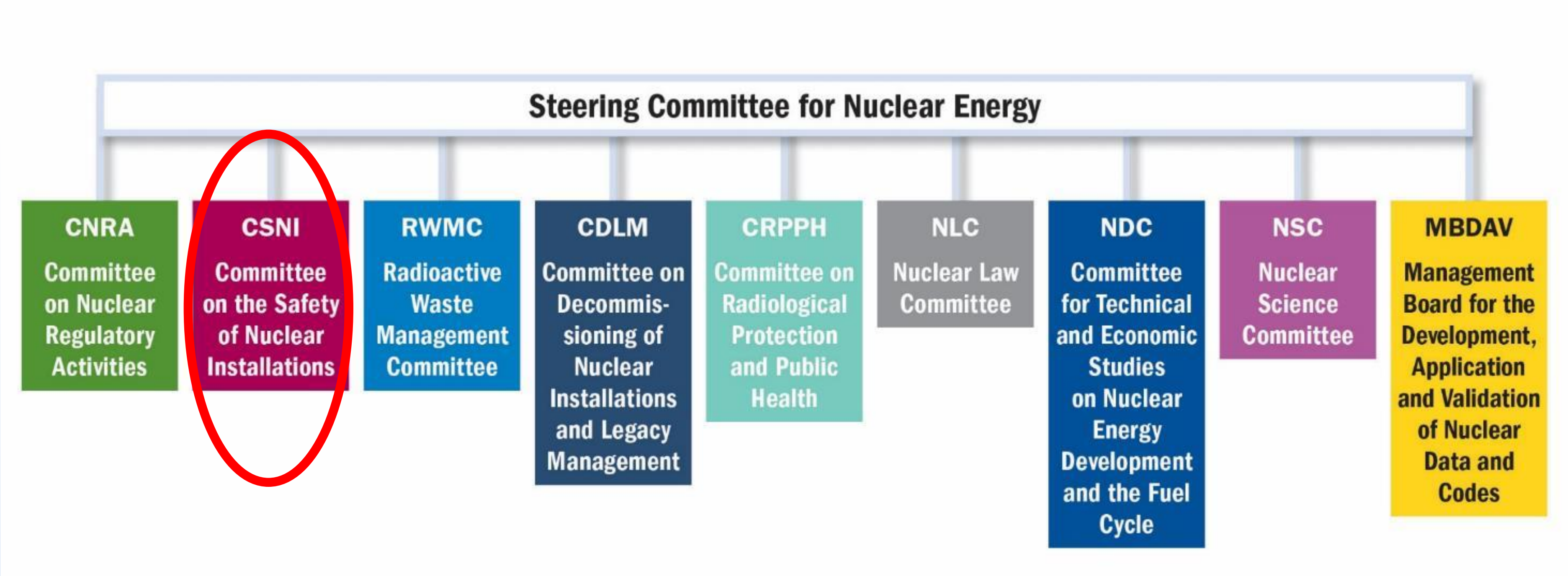
# OECD/NEA Activities on the Preservation of Experimental Infrastructures for Nuclear Safety

*François Barre (IRSN), Véronique Rouyer (OECD/NEA)*

*SNETP Forum June 2022*

# OECD/NEA Committees



# Committee on the Safety of Nuclear Intallations (CSNI)

## Committee on the Safety of Nuclear Installations (CSNI)

- CSNI Programme Review Group (PRG)
- Working Group on Human and Organizational Factors (WGHOF)
- Working Group on Risk Assessment (WGRISK)
- Working Group on Fuel Safety (WGFS)
- Working Group on Analysis and Management of Accidents (WGAMA)
- Working Group on Fuel Cycle Safety (WGFCS)
- Working Group on Integrity and Ageing of Components and Structures (WGIAGE)
  - Subgroup on the Integrity of Metal Components and Structures
  - Subgroup on the Ageing of Concrete Structures
  - Subgroup on Seismic Engineering
- Working Group on External Events (WGEV)
- Working Group on Electrical Power Systems (WGELEC)
- Expert Group on Small Modular Reactors (EGSMR)
- Senior Group on Preservation of Key Experimental datasets (SEGPD)
- Expert Group on Fire (EGFR)

