IAEA
International Atomic Energy Agency

"Atoms for Peace and Development"

Spring School on
Sodium Cooled Fast Reactor
ESFR-SMART R&D Activities &
Relevant GEN-IV Technologies
29-31 March 2021
University of Cambridge (Virtual Event)

IAEA Activities on Technology of Sodium cooled Fast Reactors

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Division of Nuclear Power
Department of Nuclear Energy
International Atomic Energy Agency
https://www.iaea.org/topics/fast-reactors

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IAEA: International Atomic Energy Agency

Established in 1957

Nuclear Technology & Applications

Nuclear Safety & Security

Safeguards & Verification

Nuclear Energy

Nuclear Sciences & Applications

Technical Cooperation

Nuclear Safety & Security

Safeguards

***"Atoms for Peace** and Development"*

IAEA in Numbers

Founded in 1957: **64 Years** of international service

168 Member States

~2500 Professional and support staff

Regular Budget (2016) ~ €360M

Extra-budgetary (voluntary) ~ €50M

Technical Cooperation Fund contributions (voluntary) **~ €90M** in 2016

12 international laboratories (Vienna, Seibersdorf and Monaco) and research centres

1+ million documents, technical reports, standards, conference proceedings, journals and books in the IAEA Library

IAEA Fast Reactor Technology Development Team

Nuclear Power Technology
Development Section **NPTDS**

"Atoms for Peace and Development"

