Spent Nuclear fuel Characterisation and Evolution Until Disposal (SFC)

Overview and status

2020-11-09 • Peter Jansson, Uppsala University

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Presented at the Extended Storage Collaboration Program (ESCP) Winter 2020 Meeting, 2020-11-09.

Outline

- The context - EURAD
- Overview of SFC
- ∀ four tasks: Scope and Status
- The users' group

The context - EURAD

- **Implementation of a JOINT strategic programme of research and knowledge management activities at the European level.**
- **Support the implementation of the Waste Directive in EU member states (across varying degree of advancement)**
- **Gathering of:**
  - WMO's
  - TSO'
  - RE's
- **Consortium of 51 organisations in 23 EU member states.**
- **6 WP's with R&D - main activities**
- **2 WP's on strategic studies**
- **1 WP on knowledge management**
- **Interaction with CSO's**

More info:
https://ejp-eurad.eu

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Overview of SFC - Objectives

- **To produce experimentally verified procedures to reliably determine the nuclide content in SNF, including realistic uncertainties, by developing:**
  - characterization techniques
  - uncertainty quantification
- **To understand the performance of SNF during prolonged storage, transport and emplacement in a deep geological repository by:**
  - enhancing the capability for safety analysis of relevant operations
- **To understand the behaviour of SNF and ageing effects under normal and postulated accident scenarios until disposal:**
  - in order to identify relevant or typical bounding cases
  - to contribute to operational safety for SNF handling at packaging facilities.
- **To contribute to education, training and building of competence in the subject.**

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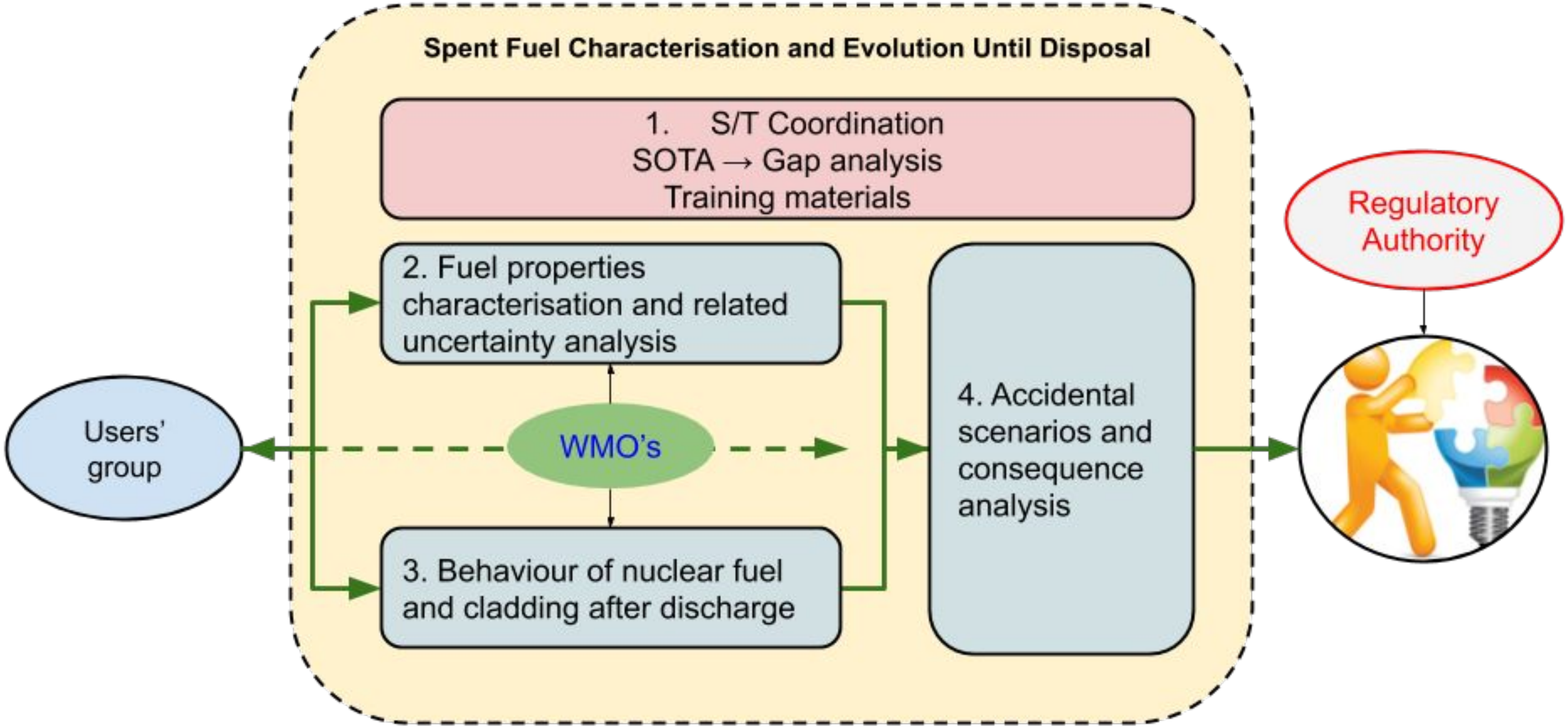
Overview of SFC - Four tasks