## Cooperating with partner-countries through joint safety research projects

- **Maintain key experimental facilities and key competencies and support the operating agents**
- **Address a wide range of high priority safety issues**
- **Facilitate cooperation between countries**
- **Anticipate needs for future technologies**
- **Preserve and disseminate high quality data**

***Guidance and principles for initiation and conduct of JPs updated in 2022***

***Works on enhancing JPs data sets preservation launched in 2022***

On-going safety joint exp. and DB projects (*recently launched*, to be launched soon)

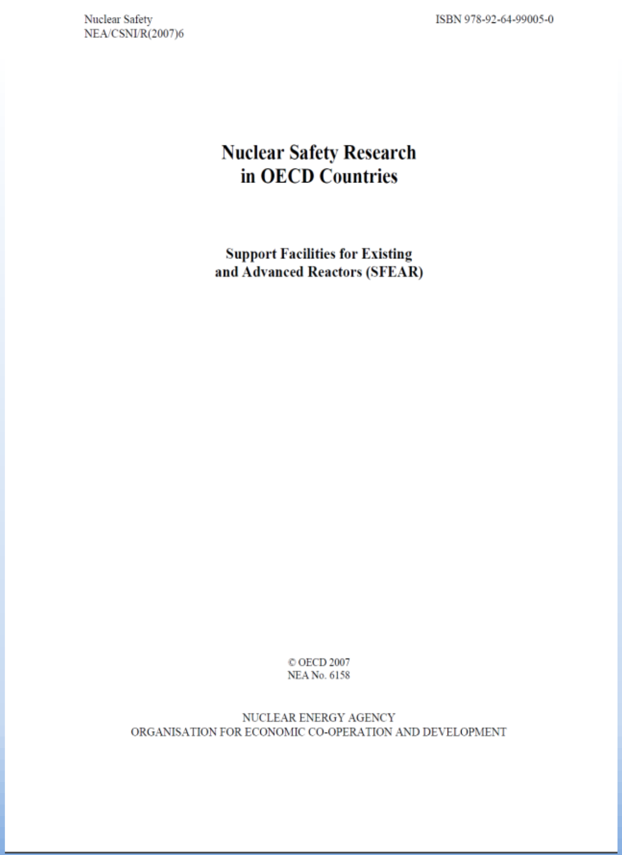
| | |
|---|---|
| Fuel and cladding behavior, fuel safety, incl. in-reactor, storage and transport | CIP; SCIP-4; Halden F&M (21-23); *FIDES JEEPs*; *Quench-ATF* |
| Thermal hydraulics data, models and tools | LOFC; RBHT; ATLAS-3; ETHARINUS; ROSAU; THEMIS; ESTER; HYMERES-2, ***PANDA*** |
| Severe accident management and post-Fukushima lessons | ARC-F; **FACE**; ***Quench-ATF***; **TCOFF-2** |
| Fire propagation, fire events high energy electrical faults | PRISME-3, **FAIR**; FIRE-DB; HEAF-2 |
| Component ageing/life extension/ common-cause failures | SMILE; Halden (ageing part); CODAP-DB; ICDE-DB |
| Human and Organisational aspects of Safety | Halden HTO |

# Senior Expert Group on Safety Research (SESAR)

Established by CSNI at its 61st meeting in ***June 2017***, to update previous assessments of capabilities and facilities required to support safety of nuclear installations.

