 4 May 2011.
- Licences are issued by the Federal Environmental, Industrial and Nuclear Supervision Service (Rostekhnadzor).
- Relevant requirements on the set of documents that is to be submitted to Rostekhnadzor as part of a licence application for activities associated with SF and HLW storage are given in the Administrative Provisions for the Federal Environmental, Industrial and Nuclear Supervision Service on Providing the State Services on Licensing Activities in the Field of Atomic Energy Use (approved by the Order of the Federal Environmental, Industrial and Nuclear Supervision Service № 453 of 8 October 2014).
- The decision on the licence validity period shall be made based on the time period for which the safety of an activity and a facility associated with the planned licensable activity is justified by

the licensee and confirmed by safety evaluation findings (safety case review). However, this period shall be no longer than 10 years.

SPAIN

As said in Q1, there are 3 ISFSIs licensed to dry store SF at 3 reactor sites. In all cases the application was submitted as a design change of the corresponding NPP and the authorisation has been issued for a 20 year period. Regulatory requirements are the same as those for the NPP where the ISFSI are located, so PSR is mandatory every 10 years. Cask storage certificates are also issued for 20-year terms, containing technical requirements and operating conditions for the authorised content.

- First ISFSI started its operation in 2002, so that there has been no application for renewal yet.
- In a renewal application for an additional 20-year term, the licensee must submit a request with any necessary supporting information describing the capability of the site and storage systems to continue the operations for another license period, including ageing considerations.
- There are no special provisions for LTIS in the regulations.
- At the time of dry cask storage, and prior to the first cask loading, the approval of an existing transportation certificate is required to guarantee that the fuel loading map fulfills not only the storage safety limits and conditions, but also the transportation safety case assumptions for subcriticality, heat removal, shielding, confinement and retrievability, as well as the conditions for damaged fuel management according to the cask storage and transportation safety cases.
- As noted above, a Almacen Temporal Centralizado, a centralised ISF (ATC), is under construction, which operation is expected in 2017, but it will not prevent the need for ISFSIs licence renewal. The ATC design will allow the storage of the total SF and HLW inventory from the Spanish NPPs.

SWEDEN

The licensing process is the same as for any other facility. There are no special provisions for LTIS.

- At least once every ten years, a new integrated analysis and assessment of the safety of a nuclear facility shall be performed by the licence holder. The analyses and assessments, as well as the measures proposed on the basis of these, must be documented and submitted to the regulatory authority, SSM, for review.

UNITED KINGDOM

- Safety assessment is carried out in a phased process to allow for design, construction, commissioning, operation and eventual decommissioning to be considered. Safety cases will be prepared for each of these phases and regulator permissions sought to process to the next phase. Safety cases for individual facilities are subject to both short term and long-term periodic review.
- PSR is carried out every 10 years in line with IAEA best practice. PSR will ensure that the cumulative effect of change including modifications and ageing is considered, in addition to undertaking a comparison with relevant modern standards.
- Transport considerations are focused on planned movement operations and are considered along with the means of retrieving material from LTIS.

UNITED STATES

- In the United States, the licensing process for dry SF storage follows the US NRC regulations in the CFR, Title 10, Part 72. NRC staff reviews applications to ensure that the structures, systems and components of a dry-storage system that are deemed important to safety meet requirements for radiation shielding, confinement, heat removal, and criticality control. Structural and materials requirements are also reviewed, and the system must provide for adequate heat removal without active cooling. The SF storage casks must be designed to store SF for the term proposed in the application, must be compatible with wet or dry SF loading and unloading facilities, and must be designed to facilitate decontamination to the extent practicable. In addition, the dry storage cask and its systems designated important to safety must demonstrate that they will reasonably maintain confinement of radioactive material under normal, off-normal, and credible accident conditions.
- NRC staff reviews applications specific licences for ISFSIs, to ensure they meet the requirements for design basis external natural events, design basis external man-induced events, potential effects of the ISFSI on the region, geological and seismological considerations, and the limits for radioactive materials in effluents and direct radiation. In addition, the applications are evaluated with respect to the frequency and the severity of external natural and man-induced events that could affect the safe operation of the ISFSI, and must consider design basis external events for each combination of proposed site and proposed ISFSI design. Finally, an environmental review under the National Environmental Policy Act (NEPA) must be completed by the NRC staff for each proposed ISFSI.
- The regulations in 10 CFR Part 72 limit the licence term for an ISFSI, or the certificate of compliance (CoC) for a cask system, to a period not to exceed 40 years from the date of issuance. Both CoCs and specific licences can be renewed for terms not exceeding 40 years. The renewal applications must include: (1) time-limited ageing analyses that demonstrate that that structures, systems, and components important to safety will continue to perform their intended function for the requested period of extended operation; and (2) descriptions of AMPs for management of issues associated with ageing that could adversely affect structures, systems, and components important to safety.
- Note that although many of the casks have associated transportation approval certificates, the regulations do not require a storage system to have an existing transportation certificate to be authorised for storage. For CoCs, the regulations require that to the extent practicable in the design of SF storage casks, consideration should be given to compatibility with removal of the stored SF from a reactor site, transportation, and ultimate disposition by the Department of Energy. For specific licences, the requirements state that storage systems must be designed to allow ready retrieval of SF for further processing or disposal.