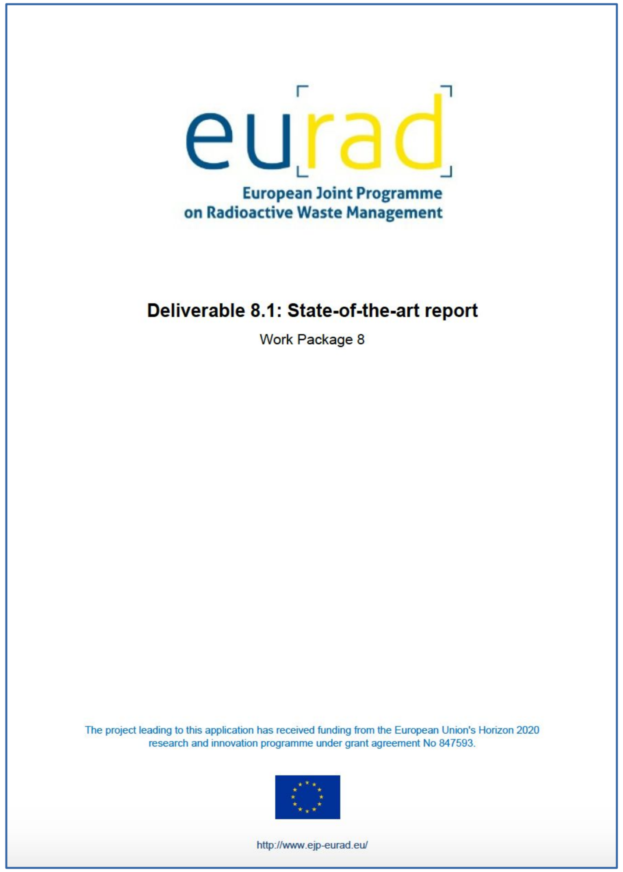
Overview of SFC - Participants

CEA
CIEMAT (IDOM, UPM)
ChRDI
CNRS-ICSM/CEMHTI (UMontpellier)
CPST
ENRESA (ENUSA)
FZJ (HZDR)
IRSN
JRC (Geel, Karlsruhe)
KIT (PEL, BAM)
LEI
MTA EK
NAGRA
PSI
SCK•CEN
SKB (UU)
SSTC NRS
SURAO (CTU)
TUS
VTT

Task 1: S/T coordination, State-of-the-art and training material

Status:

- **Three WP meetings so far:**
  - Kick-off in Stockholm Aug 2019
  - Progress in Madrid Dec 2019
  - Progress in Cyberspace Sep 2020
- **~Monthly WP board meetings**
- **Initial SOTA report under review**
- **Reporting to EC and other administrative work**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European Joint Programme on Radioactive Waste Management

Deliverable 8.1: State-of-the-art report

Work Package 8

The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 847593.

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Task 2: Fuel properties characterisation and related uncertainty analysis

2.1 Theory

2.2 NDA

2.3 Cladding

2.4 Define procedures to determine SNF source terms

- Compare best practice industrial and most advanced code
- Define **procedure** to characterise SNF based on:
  - Best practice **industrial code**
  - **Realistic NDA** measurements (time, industrial environment)

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Task 2: Fuel properties characterisation and related uncertainty analysis

Subtask 2.1 "Theoretical study of SNF source terms" (Theory)

Subtask 2.2 "Develop, improve and demonstrate NDA methods/systems for SNF characterisation" (NDA)

Subtask 2.3 "Calculate and determine experimentally the inventory of activation and FP in cladding" (Cladding)

Subtask 2.4 "Define and verify procedures to determine source terms of SNF with realistic confidence limits"

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Subtask 2.1 “Theoretical study of SNF source terms” (Theory)

