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Atoms for Peace and Development

“Enabling Flexibility in Spent Fuel Management towards Advanced Fuel Cycles”

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ATOMS FOR PEACE AND DEVELOPMENT

The Agency shall seek to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world.

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173 Member States

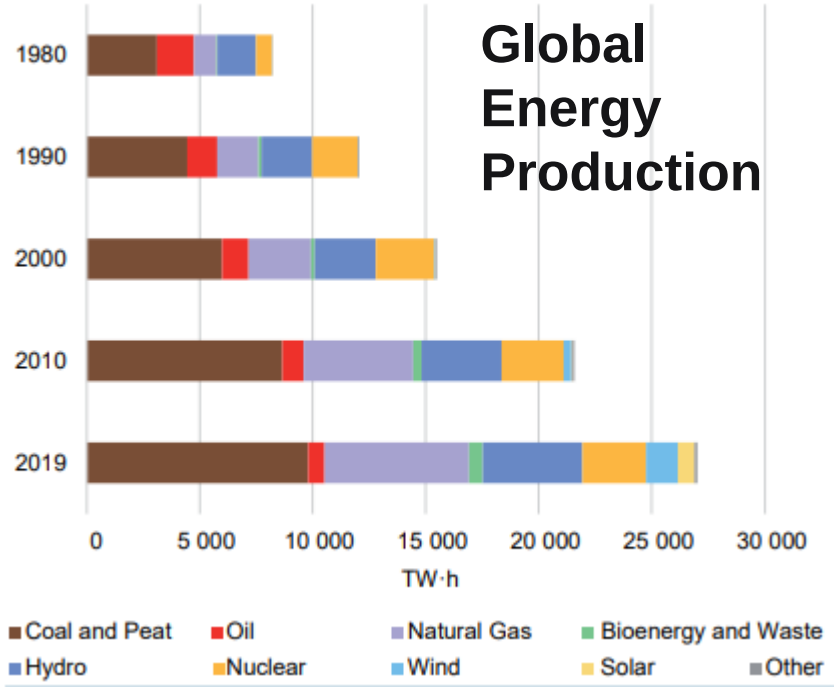
~ 2,560 multidisciplinary professional and support staff from more than 100 countries

Safeguards and Verification

Safety and Security

Science and Technology

Existing and Advanced Reactors' Deployment to Meet SDGs Energy Production Development needs to Address Decarbonization and Resilience / Security of Electricity Supply



- Many countries include Nuclear Power in their national climate plans and plan to construct new NPPs, large or small, for electricity and other applications
- Demand for circular economy favours recycling

How do we Foresee Nuclear Power beyond 2050?
Evolution of Nuclear power

Majority of Reactors

Current Designs

Future Systems

1970 1990 2010 2030 2050 2070

WH 4LP, BWR 4, Konvoi, REP1300

APR1400, CNP 600, EPR, VVER V523

SMRs

FR, HTGR , MS

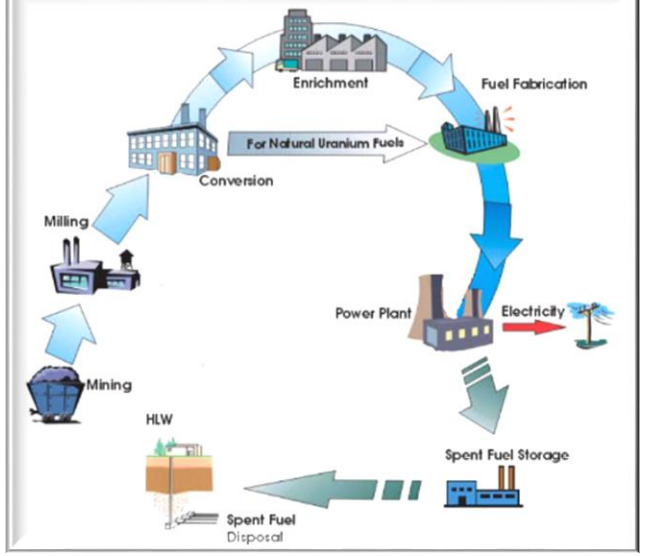
Implementation of a Nuclear Power Programme takes Many Decades, with Many Pathways and Many Unknowns

