Overview of Fast Reactor Activities in NEA

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ESFR-Smart Spring School
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Outline

- Introduction – OECD Nuclear Energy Agency (NEA)
- Fast Reactor Activities in
  - The Nuclear Science Committee (NSC)
  - The Committee on Nuclear Regulatory Activities (CNRA)
  - Generation IV International Forum (GIF)
- Looking ahead

Acknowledgments to

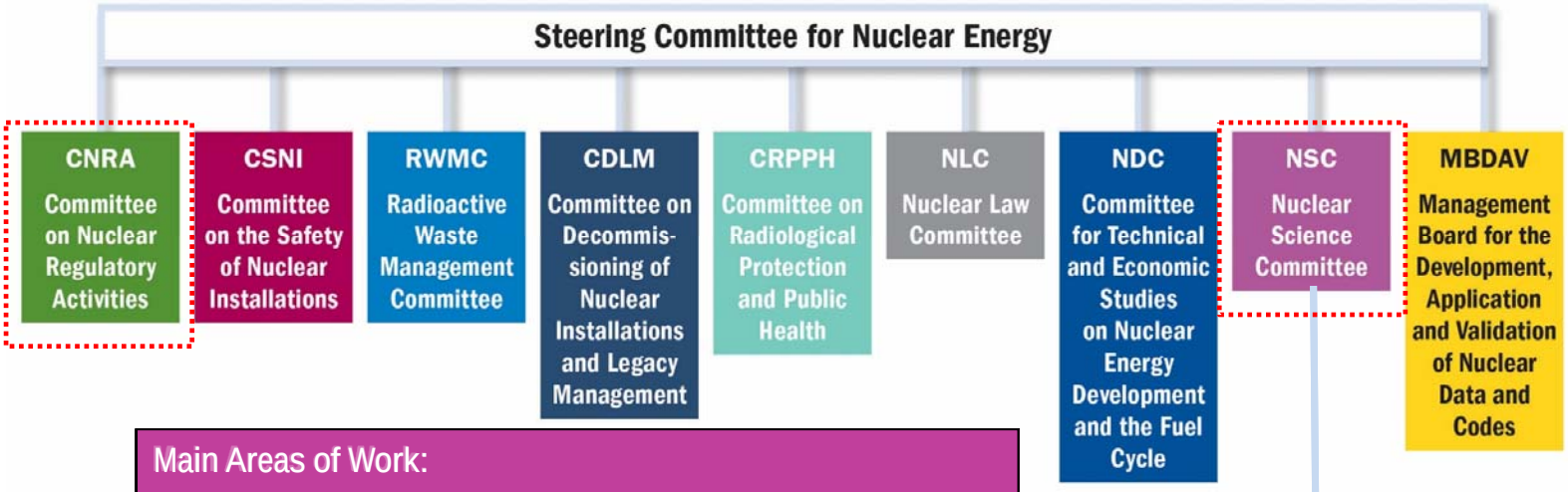
Dr Philippe Guiberteau, GIF Secretariat
Dr Marina Demeshko, CNRA Secretariat

The NEA: 34 Countries Seeking Excellence in Nuclear Safety, Technology, and Policy

- 34 member countries + strategic partners (e.g., China and India)
- 8 standing committees and more than 70 working parties and expert groups
- The NEA Data Bank - providing nuclear data, code, and validation services
- Growing global relationships with industry and universities.

NEA countries operate about 90% of the world's installed nuclear capacity

NEA Structure



Main Areas of Work:

- Reactor physics and transient studies
- Radiation shielding
- Fuel cycle physics and chemistry
- Fuel and material science
- Criticality safety
- Nuclear data
- Experimental needs
- Nuclear knowledge management, education and training

Nuclear Science Working Parties and Expert Groups

Major Multinational Nuclear Activities

NEA Serviced Organisations

- **Generation IV International Forum (GIF)**
  with the goal to improve sustainability (including effective fuel utilisation and minimisation of waste), economics, safety and reliability, proliferation resistance and physical protection.
- **Multinational Design Evaluation Programme (MDEP)**
  initiative by national safety authorities to leverage their resources and knowledge for new reactor design reviews.
- **International Framework for Nuclear Energy Cooperation (IFNEC)**
  forum for international discussion on wide array of nuclear topics involving both developed and emerging economies.