**2001***: Senior Group of Experts for Nuclear Safety Research: Facilities and Programmes* (SESAR/FAP).
**2007**: follow-on activity: *Nuclear Safety Research in OECD Countries – Support Facilities for Existing and Advanced Reactors* (2007)

- Since publication of the SESAR-SFEAR report in 2007, several facilities have been shut down.
- **Loss of critical research infrastructure (i.e. facilities, capabilities and expertise) remained a concern** and was a major factor in conducting the update.
- However, it was recognised that the **SESAR/SESAR effort led to CSNI actions that preserved several key facilities during the 2007-2019 time period, thanks to the NEA Joint Projects.**
- Canada (AECL), France (IRSN), Germany (GRS), Hungary, Italy (UNIPI), Japan (NRA), Korea (KINS), Spain (CSN), Sweden (SSM), Switzerland (ENSI), USA (NRC), Belgium (Bel-V)


Nuclear Safety
NEA/CSNI/R(2007)6
ISBN 978-92-64-99005-0

Nuclear Safety Research
in OECD Countries

Support Facilities for Existing
and Advanced Reactors (SFEAR)

© OECD 2007
NEA No. 6158

NUCLEAR ENERGY AGENCY
ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

# 2017-SESAR Group Objectives

- Summarise the currently identified safety issues , highlight those whose resolution depends upon additional research work
- Provide the current status of those research facilities unique to the nuclear industry that support resolution of the safety issues
- Where such facilities represent a substantial investment of resources and are in danger of premature closure, recommend actions the CSNI could take in the short term to help maintain them
- Provide recommendations on long-term nuclear safety research facility infrastructure needs and preservation

# 2017-SESAR Group Scope

Focused on BWR, PWR, VVER, ALWR, HTGR ; additional comments on non-WR GEN IV

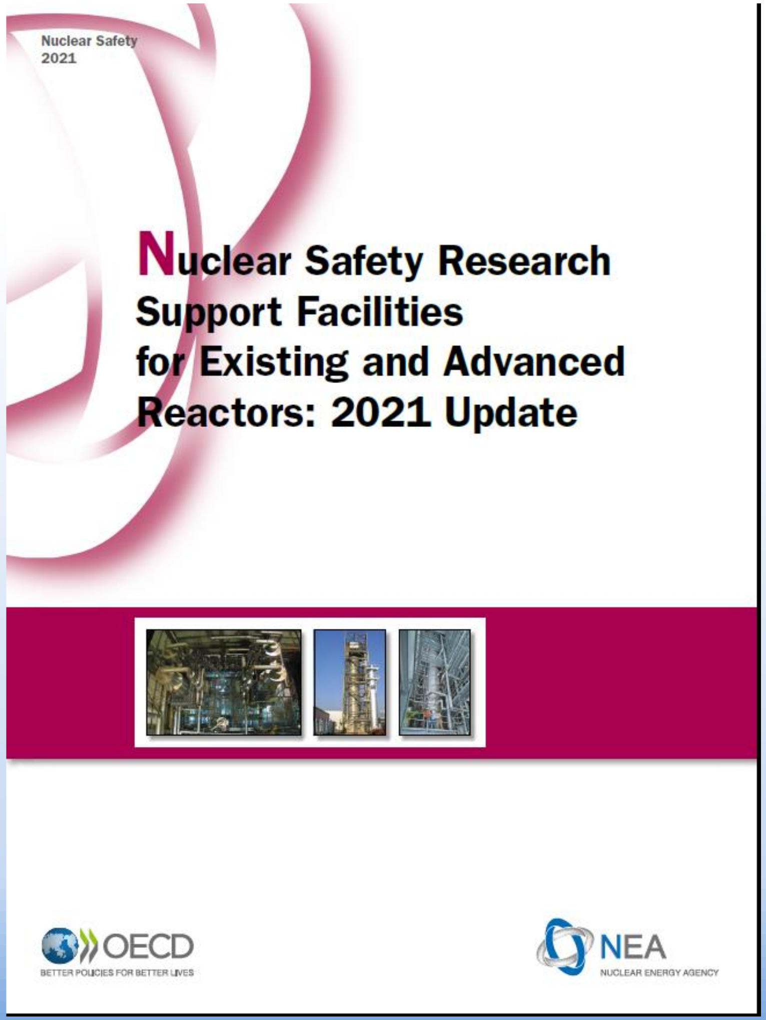
**Facilities unique to the nuclear industry:**
Thermal-hydraulics.
Fuel.
Reactor physics.
Severe Accident and containment phenomena.
Integrity of equipment and structures.