Sustainable and Flexible Backend Options

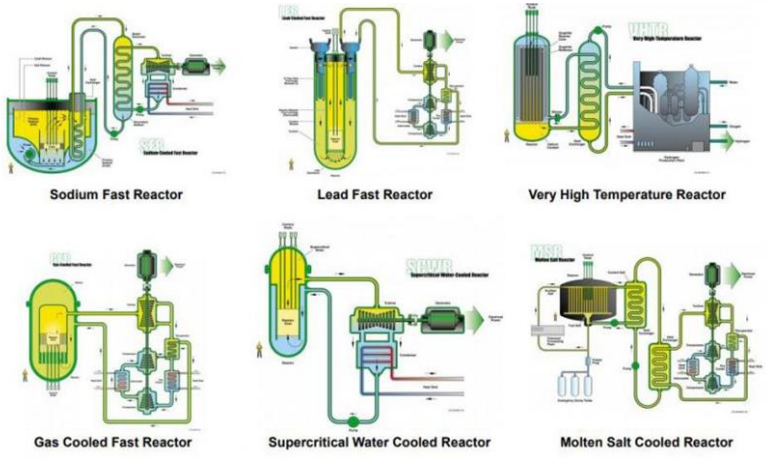
* From IAEA e-Learning Module on Spent Fuel Management
Course: Course on Spent Fuel (iaea.org)