23 Major Joint Projects

(Involving countries from within and beyond NEA membership)

- **Nuclear safety research** and experimental data (e.g., thermal-hydraulics, fuel behaviour, severe accidents).
- **Nuclear science** (e.g., fuel thermodynamics).
- **Radioactive waste management** (e.g., thermochemical database).
- **Radiological protection** (e.g., occupational exposure).
- **Nuclear Education Skills and Technology Framework (NEST)**
- **Halden Reactor Project** (fuels and materials, human factors research, etc.)
- NEA Framework for Irradiation of Fuels and Materials **(FIDES) - new**

Nuclear Data for Fast Reactors

NSC Working Party on International Nuclear Data Evaluation Co-operation (WPEC)
chair O. Iwamoto (JAEA)

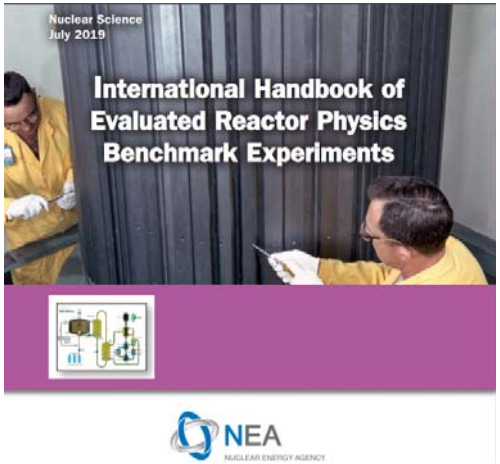
- Requirements to nuclear data (ND) for fast reactors and other advanced systems developed within WPEC Subgroup 26 and 33
- Requests included in the High-Priority Request List motivated dozens of targeted and complementary experiments (e.g. CERN/nTOF, LANL/DANCE, JAEA/ANNRI, etc.)
- NEA projects including CIELO and Subgroup 41 were launched to create state of the art evaluations for materials including U, Pu, Am and other structural materials
- Work is ongoing to re-assess target ND accuracy for new systems (including MYRRHA, ESFR-SMART, JSFR, and more) within Subgroup 46, initiated by M. Salvatores

Reactor Physics Experiments

NSC International Reactor Physics Experiment Evaluation (IRPhE) Project

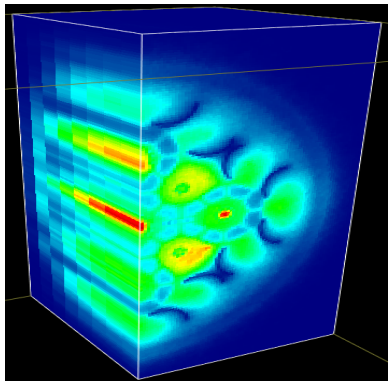
chair J. Bess (INL)

- Initiated in 1999
- IRPhE Handbook contains benchmark data for reactor-type experiments
- The 2019 edition of the Handbook contains 162 experimental series performed at 56 nuclear facilities
- **>170 Liquid Metal Fast Reactor benchmark configurations**
- Distributed on DVD, available on-line



International Reactor Physics Handbook Database and Analysis Tool (IDAT)

- Released in 2013
- Allows easy access to benchmark data and supplemented calculated data
- Trend and identify suitable benchmark experiments
- Included on the IRPhE Handbook DVD, available on-line
- https://www.oecd-nea.org/idat



Fast Reactor Benchmark Configurations in IRPhE Project

IRPhEP ID	Lab/Org	Number of Exp.
BFS1-FUND-EXP-001 - 004	IPPE	23
BFS1-LMFR-EXP-001 - 002	IPPE	4
BFS2-FUND-EXP-001	IPPE	1
BFS2-LMFR-EXP-001	IPPE	1
BR2-LMFR-RESR-001	IPPE	3
CORAL-FUND-RESR-001	CIEMAT	1
EBR2-LMFR-RESR-001	ANL	1
FCA-FUND-EXP-001	JAEA	1
FFTF-LMFR-RESR-001	Hanford	10
FR0-FUND-RESR-001 - 003	Studsvik	17
HECTOR-FUND-EXP-001 - 002	Winfrith	1
JOYO-LMFR-RESR-001	JAEA	9
KUCA-FUND-RESR-001	Kyoto University	5
LAMPRE-FUND-RESR-001	LANL	7
ORCEF-FUND-EXP-001	ORNL	1
ORSPHERE-FUND-EXP-001	ORNL	2
SNEAK-LMFR-EXP-001	Karlsruhe	2
ZEBRA-FUND-RESR-001	Winfrith	7
ZEBRA-LMFR-EXP-001 - 003	Winfrith	21
ZPPR-LMFR-EXP-001 - 011	ANL-W	25
ZPR-FUND-EXP-001 - 018	ANL-W	20
ZPR-LMFR-EXP-001 - 004	ANL	12