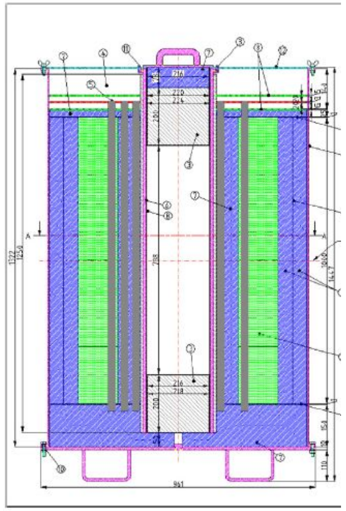
1. Select representative assemblies
2. Calculated quantities:
   isotopic concentrations, decay heat, gamma/neutron emissions
3. Cooling time: up to 1e5 years
4. Perform calculations
   (nominal and uncertainties / sensitivities / biases)

Subtask 2.1 “Theoretical study of SNF source terms” (Theory)

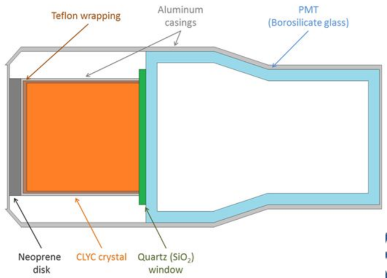
Institute	Code	Samples
JSI	SERPENT2 ALEPH2 SCALE (TRITON/NEWT) POLARIS DRAGON	SKB-50 (JRC), S1.PWR, S2.PWR, NPP Krško fuel, SF95-5 REGAL (SCK)
SCK•CEN		
JRC Geel		
KIT	MCNP/CINDER, Nucleonica	SF95-5
NAGRA	SCALE POLARIS	SF95-5, BM1 Gundremmingen-7 (B23) ENRESA-BWR SKB-50
VTT	SERPENT2	Gundremmingen-7 (B23)
CIEMAT	EVOLCODE, MCNP/CINDER	S1.PWR, SF95-5
ENRESA	Define a BWR case	

Subtask 2.2 “Develop, improve and demonstrate NDA methods/systems for SNF characterisation” (NDA)

1. **NDA techniques to characterise small samples as an alternative to radiochemical analysis**
   - Finalise design and construction of an improved neutron counter including transfer container
   - Finalise design transfer container for NRTA measurements of the SNF REGAL sample



2. **NDA techniques/method to characterise fuel assemblies**
   - Continue study of the CLAB calorimeter performance
   - New neutron detection systems (DDSI and DDA) for SNF characterisation
3. **Study new detectors**
   - Continue MC simulations of CLYC detectors



4. **Radiochemical analysis of a set of BWR samples**
   - Finalised June 2021

Subtask 2.3 "Calculate and determine experimentally the inventory of activation and FP in cladding" (Cladding)

Objectives:

- Dedicated experiments to determine the radionuclide inventories in Zircaloy samples, irradiated in a PWR.
- Zircaloy cladding samples surrounding fuel pellets (UO2 and MOX) as well as Zircaloy from plenum of a UO2 fuel rod segment will be used.
- CIEMAT, SURAO(CTU), KIT, LEI, NAGRA and VTT will calculate the inventories and compare their results to measured inventories.

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Subtask 2.3 "Calculate and determine experimentally the inventory of activation and FP in cladding" (Cladding)

Outlook:

- Comparison of codes foreseen in December.
- Experimental data should be available by beginning of 2021.
- Extensive analysis of codes, models and uncertainties should be performed in view of experimental techniques.
- Unforeseen inaccuracies due to manufacturing procedure of fuel rods and impurities will be investigated.

Subtask 2.4 "Define and verify procedures to determine source terms of SNF with realistic confidence limits"

2.4.1 Preparation of data from SKB-50 for simulation with "sophisticated" and "best practice industry" codes. If budget and time schedule allow data from SFCOMPO will be added [M13-M24].

2.4.2 Calculations and results for "best practice industry" code [M24-M36].

2.4.3 Calculations and results for "sophisticated" code [M30-M42].

2.4.4 Evaluation of results from 2.4.2 and 2.4.3 and documentation for part of report D8.6 [M36-M42].

2.4.5 Creation of correlation schemes between conventional fuel history parameters and source term strengths [M13-M36].

2.4.6 Documentation of correlation schemes for part of report D8.7 [M36-M48].

2.4.7 Formulation of procedure to estimate the SNF source terms including realistic uncertainty margins based on theoretical calculations with "best-practice industry" code and NDA measurements which can be routinely performed for part of report D8.7 [M36-M48].

2.4.8 Workshop to present results of Task [M48].

Activities just starting.

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Task 3: Behaviour of nuclear fuel and cladding after discharge

Aim:
To understand and describe the evolution of the cladding-pellet system and its ageing under conditions of extended interim storage, transportation and emplacement in a final disposal system.