Fast Reactor Technology Development Team

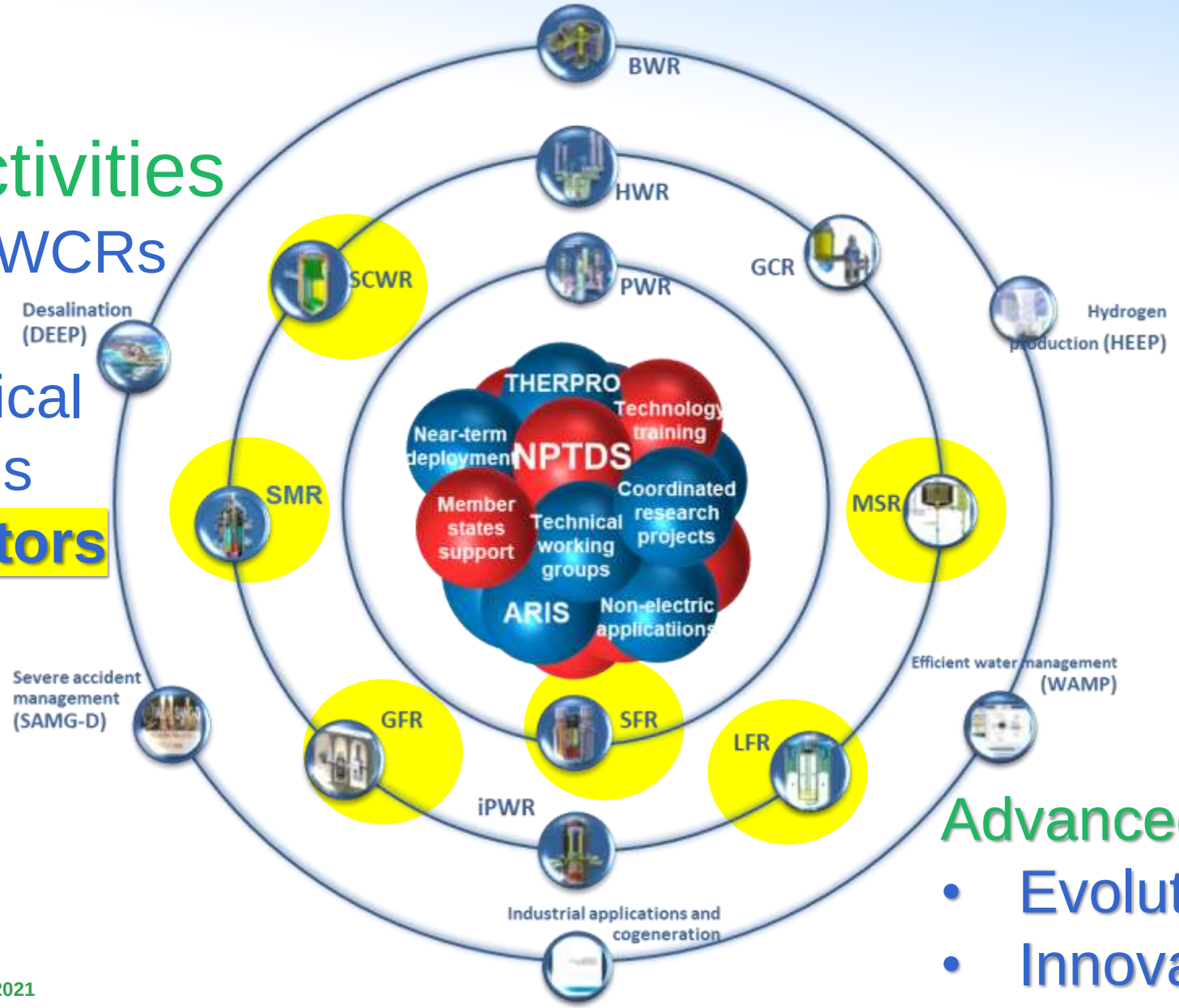
FastRTeam

Nuclear Power Technology Development Section

NPTDS:

Tasks & Activities

- Advanced WCRs
- SMRs
- Non-Electrical Applications
- **Fast Reactors**



Advanced Reactors:

- Evolutionary (Gen-III+)
- Innovative (Gen-IV)

IAEA Coordinated Research Projects

The IAEA encourages and assists research on and development and practical use of atomic energy and its applications for peaceful purposes throughout the world. It brings together research institutions from its developing and developed Member States to collaborate on research projects of common interest, so-called **Coordinated Research Projects** (**CRPs**).

CRP completed in last decade

- **BN-600** MOX Core Benchmark
- **PHENIX** – EOL Tests
- **MONJU** – Na Natural Convection
- Analytical and Experimental Benchmark Analysis of **ADS**
- **EBR-II** Shutdown Heat Removal Tests