Measured/Evaluated parameters include:

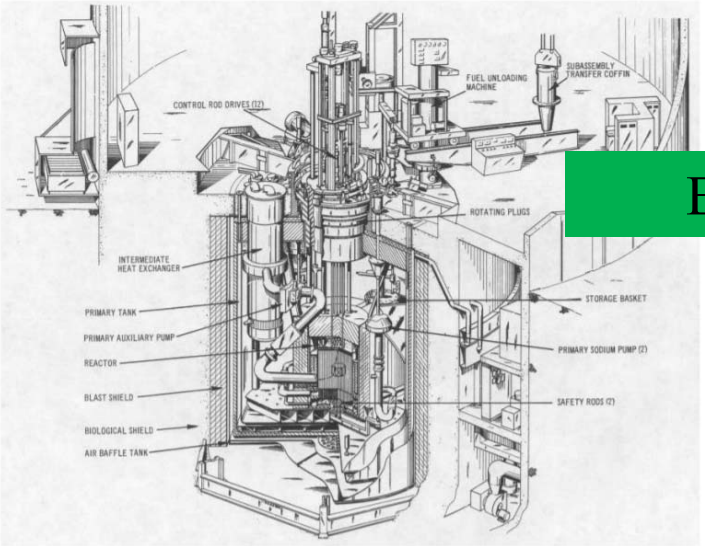
- Reaction Rates
- Spectral Indices
- Kinetics parameters
- Material/Control Rod Worth
- Reactivity coefficients

A few examples relevant to today's R&D needs include:

- Sodium-cooled Fast Reactor (SFR)
- Gas-cooled Fast Reactors (GFR)
- Lead-Cooled Fast Reactor (LFR)
- High Temperature Reactors (HTR)
- Molten Salt Reactors (MSR)
- Addressing some of the current needs in nuclear data and reactor physics

IRPhE Project Handbook Recent Additions (2018, 2019)

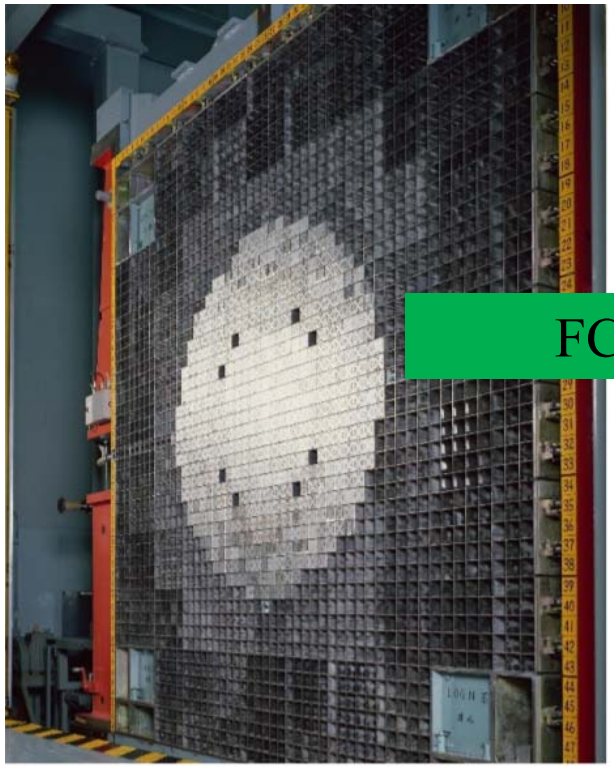
Criticality benchmarks, with the aim to expand to spectral characteristics and reactivity coefficients



EBR-II

Figure 1.1.4. EBR-II Cross-sectional View.

