

Ongoing IAEA Activities on Spent Fuel Management

Technical Meeting on the Management and Preservation of Spent Fuel Data

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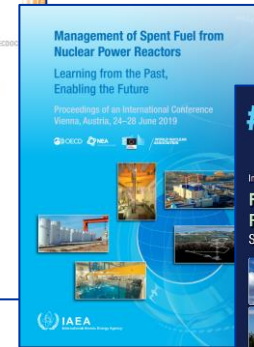
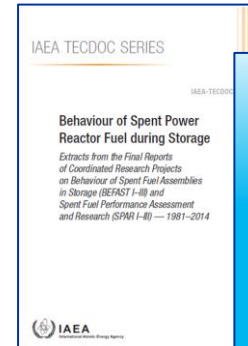
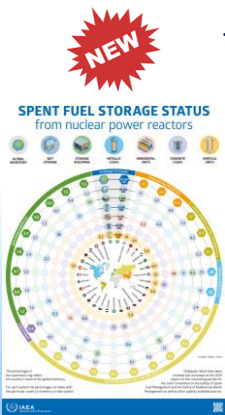
Nuclear Fuel Cycle and Materials Section (NEFW-NFCMS)

IAEA Nuclear Energy Department

IAEA actively supports the sustainable, safe, secure, reliable and economic management of SNF from nuclear power reactors by providing MSs with relevant technical information (guidance) based on operational experience and best practices about the SF management options



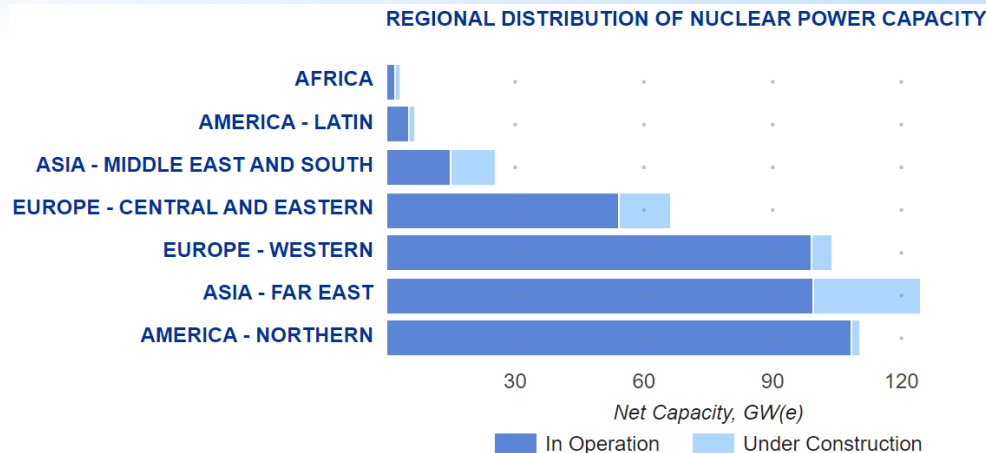
- Through:
 - International conferences and workshops
 - Publication of technical documents and reports
 - The coordination of international research activities through Coordinated Research Projects (CRPs)
 - The management of specific databases
 - E-Tools