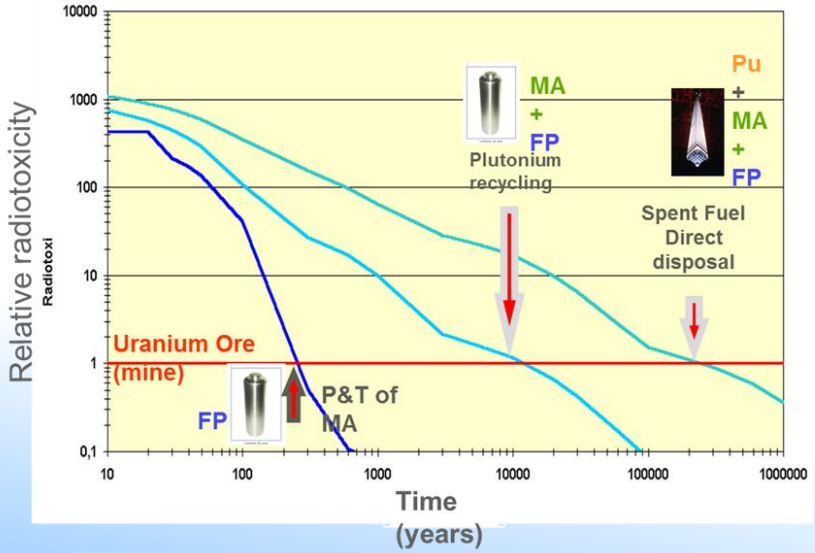
Many Pathways

LWR Open Fuel Cycle



Towards Fully Closed Cycle

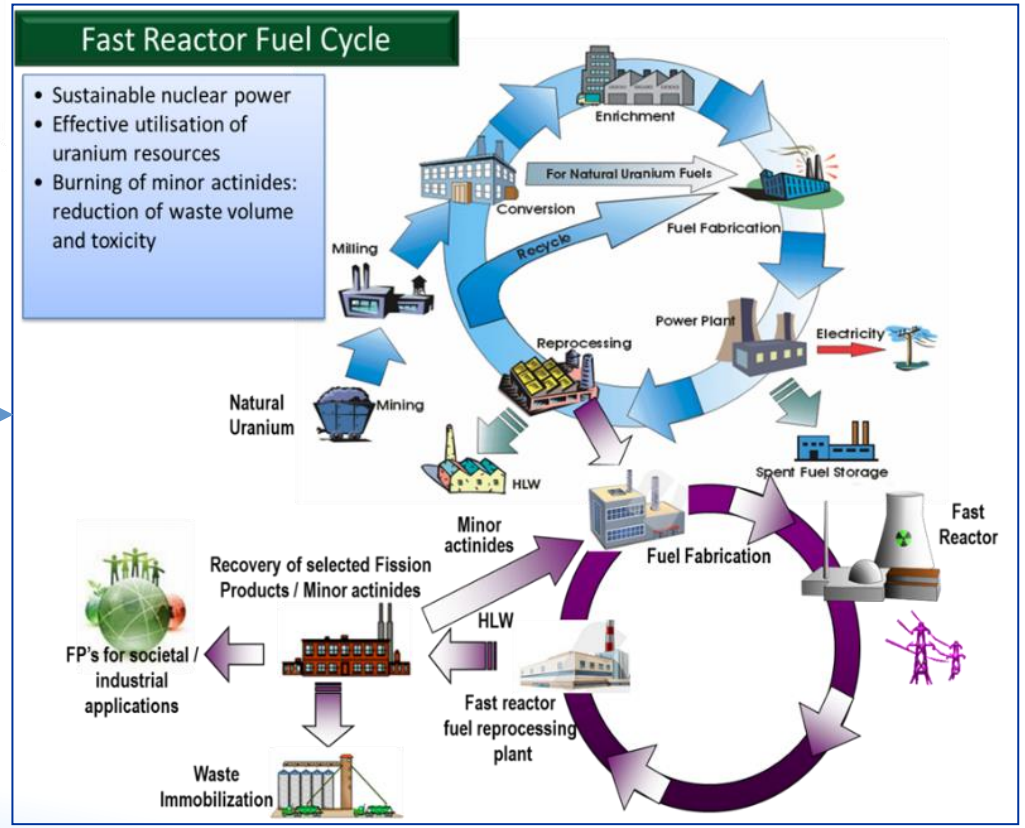




- Economically viable fuel cycles
  - Recycling of valuable materials
- Safe
- Environment-friendly
  - Waste burden minimization
- Proliferation resistant
- Flexible to adapt to any policy evolution

Fast Reactor Fuel Cycle

- Sustainable nuclear power
- Effective utilisation of uranium resources
- Burning of minor actinides: reduction of waste volume and toxicity

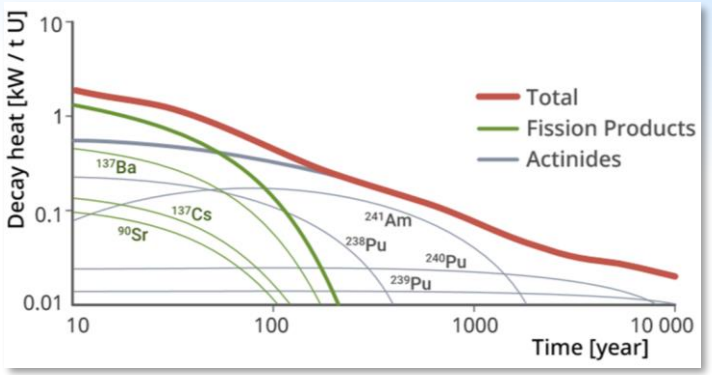


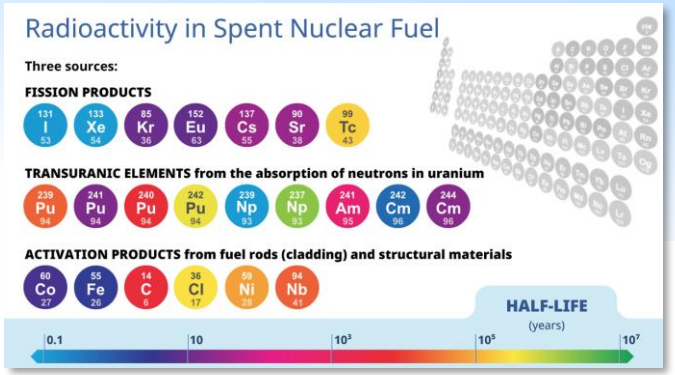
Many Unknowns

- Storage – technologies, location, duration
- Endpoint – direct disposal vs recycling
- Evolution of nuclear energy demand and new technologies and resulting impacts on spent nuclear fuels

These uncertainties and opportunities should be identified, recognized, and addressed

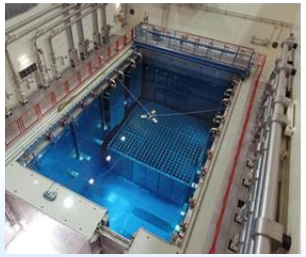
Storage: a KEY Step of Spent Fuel Management Strategies





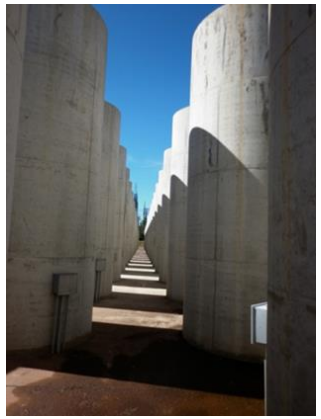
Irrespective of selected management strategy, **spent nuclear fuel (SNF) storage** solutions are needed

- SNF considered as waste: Disposal
- SNF considered as asset: Recycling



Storage duration: a Challenge or an Opportunity?

