

NEA present and future research activities for advanced fuels technologies

Didier JACQUEMAIN

Nuclear Safety Technology and
Regulation Division



NEA committees (as of 1 January 2023)



Steering Committee for Nuclear Energy



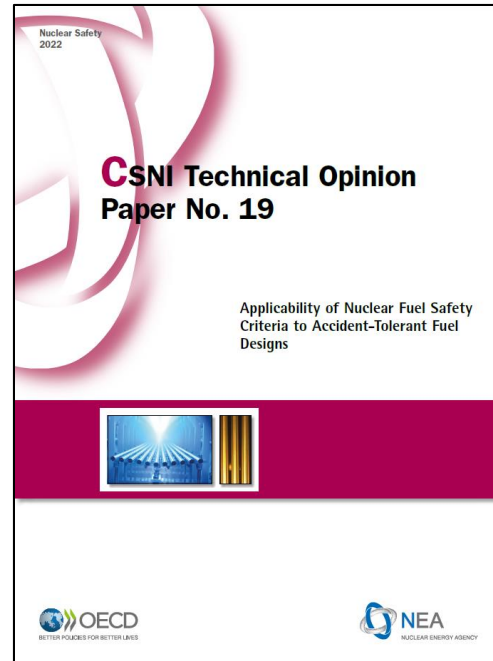
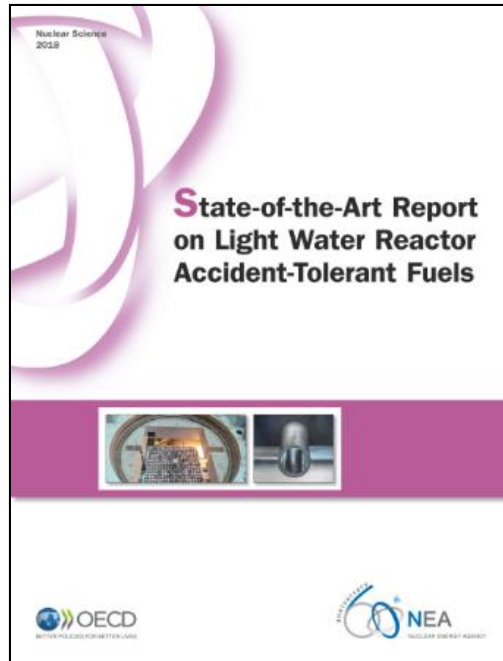
8 standing technical committees

1 management board

74 working parties and expert groups

The NEA's committees bring together top governmental officials and technical specialists from NEA member countries and strategic partners to solve difficult problems, establish best practices and to promote international collaboration

Recent activities on ATFs and HBU/HALEU fuels



- **CSNI and NSC both main contributors to ATF related studies with complementary approaches**
- **State-of-the-Art Report on Light Water Reactor Accident-Tolerant Fuels, 2018**
- **!RECENT! Technical Opinion Paper No 19 on Applicability of Nuclear Fuel Safety Criteria to ATFs, 2022**
- **!NEW! Status report on fuel safety implication of extended enrichment, in press**

Safety research needs for ATFs, HBU/HALEU and doped fuels identified

ATF design concept	EGATFL technology readiness level*	Relative impact on existing fuel safety criteria	Number of new phenomena	Relative magnitude of data gaps
Coated zirconium alloy cladding	4	Low	3	Low
FeCrAl cladding	3-4	Medium	2	Medium
Silicon carbide cladding	< 3	High	3	High
Doped UO ₂ ceramic pellets	8	Low	0	Low
Uranium silicide ceramic pellets	< 3	High	1	High

* In 2018, the EGATFL report defined a TRL for each ATF design concept from 1 to 9, with 9 defined as *routine commercial-scale operation. Multiple reactors operating.*

From CSNI TOP#19, NEA(2022)

NEA Joint Nuclear Safety Research Projects

Cooperation through projects

Share world-wide expertise on safety topics and experimentation

Share resources, leveraging investments and facilities

Maintain key research facilities and competencies, support operating agents, contribute to education

Facilitate cooperation between countries and various stakeholders

Applications and perspectives

Understand phenomena that affect safety and sensitivities to safety (e.g. data for assessing accident management)