EVALUATION OF RUN 138B AT EXPERIMENTAL BREEDER REACTOR II, A PROTOTYPIC LIQUID METAL FAST BREEDER REACTOR



FCA

FCA IX-7 ASSEMBLY EXPERIMENTS: 20% ENRICHED URANIUM METAL CORE SURROUNDED BY DEPLETED URANIUM METAL BLANKET

Shielding Experiments

'The beginning, in 1973, was marked by the so-called Utilities' Convention signed by EdF, RWE, and ENEL on the construction of Superphenix and SNR 2. In 1977, cooperation began among the reactor vendors and R&D organizations in France, Germany and Italy as weil as Belgium and the Netherlands. After the British had joined in 1984, planning for the European Fast Reactor, EFR, was started in 1988. The conceptual design phase of the 1500 MWe breeder power plant covered a period of five years and was concluded with an economic assessment and a technical safety analysis of EFR in 1983'

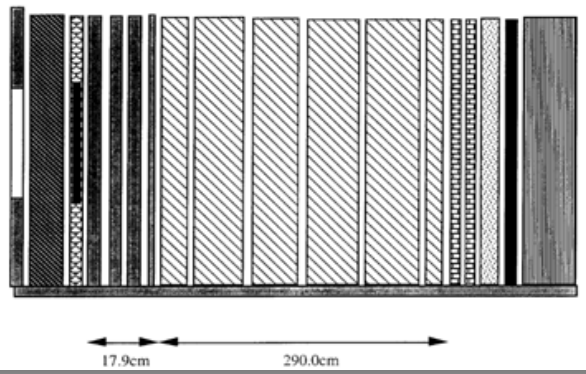
W. Marth, The Story of the European Fast Reactor Cooperation

The JANUS programme on the ASPIS facility was evolved to provide experimental data on the penetration of neutrons through stainless steel and sodium for use in the validation of the methods and data employed in the calculational routes for the design of shielding for sodium-cooled fast reactors. A key feature of the programme is the use of an absolutely calibrated fission plate and measurement techniques. This has allowed the application of adjustment procedures to the total data gathered so that critical comment can be drawn on the basic nuclear data. This document gives the complete specification of the experiment carried out under Phase 8 of the JANUS programme together with the results of the measurements. These provide data on the attenuation of neutrons through a 2900mm thick region of sodium preceded by a spectrum modifier consisting of 175 mm of mild steel. The relevant data have been extracted from the records of the JANUS studies with the aim of entering them into the SINBAD database of benchmark experiments which is being compiled by the OECD Nuclear Energy Agency.

An International Database for Integral Shielding Experiments (SINBAD):

- Developed in cooperation with RSICC, USA
- Includes +100 benchmarks, shielding, accelerators, fusion
- Distributed on DVD, available on-line
- www.oecd-nea.org/sinbad

Example: Benchmarks JANUS I, JANUS VIII for the design of SFR shielding



Uncertainty Analysis for SFR Modelling

NSC Uncertainty Analysis for Modelling (UAM)-SFR benchmark:
3600MWth oxide core and a medium 1000MWth metallic core

Phase I: Neutronics Phase

Exercise I-1: Cell Physics

Exercise I-2: Sub-assembly Physics

Exercise I-3: Core Physics
(Large oxide core; Medium metallic core;
Advanced oxide ASTRID core)

Exercise I-4: Experimental validation:

Various criticality cores taken from ICSBEP/IRPhE, β_{eff} measurements, SVRE (ZPR6+ZPPR2), Doppler (SEFOR)

Phase II:

Exercise II-1: Fuel Physics

Exercise II-2: Time-Dependent Neutronics

Exercise II-3: Bundle Thermal-Hydraulics (THORS)

Phase III:

Exercise III-1: Unprotected Transients

Exercise III-2: Control Rod inadvertent withdrawal

Exercise III-3: Superphénix Start Up benchmark

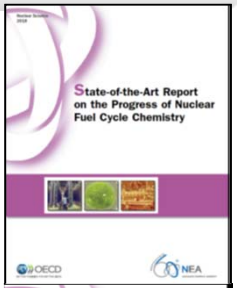
In red: specs to be finalized , in green : action in progress

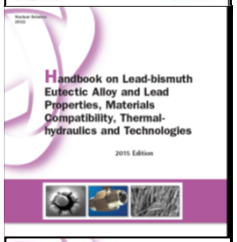
Fuel Cycle

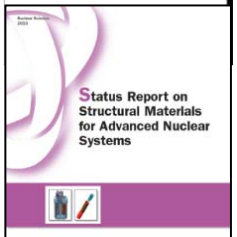
NSC Working Party on Scientific Issues of the Advance Fuel Cycles (WPFC)
chair Nathalie Chauvin (CEA)