Current Worldwide Situation of Nuclear Power



Regional Distribution of Nuclear Power Plants



56 more reactors under construction
~2/3 in Asia

427 nuclear reactors
operating in
32 countries

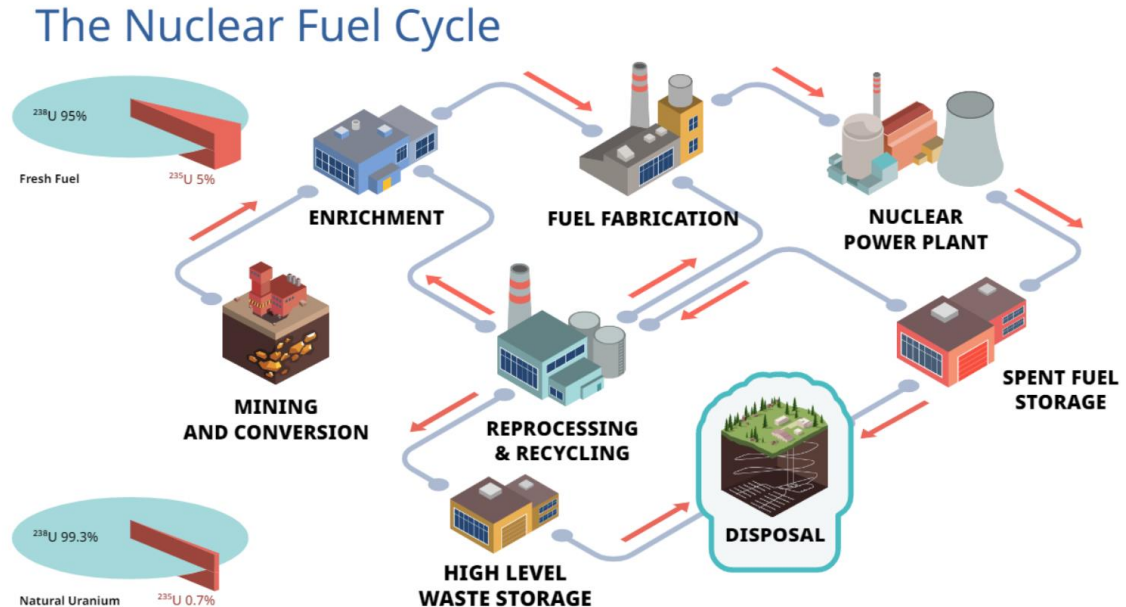


Over 10% of global electricity
1/3 of low-carbon electricity

~30 new countries
planning
or developing a nuclear
power programme

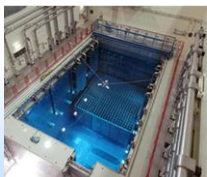
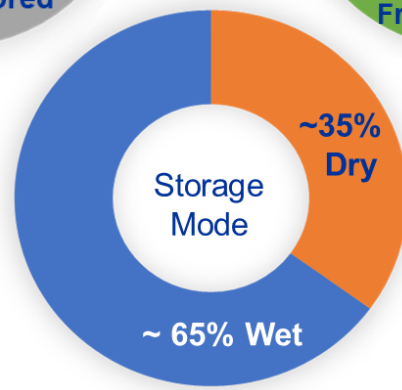
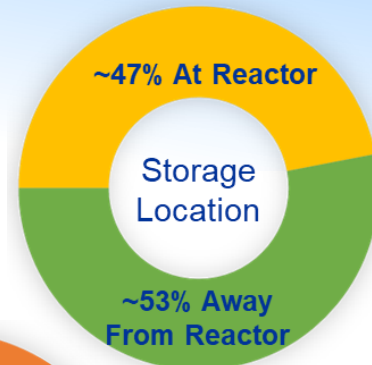
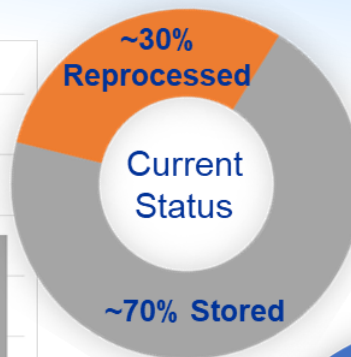
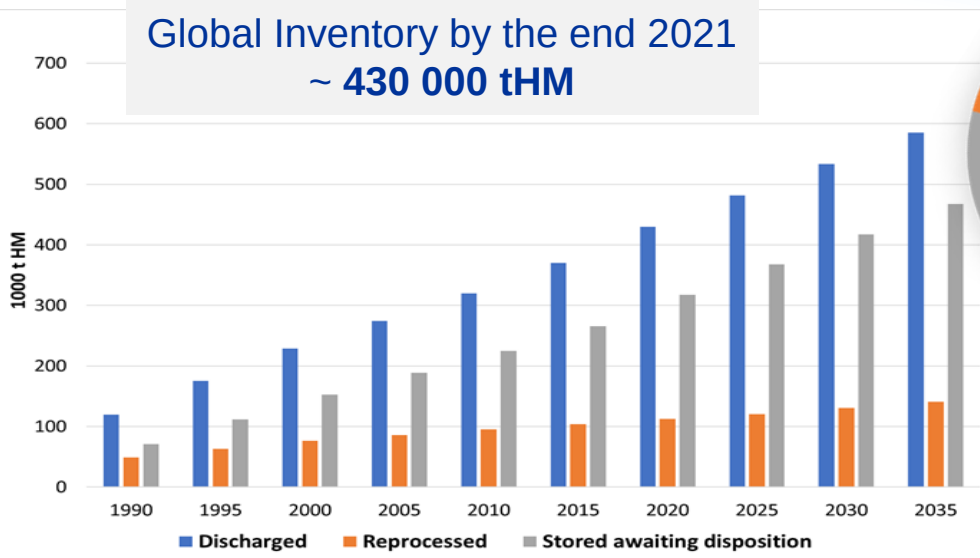
Nuclear fuel cycle options and trends

- For Nuclear power **sustainability**, nuclear fuel cycle must remain economically viable and competitive through **optimization of fissile materials' use** in reactor cores or valuable materials recycling
- This results in **different fuel cycle options**, some already implemented and others may be deployed in the future
- **Integrated approach** of the fuel cycle
- **Integration** different reactor types' fuel cycle



Spent Fuel Management: Status and Trends

Global Inventory by the end 2021
~ 430 000 tHM



Selection of storage technology depends on many factors



The type of fuel being stored



Economic factors



Preferences of operator, stakeholders, public, etc.

Challenges in Spent Fuel Management

- Planned storage durations are increasing:
 - In 1980s 20-50 years
 - In 1990s up to 100 years
 - In 2000s 100+ years
- License renewal for storage systems
- Confirming on-going SNF behaviour & integrity
- Maintenance and inspection of SSCs
- Ageing management (beyond design basis for most)
- Accommodate new SNF from SMR different types
- Implement multi-recycling in LWRs at industrial scale
- Demonstrate and scale up multi-recycling through AFCs for Gen-IV reactors
- Transportability after long storage durations and orphan sites



IAEA Coordinated Research Projects on Spent Fuel Management

Coordinated Research Projects (CRPs)



Closed

- Demonstrating Performance of Spent Fuel and Related Storage System Components During Very Long Term Storage” (DEMO) T13014 (2012-2016)
- Spent Fuel Performance Assessment and Research (SPAR IV) T13016 (2016-2020)
- Ageing Management Programmes for Dry Storage Systems T21028 (2016-2021)

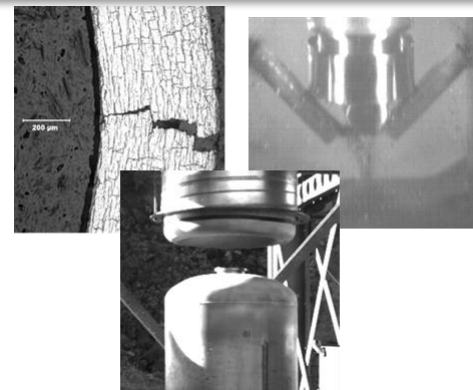
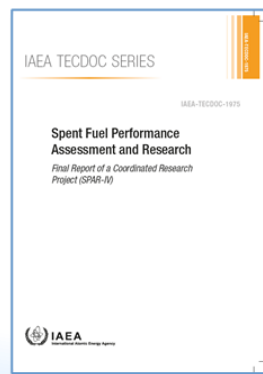
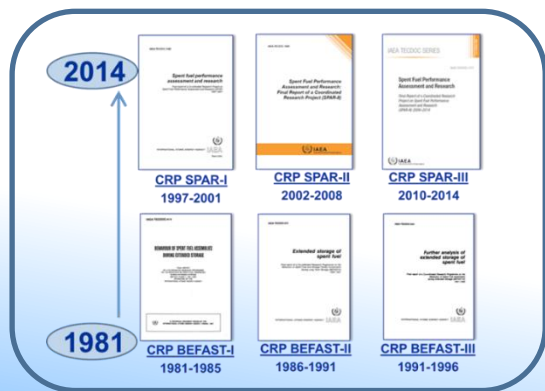
Active

- Management of Severely Damaged Spent Fuel and Corium T13015 (2016-2021)
- Spent Fuel Characterization T13018 (2020-2024)
- Spent Fuel Research and Assessment (SFERA) T13020 (2021-2025)
- Performance Assessment of Storage Systems for Extended Durations (PASSED) T13019 (2022-2026)