Quantify and reduce uncertainties

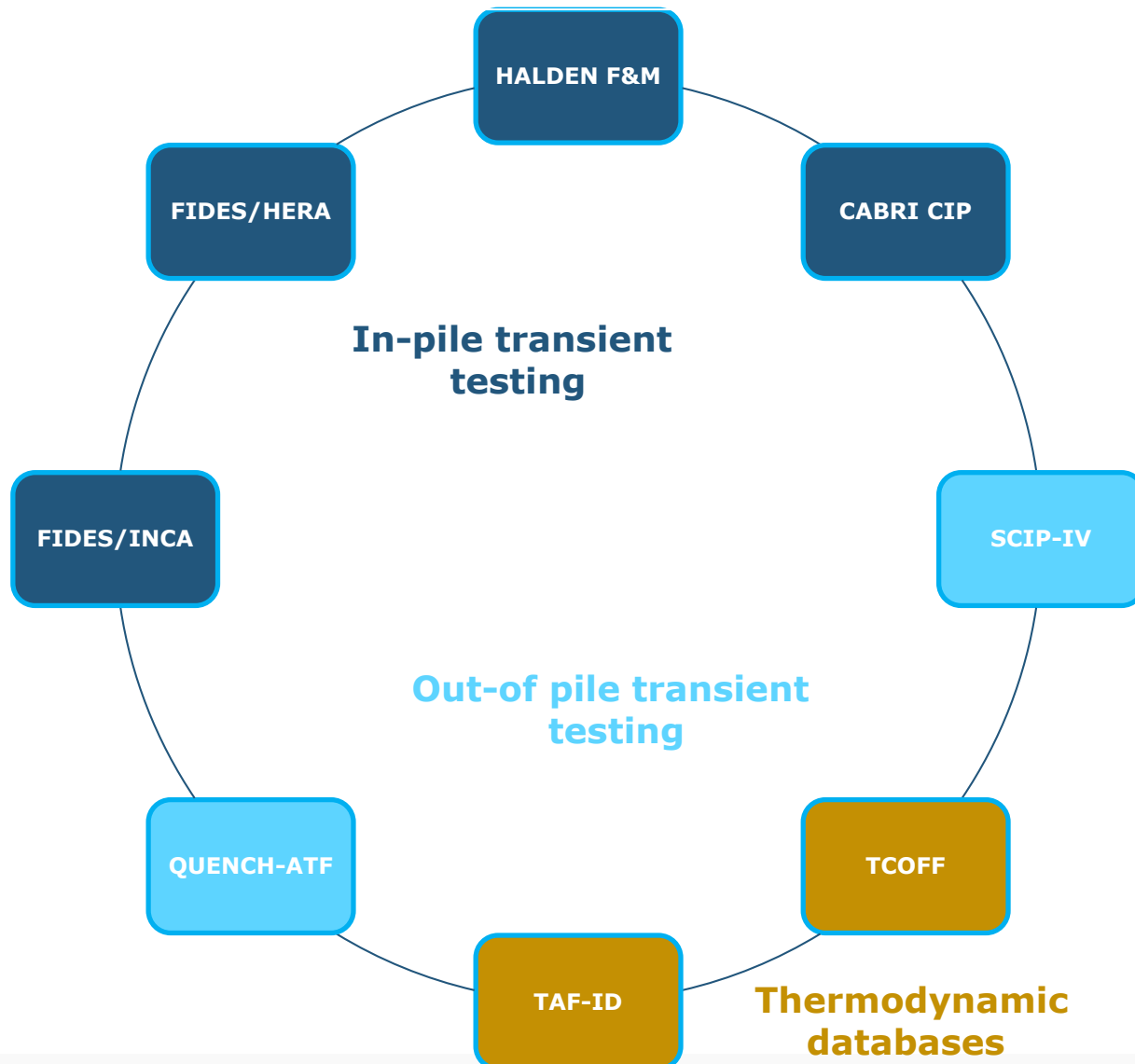
Obtain high quality data for safety code validation, benchmark safety codes