**Facilities not unique to the nuclear industry:**
Human and organisational factors.
Plant control and monitoring.
Cyber security
External events.
Fire assessment.

# General recommandations from the CSNI

- CSNI efforts aimed at facility preservation should focus on large facilities (>5M€) , whose lost mean the loss of unique capability as well as the loss of substantial investment that in the current climate of tight resources would not likely be replaced.   Such preservation  also includes maintaining the expertise, knowledge, capabilities and personnel essential to infrastructure preservation.

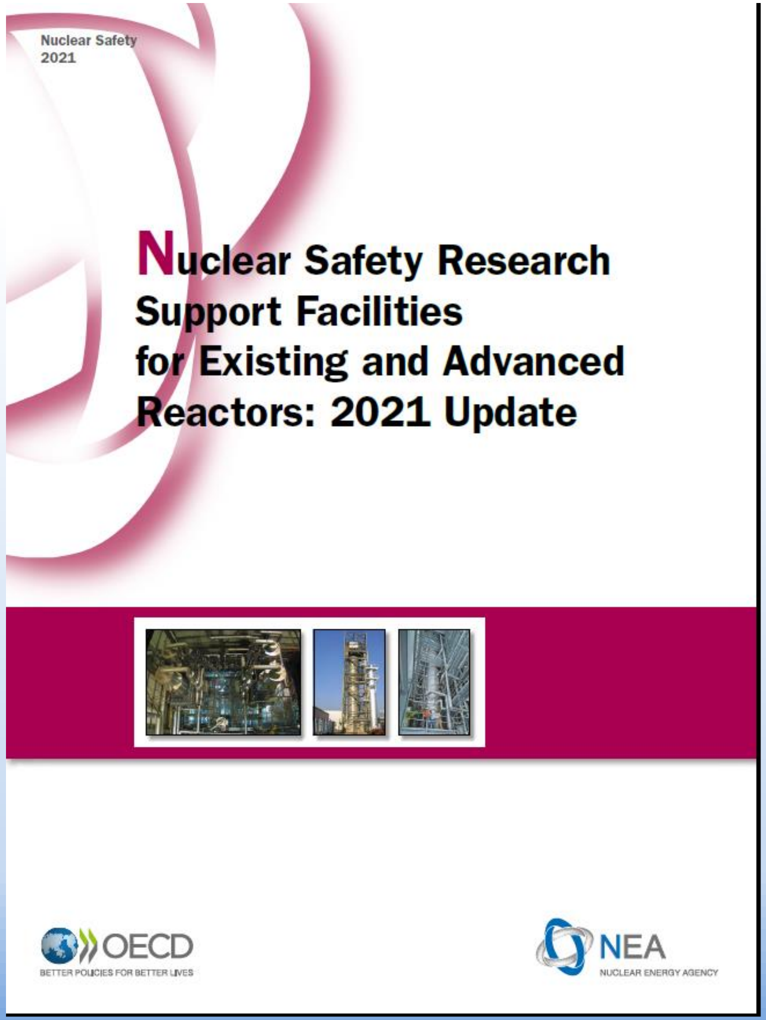
- Factors used in the report:
  - Facility operating and replacement cost
  - The ability to define a useful experimental program
  - Long-term resource implication  and priorities
  - Industry participation
  - Host country long term plans and commitment



# General recommandations from the CSNI

- high relevance to the resolution of safety issues for Gen II designs as well as the potential to be highly relevant in support of the resolution of safety issues for new and emerging GEN III and IV  designs.

- Due to the cost of operating such facilities, co-operative efforts would most likely be needed to maintain them in the longer term.