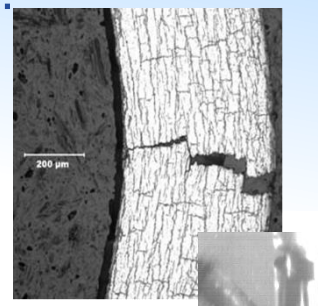
- Long Term Storage* is not an alternative to recycling or disposal
- **However it can provide flexibility for Fuel Cycle implementation to**
  - Incorporate new technologies, new recycling options
  - Accommodate socio-political demands
  - Gain public support
- **Topics of Long Term Storage**
  - Confirmation of SF good behaviour & integrity in the long term
  - Maintenance and inspection of key SSCs of Storage Systems
  - Ageing management of deployed storage systems (beyond design basis for most)
  - SF transportability after LTS



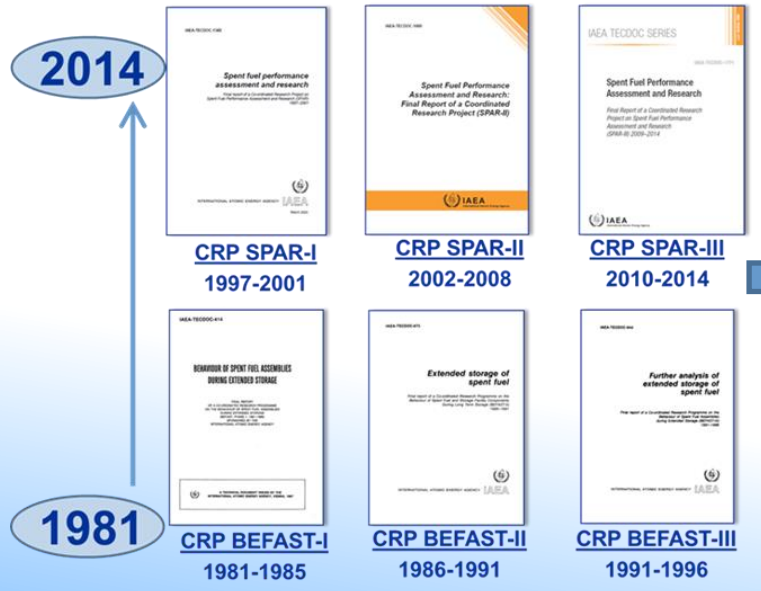
*Storage is a temporary step by definition. Spent fuel is held in a facility that provides for its containment, with the intention of retrieval

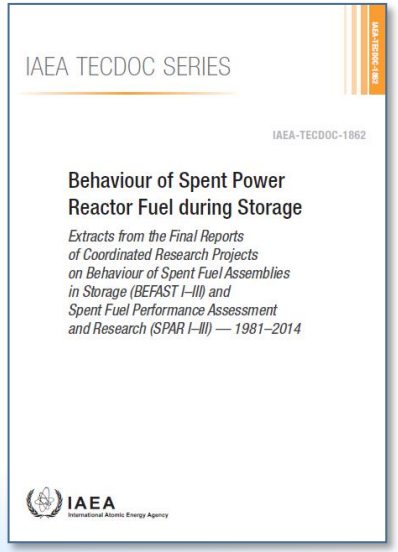
Spent Fuel Performance and Cladding Integrity

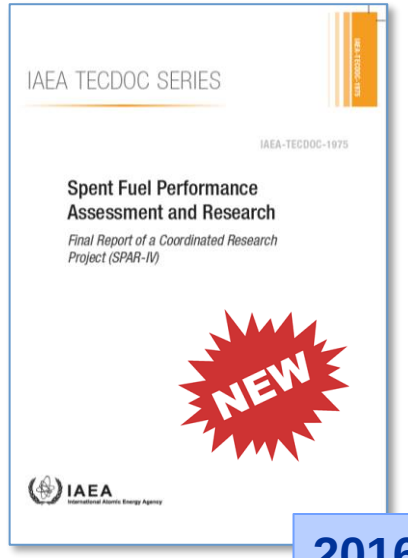
- Series of **Coordinated Research Projects (CRP)** BEFAST and SPAR, since 1991:
  - BEhaviour of spent Fuel Assemblies in STorage (BEFAST I, II and III) and later
  - Spent fuel Performance Assessment and Research (SPAR I, II, III and IV)
- Covering all power reactor fuels
  - MAGNOX, RBMK, WWER, AGR, BWR, PWR, HWR, PHWR
- Spent Fuel performance in Wet and Dry storage



On-Going CRP Spent Fuel Research & Assessment (SFERA) (2021-2025)







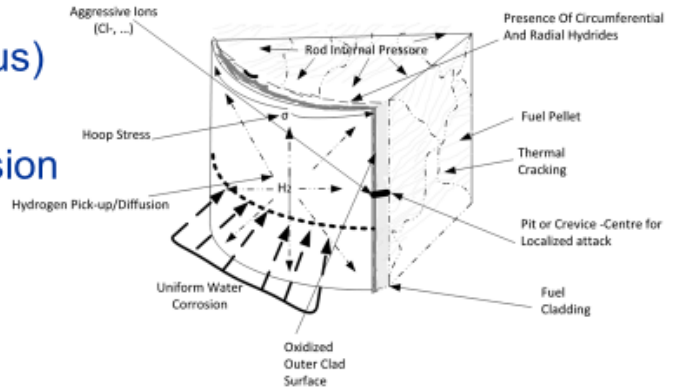
2016-2020

Spent Fuel Performance and Cladding Integrity

Degradation Mechanisms - Wet

Three potential degradation mechanisms that may affect cladding integrity during wet storage:

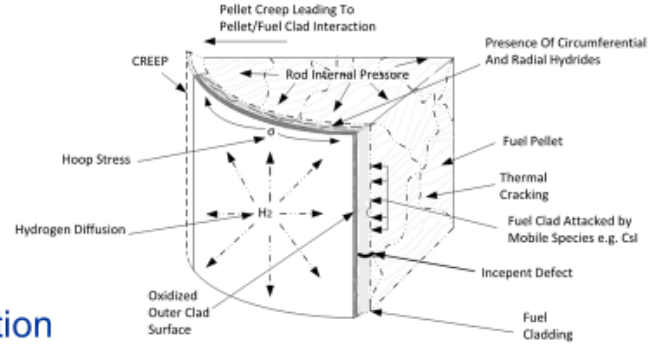
- Uniform (aqueous) corrosion
- Localized corrosion
- Hydriding



Degradation Mechanisms – Dry

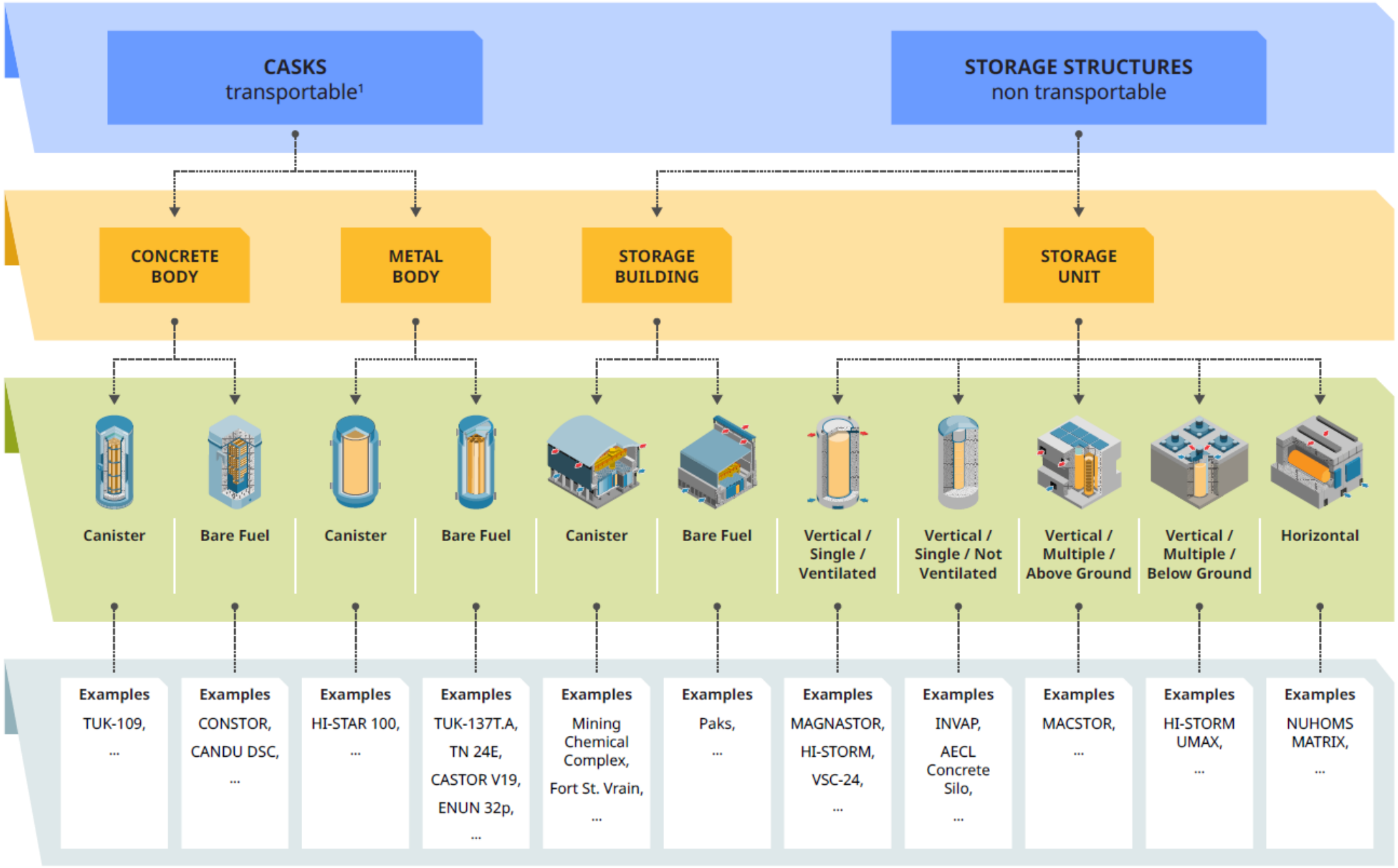
Potential degradation mechanisms that may affect cladding integrity during dry storage:

- Air oxidation
- Thermal creep
- Stress Corrosion Cracking (SCC)
- Delayed Hydride Cracking (DHC)
- Hydride reorientation
- Hydrogen migration and redistribution



- **Wet: 60+ years storage experience**. Provided pool chemistry is maintained there is no identified mechanism that would limit wet storage time
- **Dry: 40+ years dry storage experience**. The effect of hydrogen (hydride-reorientation) on zirconium cladding is under investigation for potential issues in subsequent handling & transportation

IAEA Categorization of ⟹ DRY STORAGE TECHNOLOGIES



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

Dry Storage Systems Performance

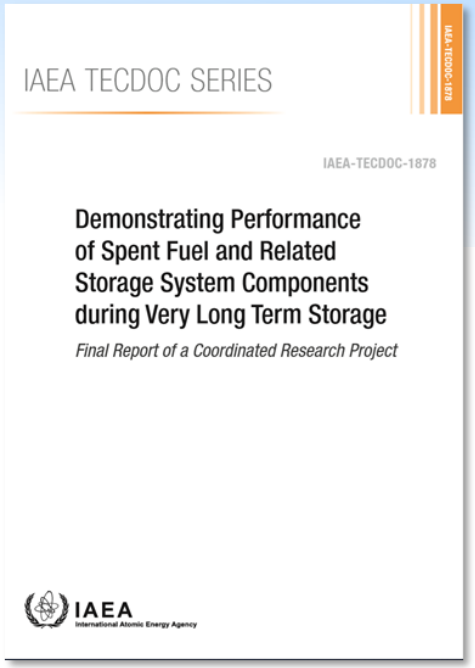
Coordinated Research Project on *"Demonstrating Performance of Spent Fuel and Related Storage System Components During Very Long Term Storage"* (**DEMO**)

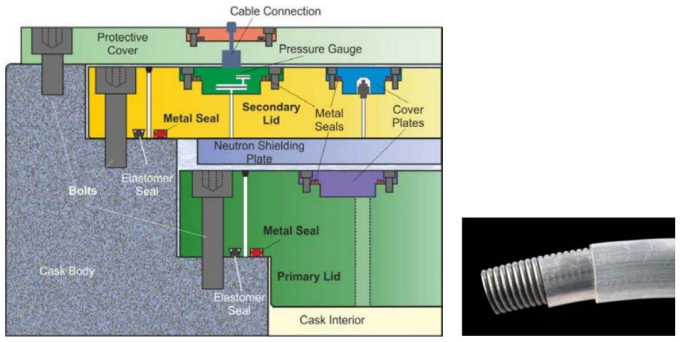
CRP No T13014 (2012-2016)

- **Overall Objective**
  - To support the technical basis for water reactor spent fuel dry storage as durations extend
  - **Specific research activities:**
    - Stress Corrosion Cracking Mechanisms
    - Concrete Systems Degradation
    - Cladding Behaviour
    - Bolted Closure Systems
    - Gamma and Neutron Shielding
    - System Demonstration (JPN and USA)

(a) (b)

FIG. 4.10. (a) Laboratory specimens (reproduced courtesy of National Building and Civil Engineering Institute (ZAG)); (b) Concrete columns exposed to marine environment (reproduced courtesy of National Building and Civil Engineering Institute (ZAG)).





(a) (b)

FIG. 1.8. (a) Typical double barrier bolted closure system of CASTOR® cask types [1.7]; (b) A metal seal of the HELICOFLEX® type (reproduced courtesy of Bundesanstalt für Materialforschung und -prüfung (BAM)).