CRPs on Spent Fuel Behaviour (+40y Operational Experiences and Research Worldwide)

- **Series of Coordinated Research Projects BEFAST and SPAR (1981-2020)**
 - BEHAVIOUR of spent Fuel Assemblies in STORAGE (BEFAST I, II and III) and later
 - Spent fuel Performance Assessment and Research (SPAR I, II, III and IV)
- Covering all power reactor fuels and
 - MAGNOX, RBMK, WWER, AGR, BWR, PWR, HWR, PHWR
- Spent Fuel performance in Wet and Dry storage



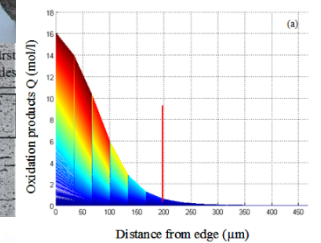
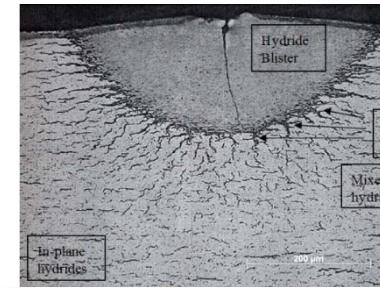
CRPs on SF Storage Systems Behaviour

“Demonstrating Performance of Spent Fuel and Related Storage System Components During Very Long Term Storage”
(DEMO) CRP T13014 (Closed, 2012-2016)

Specific Objectives

Wide range of complementary aspects:

- SCC mechanism investigations and monitoring
- Effect of drying and storage on cladding
- Concrete cask confinement capability
- Bolted closure system assessments
- Long term neutron & gamma shielding capability
- System demonstration tests



Linked to Extended Storage Collaboration Programme (ESCP) International Sub-committee of EPRI

CRPs on SF Storage Systems Behaviour

“Ageing Management Programmes for Dry Storage Systems” (AMP) CRP T21028
(Closed, 2016-2020) (Final Report in Drafting)

- CRP Overall Objective: To develop the technical basis and methodology to enable guidance to be provided to Member States on how to generate an ageing management programme for spent fuel dry storage systems
- Specific activities on
 - National regulations (License renewal for extended storage)
 - Process for generating an AMP (generic flowchart)
 - Identification of SSC (Categorization)
 - Technical underpinning (SF, Materials, Systems)
 - Operating experience (DPCS, MVDS, Silos)
 - Monitoring, Mitigation and Repair Technologies

DCSS Visual Inspection – Lid Weld

Courtesy of EPRI

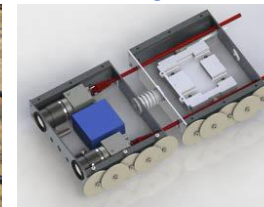


Freshly-loaded canister

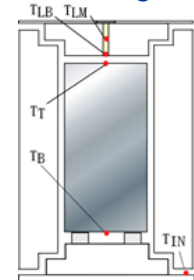


DCSS loaded in 2008

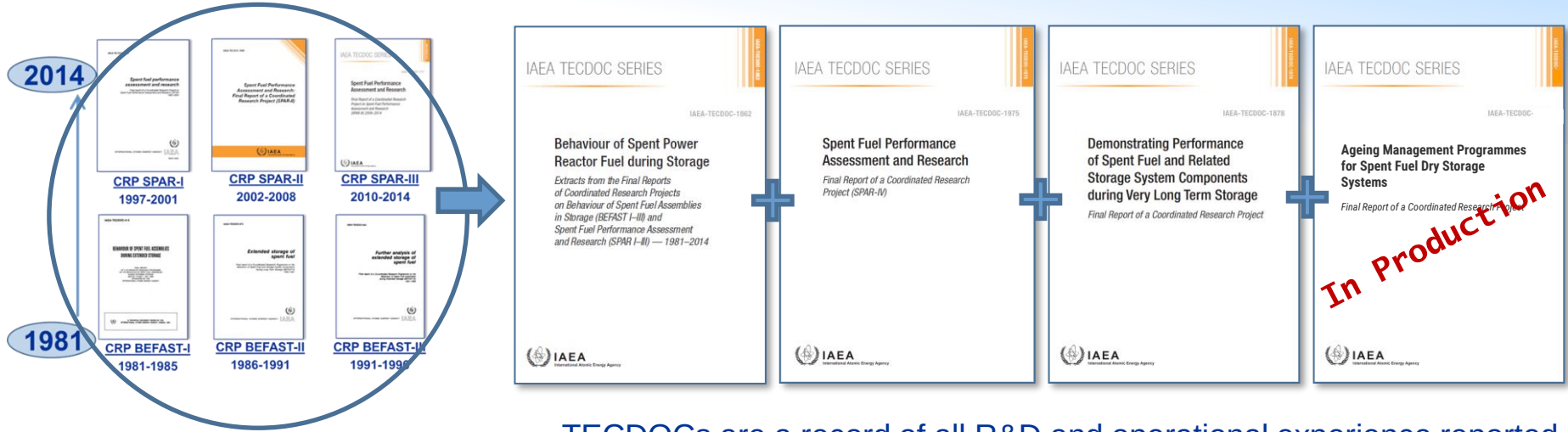
Overview about development of inspection technologies



Thermal monitoring to ensure leak tightness



The work continues!



TECDOCs are a record of all R&D and operational experience reported during the BEFAST, SPAR, DEMO and AMP CRPs

- Spent Fuel Research & Assessment (SFERA) CRP T13020 (Open, 2021-2025)
- Performance and Assessment of Storage Systems for extended Durations (PASSED) CRP T13019 (Open, 2022-2026)

Still open for proposals!