7. Describe the main identified gaps and challenges for LTIS, as well as the national programmes developed to address them. Please include considerations on how cross-cutting issues (knowledge management, recordskeeping...) as well as non-technical aspects (e.g. public confidence and political commitment) are addressed

CANADA

- As a responsible regulator, the CNSC is committed to continuous improvement of its regulatory framework and licensing process. Although the CNSC's waste framework provides adequate oversight to meet current needs for the safety of the facilities, there are areas where clarity could

be improved to ensure the CNSC will continue to efficiently and consistently deliver on its mandate.

- The CNSC is currently developing a discussion paper to seek early feedback from stakeholders on the opportunities presented to improve the CNSC regulatory framework for waste and decommissioning. This includes potentially consolidating and updating the requirements for the waste management programme, which encompasses the LTIS of HLW.
- Further to this, Canada's waste owners are in the process of developing a radioactive waste management industry forum for the purpose of identifying challenges among the industry and sharing best practices.

FINLAND

- In Finland these issues are not seen as challenge for interim storage since the disposal programme is progressing as planned and interim storages are situated at operational NPP sites.

FRANCE

- The order of magnitude of the “long-term” is considerably longer when compared to a few decades used in the designing of the existing interim storages. The codes and standards used for the facility design are often valid only for a period of several decades (e.g. 50 years). Beyond this period, codes and standards may need to be developed.
- During LTIS, surveillance of the facility and of the stored objects is a key issue. Monitoring throughout the storage period should be performed both by monitoring the facility and its environment (monitoring containment barriers, radiation monitoring and environmental surveillance) and by monitoring the stored objects. This should include the periodic retrieval of some adequately selected “control” packages in accordance with a defined monitoring plan to estimate the effect of ageing and to anticipate generalised damages on packages which can lead to their necessary reconditioning.
- This “active” monitoring requires:
 - to have adequate access to stored packages;
 - to have an examination cell for stored packages.
- In some cases, samples can be pre-positioned in the facility in order to follow evolution rates.
- Different phenomena have to be monitored including, corrosion, radiolysis phenomena, thermal phenomena and concrete alteration. Different parameters could be monitored including barrier thickness, pressure and temperature.
- In order to minimise human intervention and waste generation, non-destructive monitoring methods should be developed.
- Fuel drying affects subsequent storage behaviour but is constrained by the performance of the fuel during drying.

- If ageing phenomenon cannot be avoided, it is necessary to predict its magnitude, in order to define acceptable margins during the storage lifetime. R&D works could be carried out on this topic.
- After LTIS, SF and HLW could in principle be retrieved for recycle or disposal. Transportation is necessary in any case. The ageing of the fuel and of the waste may have implications for such activities. For example, talking about SF, understanding is needed of:
 - impact of radionuclide decay of isotopic and elemental composition;
 - impact of degradation products;
 - definition of the suitability criteria for recycling; and
 - effects of long-term storage on fuel mechanical properties and head end reprocessing activities such as shearing.
- Otherwise, in 2010, the French national agency for radioactive waste management (Andra) launched the “memory” project, which on the one hand comprises work designed to continue to create and improve the memory of and records about the disposal facilities and, on the other, scientific studies concerning materials ageing and issues specific to human and social sciences (HSS). In addition, in 2011, Andra set up a multidisciplinary steering committee to create a grouping of cross-cutting human and social sciences laboratories (GL-SHS). It comprises researchers from CNRS, SciencesPo Paris, *Ecole des hautes études en sciences sociales*, the *Institut Francilien Recherche Innovation Société*, Mines ParisTech and other university institutions. The general central research topic for the grouping is “transmission between generations and understanding of long time scales”.

GERMANY

- Conditions for extended interim storage, subsequent transportation and disposal are not yet defined. Since 2008, two projects related to safety aspects of long-term storage of SF and heat-generating waste have been funded by the BMUB. In the currently funded project, the BMUB compiles, as a precaution, basic information and data on national and international experience, in order to assess at an early stage the safety issues related to the long-term storage of fuel assemblies and to be able to make competent assessments of corresponding concepts and strategies for their future storage. The project has focused on the topics of ageing management during storage, the long-term behaviour of casks and cask inventories, and the exchange of experience at national and international level.
- Descriptions of national and comparisons with international conditions of dry storage in transport and storage casks form the basis for the assessment of the state of the art in science and technology. Here, in particular the regulatory constraints and previous experiences with the operation of storage facilities are compared and available findings evaluated. Regarding the topic of ageing management, technical and non-technical aspects are considered. The measures performed on the casks and structures, such as measuring programmes and inspections, are mirrored on international standards, and the results of studies into the long-term behaviour of casks systems or safety-relevant components, such as seals and moderator material, are taken into account. The transportability of the cask must be ensured at all times during the entire storage period. Requirements for the cask-specific safety demonstration must be valid for longer storage periods. Operational management, safety management, as well as knowledge and quality

management will also be addressed under the aspect of ageing. Boundary conditions changing over time also have to be considered, such as the transition of the decentralised storage facilities to self-sufficient operations with the progressive dismantling of NPPs. With regard to the identification of safety-relevant aspects, the exchange of experience of the various parties involved – such as operators, manufacturers, regulators and technical safety organisations – at both national and international level plays an essential role since it will result in a broader understanding and, thus, a benefit in the ability to act in a timely manner.

- The Federal Institute for Materials Research and Testing (BAM), as a member of the ESCP European subcommittee group, participates in the gaps analysis report. From their R&D needs, gaps for Germany were defined. Also the GRS contributed to the last update of the report. Knowledge gaps are represented by possible long-term material degradation effects due to the extended exposure to radiation, heat and mechanical loads. These apply to fuel claddings, as well as to safety related cask components, like metal gaskets or the polymer neutron shielding components.
- Cross-cutting issues, like knowledge or personnel management and record keeping, are already addressed in the current “Guidelines for dry cask storage of SF and heat-generating waste”.