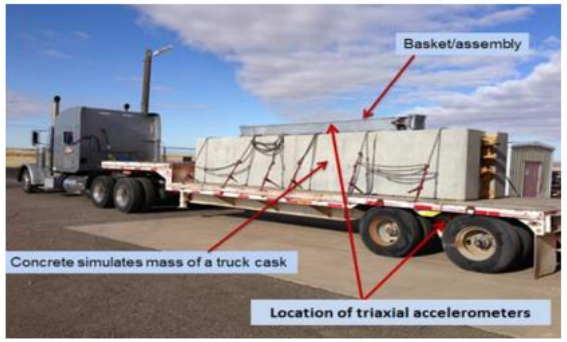


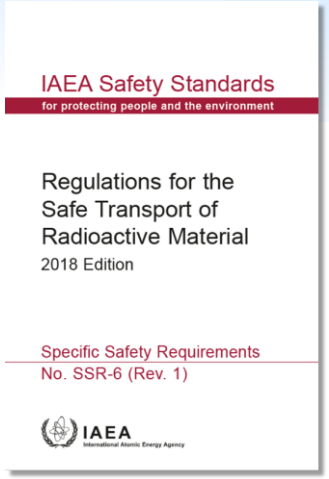
FIG. 7.4. Over-the-Road Truck Test- Simulated Over-the-Road Test conducted over 64 km to simulate various road conditions and speeds (reproduced courtesy of US DOE)

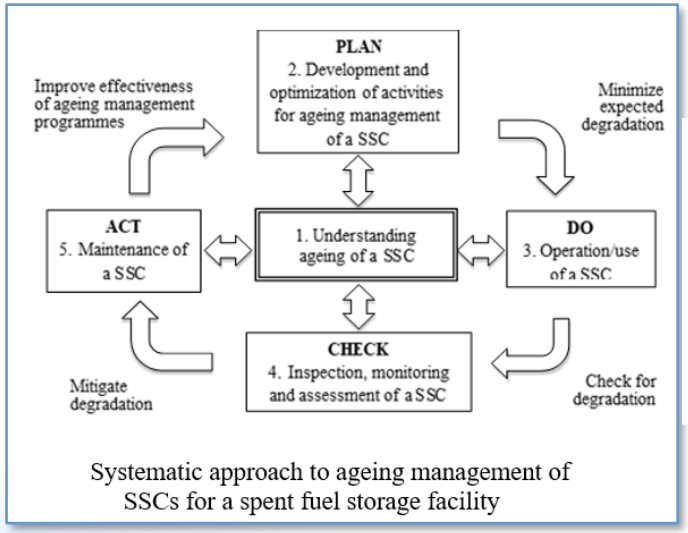
Linked to Extended Storage Collaboration Programme (ESCP) International Sub-committee of EPRI

Dry Storage Systems Performance

Coordinated Research Project on "Ageing Management Programmes for Dry Storage Systems" CRP No T21028 (2016-2020)

- **Background**
  - Challenge: concern with respect to the transportation of storage packages after extended storage
  - Ageing Management Programmes (AMP) aim at timely detection and control of age-related degradation and other conditions that may jeopardize future handling and transport, contributing to ensuring safety along time
  - AMP is a requirement in the new SSR-6
- **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 all dry storage systems for power reactor spent fuel
- **Specific activities on**
  - National regulations (License renewal for extended storage)
  - Process for generating am AMP (generic flowchart)
  - Identification of SSC (Categorization)
  - Technical underpinning (SF, Materials, Systems)
  - Operating experience (DPCs, Vaults, Silos)





Systematic approach to ageing management of SSCs for a spent fuel storage facility