- Behaviour / stability of SNF
- Integrity / stability of hydrided (irradiated) cladding
- Fuel/cladding chemical interaction (FCCI)

- **Subtask 3.1:**
  - Thermo-mechanical-chemical properties of SNF rods and cladding
- **Subtask 3.2:**
  - Behaviour of SNF pellets under interim storage conditions
- **Subtask 3.3:**
  - Pellet-cladding interaction

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Subtask 3.1 Thermo-mechanical-chemical properties of the SNF rods and cladding

Work plan & objectives:

- Quantification of the effects of hydrogen load, hydride distribution and reorientation as well as mechanical loading
- Evaluation of validity and significance of laboratory tests outside of hot cells
- Physicochemical and fracture mechanical properties of claddings

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Subtask 3.1 Thermo-mechanical-chemical properties of the SNF rods and cladding

- **Experimental results on irradiated specimens**
  - One ring compression test on an irradiated cladding specimen. One impact test on a SNF PWR fuel rod
  - Characterisation of inhomogeneous hydrogen distribution on irradiated cladding samples due to impact of pellet on cladding
- **Experimental results on unirradiated specimens**
  - Hydrogen charging and reorientation treatments to precipitate radial hydrides on ZIRLO® cladding
  - Ring compression tests on ZIRLO® cladding with radial hydrides followed by Analysis of failure mechanism
  - Creep tests on Russian E110 cladding at 400°C and 11 MPa pressure
- **Modelling results**
  - Finite Element Analysis of brittle failure in samples with radial hydrides after ring compression test
  - Sensitivity analysis of numerical and physical parameters in a finite element model of three-point bending
  - Simulation with FRAPCON-xt and BISON codes (beginning September 2020)
  - Collection and analysis of data from Kozloduy NPP and State Enterprise Radioactive Waste (SERAW) and information update for quantification and qualification for actual characterisations of SNF for previous periods of operation of the units

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Subtask 3.2 Behaviour of SNF pellets under interim storage conditions

Work plan & objectives:

- New insights on the ageing and degradation mechanisms of the SNF (e.g. He build-up, oxidation of the SNF, influence of the various fission products, etc.)
- Potential evolution of the SNF in case of mal operation conditions (e.g. moisture, aqueous dissolution of the UO2 matrix, corrosion of the SNF, etc.)

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Subtask 3.2 Behaviour of SNF pellets under interim storage conditions

- **CNRS-ICSM:**
  - Synthesis of some materials affected by the COVID 19 pandemic
  - First leaching tests on the prepared pellets shifted by ~2 months
- **CNRS-CEMHTI :**
  - Delivery of doped-UO_2 samples from CNRS-ICSM labs delayed due to COVID 19 until Oct 2020
  - Experiments La-doped UO_2 will begin at the end of 2020, on Nd/Ce-doped UO_2 in mid 2021

Subtask 3.2 Behaviour of SNF pellets under interim storage conditions

- **HZDR:**
  - Raw material characterization, pellet fabrication, improvements, surface characterisation are in progress
  - Oxidation tests will begin presumably in 2021
- **CIEMAT:**
  - Synthesis of materials, initially expected in Sept 2020, now postponed to Jan 2021
  - Dry oxidation experiments will begin in mid 2021; wet experiments will begin at the end of 2021

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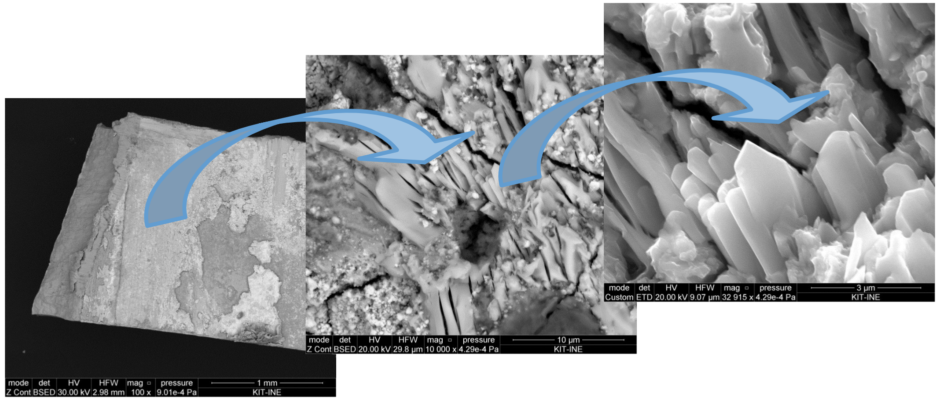
Subtask 3.3 Pellet-cladding interaction