SFERA (CRP T13020)

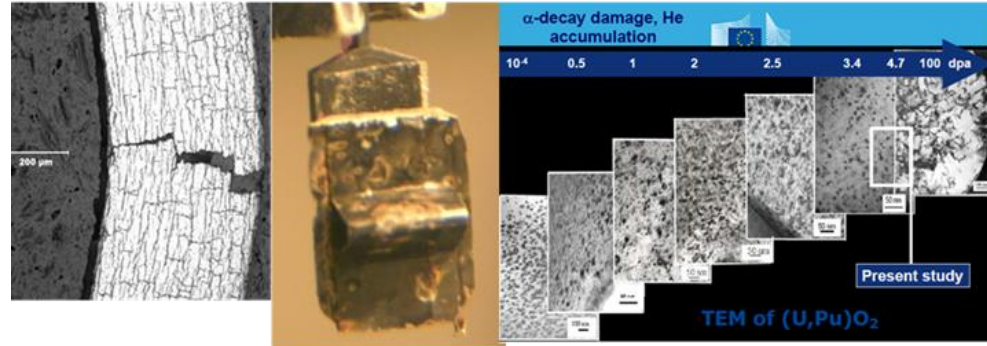
Still accepting proposals

Objective

- To sustain and improve IAEA's Member States' technical knowledge base on the long-term behaviour of power reactor spent fuel through sharing and disseminating information, reporting topical research carried-out in participating Member States, and by documenting ongoing spent fuel performance

Scope limited to fuel

- Fuel material
- Cladding
- Fuel assembly structural components



Looking at both wet & dry storage conditions

PASSED (CRP T13019)

Open for proposals

Objective

- To sustain and improve IAEA Member States' technical knowledge base on the long term behaviour of spent fuel storage systems, inspections possibilities and monitoring technologies, through the sharing and disseminating of technical information, the reporting on topical researches carried-out in participating Member States and the documentation of on-going storage systems' performance

Covers wet & dry storage system related aspects

- Performance
- Monitoring & inspection
- Ageing Management Programmes
- Remedial action
-

DCSS Visual Inspection – Lid Weld

Courtesy of EPRI



Freshly-loaded canister



DCSS loaded in 2008

Planning to hold a meeting/workshop in conjunction with SFERA to facilitate information exchange between fuel & system communities

Spent Fuel Characterization (CRP T13018)



Objective

- To support and share information between concerned Member States on issues related to the characterization of spent nuclear fuel in the various steps of its management

still accepting proposals

eurad
European Joint Programme
on Radioactive Waste Management

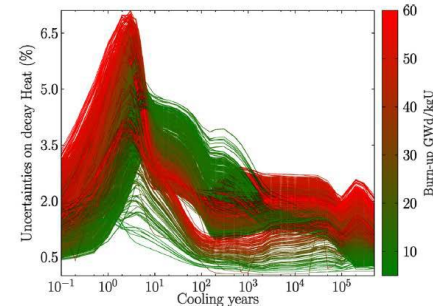
Complementary to EURAD project's WP8: "Spent Fuel Characterization and evolution until disposal"

- WP8 looks only at LWR fuel and involves EC members around 4 tasks:

1. *State of the art*
2. **Fuel properties characterization and related uncertainty analysis**
 - Modelling and NDA technique validation and harmonization
3. **Behaviour of nuclear fuel and cladding after discharge**
 - Destructive Analysis
4. *Accidental scenarios and consequence analysis*
 - Application of Task 2 and 3 results to consequence analysis of postulated r

➔ IAEA CRP introduces more fuel types and wider participation

- CRP Project aligns with Task 2 and Task 3 of WP8



Other Ongoing IAEA Activities on Spent Fuel Management:

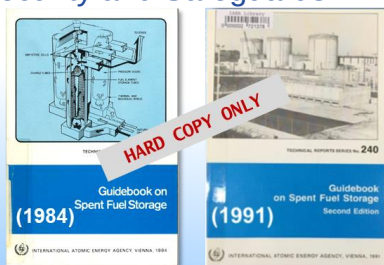
- Recent Publications
- Ongoing Activities
- Future Meetings

Spent Fuel Storage Guidebook, 3rd Edition

Revision of the 1991 guide, available only in hardcopy

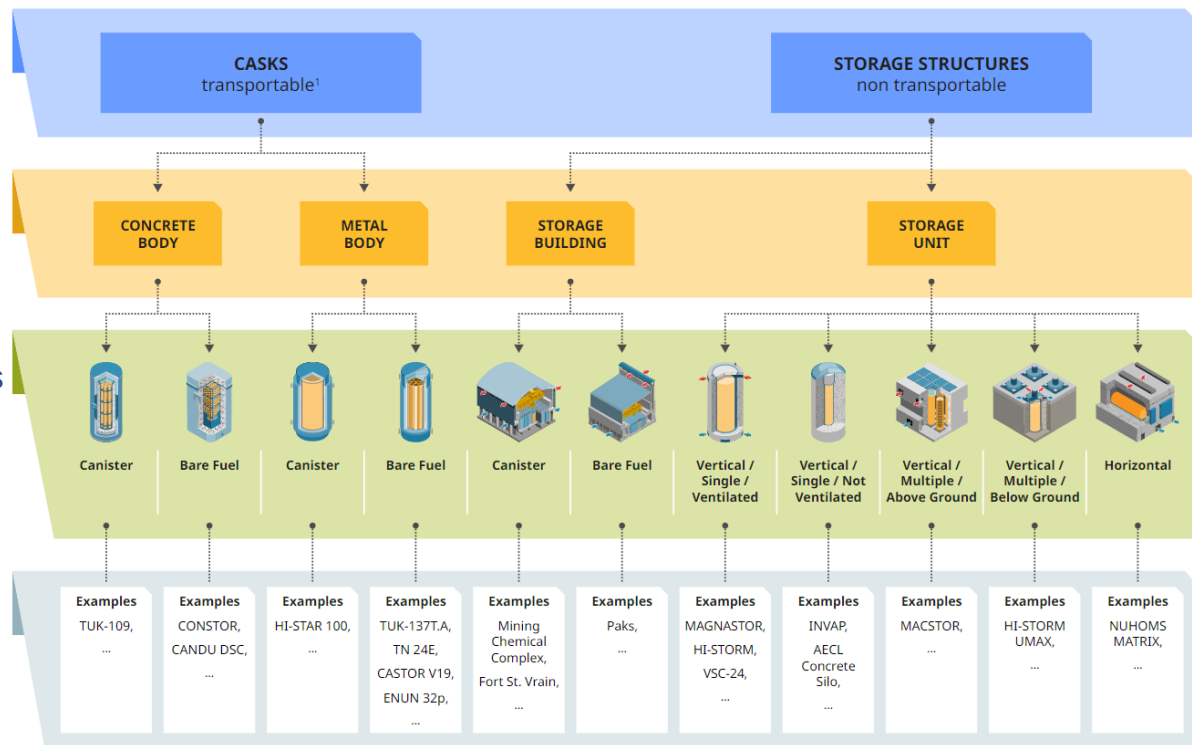
- Aims of the Guide:

- Harmonise dry storage technologies classification and description
- Harmonise terminologies on SFS for better understanding
- Provide figures of the current inventory distribution
- Description of Storage Technologies
- Safety, Security and Safeguards aspects
- Ageing management
- Transportation
- Security and Safeguards



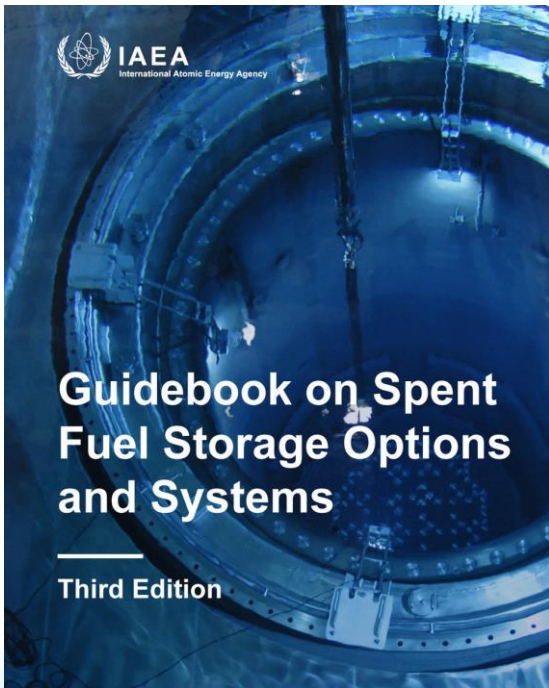
Available as preprint!

DRY STORAGE TECHNOLOGIES



¹ able to obtain a type B(U) package approval for transportation.

Interactive Online Version



Guidebook on Spent Fuel Storage Options and Systems

Third Edition

2. SPENT FUEL STORAGE

2. SPENT FUEL STORAGE

Spent Fuel Storage Options and Systems Guide

Nuclear fuel that can no longer efficiently sustain nuclear fission and cannot be used as fuel in its present form is termed 'spent fuel' (SF). The decay of radioisotopes present results in high radioactivity and heat. Therefore spent fuel requires a minimum storage period prior to the implementation of a disposition path (recycling or disposal). Storage of spent fuel is defined in the IAEA Safety Glossary as "the holding of spent fuel in a facility that provides for its containment with the intention of eventual disposal" (2). Spent fuel storage is a definition an interim step. However, the term 'interim storage' is widely used to refer to an intermediate storage step before spent fuel disposition is implemented.

Once spent fuel is removed from the reactor a period of time is required for the initial decay of radioisotopes to enable loading it to a cask for transport; after to further storage, a reprocessing facility for subsequent recycling, or to a conditioning facility for disposal. This initial decay of radioisotopes is predominantly undertaken underground in spent fuel pools located next to the reactor vessel. Spent fuel storage pools have the capability to manage high heat loads and provide flexibility for future handling. The exceptions are gas cooled reactors (GCR) where initial decay of radioisotopes in fuel strings is undertaken in carbon dioxide cooled decay tubes before the string is broken down and transferred to the reactor pool for further decay.

A range of terms are used to describe the options available for locating spent fuel storage facilities. These are described below and depicted in FIG. 13b, 13c.

- At-Reactor (AR) storage:** a pool co-located with the reactor inside the containment building.
- Away-From-Reactor (AFR) storage:** a wet or dry storage facility which is not co-located with the reactor. The fuel has to be transferred or transported to the storage facility. There are two classifications of AFR storage facilities: Reactor Site (RS) and Off-Site (OS).
- Reactor Site (RS):** is a storage facility located within the reactor site boundary. Spent fuel is transferred from one facility to the other. A further distinction can be made for an AFR(SD) in terms of those that are stand alone and can still support operations if the reactor is decommissioned and those which are reliant on reactor services.
- Off-Site (OS):** is a storage facility located outside the reactor site boundary. In this case, spent fuel is transported on public roads.

3.2.1 Dry Storage Casks (Metal and Concrete)

3.2.1.2 Concrete casks

Concrete casks are used for storage, and in some cases transport, of spent fuel. Structural strength and radiological shielding are provided by reinforced regular or high-density concrete. They may use a permitted metal liner on the outside and another one in the cask cavity to contain spent fuel. Heat transfer may take place solely by conduction through the concrete structure, therefore this type of cask has more thermal insulation than those systems using natural convection or passages. Concrete casks can use either a single or double lid closure system, that depending on the design can be sealed or bolted closed, and then tested for leak tightness. Concrete cask systems may or may not depend on regulatory requirements, but tend to be for less tightness. Figure 17 shows a cutaway of a concrete cask.

Spent fuel is vertically loaded directly into the cavity of the concrete cask in the fuel loading station, and then transferred to the storage facility. The concrete casks are stored in a vertical orientation.

Concrete casks are used in a number of countries such as Bulgaria, Canada (FIG. 23) and Lithuania (FIG. 25). Gesellschaft für Nuklear Service (GNS) has developed the concrete cask CONATOR which is available with and without cooling fins (FIG. 26). Pakistan has developed a domestic design, Ontario Power Generation's (OPG) concrete dry storage container (CDS) is also designed for off-site transport.

FIG. 21. Cutaway of a concrete cask.

FIG. 22. CONATOR concrete cask.

FIG. 23. Ontario Power Generation's OPG has concrete dry storage container (CDS), Canada.

FIG. 24. CONATOR concrete cask.

Distribution of the global inventory of spent fuel stored in dry storage casks (metal and concrete) by region and by country is shown in FIG. 25 and FIG. 26 respectively. By the end of 2019, dry cask storage facilities were available in Belgium, Bulgaria, Canada, Czech Republic, Germany, Japan, Kazakhstan, Lithuania, Russia, South Africa, Spain, Switzerland, and USA using a variety of designs. Additionally further cask facilities are under ordering and construction in Japan and Spain.

3.2.1.2 Concrete casks

FIG. 7. Examples of the spent fuel storage pools.