JAPAN

- To expand the storage capacity for SF is an urgently important issue. It is necessary that the GOJ take appropriate measures in solving this challenge as it relates to generating nuclear power, and facilitation of decommissioning and designing flexible policies and responses will be important. In the future, examination of a wide range of locations as possible sites will be conducted, regardless of whether they are inside or outside the premises of a power plant. For facilitating construction and utilisation of new intermediate storage facilities and dry-storage facilities, concerted efforts of each electric utility, business promotion by conjunction or co-operation between electric utilities, and strengthening of government efforts will be considered specifically.

NETHERLANDS

- Ensuring the availability of qualified staff through the years is always a challenge in countries with a small nuclear programme. As COVRA is the only organisation in the Netherlands licensed to manage and store RW and SF, it will have to preserve at least a minimum of qualified staff for the foreseen storage period of 100 years. Additional expertise could be hired from abroad.
- The preservation of information on the stored waste and its history is ensured by technical means: all data are preserved in a double archive, using both digital as well as conventional paper data storage. A distinction is made between the short-term archives (<15 years) and the long-term archives (>15 years). For the long-term archive additional measures are taken. The digital information is stored in two different buildings and a procedure exists to update this information at regular intervals. Paper information carriers are printed on certified durable paper and ink and stored in a conditioned room.
- Transparency and communication are an integrated part of the operations of the RW management organisation COVRA. Because of the long-term activities, COVRA can only function effectively when it has a good, open and transparent relationship with the public and particularly with the local population. When COVRA in 1992 constructed its facilities at a new site, it took it as a challenge to build a good relationship with the local population. From the beginning attention was paid to psychological and emotional factors in the design of the technical facilities. All the installations have been designed so that visitors can have a look at the work as it is done.

Creating a good working atmosphere open to visitors was aimed at. The idea was not to create just a visitors centre at the site, but to make the site and all of its facilities the visitors centre.

- Recently the concept of the National Waste Programme related to the European Waste and Decommissioning Directive was published for public comments. In several reactions the policy of decision making in 2100 on a disposal solution is challenged.

RUSSIA

- The main challenges identified are associated with processing of the accumulated inventory of liquid HLW characterised by complex chemical composition. This waste was generated under military programmes involving the production of weapons grade plutonium. The RW inventory includes sludge, slurries and strong solutions that are stored in storage tanks at PA “Mayak”.

SPAIN

- Spain is a member of the ESCP project. Within this framework, an International Technical Data Gap Report for LTIS and transportation has been prepared. The views of the Spanish organisations on this matter are included in the table below, which is a part of the report mentioned above.
- There has been no co-ordinated effort to tackle cross-cutting issues so far. The issues of concern that are being discussed are the following:
 - Knowledge preservation and management. Involvement of young generations in SF and HLW storage, transportation and disposition.
 - Preservation of records containing relevant information on the stored SF and HLW.
 - Societal issues: public acceptance of facility sites and SF transportation routes, adequate balance between political and technical arguments for the decisions to be taken, long-term commitment of national institutions and companies.

SCC	Degradation Mechanism	Importance of R&D	Approach to closing gaps
Cladding	Oxide thickness (remaining base metal thickness, stress/strain concentration)	Low	Perform and analyse tests of high oxide thickness (~100 µm) samples to determine the margin to creep rupture/strain limits including strain localisation effects from oxide cracking (storage). Perform and analyse impact tests on high oxide thickness samples (transportation).
	Oxide spalling (local embrittlement by hydride blisters)	High	Burst tests on samples with and without hydride blisters after a temperature cycle representative of drying and storage conditions (storage). Bending and impact tests on samples with and without hydride blisters (transportation).
	Hydrogen embrittlement	High	Perform mechanical tests (RCT) to determine remaining ductility as a function of radial hydride concentration. Develop analytical models of radial hydride precipitation under variable stress and temperature conditions based on experimental test of hydride dissolution and re-orientation (focus on Zry-2).
	Creep (annealing of radiation damage, hydrogen/hydride effects)	Medium	Separate effects test to quantify the contribution of the annealing of radiation damage on creep softening and hydride concentration (hardening). Focused on modern materials.
	DHC at low temperature	Low	
	Ductile-brittle transition of cladding	High	Determination of DBTT for modern irradiated cladding materials. Realistic modelling of the temperature profile in the cask at the time of transportation.
Pellet	Pellet cracking and bonding to cladding	Medium	Determine the overall mechanical response of the cladding-pellet system under pinch loads (low and high-burnup samples).
	Oxidation in low steam pressure conditions	Low	Perform tests to determine the water remaining after drying in a cask with damaged and non-damaged fuel.
Assembly hardware	Corrosion, stress corrosion cracking	Medium	Perform tests to determine the water remaining after drying in a cask with damaged and non-damaged fuel. Mechanical testing.
Neutron poisons and cask shielding	Radiation and environmental effects (corrosion, thermal ageing, creep)	Medium	Experimental assessment of long-term degradation and loss of absorption efficiency on modern materials under representative ambient conditions. Model development.
Welded canister	Atmospheric corrosion of weld	Medium	Test higher resistance stainless steels and welding materials.
	Aqueous corrosion of weld	Medium	
Overpack/cask	Thermal cycling (including freezing)	Low	Determine limiting conditions and applicability to specific cases. Accelerated experiments and model development. Surveillance techniques for anticipated detection of degradation.
	Corrosion		