CRPs on Fast Reactors Technology

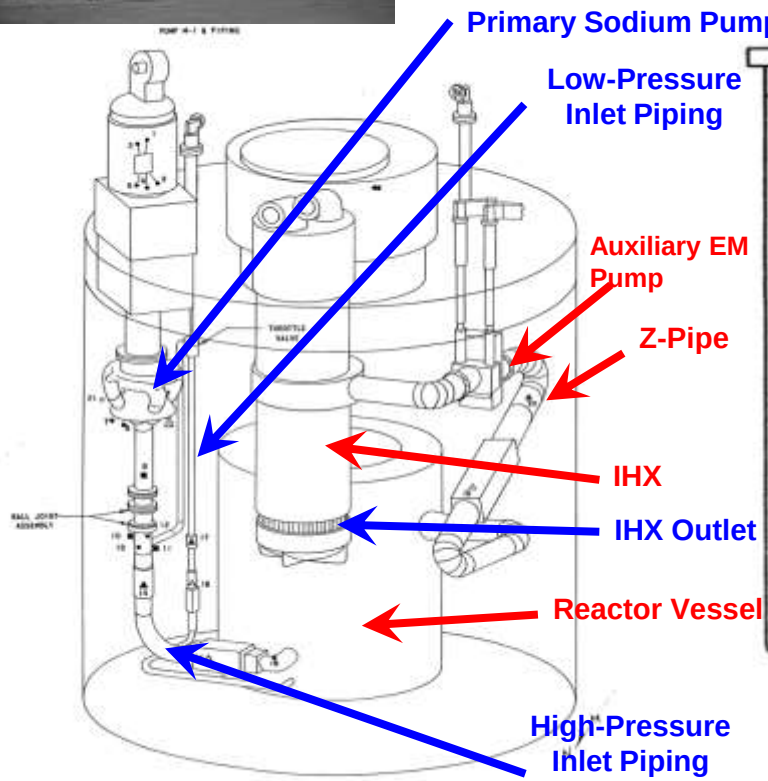
On-going CRPs

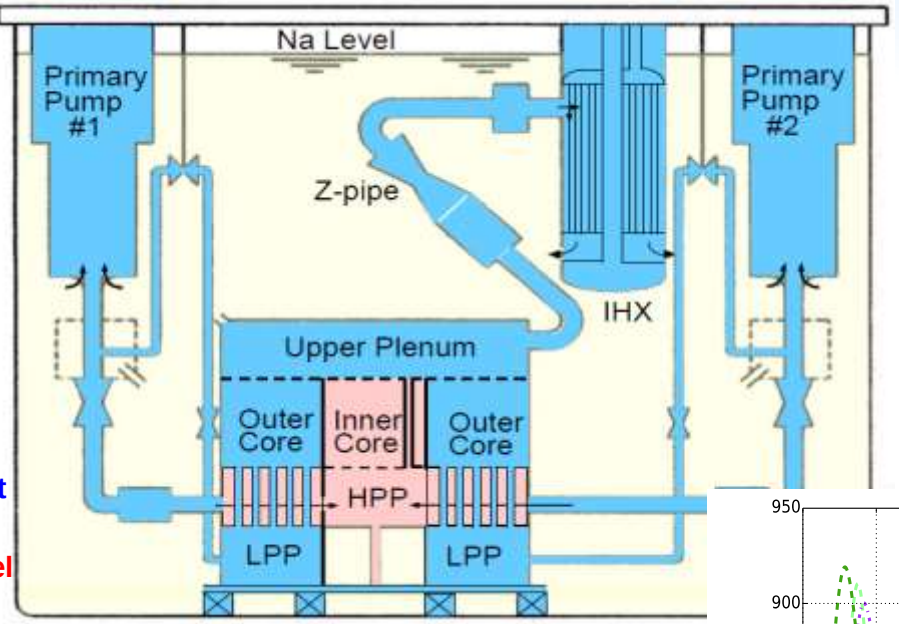
- **PSFR Source Term** – Radioactive Release Under Severe Accident Conditions
- Neutronics Benchmark of **CEFR** Start-Up Tests (29 participants)
- Benchmark Analysis of **FFTF** Loss of Flow Without Scram Test (25 participants)
- **NAPRO** – Na Properties and Safe Operations of Exp. Facilities
  Ended in Sept 2018
  2 TECDOCs in Publishing