# Example of identified list of issues (severe accident) and application (reactor technology)

Table 3.1.4-1. Current severe accident issues

| Issues and relevant reactors | Description |
|---|---|
| A) In-vessel phenomena | |
| 1) Pre-core melt conditions: PWR, BWR, VVER, PHWR, ALWR, APHWR | Understanding the conditions that can lead to core melt and the thermal-hydraulic conditions of the core prior to core melt are essential to understanding whether or not implementation of accident management strategies will be successful in preventing core melt (e.g. has flow blockage occurred?). Good knowledge of pre-core melt thermal-hydraulic conditions in the core will also help to refine accident management strategies so as to understand and be prepared for the outcome of actions taken by the operator. This issue is closely coupled with issue #17. |
| 2) In-vessel melt progression: PWR, BWR, VVER, PHWR, ALWR, APHWR | The amount, composition, rate and timing of a core melt are important to determining the effectiveness of accident management measures and, the ability of the RPV or reactor calandria to maintain its integrity. The type of fuel ($UO_2$ or MOX), cladding material, burn-up and other factors which affect the composition of the melt, are also important in this determination. In-vessel melt progression includes relocation in the core and to the lower portion of the RPV and determines the heat load on the RPV during a core melt accident. |
| 3) In-vessel fuel-coolant interaction: PWR, BWR, VVER, PHWR, ALWR, APHWR | Molten fuel contacting reactor coolant or moderator (PHWR, APHWR) may cause the rapid generation of steam and this is an important component of the load on the RPV or calandria. |
| 4) Effect of air on core melt progression: PWR, BWR, VVER, ALWR | Core melt accidents where air is present in the RPV (such as during refuelling) could behave differently than those where no air is present. This could include the dynamics of the melt progression and the FP release. |
| 5) Effect of high burn-up and MOX fuel: PWR, BWR, VVER, ALWR | The use of high burn-up or MOX fuel could change the dynamics of melt progression and fission product release. Data on these effects is needed to properly assess consequences and risk from accident sequences involving high burn-up or MOX fuel. |
| 6) RPV pressure: PWR, VVER | Depressurising the primary coolant system is important during the in-vessel melt progression phase to reduce stress on the RPV and to facilitate water injection into the RPV. Accordingly, if the design does not have the capability to depressurise the primary system. It is important to understand the effect of high pressure on RPV and other RCS components' integrity and the subsequent effect on core melt progression. This is primarily an analysis issue. |
| 7) Maintaining RPV integrity: PWR, BWR, VVER, PHWR, ALWR, APHWR | Maintaining the integrity of the RPV or reactor calandria vessel is important to terminating and confining a core melt accident, thus eliminating ex-vessel severe accident phenomena and their challenge to containment integrity. Cooling the RPV or reactor calandria both internally and/or externally are potential strategies for maintaining RPV integrity in the event of a core melt accident. However, higher core power densities will make it more difficult to maintain RPV integrity due to the higher heat flux on the RPV. Knowledge of RPV integrity as a function of heat flux is important in assessing the success of accident management strategies. |
| 8) Pressure tube integrity: PHWR, APHWR | Maintaining the integrity of the pressure tubes in a pressure tube reactor is important for maintaining cooling of the fuel in the tube and preventing over-pressurisation and failure of the calandria due to high pressure water injection and/or molten fuel injection and FCI. |

Table 3.1.4-1. Current severe accident issues (Cont'd)