AFR Wet Storage (~ 62,800 tHM)

- Western Europe 45%
- Eastern Europe and Central Asia 41%
- Asia and the Pacific 1%
- Latin America and the Caribbean 3%
- North America 2%

FIG. 8. Regional Distribution of Away from Reactor inventory in wet storage.

There are a variety of AFR wet storage facilities in use, providing extended operational capacity to reactors once their AR pool is full, acting as a centralized facility, or serving as a storage buffer at a reprocessing facility. Distribution of spent fuel inventory in AFR pools by region is shown in FIG. 8. AFR spent fuel storage pools can be located above ground, semi-buried or underground; the Clab centralized facility in Sweden is located wholly underground. While some early AFR pools were open to the atmosphere, operational experience and the need to control pool water purity resulted in all new pools having a covering building. Both the pool's reinforced concrete structure and the covering building require seismic qualification as per the requirements of the national regulation. Depending upon national safety requirements, additional requirements on withstanding the impact of a design basis aircraft may apply.

Most spent fuel pool designs are similar: rectangular in horizontal cross-section and 10 to 13 m deep. As spent fuel contains fissile isotopes, the overall storage array in both AR and AFR pools is determined by criticality considerations and takes into account the use of neutron absorbing materials, fuel spacing, and (in some cases) burnup credit. To maintain the prescribed fuel spacing, fuel assemblies are placed in storage racks or baskets placed at the bottom of the pool (see Fig. 9 for an example). These can generally be described as:

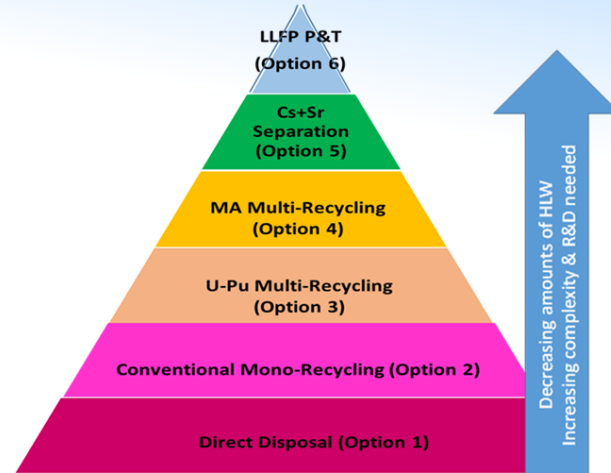
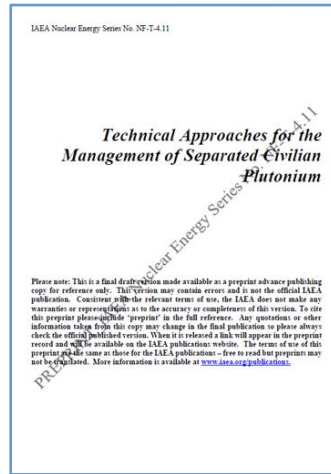
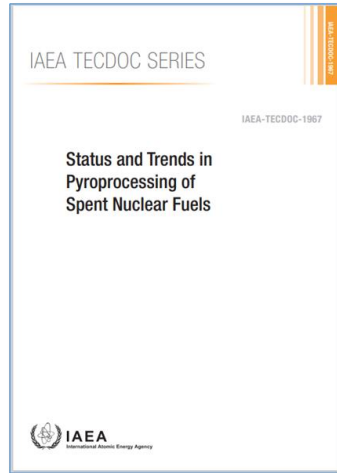
- Racks, a fixed array of storage cells in the base of the pool;
- Baskets, a movable feature holding a number of spent fuel assemblies;

Trays (CANDU), storage structures that can hold 24 fuel bundles in

- two rows of 12 each.

FIG. 9. Trays (CANDU) storage structures that can hold 24 fuel bundles in two rows of 12 each.

Activities on Advanced Fuel Cycles for Gen-IV



Publications under development

- **IAEA Nuclear Energy Series** on *“Existing and Advanced Nuclear Fuel Cycle Technical Options for Waste Burden Minimization”*
- **IAEA-TECDOC** on *“A Collection of Some Member States’ Environmental Impact Studies of Existing and Future Spent Fuel Management Options on Waste Minimization”*
- **IAEA-TECDOC** on *“Spent Fuel Management in the Longer Term (National Perspectives)”*

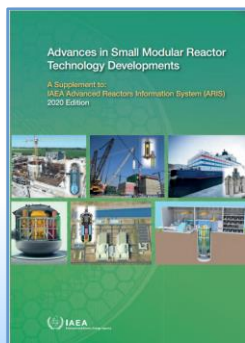
IAEA Activities Integrating the Fuel Cycle



TECDOC-1774 (2015) and **NES NF-T-3.3** (2019)



Drafting a Nuclear Energy Series Report gathering information and discussions collected during a Technical Meeting (held in Vienna, July 2018) and during the International Conference on Spent Fuel Management from Power Reactors (held in Vienna, June 2019, *Proceedings published in 2020*)



TM to Identify Opportunities and Challenges in the Back End of the Fuel Cycle for Evolutionary Accident Tolerant Fuels (Held Virtually 14-17 June 2022)

Near-term needs

TM on Back End of the Fuel Cycle Considerations for Small Modular Reactors (Held in Vienna in 20-23 September 2022)

Longer-term needs

TM to Identify Opportunities and Challenges in the Back End of the Fuel Cycle for eATFs

14-17 June 2022



33 participating Experts from
16 Member States and
1 International Organization

- A lot of work underway to understand the impact on back end activities.
 - More activity is needed to understand the key questions.
 - There was a common recognition of need for irradiated fuel characterization data and testing to validate models that support the back end fuel cycle stages.
- Relatively few major concerns have been identified so far, although limited data available for analyses.
- The importance of multilateral cooperation was remarked upon by several participants.
 - Loss of Halden & other national test reactors, now even more limited resources for materials irradiation testing, leading to slower developments
 - Sharing materials, data and results prevents rework and represents a more cost effective approach.