DCSS Visual Inspection – Lid Weld

Courtesy of EPRI

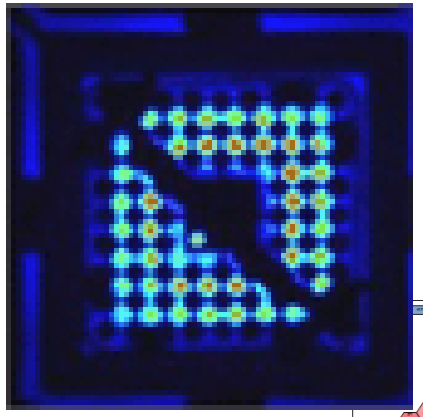
Freshly-loaded canister

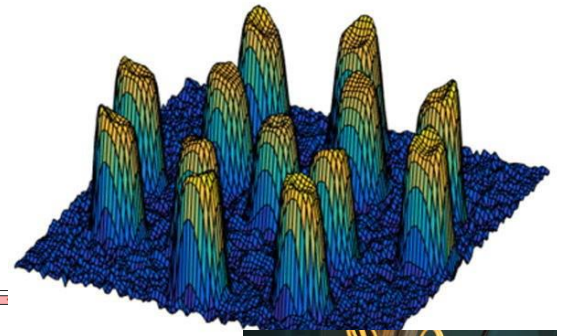
DCSS loaded in 2008

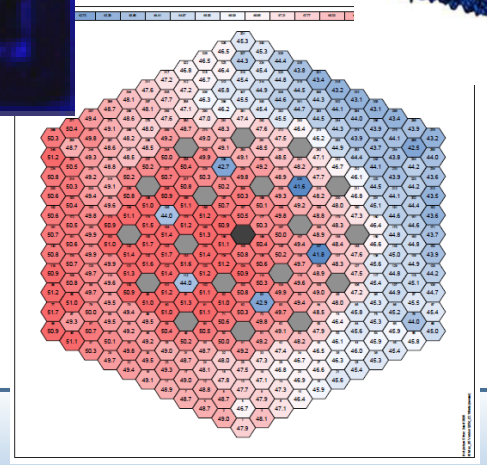
New CRP on Spent Fuel Storage Systems to be launched in 2022

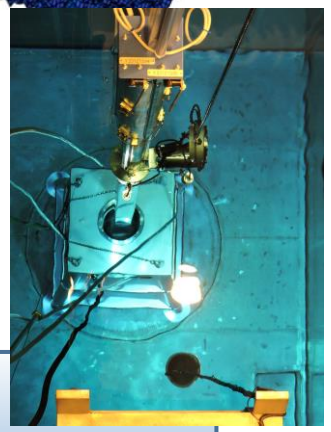
Coordinated Research Project on Spent Fuel Characterization

- **Overall objective:** To support and share information on issues related to the characterization of spent nuclear fuel in the various steps of its management, including the validation of models, techniques and procedures
- Covering a wide range of power reactor fuels: BWR, PWR, RBMK, WWER, CANDU and AGR fuels
- **Specific Research Activities:**
  - Non destructive analysis technique development
  - Refining bias and uncertainties in performance codes and models
  - Validating modelling data against results gathered through destructive analysis
  - Development and training of young professionals in destructive analytical techniques
  - Development of databases to enable efficient management of data across the back end of the fuel cycle





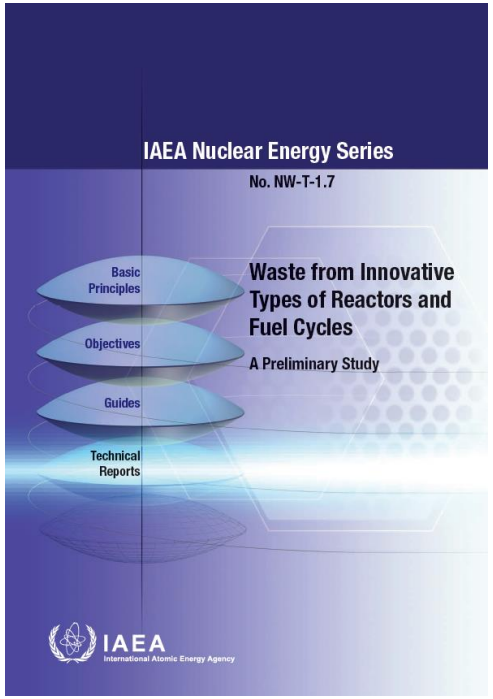




New CRP on
Spent Fuel Management Options to Enhance Nuclear Energy Sustainability
to be launched in 2022

Other IAEA Collaborative Projects (INPRO)

- **Cooperative Approaches to the Back End of the NFC: Drivers and Institutional, Economic and Legal Impediments**
  - Analyze institutional and economic impediments
  - Analyze legal aspects of international cooperation
  - Feasibility analyses of mechanisms of international cooperation
  - Covers all backend activities for both open and closed fuel cycles
  - Draft report under review
- **Waste from Innovative types of Reactors and Fuel Cycles (WIRAF)**
  - Main objective is to raise the profile of waste management issues within the advanced reactor/fuel cycle development community
  - Phase 1 report issued in 2019 – framework established to identify and address waste streams from advanced reactors and fuel cycles
  - Phase 2 scope under development – case studies and possibly an approach to quantify waste streams with a focus on problematic/challenging wastes



Ensuring Flexibility provides Opportunities for any anticipated or innovative future situation

- Spent fuel management lasts decades and implies multiple decisions
- Unknown factors condition the decisional options for the future
- No fixed scenarios: alternatives arise as the market conditions evolve and new technological options appear. Also integrates socio-political considerations

Storage for long period contribute to flexibility

- Experience and research bring a good level of confidence on safety and sustainability of extended period when necessary

Flexibility ≠ “Wait and See”

- Preserving flexibility is not a ‘do nothing’ or ‘wait and see’ approach
- Flexibility enables to adapt to a range of possible scenarios and to capitalize on available opportunities

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and not stopping for a single minute