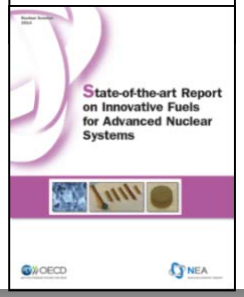
- Dedicated to **existing and advanced nuclear fuel cycles** and **focus mainly on advanced systems**
- Covers all **areas of the fuel cycle**: fuel cycle scenarios, innovative fuels, coolant/components technology, fuel recycling and waste technology.
- **Main publications:**
  - State-of-the-art report on the Progress on Nuclear Fuel Cycle Chemistry (2018).
  - The effects of the uncertainty of input parameters on Nuclear Fuel Cycle Scenarios studies (2017).
  - Handbook on Lead-bismuth Eutectic Alloy and Lead Properties, Materials Compatibility, Thermal-hydraulics and Technologies (2015).
  - State-of-the-art report on Innovative Fuels for Advanced Nuclear Systems (2014).
  - Status report on Structural Materials for Advanced Nuclear Systems (2013).
  - Transition Towards a Sustainable Nuclear Fuel Cycle (2013).
  - Benchmark Study on Nuclear Fuel Cycle Transition Scenarios Analysis Codes (2012).
  - Potential Benefits and Impacts of Advanced Nuclear Fuel Cycles with Actinide Partitioning and Transmutation (2011).

www.oecd-nea.org/science/wpfc/









Fast Reactor Activities in the WPFC Expert Groups (EGs)

EG on Advanced Fuel Cycle Scenarios

- Transuranic (TRU) Management Study
- Online catalogue of tools for fuel cycle modelling

EG on Innovative Fuel Elements

- Benchmark Study on Innovative Fuels for Fast Reactors in transient conditions
- Recommendations on fuel properties for fuel performance codes

EG on Reactor Coolants/Components Technology

- State-of-the-art report on the liquid metal environment effects on materials for safe and reliable operation, inspection, handling, maintenance, decommissioning and waste management of liquid metal cooled reactors
- Template on materials behaviour and chemistry issues (including TRL)

EG on Fuel Recycling and Waste Technology

- Report on Treatment of Volatiles Fission Products
- International Review on Recycle and Reuse of Components from Spent Fuels
- International Database on Extractant Ligands (IDEaL) –β-testing ongoing
- Article in Progress in Nuclear Energy, September 2019: 'A review of separation processes proposed for advanced fuel cycles based on technology readiness level assessments' https://doi.org/10.1016/j.pnucene.2019.103091

Upcoming Workshop

- 16 Information Exchange Meeting on Actinide and Fission Product Partitioning and Transmutation (IEMPT), co-organised by Rosatom, NEA and IAEA, postponed to June 2022

www.oecd-nea.org/science/wpfc/

New Task Force on Demonstration of Fuel Cycle Closure including P&T towards Industrialisation by 2050

chair H. Aït Abderrahim (SCK CEN)

- Originated from NEA Nuclear Innovation (NI) 2050 initiative.
- Kicked off in January 2021.
- The main objective is to address technological, economical and societal aspects of advanced fuel cycles and P&T options in a High-level Paper that will
  - Review the work done over the past 30 years
  - Assess the status of TRL and recommend work on TRL increase
  - Cover different P&T options looking at all existing and emerging technologies
  - Identify R&D needs and gaps, infrastructure needs
  - Include an economic study, jointly with the Committee for Technical and Economic Studies on Nuclear Energy Development and the Fuel Cycle (NDC)

Fuel Performance Data

Overseen by the **NSC Expert Group on Reactor Fuel Performance (EGRFP)**
chair G. Rossiter (NNL)

International Fuel Performance Experiment Database (IFPE):

- Developed in cooperation with IAEA
- Includes 1452 rods/samples (mainly Zircaloy+UO2)
- from various sources encompassing BWR, PHWR, PWR, and VVER
- Used for **validation** of fuel modelling codes
- Experimental data for advanced reactors (FR, VHTR) fuel can be included
- Includes some Halden data
- **Proposed to be repository for FIDES data**

Program name	Package id	Status
IFPE/IFA 432	NEA 1488/02	Arrived

Machines used:

Package ID	Orig. computer	Test co
NEA-1488/02	Many Computers	

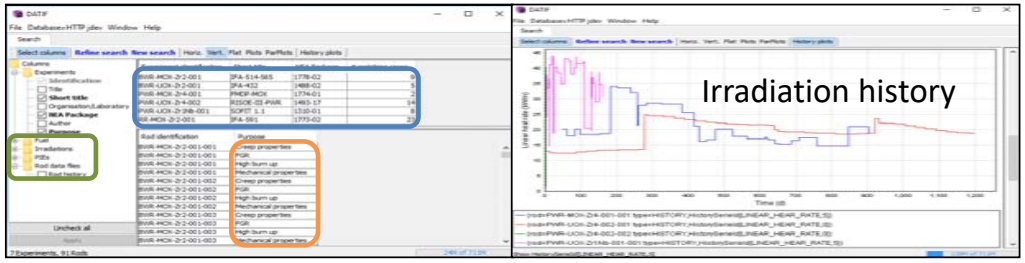
3. DESCRIPTION

It contains data from experiments that have been performed at the IFE/OECD Halden use in fuel performance studies. It covers experiments on thermal performance, fi properties and pellet clad mechanical interaction. It includes also experimental behaviour.
IFA-432: Measurements of fuel temperature response, fission gas release and mecha fuel rods up to high burn ups. The assembly featured several variations in rod d type, fuel/cladding gap size, fill gas composition (He and Xe) and fuel stability rods with fuel centre thermocouples at two horizontal planes, rods were also equi and cladding extensometers. Only data from 6 rods are compiled here.

On-going modernisation

- New relational database - DATIF
- Enhanced accessibility of data packages
- Set of metadata and database schema
- Standardised format for experimental data
- Plotting capabilities
- Automatic generation of inputs for fuel performance codes
- Uncertainty analysis capabilities
- Custom accessibility

Beta-version of DATIF database GUI, July 2019



Safety of Advanced Reactors

CNRA Working Group on the Safety of Advanced Reactor (WGSAR)

Chair A. Cubbage (NRC), vice-chair O. Baudrand (IRSN)

Recent reports on Regulatory Perspectives on Safety Aspects Related to Advanced Sodium Fast Reactors (approved by CNRA):

- Technical Report on Severe Accidents Prevention and Mitigation Measures in SFRs
- Technical Report on Neutronics and Criticality Safety of SFRs
- Technical Report on Analytical Codes and Methods for SFRs
- Technical Report on Fuel Qualification for SFRs
- Report on Regulatory Approaches on Fuel Qualification for Advanced Reactors

Ongoing activities:

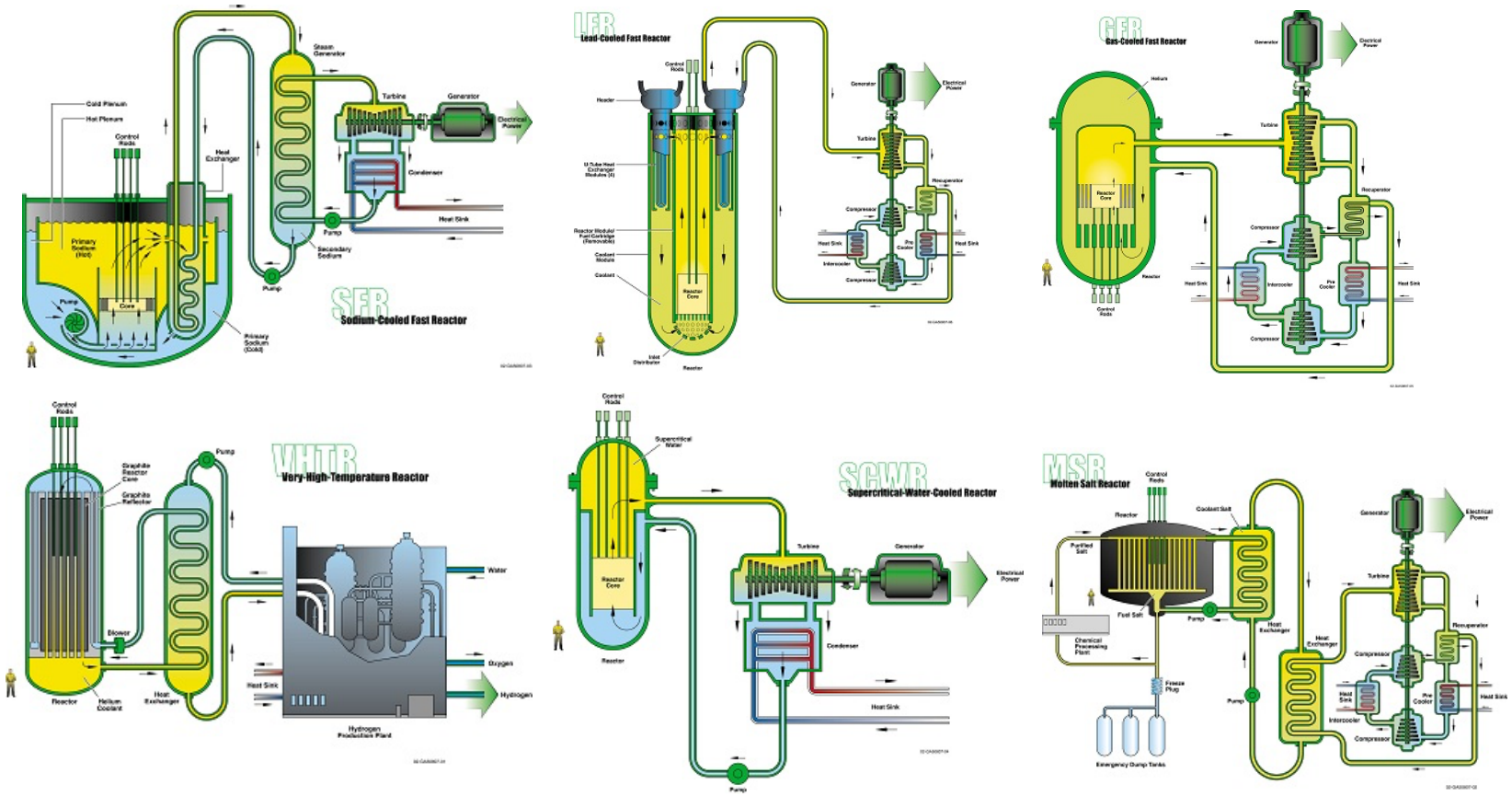
- Report on Regulatory approaches related to use of analytical codes and methods in safety assessment of advanced reactors
- International benchmark considering a core damage scenario in a LFR type to assess code capabilities and knowledge gaps relevant to regulators questions
- Common regulatory practices to ensure appropriate qualification and through life performance of materials in advanced reactors.