Be ready for the future

- License renewal of existing reactors
- New reactor applications (light water, non-light water, SMRs)

Nuclear Energy Agency (NEA) - Nuclear Safety Research Joint Projects ([oecd-nea.org](https://www.oecd-nea.org))

NEA Joint Projects addressing advanced fuels

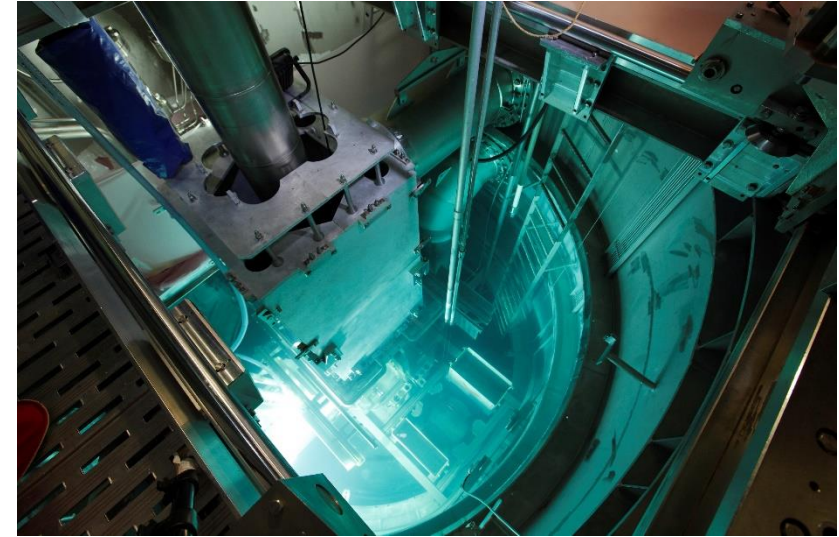


On-going joint undertakings addressing advanced fuels

- **HALDEN F&M** (2021-23)
- **CABRI CIP** (2000-26)
- **FIDES/HERA** (2021-24)
- **FIDES/INCA** (2021-24)
- **SCIP-IV** (2019-24)
- **QUENCH-ATF** (2021-24)
- **TCOFF-2** (2022-26)
- **TAF-ID** (2022-26)

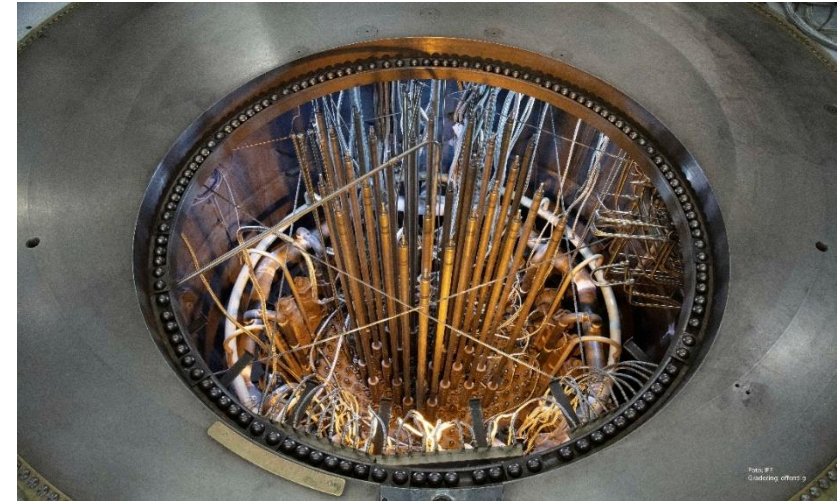
HALDEN F&M and CABRI CIP in-pile ATFs testing

CABRI CIP: HBU fuel and clad behavior in RIA (mandate 2018-2026, 12 countries, operated by IRSN, complementary tests at NSRR in Japan)
CIPQ test (1st test in water loop) in 2018
Leaks on hodoscope irradiation channel and water storage vessel delayed testing, reactor restarted in September 2022
CIP1-2B performed in November 2022
Next four tests planned in 2023 and 2024
Advanced fuels and claddings are getting higher priority (e.g. doped fuel and cladding with liner)