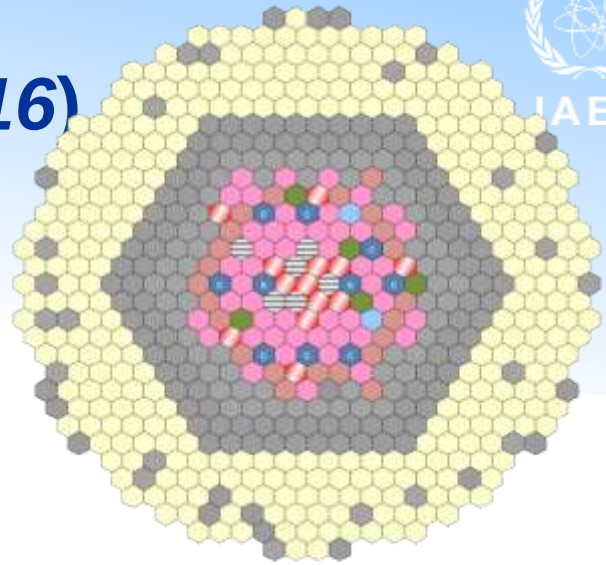
New Proposals

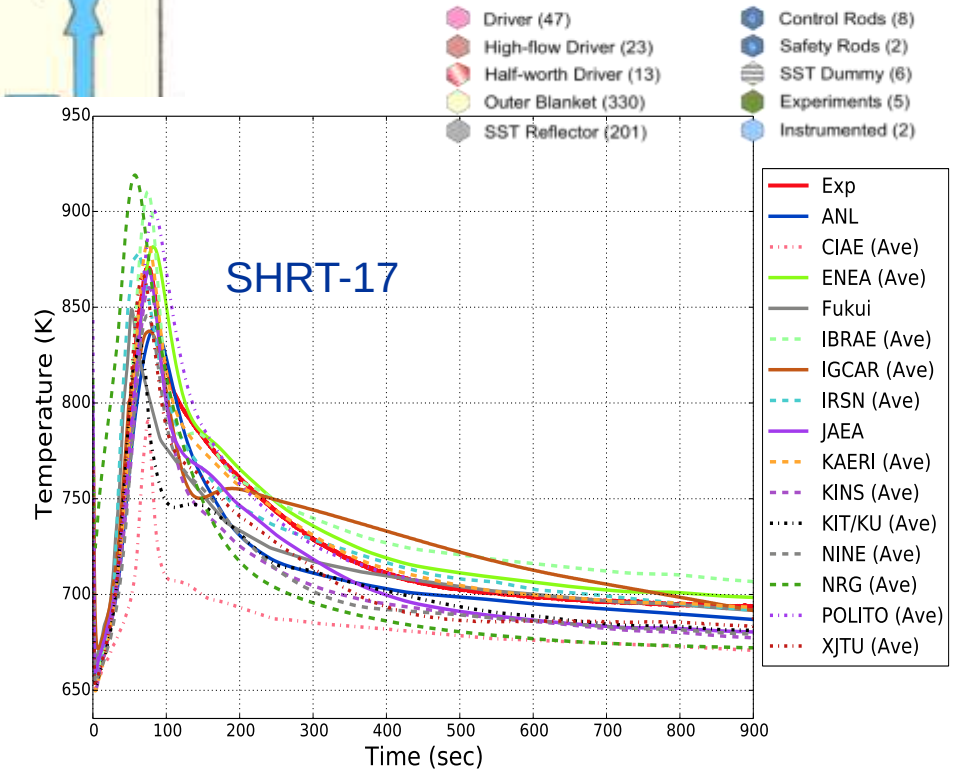
- Total Instantaneous Blockage of SFR Fuel Assembly
- Simulation of **CLEAR-S** Loss-of-Flow Experiment
- Benchmark Analysis of **STELLA-2** LOHS/LOF Tests
- Natural Circulation in LBE Sub/Assembly: **NACIE** Tests

CRP on Benchmark Analysis of *EBR-II* Shutdown Heat Removal Tests (*2012-2016*)