WGSAR objectives:

- Exchange information and experience from licensing and oversight of past and current nuclear facilities
- Provide regulatory perspectives through the issuance of technical reports
- Take into consideration the GIF safety design criteria and the development of the GIF safety design guidelines

Generation IV Systems

GEN IV International Forum
Expertise | Collaboration | Excellence



Aiming at improvements in:

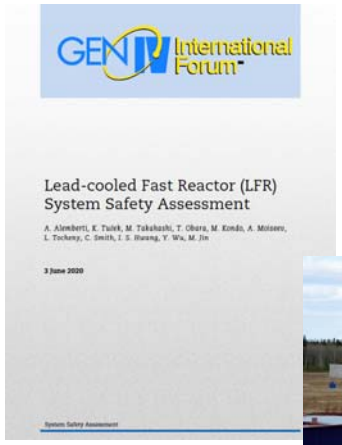
- Sustainability
- Economics
- Safety and reliability
- Proliferation resistance and physical protection

https://www.gen-4.org

Highlights related to LFR and HLM Technologies

GEN IV International Forum
Expertise | Collaboration | Excellence

- Within GIF, LFR members work under the framework of MoU
- Activities concentrate on the development of top-level reports
  - **LFR System Safety Assessment (SSA)** was published in June 2020
  - **White Paper on the LFR PRPP aspects** has been finalised in cooperation with GIF PRPPWG and transmitted to EG
  - **LFR Safety Design Criteria (SDC)** document is being prepared in collaboration with GIF RSWG, and is expected to be finalised and transmitted to GIF Expert Group in early 2021
- **World**: The licensing of the BREST LFR research demonstrator is currently being completed with site preparations ongoing in Tomsk, Russian Federation
- **Europe**: Two main projects: (i) **MYRRHA** R&D infrastructure (ADS demonstrator) under construction in Belgium; and (ii) LFR demonstrator **ALFRED** in Romania. Euratom collaborative projects supporting LFR- and heavy liquid metal (HLM)-R&D activities: **GEMMA, PATRICIA** and **PASCAL**



Site preparations for the BREST-OD-300 construction

https://www.gen-4.org/gif/upload/docs/application/pdf/2020-06/gif_lfr_ssa_june_2020_2020-06-09_17-26-41_202.pdf
https://www.riatomsk.ru/article/20201109/seversk-brest-300-sroki/
http://www.eera-jpnm.eu/gemma/
https://patricia-h2020.eu/
https://cordis.europa.eu/project/id/847715
https://cordis.europa.eu/project/id/945341