Cross-cutting need	Description	Importance of R&D	Approach to closing gaps
Impact of normal transport conditions loads on cladding integrity	Need for a quantification of the loadings associated to normal transportation conditions and an assessment of the effects on irradiated cladding.	High	Perform fuel vibration tests based on real transport accelerations. Develop analytical models based on the experiments to integrate accelerations at cask rack during normal transport conditions with loads transferred to the cladding. Assess ability of degraded cladding to bear these loads.
Retrieval of the fuel assembly after a transportation accident	After a transportation accident the fuel assembly (nozzles, structure, etc.) is deformed and special tooling, system, procedures and facilities should be available.	Low	Review and determine existing experiments. Perform modelling and determine needs.
Verification of the fuel conditions during drying and storage	The verification of compliance with the fuel criteria (i.e. cladding hoop stress, DBT occurrence) requires knowledge of the temperature profile and its evolution during the drying and short term duration events, as well as during extended storage. Cask licensing conditions can be overly conservative for some criterion but non-conservative for others.	Medium	Determine a realistic temperature profile (Residual heat + CFD + heat transfer) and pressure inside the cask to perform calculation of the fuel condition and determine margins. Validate with experiments.
Accurate fuel classification	Potential lack of coherence of the ISG-1 radio-chemistry definition of a pin-hole versus evidence of actually released isotopes.	High	Task Force to develop an operational definition of pinhole and hairline crack (Radio-Chemistry vs. Visual -ISG-).
	Available inspection techniques for very old – cold – fuel classification may not be reliable enough.	High	Develop inspection techniques (improved UT, hot in-can sipping, etc.) to ensure that old leakers are detected.
	Evolution of incipient defects.	Low	Determine the potential incipient defects in the fuel rod that may affect the cladding integrity and relevant tests to check its performance.
Definition of damaged fuel rod (>45 MWd/kgU) for transportation.	High-burnup fuel transportation should be analysed on case-by-case basis (ISG-11). However, the analyses to be performed are not defined. There is no a priori performance based, operational definition of damaged fuel.	High	Define failure criterion, tests and operational limits to ensure compliance.
Fuel transfer from transport casks to storage canisters (retrievability after transportation).	Inspections, methods and tools required to open the cask and transfer the fuel to the centralised repository vault.	High	Analyse existing experience.
Monitoring and surveillance.	Need for gathering information on the long-term overall system performance and evolution of parameters important for safety.	High	Development of new instrumentation and measurement methods.
Subcriticality.	Licensing of Burnup Credit techniques and its extension to BWR fuel require additional validation and model development efforts.	High	Obtain experimental fuel assay data, especially for high-burnup BWR fuel, and validate the methods and models developed.

SWEDEN

- No information specific to LTIS has been provided.
- The very long timescales associated with a repository programme requires a good strategy for maintaining review competence. Although SSM has been preparing for the licensing of a spent nuclear fuel repository for decades, it has not been possible to fully take advantage of these preparations due to staff turnover. SSM has compensated for this problem by procuring international experts in the review process, including an international peer review. Nevertheless, knowledge management and systematic transfer of staff experience to newly employed staff comprise an area of improvement.

UNITED KINGDOM

- The NDA is required to promote and, where necessary, carry out research in relation to its primary function of decommissioning and clean-up. There are close links to other requirements such as sharing of good practice, enabling innovation and developing skills. The R&D Strategy covers technical underpinning work carried out by the SLCs and R&D sponsored directly by the NDA. Technology and the underpinning R&D are fundamental to ensuring the safe, cost-effective delivery of the mission.
- Direct research portfolio (DRP). This portfolio addresses issues that could affect multiple sites, or SLCs, in areas of strategy, technology innovation and skills. These projects are delivered through competed framework contracts awarded to a wide range of supply chain organisations, based on the following themes:
 - university-based work;
 - managing waste (radioactive and conventional);
 - decommissioning and restoring sites;
 - managing SF and nuclear materials.
- Technical innovation. This work is focused on supporting the supply chain to develop new ideas and technologies. Projects are often jointly funded with other public sector partners, such as InnovateUK whose interests cross all sectors of United Kingdom industry including nuclear decommissioning. Collaboration such as this can more than double the funding available for projects and brings in additional expertise and technologies from outside decommissioning.
- International collaboration. Our focus is on sharing and gaining access to global good practice, experience and information about innovative technologies. NDA has bilateral agreements with key international organisations, where R&D is a common theme in these.
- Radiation epidemiology & radiobiology research. Public Health England investigates, on our behalf, the health impact on our workforce of exposure to man-made radiation.
- United Kingdom inventory of RW & materials. NDA produces the comprehensive inventory of RW and materials across the United Kingdom which is currently updated every three years.
- An example relevant to LTIS is given below.

- From 2018 onwards, SF from the United Kingdom's second fleet of nuclear power stations, the AGR, will be stored in ponds awaiting geological disposal. This follows the planned closure of reprocessing facilities at Sellafield. During wet storage, however, the fuel's cladding can be susceptible to corrosion due to radiation exposure during reactor operation. This phenomenon, known as radiation induced sensitisation (RIS), has seen significant research over the last decades. Experiments with actual spent AGR fuel cladding present obvious difficulties but understanding has increased in recent years. This follows improvements in corrosion modelling and material characterisation, alongside the availability of irradiation facilities such as the Dalton Cumbrian Facility (DCF), with a particular focus on whether RIS will limit long-term (i.e. more than 25 years) wet storage of AGR fuel. The DCF, will be used to irradiate small samples of cladding materials to induce RIS and the characterisation results used to validate our corrosion models. This will reduce the level of experimental work required on actual spent AGR fuel.