| Issues and relevant reactors | Description |
|---|---|
| B) Ex-vessel phenomena | |
| 9) Ex-vessel melt progression and debris coolability: PWR, BWR, VVER, PHWR, ALWR, APHWR | The amount, rate, timing and spreading of molten core material released following RPV failure are important to determining the ability of the concrete basemat to maintain its integrity and the ability of an overlying pool of water or basemat cooling system to cool the debris and terminate the core-concrete reaction (i.e. ex-vessel melt coolability). Debris coolability can be affected by the amount of water overlying the core debris and the porosity of the debris or the strength of the crust formed on top of molten core debris. Obtaining the properties of the crust and underlying debris is important to understanding debris coolability and its uncertainties. In addition, high pressure melt ejection could result in molten core material being relocated to other parts of containment and a rapid pressure rise in containment due to the sudden release of steam and combustible gases from the RPV to containment. |
| 10) Core-concrete interaction: PWR, BWR, VVER, ALWR, PHWR, APHWR | When molten core material leaves the reactor pressure vessel, it will likely come in contact with concrete. Depending upon the amount and depth of the molten core material and the composition of the concrete, various amounts of combustible and non-combustible gas will be released into the containment, thus raising its pressure. These gases can also be a source of additional energy if they ignite, thus causing additional pressure and temperature rise in containment. If not stopped, the core concrete interaction can potentially also penetrate the reactor containment basemat, thus failing containment. Understanding the rate and amount of gas generated from core-concrete interactions is important to understanding the potential for containment failure, the potential for success of mitigation strategies and, in the case of new plant designs, selecting materials and configurations to minimise core-concrete interactions. |
| 11) Ex-vessel fuel coolant interaction: PWR, BWR, VVER, PHWR, ALWR, APHWR | Upon failure of the reactor pressure vessel, molten core material may fall or be ejected into water, if the reactor cavity has been partially or fully flooded. Such contact with water has the potential to cause rapid steam generation and, depending upon the amount, rate, fragmentation and mixing of the molten material, release a large amount of energy should be taken into account in assessing, which structural integrity of containment. |
| 12) Combustible gas control: PWR, BWR, VVER, PHWR, ALWR, APHWR | Combustible gas ($H_2$ and CO) generated from metal-water reactions or core- concrete reactions in the in-vessel and ex-vessel phases of a core melt accident can ignite heat and/or pressurise containment, thus challenging containment integrity. |

# Example of identified list of issues (severe accident) and research facilities to address them

Table 3.1.4-2. Issues versus facilities (Severe accidents)

| Issue | Applicability of issue | Safety relevance of issue | State of knowledge on issue |
|---|---|---|---|
| 1) Pre-core melt conditions. | PWR, BWR, VVER, PHWR, ALWR, APHWR. | High | High |
| 2) In-vessel melt progression. | PWR, BWR, VVER, PHWR, ALWR, APHWR. | High | Medium |
| 3) In-vessel fuel coolant interaction. | PWR, BWR, VVER, PHWR, ALWR, APHWR. | Medium | Medium |
| 4) Effect of air on core-melt progression. | PWR, BWR,VVER, ALWR | Low | Medium |
| 5) Effect of high burn-up and MOX fuel. | PWR, BWR, VVER, ALWR. | Medium | Medium |
| 7) Maintaining RPV integrity. | PWR, BWR, VVER, PHWR, ALWR, APHWR. | High | Medium |
| 8) Pressure tube integrity. | PHWR, APHWR. | Medium | Medium |
| 9) Ex-vessel melt progression and debris coolability. | PWR, BWR, VVER, ALWR, PHWR, APHWR. | High | Medium |
| 10) Core-concrete interaction. | PWR, BWR, VVER, ALWR, PHWR, APHWR. | High | Medium |
| 11) Ex-vessel fuel coolant interaction. | BWR, PWR, VVER, PHWR, ALWR, APHWR. | Medium | Medium |

Table 3.1.4-2. Issues versus facilities (Severe accidents)

| Facility | | |
|---|---|---|
| Name | Importance of facility to resolution of the issue? | Versatility |
| PHEBUS | High | Can be used for various small bundle tests up to and beyond melting and tests on coolability of over-heated core. |
| Core disassembly test facility | High | Can be used to assess PHWR fuel bundle behaviour up to melting. |
| Fuel channel safety facility | High | Can be used to assess integrity of PHWR fuel channel. |
| QUENCH | High | Can be used to assess effectiveness of core-melt prevention strategies. |
| PHEBUS | High | Capable of small bundle in-core melt tests. |
| LIVE-FZK | Medium | Uses simulant material. |
| QUENCH | Medium | Can assess partially degraded core. |
| KROTOS | High | Capable of using prototypic materials. |
| MFMI | High | High and low pressure PHWR melt ejection. |
| TROI | Medium | Uses prototypic materials (20 kg). |
| PHEBUS | High | Capable of small bundle in-core melt tests with air. |
| VERDON | Medium | Can conduct hot cell experiment with irradiated fuel or air. |
| PHEBUS | High | Can conduct in-reactor experiments with high burn-up or MOX fuel. |
| VERDON (LECA-STAR) | Medium | Can conduct hot cell experiments with irradiated fuel. |
| MASCA/RASPLAV | High | Can obtain material properties using real materials. |
| LIVE-FZK | Medium | Uses simulant material. |
| Fuel ch. safety facility | High | Fuel channel thermal- mechanical behaviour. |
| MCCI | High | Can use prototypic materials. |
| VULCANO | High | Can use prototypic materials. |
| ARTEMIS | Medium | Uses simulant materials. |
| MCCI | High | Large-scale test (1 $m^3$) with real materials, simulated decay heat and with or w/o overlaying water cooling. |
| COMET-FZK | Medium | Uses simulant material. |
| VULCANO | High | Uses prototypic materials (oxide and metal). |
| ARTEMIS | Medium | Uses simulant material. |
| KROTOS | High | Can test with real materials. |
| MFMI | Medium | Facility for PHWR test configurations Uses simulant material. |
| TROI | Medium | Uses prototypic materials. |