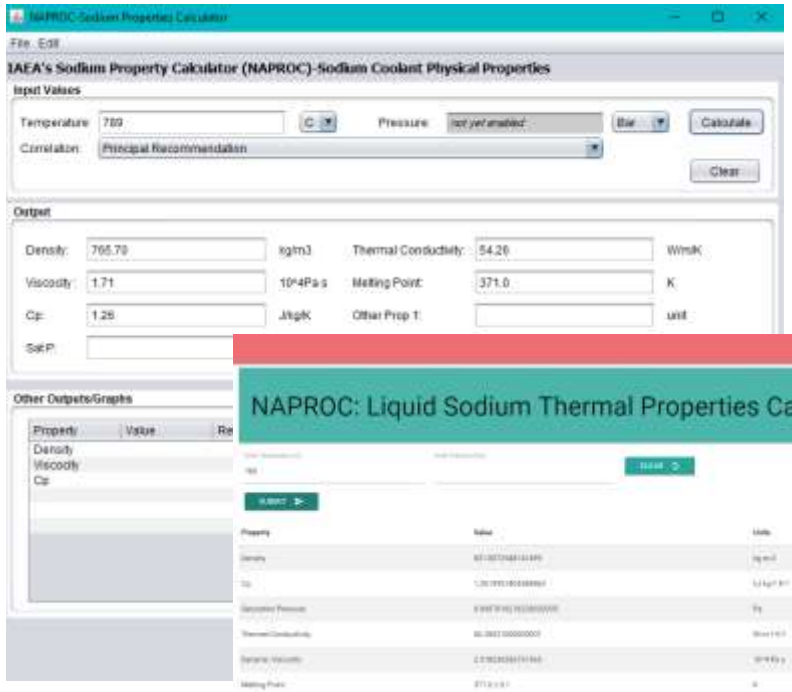




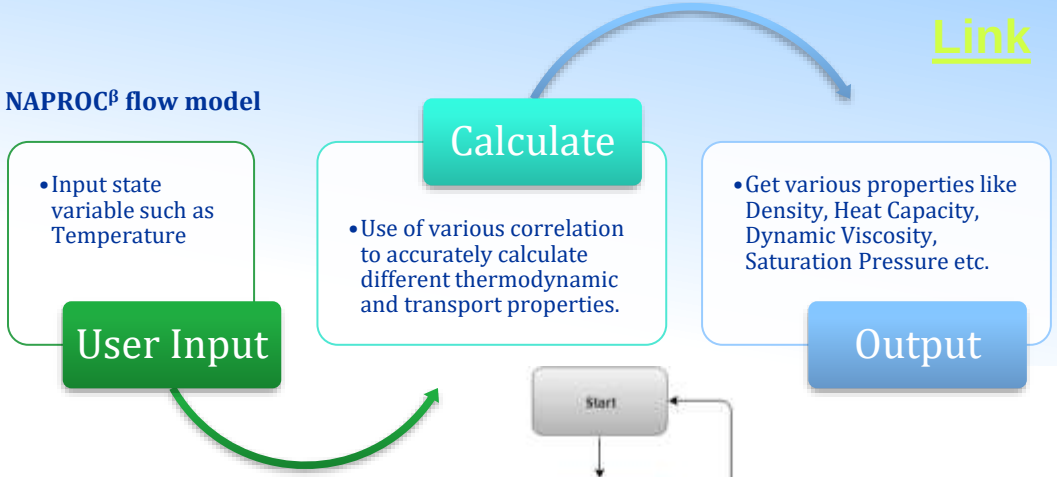
- Coupled Neutronics and Thermalhydraulic Transient Simulations
- SHRT-17 (Protected): Loss of normal and emergency pumping
- SHRT-45 (Unprotected): Loss of normal flow, scram disabled, station blackout
- 20 Organizations from 12 Countries jointly produced simulations predicting most plant parameters with acceptable accuracy