UNITED STATES

- In 2010, the NRC staff was directed by the Commission to examine potential issues related to EST of SF in conjunction with considerations for a possible update to its Waste Confidence Decision and Rule covering a longer time period. This latter aspect of the project was subsequently separated from EST and addressed by the Continued Storage Generic Environmental Impact Statement and revised Final Rule published in September 2014.
- Most existing ISFSI licences and storage system Certificates of Compliance (COC) were initially issued for 20 years, consistent with 10 CFR Part 72 requirements that were in place when these licences and certificates were issued. 10 CFR 72.42 was subsequently modified in 2011 to allow both initial and renewed licences for dry storage to be issued for periods up to 40 years each. Within the EST regulatory programme, the staff views the ageing of systems and components as occurring on a continuum that extends from initial licensing and renewal through longer periods of extended storage. In this regard, in evaluating component and system ageing, the staff considered a period of up to 300 years of dry storage, and this is reflected in the staff's approach for time-limited ageing analysis.
- The goal of the EST programme continues to be the identification of changes in the NRC's regulatory framework that might be needed to support EST of SF. Achieving this goal requires assessment of both technical and potential regulatory issues. Currently, there are no regulatory gaps, but a list of technical information needs was published in a May 2014 report titled: "Identification and Prioritization of the Technical Information Needs Affecting Potential Regulation of Extended Storage and Transportation of Spent Nuclear Fuel". This report, commonly referred to as the "EST TIN" report, provides a prioritised list of research needs for extended storage and transportation (see response to Q7 below for details of the "Technical Information Needs").

8. Describe the needs for R&D identified for LTIS

CANADA

- Canada's practice has been to move SF from the reactor wet bays into dry storage after several years. About 40% of the SF has been transferred so far. The primary dry storage structures are steel-and-concrete containers used by OPG and concrete structures (MACSTOR or Canisters) used by CNL (formerly AECL), Hydro Quebec and New Brunswick Power.
- The performance of these interim storage containers and structures continues to be monitored through normal ageing management activities. The ageing management programme for CNL's

SF dry-storage concrete canisters includes periodic condition survey; non-destructive tests and laboratory testing of extracted concrete cores.

- There have been studies in Canada on the mechanical integrity of the used fuel bundles during long-term storage. Some results from that work are summarised in NWMO technical report TR-2011-04 available at www.nwmo.ca. Although not identified as a critical issue, further information on the mechanical integrity of aged bundles remains of interest. Durability of irradiated CANDU fuel bundles under transportation conditions was investigated using drop tests and vibration tests in CNL's hot-cell facilities. Post-transportation examinations on irradiated CANDU fuel bundles transported to CNL's Whiteshell site were also performed in the hot-cell to assess fuel conditions before placing them into long-term dry storage. Most of CNL's SF has been dry stored in the canisters for about three decades.
- CNL is currently evaluating the need for an R&D programme to investigate the current conditions of the stored fuel. The goal of the investigation would be to obtain information required to support the long-term SF management strategy. Broad objectives could include providing the basis for potential life extension of the existing storage systems, for improving dry-storage technology, and for preparing the stored fuel for repository disposition in a safe and most cost-effective way.

FINLAND

- No storage specific needs related to LTIS. Of course, ageing management of storage structures and systems is a possible need for further R&D similar as in NPPs.

FRANCE

- Some specific topics of interest are listed below for SF:
 - fuel mechanical behaviour (swelling, creep, fragmentation, etc.);
 - additional clad oxidation and hydrogen pick;
 - cladding mechanical behaviour and clad failure conditions;
 - the effects of helium build-up in SF during extended periods.
- Concerning dry storage of SF, important topic areas include the evolution, qualification and monitoring of:
 - fuel matrix and cladding;
 - steel canister corrosion;
 - cask seal integrity and bolt ageing;
 - thermal and age-related degradation of neutron absorbers;
 - concrete overpack and pads;

- development of improved modelling, particularly for thermal modelling where existing models are non-conservative with respect to some storage behaviours such as condensation on canister surfaces;
- degradation of fuel baskets during interim storage periods.
- There is a need to develop techniques to monitor evolution of fuel in storage, to qualify fuel for subsequent activities and to provide recommendations on the periodicity of monitoring/inspections.
- Also, regarding long-term storage, Andra has undertaken researches on the following issues:
 - the ageing of concrete structures and containers: carbonation in non-saturated environment and in temperature, creep of concrete in temperature, gaseous and aqueous transfers in unsaturated concrete materials, physico-chemical damages because of irradiation;
 - the ageing of metallic structures and containers: atmospheric corrosion (kinetic description, corrosion phenomena, corrosive species formed by radiolysis), coupled modelling corrosion/mechanical;
 - thermo-hydraulic simulation in conditions similar to facilities considered, as the study of the phenomena of ventilation by natural thermal convection can be complex to model using of digital tools;
 - the development of auscultation systems for the observation and monitoring of facilities and packages.

GERMANY

- As already described in Q6, the needs of R&D on safety related long-term storage issues are given. Safety goals have to provide evidence for long term, and the damage mechanisms, which are only relevant for long term have to be considered. At international level, the issue of inaccessible cask areas is pursued in particular by the United States (US-NRC, EPRI, US-DOE) jointly with the IAEA by means of strategic and targeted R&D, and a prioritisation of the research needs is sought. The publications on the issue reflect the current state of international R&D and allow the derivation of suitable fields of action adapted to the existing storage concept.