# Example of identified list of issues (fire) and research facilities to address them

Table 3.2.4-1. Current fire assessment issues

| Issues and relevant reactors | Description |
|---|---|
| 1) Fire growth and propagation: PWR, BWR, VVER, PHWR, ALWR, APHWR, HTGR | Accurate modelling of fire growth and propagation is the key to determining the time and extent of equipment affected. While the best CFD simulation models are able to predict consequences for given fires rather satisfactorily common efforts should be taken to simulate most safety relevant typical scenarios as benchmarks, and make the results available in data bases as example and study material for plant specific work.<br>Efforts should be taken to utilise the emerging technology of flame spread modelling on solids. Actions should be taken to test various proposed models at all relevant scales, and implement the promising models in the best CFD codes. Special efforts are needed to select the most suitable testing methods from existing or new concepts, which are needed to determine flame spread parameters for practical commercial products. For example for cables, none of the available methods are able to determine them at present. Benchmarking efforts are needed to transfer the technology from laboratories to industrial practice. |
| 2) Hot shorts: PWR, BWR, VVER, PHWR, ALWR, APHWR, HTGR | Fires in cable trays can not only cause the loss of the cable but can also cause inadvertent signals in control cables affecting equipment. The likelihood and consequences of such "hot shorts" are not well understood or modelled in safety analysis. Experimental data is needed. There are some data already available for simple basic scenarios. Theoretical modelling is needed for assessing effects on systems performance. |
| 3) Smoke propagation: PWR, BWR, VVER, PHWR, ALWR, APHWR, HTGR | The spread of smoke during a fire is generally not modelled, although most of the needed technology exists. Smoke can affect the operability of certain equipment and inhibit human fire fighting efforts by limiting access and visibility. However, this is not unique to the nuclear industry and steps should be taken to implement existing technology. |
| 4) Equipment vulnerability: PWR, BWR, VVER, PHWR, ALWR, HTGR | When and how equipment fails under fire conditions is essential to fire assessments. This includes failures from heat, smoke, suppression system activation, shorts, etc. Experimental data will likely be needed to address this issue.<br>There are some data and basic calculation models available on heat and smoke effects for some equipment. Establishing a data bank with benchmarking examples would be a good way to educate utilities to use that information. For Monte Carlo analyses establishing these data banks is mandatory. |
| 5) High energy arcing faults: PWR, BWR, VVER, PHWR, ALWR, HTGR | Fires caused by arcing from high energy lines need to be modelled and included in risk assessments. |