CABRI reactor
Figure
source: IRSN

HALDEN F&M: Experiments on fuel safety and operational margins, incl. fuel and cladding performance and behaviour for normal operation and transient conditions (mandate 2021-2023, 17 countries and EC, operated by IFE)
ATFs investigation have been performed and were planned before reactor closure in 2018: Cr, CrAl and FeCrAl coated claddings, UN, U₃Si₂, doped UO₂
ATFs LOCA testing planned in future Studsvik's SPARE project with samples from HALDEN



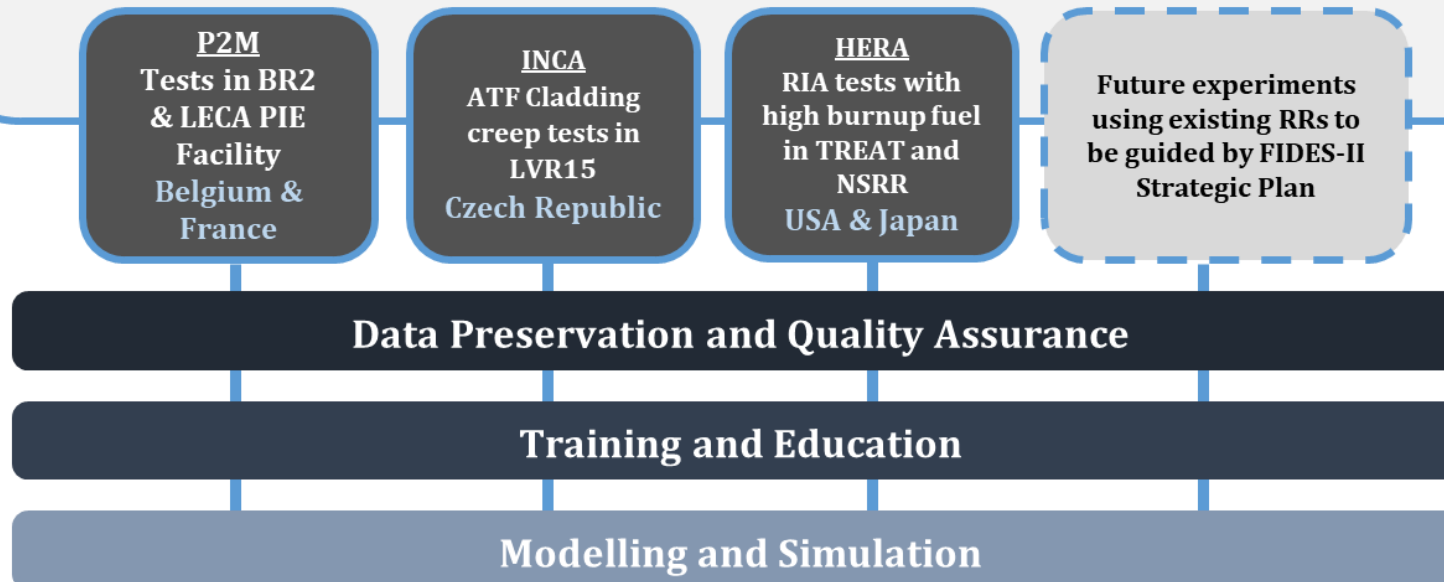
Halden reactor
Figure
source: IFE

Enhancing in-reactor testing capabilities: NEA Framework for Irradiation Experiments (FIDES)

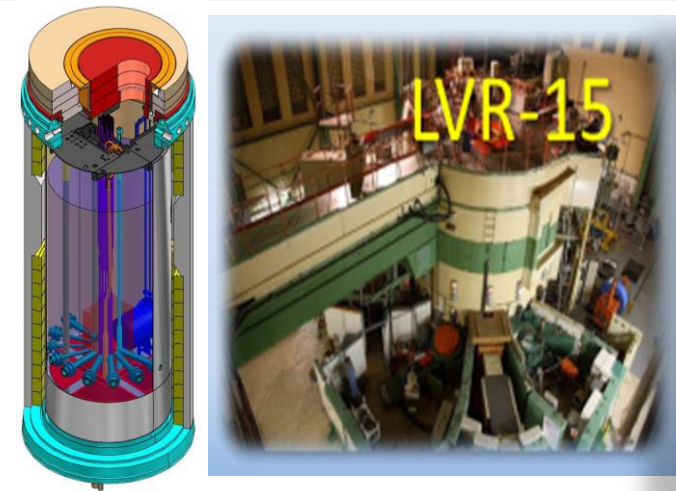
FIDES II Program of Work 2022-2024 (12 countries and EC) *International partnerships & research on key questions*