JAPAN

- For spent fuel:
 - R&D for the practical use of concrete cask systems;
 - development relating to evaluation, countermeasure, and inspection for stress corrosion.
- R&D for the advancement of metal cask systems and concrete cask systems:
 - Investigation into advancement of collection methods and evaluation methods for soundness evaluation data for fuel clad piping.
 - Technological development for housing body improvement.

- For vitrified waste:
 - No R&D is necessary because it has been put to practical use.

NETHERLANDS

- The R&D programmes are mainly directed at the final solution the deep underground burial of the waste.
- No specific needs for LTIS.

RUSSIA

- R&D performed in the field of SF storage have justified operational safety of dry and wet centralised storage facilities for a minimum period of 50 years.
- Processing the liquid HLW inventory accumulated at FSUE “PA “Mayak” is an issue that has to be addressed.
- Technologies developed under the FTP NRS to address this issue are designed:
 - To ensure the retrieval of sludge and slurries from the storage tanks.
 - To perform their pre-treatment prior to their solidification through vitrification or cementation. This method involves segregation of different waste streams aimed at minimising the amount of glass: waste components impeding the operation of electric furnace are transferred to ILW cementation facility.
- Small-sized remotely removed induction melter is being designed to ensure vitrification of most challenging RW in terms of their chemical composition and high-level hardly soluble sediments. Pilot-industrial facilities enabling HLW retrieval from storage tanks and their pre-solidification treatment will be commissioned in 2015. Efforts on HLW retrieval and processing are scheduled to start in 2016. These operations will help to elaborate the retrieval technologies, in particular, those associated with HLW pre-solidification treatment. The main challenge – complete HLW retrieval from storage tanks and the retrieved waste processing – can be addressed using an industrial complex designed and constructed based on the data on the operation of the pilot-industrial facilities. This complex will be commissioned around 2021. According to current estimates and based on the capacities of the pilot-industrial facilities and small-sized remotely removed induction melter providing vitrification of most challenging RW in terms of their chemical composition and high-level hardly soluble sediments, this challenge can be addressed in some 45-50 years.

SPAIN

- The needs for R&D stem from the technical issues and knowledge gaps identified in the table included in the answer to Q6.
- A substantial amount of work has been done to explore the behaviour of SF cladding under storage and transportation conditions, including high-burnup fuel. Some of the issues addressed are the following:
 - High-burnup fuel cladding mechanical properties.

- Effect of hydrogen and hydrides in the cladding mechanical properties, including the impact of hydride re-orientation.
- Mechanical properties of highly corroded and spalled cladding.
- The main concern that should be the subject of a continued R&D effort is the high-burnup SF behaviour under transportation accident conditions after long dry-storage periods.
- Work is also ongoing regarding ageing of concrete. Additional R&D should be performed to study corrosion behaviour of metallic materials under ambient conditions.

SWEDEN

- No information specific to LTIS has been provided.

UNITED KINGDOM

- R&D for LTIS of AGR fuel:
 - Demonstration of the storage regime by Post Storage Examination of long stored (25 year) intact fuel and long stored (29 year) failed fuel.
 - Ongoing lead-time container corrosion trials.
 - Post irradiation examination of modern high burn up fuel discharges, including the effect of fuel design changes.
 - Thermal modelling of the storage pond and new high density storage racks.
 - Studying the effect of higher storage temperatures (e.g. from loss of cooling) on the ability of the pond water chemistry to inhibit corrosion of sensitised fuel cladding.
 - Development of contingency plans for fuel cladding failures occurring.
 - Development of techniques for fuel condition monitoring.
- R&D for LTIS of LWR fuel:
 - No outstanding gaps based on work completed to date and extensive international experience.
- R&D for HLW:
 - Mature process for storage, evaporation and vitrification. Extensive development experience is available for vitrification technology (AREVA). A vitrification test rig is available for optimisation studies. Research focus will be around durability studies of containers associated with eventual geological disposal.

UNITED STATES

- As discussed in Q6, NRC completed the EST TIN report in May 2014. The staff evaluated the level of knowledge of the potential degradation of components of the dry-storage system, as related to their expected safety functions and regulatory requirements for storage and

transportation. Staff used this evaluation to prioritise further research in the identification of changes in the NRC's regulatory framework that might be needed to support EST of SF.

- NRC staff concluded that the following potential degradation mechanisms or drivers should be addressed first as "Priority 1":
 - Stress corrosion cracking (SCC), pitting, and crevice corrosion of stainless steel canister body and welds.
 - Swelling of fuel pellets due to helium in-growth, and fuel rod pressurisation due to additional fuel fragmentation, helium release, and fission gas release during accidents.
 - Thermal calculations.
 - Effects of residual moisture after normal drying.
 - In-service monitoring methods for storage systems and components.
- Other potential types of degradation rated as high overall for further research should be addressed next, and are considered "Priority 2" including:
 - Propagation of existing flaws in cladding.
 - Wet corrosion, SCC, and metal fatigue of fuel assembly hardware.
 - Metal fatigue of cladding caused by temperature fluctuations, SCC, and DHC.
 - Low temperature creep and galvanic corrosion of cladding.
 - Microbiologically influenced corrosion of stainless steel, carbon steel, and cast iron body, welds, lids, and seals.
 - Embrittlement of fuel basket welds at low temperature, and metal fatigue due to temperature fluctuations.
 - Thermal ageing and creep of neutron absorbers.
 - Concrete degradation; priority of specific mechanisms depends on availability of monitoring methods and accessibility of the component.