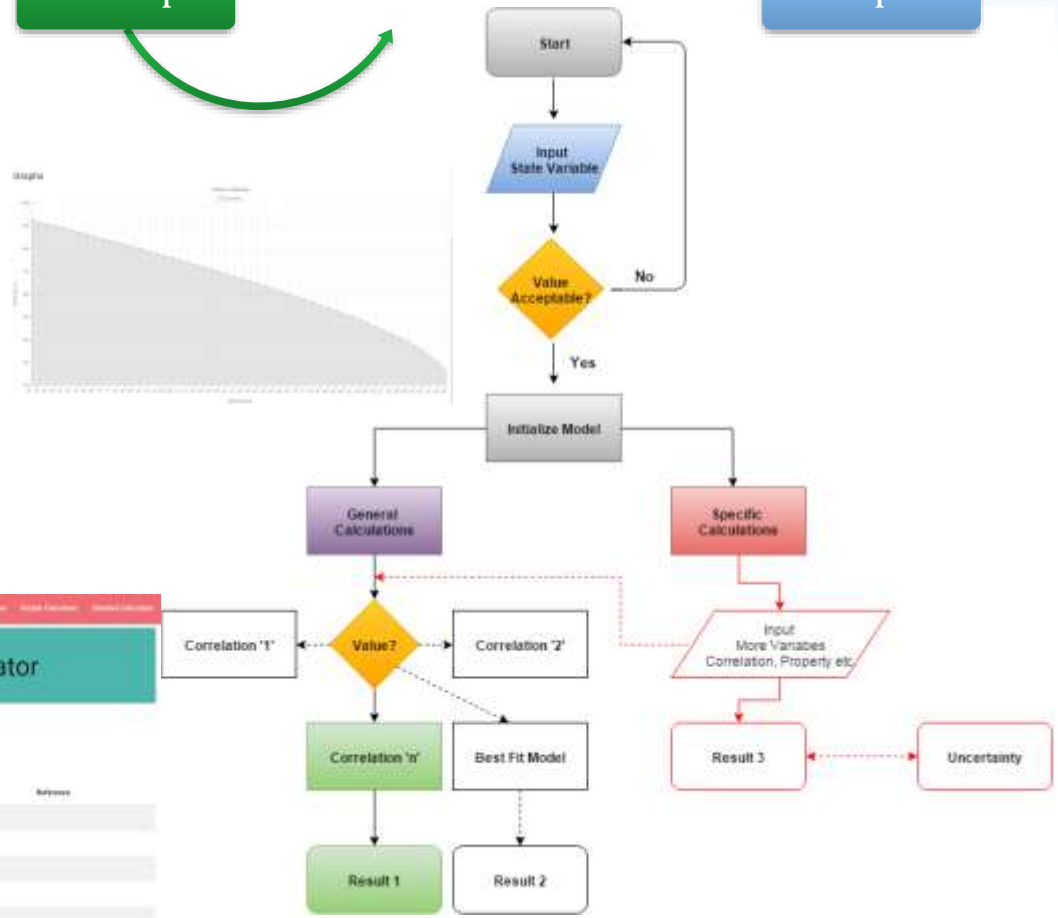
NAPROC β: The Sodium Properties Calculator

- Easy to use software to get the thermophysical of liquid sodium.
- Input the required state variables and get all desired properties.
- Beta version under development.
- Modelling based on the use of various correlations.

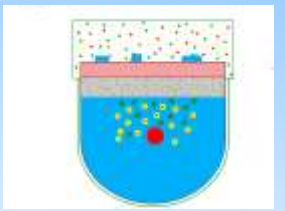


NAPROCβ flow model

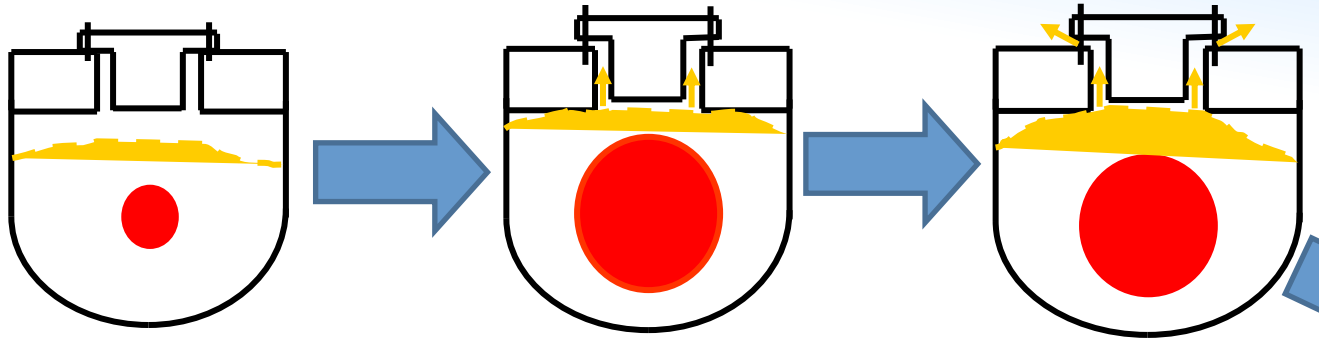




CRP on Radioactive Release from Prototype SFR under Severe Accident Conditions (2016- 2020)