Second Framework for Irradiation Experiments – FIDES-II

- NEA joint undertaking, established pursuant to Article 5 of the NEA Statutes in co-ordination with the Nuclear Science Committee (NSC) and the Committee on the Safety of Nuclear Installations (CSNI)
- A stable, sustainable, reliable platform for fuel and material testing using nuclear research reactors (RRs) in NEA member countries
- Generates experimental results and expertise for shared costs
- **FIDES-II Program of Work includes 3 Joint Experimental Programmes (JEEPs) & 3 cross cutting pillars**

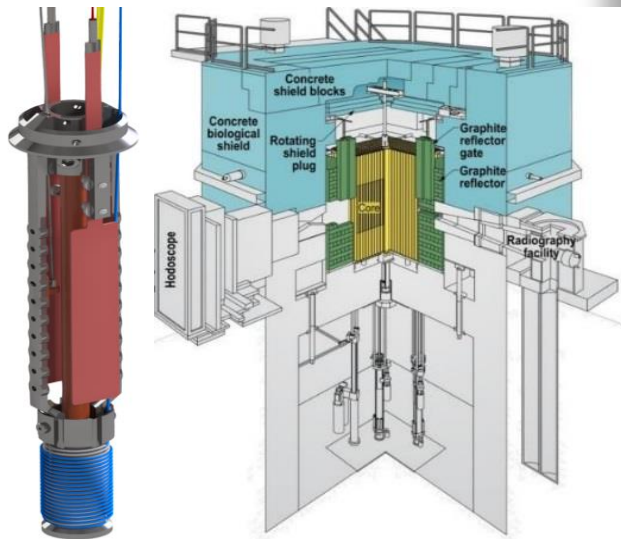


FIDES JEEPS addressing ATFs in-pile testing



INCA in-pile testing.

Figure source: CVR, UJV Rez



HERA in pile-testing

Figure source: INL

INCA: In-pile Creep Studies of ATF Cladding

- **Objective:** provide comparative data on the irradiation induced creep of current Zr alloys and Cr coated samples under steady state conditions
- **Material:** coated ATF claddings
- **Facilities:** LVR-15 Reactor and hot cells (Czech Republic)
- **Core Group:** CVR, UJV REZ, Alvel (CZ), VTT (Finland), CEA (France)
- **Experiment status:** irradiation began May 2022

HERA: High Burnup Experiments in Reactivity Initiated Accident

- **Objective:** investigate performance of modern HBU fuel at representative pulse widths
- **Material:** HBU fuels (ATFs in later phase)
- **Facilities:** TREAT reactor and hot cells (US) and NSRR reactor (Japan)
- **Core Group:** DOE, NRC, Westinghouse (US), JAEA (Japan), IRSN (France)
- **Experiment status:** pre-hydride and pre-irradiation tests in 22-23
- Blind calculations on RIA experiments recently launched

QUENCH-ATF: out-of-pile bundle testing of ATF claddings

A joint project to investigate **ATF claddings** for enhanced performance and safety:

- Three large-scale bundle tests performed at the QUENCH facility (KIT, Germany) with ATF cladding materials:
- Simulating design-basis and severe accident scenarios
- Supporting separate-effects tests
- Complementary tests performed by IRSN
- Numerical simulation exercise: blind post-test benchmark coordinated by GRS

Participants: 19 organisations from 9 NEA countries

Project started in Autumn 2021, for 4 years



QUENCH-ATF #1 (Jul. 2022)

- Cr coated Zr (Westinghouse US)
- Bundle with 24 heated rods
- Extended LOCA conditions
- Peak local temperature 1600 K
- Compares with QUENCH-L3HT