9. Describe the considerations on LTIS resulting from the Fukushima lessons learnt

CANADA

- The lessons learnt implemented by licensees focused on the interim wet storage of SF. As per the CNSC Fukushima Action Plan, available on the CNSC's website, licensees were requested to complete an analysis of the structural integrity of the SFP at temperatures in excess of the design temperature limit. If structural failure could not be precluded, they were to then demonstrate what additional mitigation (e.g. high capacity makeup or sprays) would be provided.

- In addition, licensees were requested to evaluate the consequences in the event of a loss of shielding and the potential for hydrogen generation in the SFP area. The CNSC has found the structural integrity analyses of SFPs at Canadian NPPs acceptable. The analyses predicted some leakage at elevated temperatures; however, this is well within the makeup capability that has been implemented and thus assuring fuel cooling is maintained (SF covered) during an accident.
- As a result of the analyses, NPPs implemented accessible pool makeup water connections and better monitoring instrumentation.

FINLAND

- Interim storages were evaluated as part of national safety assessment in relation to Fukushima Daiichi accident. Main modifications, which implementation is ongoing, are the following:
- Olkiluoto SF storage
 - External cooling water connection, transportable fire water pumps and improved availability of raw water.
 - Water level & temperature monitoring independent from power supply.
- Loviisa SF storage
 - Possibility to use air-cooled cooling towers as an alternative ultimate heat sink of SF pools.
 - Improved steam out-flow via exhaust air conditioning and external cooling water connection.
 - Water level and temperature monitoring independent from power supply.

FRANCE

- The feedback of Fukushima Daiichi accident shows the interests to work on some severe accidents (extreme aggressions for example). It is an interesting way to increase the safety level of the installations, provided to take into account the specificities of each installation to define these accidents.
- Severe external aggression (flooding, earthquake...) has to be defined and studied. Taking into account the long period of time envisaged for LTIS, margins have to be considered. Moreover, the loss of cooling has to be postulated and the robustness of the storage installation has to be demonstrated. One of the main issues is the recovery of the stored objects and their transfer to a safe storage place.

GERMANY

- The earthquake off the eastern coast of Japan on 11 March 2011 and the resulting flooding by a tsunami triggered a nuclear disaster at the Fukushima site. Even though the initiating events of the nuclear disaster in Japan, in particular the magnitude of the earthquake and the height of the tidal wave, cannot be applied directly to European and German conditions, the BMU deemed it nevertheless necessary to perform not only a stress test for German NPPs and research reactors, but also for the facilities for the management of SF and RW. The ESK was commissioned to develop appropriate assessment concepts for these facilities. The results of the stress test are documented in two ESK statements issued in 2013.

- The review was based on a questionnaire that was answered by the operators of the storage facilities. Apart from questions about 10 different load cases (earthquake, flooding, heavy rain, other weather-related events, failure of the electrical energy supply, plant-internal fire, fires outside the plant, aircraft crash, and blast pressure wave), the questionnaire also contained the stress level(s) of protection that the ESK applied as a basis in the assessment. The following questions were used as assessment criteria:
 - a) Will the vital functions be maintained at the stress levels?
 - b) Which maximum effects are realistically conceivable at the stress levels?
 - c) Are any cliff edge effects foreseeable and if so, have they been taken into account?
 - d) On which basis has the assessment been made and is it plausible and comprehensible?
- Issues related to the security (physical protection) of facilities were not considered in this review. In terms of the nuclear waste management facilities, the results of the stress test can be summarised as follows:
 - The storage of the SF and heat-generating waste is based on a robust protection strategy, in which compliance with the essential protection goals during storage in normal operation and in case of accidents is ensured primarily by the metallic thick-walled containers. The design of the containers furthermore ensures that, even in the event of a beyond-design-basis accident; no major disaster control measures are required. The investigations and reviews have shown that the storage of SF and heat-generating waste fulfils the highest stress level and achieve the highest degree of protection in almost all load cases.

JAPAN

- Strengthen measures against earthquakes and tsunamis.
- Ensure power supplies.
- Ensure reliable cooling functions of spent fuel pools.
- Thorough accident management (AM) measures.
- Ensuring the water tightness of essential equipment and facilities.
- Improvements to the accident response environment.
- Enhancement of the radiation exposure management system at the time of the accident.
- Enhancement of training for responding to severe accidents.
- Central control of emergency supplies and setting up of rescue teams.
- Response to a combined situation of massive natural disaster and nuclear emergency.
- Reinforcement of environmental monitoring.
- Clarification of the allotment of roles between central and local organisations.
- Enhancement of communication regarding the accident.
- Enhancement of responses to assistance from other countries and communication to the international community.

- Accurate understanding and prediction of the effect of released radioactive materials.
- Clear definition of the criteria for wide-area evacuations and radiological protection standards in nuclear emergencies.
- Enhancement of safety regulatory and administrative systems.
- Establishment and reinforcement of legal frameworks, standards and guidelines.
- Human resources for nuclear safety and nuclear emergency preparedness and responses.
- Ensuring the independence and diversity of safety systems.
- Effective use of probabilistic safety assessment (PSA) in risk management.
- Thoroughly instil a safety culture.