Planning to convene a workshop in 2023 Q4 to identify common needs and drivers, as well as potential collaborative opportunities

Compiled material publicly available here



[TM to Identify Opportunities and Challenges in the Back End of the Fuel Cycle for Evolutionary Accident Tolerant Fuels 2022 - All Documents \(iaea.org\)](#)

TM on Backend of the Fuel Cycle Considerations for Small Modular Reactors

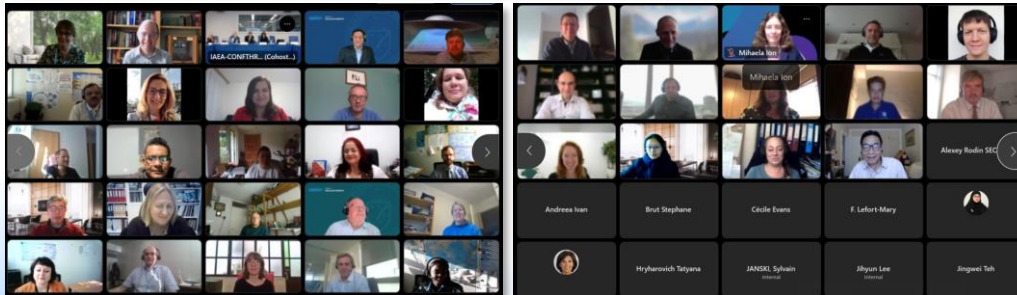
20-23 September 2022



107 participating Experts from
35 Member States and
3 International Organizations

~ 40 Presentations and Extended
Abstracts

Compiled material publicly available here



[Technical Meeting on Back End of the Fuel Cycle Considerations for Small Modular Reactors \(20-23 September 2022\): Overview - Indico for IAEA Conferences \(Indico\)](#)

Key Takeaways

- Understanding the implications of the different stages for managing SMR spent fuels (including transportation) is paramount to make informed decision on the SMR technology to be deployed and on the associated fuel cycle option
 - This applies to countries embarking or willing to embark with SMRs whether they are nuclear countries or newcomers
- Characterizing SMR spent fuels is key to anticipate challenges/gaps/opportunities for their management
- Integrating the selected spent fuel management strategy for a given SMR technology with the one, already implemented for LWRs, is key
 - This also applies to countries envisaging deploying different SMR technologies
- Transportation applies to all stages of the nuclear fuel cycle and is content specific
 - New package designs and regulations will be needed
- International collaboration is essential
- The IAEA has launched an SMR Platform to provide national governments, experts and regulators with an integrated Agency-wide support on all aspects of SMRs' development and oversight
 - Effectively coordinating activities implemented by 4 Departments (Nuclear Energy, Nuclear Safety&Security, Technical Cooperation and Safeguards)

TM on Operational Experiences of Spent Fuel and High Level Waste Transportation

24-28 October 2022



39 participating Experts from
14 Member States and
3 International Organization

- Successful transport campaigns were presented and discussed
 - Depending on the national strategy, transport can be a routine operation or a rare undertaking
 - In assessing each transport proposal, each mode of transport (road, rail or ship) should be considered
- Over the many decades of spent fuel transport, no accident has ever occurred
- The importance of multilateral cooperation in case of international shipments was remarked upon by several participants
 - Development of new transport casks is a time-consuming process
 - Preparation of shipments should be done well in advance
 - Identifying all involved authorities on all levels and notifying them in time is a key step



Compiled material publicly available here



[TM on Operational Experiences of Spent Fuel and High Level Waste Transportation 2022 - All Documents \(iaea.org\)](https://www.iaea.org/documents/iaea/program_management/TF/Operational%20Experiences%20of%20Spent%20Fuel%20and%20High%20Level%20Waste%20Transportation%202022.pdf)

Upcoming Activities

Expanding activities in the field of:

- eATF Fuels
- Advanced reactor and SMR fuel cycles

IAEA e-Tools on Spent Fuel Management

Webinars Spent Fuel Management



Nuclear Back End Webinar Series

Accident Tolerant Fuels and their Impact on Spent Fuel Management (December 2020)



Dr David Hambley
Laboratory Fellow for Spent Fuel Management and Disposal, NNL (UK)



Dr Mikhail Veshchunov
Team Leader Fuel Engineering Nuclear Fuel Cycle and Materials Section (IAEA)



Dr Aladar A. Csontos
Technical Executive Fuel, Chemistry, LLW and HLW Nuclear Sector, EPRI (USA)

IAEA Nuclear Back End Webinar Series

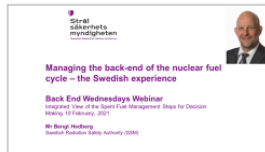
Integrated View of the Spent Fuel Management Steps for Decision Making (February 2021)



Mr Brett Carlsen
Idaho National Laboratory USA



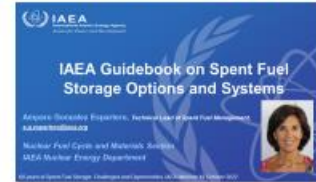
Ms Cécile Evans
Orano France

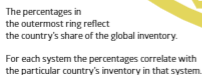


Mr Bengt Hedberg
Strålsäkerhetsmyndigheten, (SSM), Swedish Radiation Safety Authority Sweden

Nuclear Back End Webinar Series October 2022

60 years of Spent Fuel Storage: Challenges and Opportunities





THE TIMELINE

WET STORAGE POOLS

Since the inception of nuclear power in the 1950s spent fuel has been stored wet.

1971 STORAGE BUILDINGS

Storage building Wyifa, UK

Over the past 50 years, dry storage has been increasingly used to provide additional storage capacity according to each facility's needs.

1977 VERTICAL UNITS

SINGLE, NON-VENTILATED
Vertical unit: Whiteshell, Canada

1986 METALLIC CASKS

STORAGE-ONLY
Metallic cask: Surry, USA

Ongoing research and development ensures continuous evolution in dry storage system technology.

1989 HORIZONTAL UNITS

Horizontal unit: H. B. Robinson, USA

1990 METALLIC CASKS

TRANSPORT AND STORAGE
Metallic cask transportable Surry, USA

1993 VERTICAL UNITS

SINGLE, VENTILATED
Vertical unit: Palisades, USA

1996 CONCRETE CASKS

TRANSPORT AND STORAGE
Concrete cask: Pickering, Canada

Deployed values have been rounded and are based on the 2010 reports of the contracting parties for the Joint Convention on the Safety of Spent Fuel Management and the Society of Radioactive Waste Management as well as other publicly available sources.