Highlights related to GFRs

GEN IV International Forum
Expertise | Collaboration | Excellence

GFR System Arrangement signed by Euratom, France, and Japan

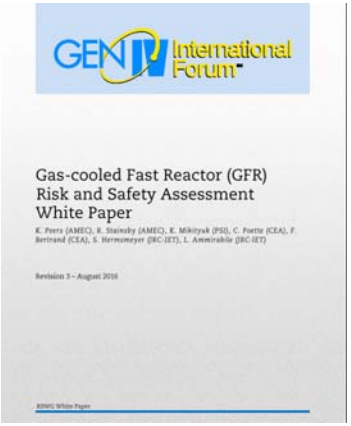
- Existing Project Arrangement on Conceptual Design and Safety
- Provisional project on Fuel and core materials
- Proposed project on GFR Technology

Development of GFR reference documents

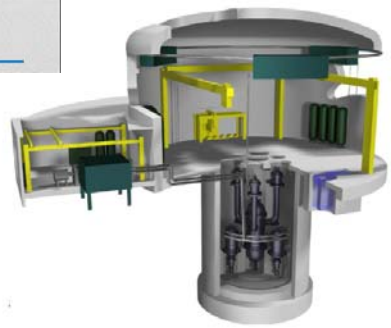
- GFR Risk and Safety Assessment White Paper (completed in 2016)
- GFR System Safety Assessment (draft)
- GFR Safety Design Criteria (draft)

Europe: The main project **ALLEGRO** - preparatory phase is carried out by the V4G4 Centre of Excellence. The work is being supported by the Euratom collaborative project **SafeG**, among others aiming at:

- strengthening of inherent safety
- resolving remaining open questions in residual heat removal in accident conditions



ALLEGRO concept



https://www.gen-4.org/gif/upload/docs/application/pdf/2016-10/rswg_gfr_white_paper_final_2016.pdf
https://cordis.europa.eu/project/id/945041

Highlights related to SFRs

GEN IV International Forum
Expertise | Collaboration | Excellence

Most active GIF system (together with VHTR) with four R&D Projects running:

- System Integration and Assessment (SIA)
- Safety and Operations (S&O)
- Advanced Fuel (AF)
- Component Design and Balance of Plant (CD&BOP)

Five SFR Design Concepts:

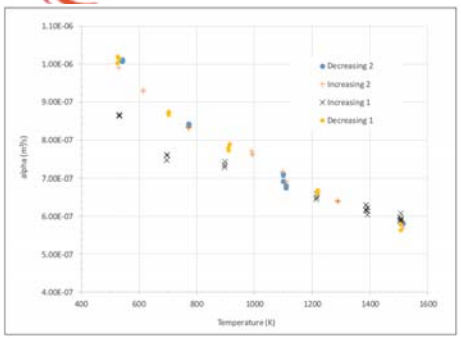
- Loop Option (JSFR Design Track)
- Pool Option (KALIMER-600, ESFR, and BN1200 Design Tracks)
- Small Modular Option (SMFR Design Track)

Revision of **SFR System Research Plan** was completed and approved by System Steering Committee in October 2019

White Paper on the SFR PRPP aspects has been finalised and transmitted to EG

World: Construction of two pilot SFR units (CFR-600) is ongoing in China

ESFR-SMART
sodium fast reactor safety



Thermal diffusivity measurements of $(U,Am)O_{2-x}$ at JRC Karlsruhe

https://www.gen-4.org/gif/jcms/c_95916/gif-sfr-safetyassessment-20170427-final
https://world-nuclear-news.org/Articles/China-starts-building-second-CFR-600-fast-reactor
http://esfr-smart.eu/

Looking Ahead

- **Regulatory Perspectives on SFR Safety**
  - Topics for further studies include material selection, integrity and through life challenges, in-service inspection; source term, etc.
- **Nuclear Data**
  - Updated requirements to ND accuracy for advanced systems, including FRs
- **Reactor physics**
  - Further focus on FR data preservation by mining the experimental data generated in the past and transforming them into easy to use benchmarks, with well quantified uncertainties
  - Further improvements in VV&QA methods
- **Fuel Cycle**
  - Proposal for a Joint Project on experimental demonstration of fuel cycle closure following recommendations by the New Task Force on Demonstration of Fuel Cycle Closure including P&T towards Industrialisation by 2050
- **Fuel Performance**
  - Further studies of FR fuels and IFPE update with FR fuel data
- **Experimental Needs**
  - New NSC Task Force to highlight the importance of sustaining experimental capacities of zero-power reactors