Work plan & objectives:

- Chemical effects of activation and fission products on the cladding integrity, and activity release considerations under dry storage and subsequent transportation conditions
- Analyses of pellet/cladding interactions performed using non-irradiated UO2 fuel, high burn-up UO2 fuel and MOX fuel irradiated in commercial PWR
- Morphological and chemical/spectroscopic analyses of the fuel/cladding interfaces and claddings
- High energy resolution XAS (X-ray absorption spectroscopy) analyses of radionuclide speciation at the interface of fuel types and claddings

Subtask 3.3 Pellet-cladding interaction



- **KIT INE:**
  - Zirconium alloy specimens in contact with spent UO_2 and MOX fuel were prepared for investigation of fuel-cladding interaction layers using various spectroscopic techniques
  - Preliminary results show precipitates in fuel-cladding interaction layers
- **CIEMAT:**
  - In-situ oxidation measurement by Raman established in 2019-2020
  - Oxidation tests and post-oxidized sample characterisation delayed
- **PSI:**
  - Synchrotron campaign for active samples shifted to first quarter 2021
  - Hot-lab shielded FIB/SEM commissioning delayed – start with radioactive samples presumably this fall
- **MTA EK:**
  - All samples for Mandrel tests were prepared by May
  - Continuous decrease in ductility with increasing hydrogen content found in Mandrel tests on samples of E110

Task 4: Accident scenario and consequence analysis

Objectives

- To study SNF behaviour under accident conditions which may lead to a potential loss of confinement during storage, transport and predisposal activities.
- To perform criticality safety analysis for credible transport accident scenarios after long-term storage (including fuel rod failure and in-cask fuel distribution).
- To determine the accumulated dose in materials relevant for moderation and/or shielding.

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Task 4: Accident scenario and consequence analysis

Remarks

- Tight bond with Tasks 2 & 3 (empirical correlations and models).
- Vision on developing concepts of mitigation of accident consequences.
- Phenomena cited: radial hydride reorientation; fuel oxidation (clad barrier failure assumed).

Subtask 4.1:
Accident scenario for fuel under dry interim storage conditions.

Subtask 4.2:
Consequence analysis of accident scenarios

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Subtask 4.1: Accident scenario for fuel under dry interim storage conditions.

Objectives

- Synthetic analysis of identified potential accident scenarios during long-term dry storage, transportation and handling of SFAs.
- Support National Programs in relation of a safe management of SNF in back-end activities.

Approach and deliverables

- Identification and analysis of potential accident scenarios for fuel assembly damage and fuel material release during fuel handling
- Assessment of fuel performances for a postulated accident scenario under storage conditions: re-criticality, integrity under mechanical loads and container degradation studies

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Subtask 4.2: Consequence analysis of accident scenarios

Objectives

- Study of SNF behavior under accident conditions, which may or will lead to loss of confinement during storage, transport and pre-disposal activities.
- Support National Programs in relation of a safe management of SNF in back-end activities.

Approach and deliverables

- Analysis of the conditions of the state-of-emergency radioactive wastes packages contained SNF, FCM or HLW/LLW generated due to ChNPP accident

The users' group

- Analytical Research Bureau for NPP Safety (ARB-NPPS)
- Chalmers University of Technology, Department of Chemistry and Chemical Engineering
- Czech Radioactive Waste Repository Authority (SÚRAO)
- Electric Power Research Institute (EPRI)
- Energorisk LLC
- Framatome GmbH
- Gesellschaft für Anlagen- und Reaktorsicherheit (GRS)
- Institute for Energy Technology (IFE)
- International Atomic Energy Agency (IAEA)
- Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA)
- Kernkraftwerk Gösgen-Däniken AG
- Kharkov Institute of Physics and Technology
- Laboratoire de Physique Atomique et Technologies Associée (SUBATECH)
- Lawrence Livermore National Laboratory (LLNL)
- National Nuclear Laboratory (NNL)
- Nuclear research and consultancy Group (NRG)
- Oak Ridge National Laboratory (ORNL)
- OECD NEA Data Bank
- Pacific Northwest National Laboratory (PNNL)
- POSIVA
- Radioactive Waste Management (RWM)
- Spectra Tech
- Studsvik Nuclear AB
- Swedish Radiation Safety Authority (SSM)
- The Research Centre Rez (CV Rez)
- Tokyo Institute of Technology
- TS Enercon
- Teollisuuden Voima Oyj (TVO)
- University of Sheffield (USFD)