For details, see “*Additional Report of the Japanese Government to the IAEA – The Accident at TEPCO’s Fukushima Nuclear Power Stations – Summary, Second Report*”, Nuclear Emergency Response Headquarters, Government of Japan, September 2011. (This document is attached to “*National Report of JAPAN for the Fourth Review Meeting, Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management*”, Government of Japan, October 2011.)

NETHERLANDS

- Apart from the fact that also a stress test has been carried out and some robustness enhancing measures have been implemented, no other considerations.

RUSSIA

- Following the Fukushima Daiichi accident, a set of efforts has been implemented at MCC being the main site engaged in the development of SF management technologies, involving:
 - The development of geodynamic, seismic and geotechnical systems to monitor the site, MCC buildings and structures and construction of additional seismological and geodetic network stations.
 - Efforts aimed at managing beyond-design-basis accidents (“crash-tests” at “wet” and “dry” SF storage facilities).
 - Installation of emergency cooling and irrigation system in KhOT-1 SFA compartments. In case of blackout and failure of containment in the four cooling pools, SF cooling will be provided for 72 hours.
 - Analysis of beyond-design-basis accidents has been performed for KhOT-2 storage facility resulting in the identification of relevant measures ensuring effective management of such accidents. Seismic resistance of KhOT-2 storage facility has been increased to 9.6 on MSK-64 scale, passive heat removal systems are provided.

SPAIN

- The fuel cycle facilities in Spain have been subjected to stress tests, ISFSIs as an integral part of corresponding NPPs, and the results have been made public. As a result of the tests, some design changes have been made to increase equipment reliability and facility resilience.

SWEDEN

- As a follow-up to the severe Fukushima Daiichi NPP accident, SSM decided in May 2011 that all Swedish NPPs as well as the ISF for spent nuclear fuel (Clab) should be analysed due to requirements specified by the European Nuclear Safety Regulators Group, ENSREG. The aim was to assess the robustness of the facility beyond-design-basis.
- SKB's stress test analysis of Clab indicated that the facility is robust and able to withstand the events it is designed for, as well as having adequate margins in many of the extreme situations analysed. The analysis, however, identified areas for improvement regarding the facility's resistance and ability to withstand some of the extreme events. SSM's review of SKB's stress test analysis in particular identified the need for further earthquake analysis and analyses on the consequences of loss of water coverage of the fuel.
- As a result of the stress test assessments, some areas of improvement for the SF pools in Swedish NPPs have been identified by the licensees and the regulator.

UNITED KINGDOM

- The Sellafield site comprises a wide range of nuclear facilities, including operating facilities associated with the Magnox reprocessing programme, the THORP and a range of waste treatment plants and interim storage facilities. Interim storage facilities include fuel storage ponds, legacy waste silos, solid intermediate-level waste stores and encapsulated waste stores.
- While reprocessing operations are planned to cease in the next five to seven years, the operational life of some of the site facilities currently extends to 2120, requiring the retrieval, treatment, consolidation and safe extended storage of a variety of radioactive materials. Sellafield has utilised its existing safety assessment processes to inform and prioritise studies into beyond-design-basis events and resilience evaluation required following Fukushima by the United Kingdom regulators and industry bodies such as WANO.
- There are significant differences between NPPs, for which the ENSREG "stress tests" were originally intended, and the Sellafield site which is instead centred around two reprocessing facilities (Magnox and THORP), with a supporting infrastructure of waste processing and storage facilities, coupled with a legacy of high hazard older facilities.
- The effective application of resilience learning to SF management facilities presents an unusual challenge, as the tests have typically been framed with a LWR in mind. To support the requirement to analyse beyond-design-basis events and the subsequent loss of safety critical utilities (as experienced at Fukushima), Sellafield Ltd. has developed two further processes, Severe Accident Analysis and Resilience Evaluation, to enable a more developed understanding of both potential fault states and the required responses. These processes use the very developed understanding already in place as a result of a comprehensive programme of safety cases.
- These approaches to resilience analysis and improvement have enabled new learning to be derived, while residing effectively within existing IAEA standards and within the existing national regulatory framework. This further demonstrates the effectiveness of both existing standards and regulatory frameworks. The techniques developed since Fukushima have been effectively applied to the range of fuel cycle facilities covering fuel receipt ponds, reprocessing plants, waste treatment facilities and product stores. These reviews have considered the resilience of complex, diverse fuel management facilities, comprising many tens of plants, with different functions. Some plants have already been operated for up to 60 years, and the operational life of

some of the site facilities currently extends to 2120. The driving objective was to improve protection to the workforce and the public by maximising the learning from Fukushima. Specific areas have been considered in relation to beyond design basis accidents affecting LTIS, such as prolonged loss of cooling, effect of loss of pond water and the effect of quenching dried fuel cladding.

UNITED STATES

- In response to the Fukushima Daiichii accident, the NRC established the Near-Term Task Force (NTTF) to conduct a systematic and methodical review of NRC processes and regulations and determine if the agency should make improvements to its regulatory programme. On 12 July 2011, the NTTF issued its report, titled “*Near-Term Report and Recommendations for Agency Actions Following the Events in Japan*” (ADAMS Accession No. ML11186A950), which includes 12 recommendations. NRC staff evaluated SF storage designs to determine the effect of severe natural phenomena hazards and the applicability of the NTTF recommendations. As presented in a public meeting on 13 March 2015, NRC staff found that the NRC’s existing regulatory framework ensures the safe and secure storage and transportation for spent nuclear fuel licensed by the NRC. Based on the qualitative assessment, NRC staff did not find safety concerns associated with the designs of SF storage and transportation systems.