Table 3.2.4-2. Facilities in the area of fire assessment

| Facility name | Cost/year, operation | Replacement cost | Issues covered | Capabilities | Planned duration of operation |
|---|---|---|---|---|---|
| GALAXIE (France) | High | High | 1,3,4 | Facility composed of compartments (from 1 to 680 $m^3$) and needs (up to 30 000 $m^3$/hr for fire intensities up to 2 MW). | |
| Sandia Labs (USA) | Medium | Medium | 1,3,4 | Fire growth, propagation, effects of temperature and smoke on equipment. | In-stand by |
| Omega Point (USA) | Medium | Medium | 2 | Issues covered include spurious actuation of equipment. | Indefinite |
| U.S. National Institute of Standards and Technology (NIST, USA) | Medium | Medium | 1,3 | Issues covered include fire growth and propagation. | Indefinite |
| VTT (Finland) | Medium | Medium | 1,4 | Experimental/fire modelling | |
| DIVA (France) | Medium | Medium | 1,3,4 | Part of GALAXIE (5 rooms connected by a ventilation system) to investigate electrical cabinet fires, heat, and smoke propagation from room to room. | Through 2010 |

Notes:
Specify Range : Low, Medium, High.
Operational Cost : Low is < 1.0 MUS $/yr.: Medium is 1.0-2.0 MUS $/yr.: High is > 2 MUS $/yr.
Replacement Cost : Low is < 2.0 MUS $: Medium is 2-10 MUS $: High is > 10 MUS$.

# Short term recommandations

- Identification of facilities that were unique, versatile, and in danger of being shut down in the next 1-3 years: CSNI is encouraged to support joint projects proposed in these facilities.
- Identification of several facilities in short-term danger, in domain where already several major infrastructures disappeared:
  - Thermal-hydraulics (3)
  - Severe accidents and containment behaviour (4)
  - Fire in confined buildings (1)
- In the fuel and materials areas, several large, versatile reactors have been closed since 2007:
  - ➢ E.G.: PHEBUS (France), NRU (Canada), HALDEN (Norway), JMTR (Japan), ….
  - ➢ Significant loss worldwide, for both materials and fuel testing
  - ➢ Reactors worldwide, including CABRI, BR-2, LVR-15, MIR, TREAT, HFR, ATR and others have been identified as being suitable to replace some of the capabilities lost by the closure of these reactors.
  - ➢ The NEA has recently taken some measures to protect existing infrastructure: establishment of the FIDES network, which, along with joint projects will allow members to access various reactors and test programs for materials and fuels.
- It should be noted that some of those facilities was already identified as early as 2001 but have been used to conduct several important CSNI research initiatives via NEA joint projects in the intervening years…

# Longer term recommandations

- Many of the factors used in the last two reports to arrive at conclusions and recommendations have resulted in effective measures for retaining key facilities at risk. These measures should continue to be used in the future, with consideration of the factors below:
  - Cost of facility operation and replacement (i.e., limit CSNI involvement to large facilities needing multi-national support).
  - Consistency with SFEAR recommended list of facilities for long-term preservation (discussed below).
  - Ability to define a useful experimental programme (i.e., one that will provide information useful to the resolution of one or more safety issues).
  - Long-term planning to ensure the most important facilities receive the highest priority for long-term preservation (i.e. not first come first served). This would include assessing the long-term resource implications (i.e. consider impact of cost of a co-operative programme on resources available for other projects) and the host country's long-term plans for the facility.
  - Industry participation.
  - Host country commitment.

# General conclusions and recommendations

- **Recommendation:** NEA Joint Safety Research projects should clearly outline their plan for data preservation, and should stipulate that a copy of the primary data needs to be sent to the NEA for storage.

  → *Under implementation in on-going projects*
- **Recommendation**: CSNI working groups should be asked to identify key datasets in their areas. Some of this may have been done with code validation matrices and datasets to support the development and implementation of standards. → *Pilot activities launched in WGFS and WGAMA*
- **Recommendation:** There should be a cross-functional (CSNI, NSC, etc.) NEA task group established to consider what should be done to preserve the key experimental datasets. This could include possible options for data libraries, how to screen datasets, what information needs to accompany the primary data, etc. → *Senior expert group on key data sets preservation*
- **Recommendation**: CSNI working groups to select an appropriate option for preserving each key dataset and develop an activity to put it in place (CAPS, joint project, etc.). → *Pilot activities on preservation of Halden data sets, of RIA and thermal-hydraulics key data sets under respectively WGFS and WGAMA*