QUENCH-ATF #2 (S1 2023)

- Cr coated Zr
- Severe accident conditions
- Above Zr-Cr eutectic

QUENCH-ATF #3 (2024)

- Cr coated Zr, or SiC
- Scenario depending on material and results of previous tests

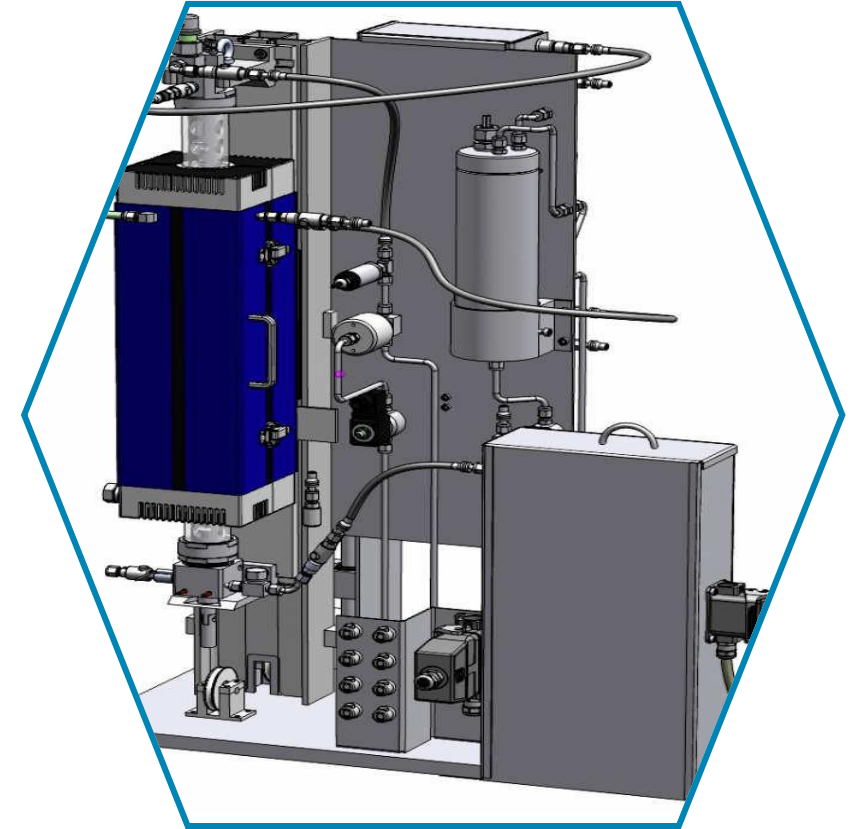
SCIP-IV: Studsvik Cladding Integrity Project

Objectives

- Understanding fuel and cladding performance in interim storage conditions
- Investigate fuel behavior during LOCA
- Analyse the influence of the microstructure on PCI
- Support experimental investigations with pre-and post-test modeling

Status of the project

- Phases 1-3 completed (start in 2004)
- Phase 4 ongoing (2019-2024), back-end topics included for the first time
- Participants: 38 organisations from 15 countries
- Broad range of materials are used for the investigations (PWR, BWR, VVER, non-standard) including doped fuel (ADOPT, ALSi, GD, IFBA)

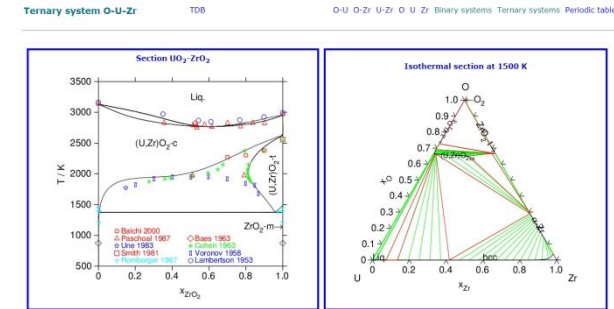


New LOCA apparatus.
Figure source: Studsvik

TCOFF and TAF-ID: Development of thermodynamic databases for supporting modeling of material interactions in severe accident analysis