2015 VERTICAL UNITS BELOW GROUND

SINGLE, VENTILATED
Vertical unit: Calday NP, USA

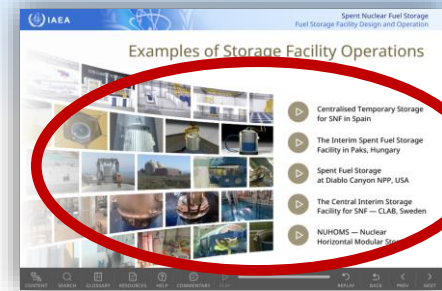
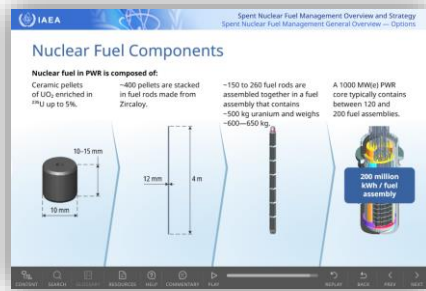
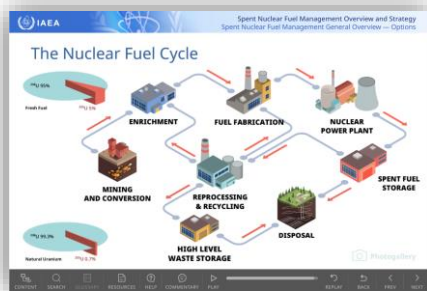
Global Inventory Distribution in Dry Storage Systems
(-105,900 tHM)

Storage Technology	Percentage of Inventory
Storage Buildings	21%
Vertical Storage Units, non-ventilated	16%
Vertical Storage Units, ventilated	10%
Horizontal Storage Units	5%
Concrete Casks	4%
Transportable Casks	3%
Below Ground Units	2%
Other	1%

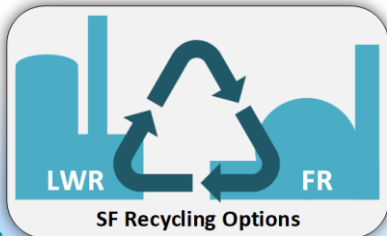
*Taiwan, China

E-Learning Course on Spent Fuel Management

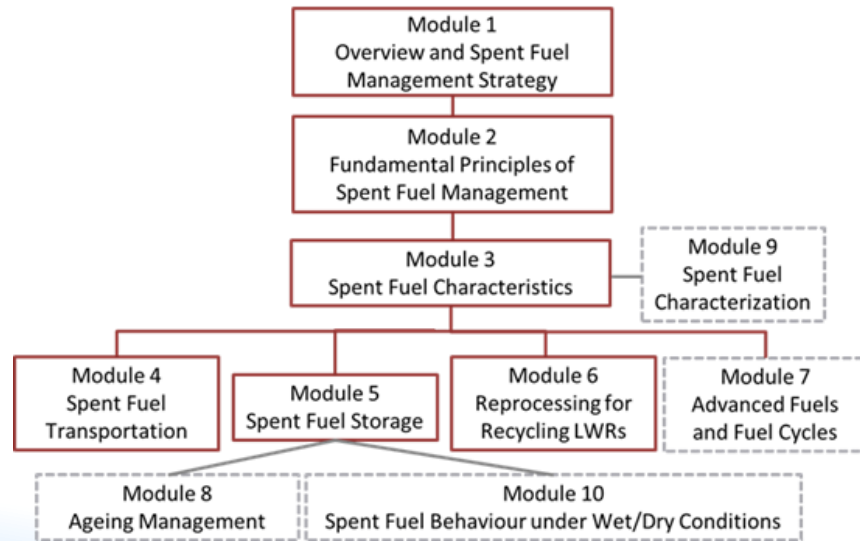
5 Modules (7 Lectures)



Coming soon



Available



Spent Fuel Management Network



Not a member yet?

Introductory video



Now available in Japanese & Russian!

Welcome to the IAEA International Network on Spent Fuel Management - SFM Net

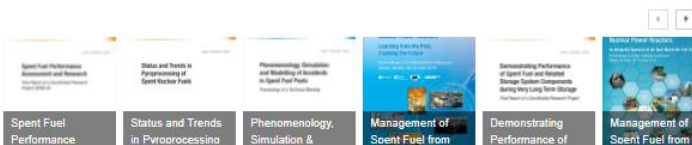
The spent fuel management (SFM) network is a forum for the sharing of practical experience and international developments on spent fuel management.

Its main objectives are to facilitate the efficient exchange of information, communication and cooperation amongst professionals working in the back end of the fuel cycle – from its removal from a reactor core to its final disposition (i.e. SNF wet and dry storage, transportation, handling and retrieval, reprocessing and recycling, economics of the back-end of nuclear fuel cycle, damaged SNF management, stakeholder involvement, communication issues, etc.)

The establishment of the SFM Net is aimed at fostering safe, sustainable and efficient spent nuclear fuel management practices across all IAEA Member States.

For further information or questions please contact SFM.Contact-Point@iaea.org.

Featured Publications



Events 2022

- First Research Coordination Meeting on Spent Fuel Research and Assessment (SFERA) (23-27 May 2022, Virtual)
- Technical Meeting to Identify Opportunities and Challenges in the Back End of the Fuel Cycle for Evolutionary Accident Tolerant Fuels (14 – 17 Jun 2022, Virtual)
- Third Research Coordination Meeting on Management of Severely Damaged Spent Fuel and Corium (29 Aug - 2 Sep 2022, Vienna, Austria)
- Second Research Coordination Meeting on Spent Fuel Characterization (19-23 Sep 2022, Oskarshamn, Sweden)
- Technical Meeting on Back End of the Fuel Cycle Considerations for Small Modular Reactor Fuels (20-23 Sep. 2022, Vienna, Austria)
- Technical Meeting on Operational Experiences of Spent Fuel and High Level Waste Transportation (17-21 Oct 2022, Santander, Spain)
- First Research Coordination Meeting on Spent Fuel Storage Systems Performance and Assessment (7 – 11 Nov 2022, Vienna, Austria)
- Technical Meeting on the Management and Preservation of Spent Fuel Data (6 – 8 Dec 2022, Virtual)

New infographics now available!



Active CRPs

E-Learning Course on Spent Fuel Management

Webinars on Spent Fuel Management

<https://nucleus.iaea.org/sites/connect/SFMpublic/Pages/default.aspx>

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Thank you!

Spent Fuel
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