TCOFF-2

- Recently launched: broadened scope in terms of reactor design and materials (the effect of **potential deployment of ATF materials** will be evaluated): U_3Si_2 , UN, Cr_2O_3 doped UO_2 , Cr-coated Zry, FeCrAl, SiC/SiC
 - Task-1: Prioritisation of the material science issues related to the severe accidents study
 - Task-2: Improvement of the materials science knowledge on fuel core degradation and FP release (UO_2 -Zry and ATFs)
 - Task-3: Implementation of improved knowledge for the simulation of the accident behavior (UO_2 -Zry and ATFs)
 - Task-4: Leaching

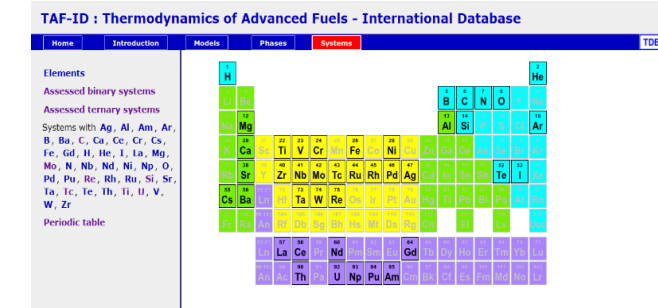


Phase relations in U-Zr-Fe-O system (metallic/oxidic melts in corium)

V. Almahisev et al., NITI
TCOFF R&D report (2019).

TAF-ID

- Develop a thermodynamic database for advanced fuel materials using the Calphad method
- Fuels: UO_2 , $(\text{U,Pu,Am,Np})\text{O}_2$, $(\text{U,Th})\text{O}_2$, (U,Pu,Zr,Am,Np) , **UN**, **(U,Pu)C**
- Phase 3 under preparation: **increased focus on ATF materials** (UN, U_3Si_2 , encapsulated fuels) and ATF cladding materials (Cr-coated Zry, FeCrAl, SiC) and their interactions with fission products, coolants, and structural materials



<https://www.oecd-nea.org/science/taf-id/>

WGFS: Advancing the understanding of fuel and clad behaviour in accidents and methods, tools for fuel safety analysis

Opportunities	Challenges	Possible ways forward
• Amassed expertise for safety of conventional fuels and clads (LWRs) with large knowledge base, research needs for near-term ATFs, HBU/HALEU and doped fuels safety identified • Large on-going R&D efforts to establish technology readiness of advanced designs and fuels • Advanced simulation tools under development • Established frames for in-reactor transient testing (FIDES II) and other related projects (QUENCH-ATF, SCIP)	• Extend WG expertise to new designs (non-LWRs) and materials (e.g. SiC, TRISO) • Limited research capacities, in particular research reactors for transient testing, when many new designs and materials are considered • Address timely knowledge gaps for supporting licensing for designs with near-term deployment • Data preservation, sharing and dissemination with export control/proprietary issues	• Promote optimizing or building research capacities, in particular for transient testing • Promote increasing lead rod and lead assembly irradiation in commercial reactors with sharing of gained knowledge • Extend WGFS expertise in new fuels and materials with connecting to relevant NSC experts WGs • WGFS to provide directions on research priorities in relation with FIDES II • Continue actions on data preservation and define a strategy for fuel safety DB developments at NEA

Looking ahead

Establish
a **global
research
roadmap**
for
advanced
fuels

- Identify **gaps** and research platform to maintain/develop incl. **transient research reactors**

Increase
**industry
involvement**

- Address industry's needs for **licensing**
- Launch activities to **facilitate lead rod/assembly testing in reactor**

Enhance the
**integrated
approach**
for advanced
fuels
transient
testing

- **FIDES II frame** provides an integrated approach for in-reactor testing
- Enhance **interactions** between FIDES and out-of-pile projects

Promote
durable
**preservation
of JPs data**

- Engage further projects in data preservation
- Promote **benchmarks on key data sets**
- Define a **strategy for fuel safety databases**



Thank you for your
attention!

JACQUEMAIN Didier

Senior Nuclear Safety Specialist

OECD Nuclear Energy Agency

Didier.Jacquemain@oecd-neo.org