CDA development and propagation in pool type SFR

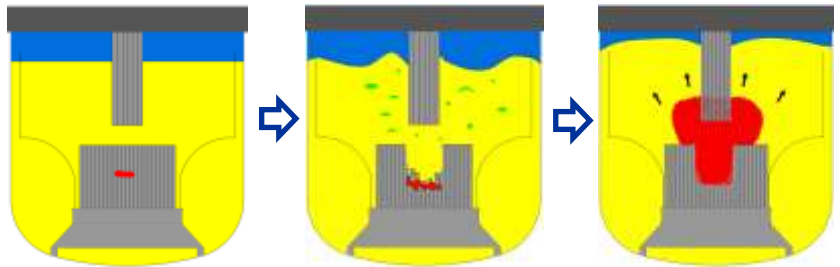


Initiation *(neutronics), and* ***Transition*** *(fuel relocation) Phases*

Core Melt/Bubble is formed

I. ***Expansion Phase***

Core bubble expands in sub-cooled sodium



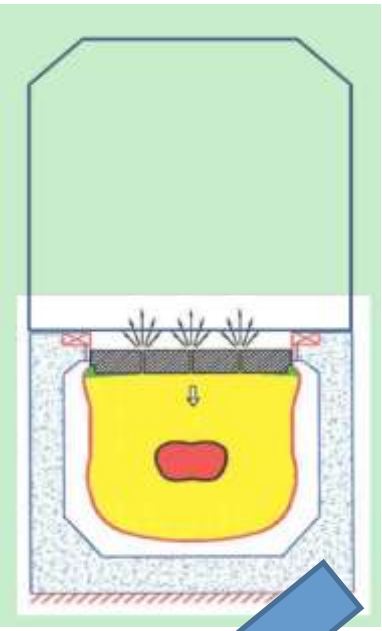
Incipient melting and early relocation

Extended relocation and core compaction

Rapid fuel vapor bubble expansion

II. ***Quasi-static Phase***

Release of sodium to the Reactor Containment Building (RCB)



III. ***Containment Source Term***

- Evaluation of multi-component aerosol evolution is required

- Two typical sodium fire accidents:

- *sodium pool fire accident*
- *sodium spray fire accident*

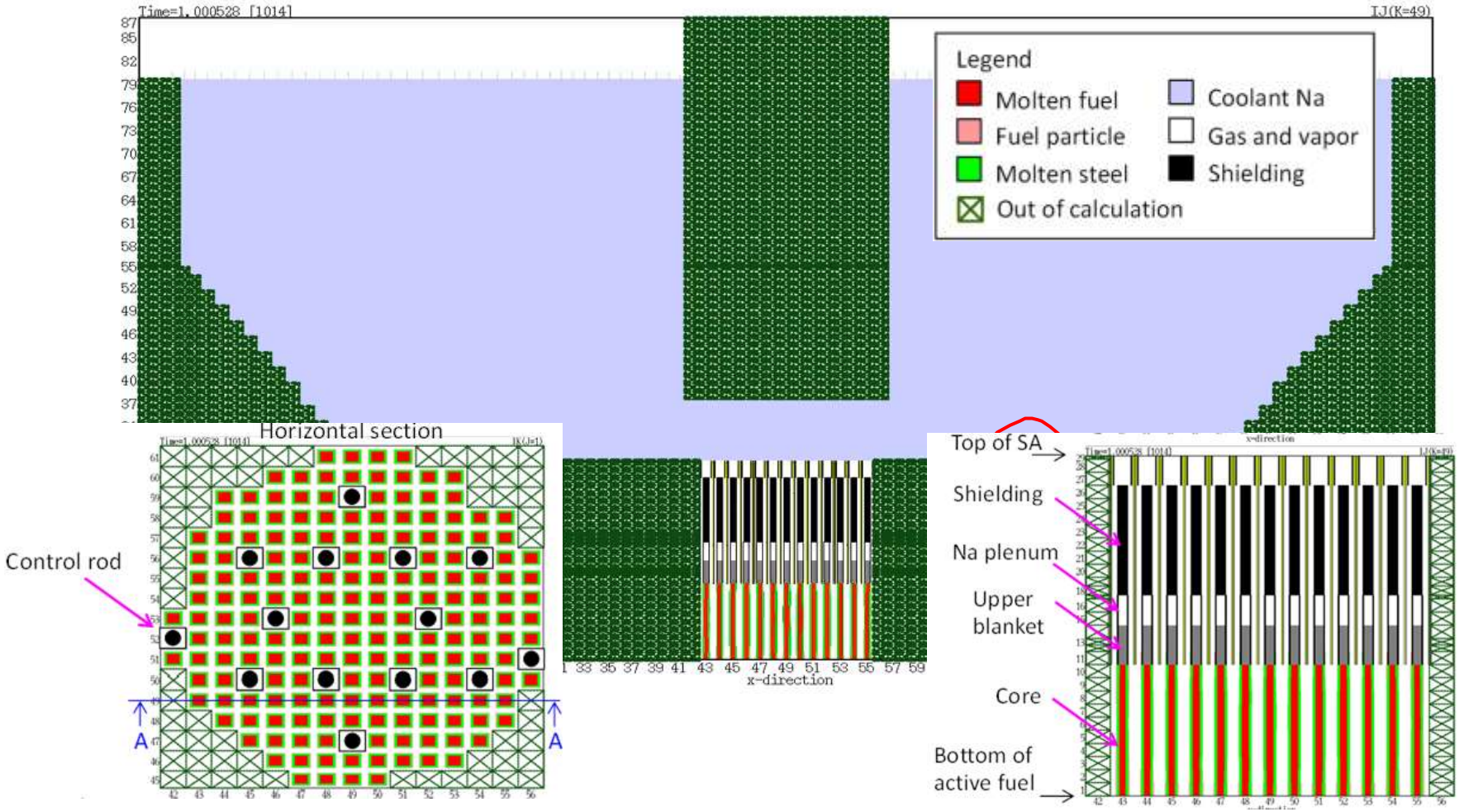
Reference design for the safety analysis:

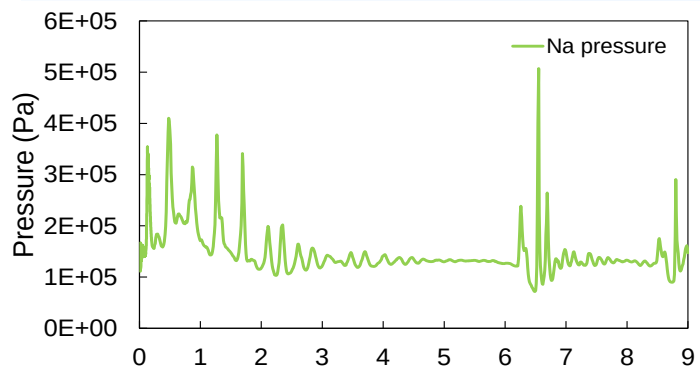
500 MWe pool type PFBR

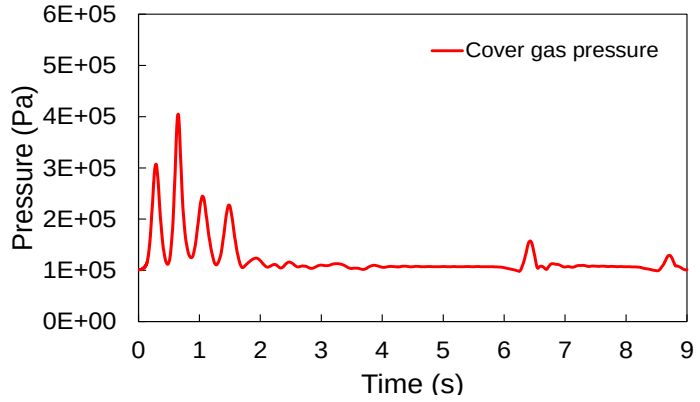
Very complicated multi-physics phenomenon
Can be a Standard Benchmark for Verification of Safety Analysis Codes and Models

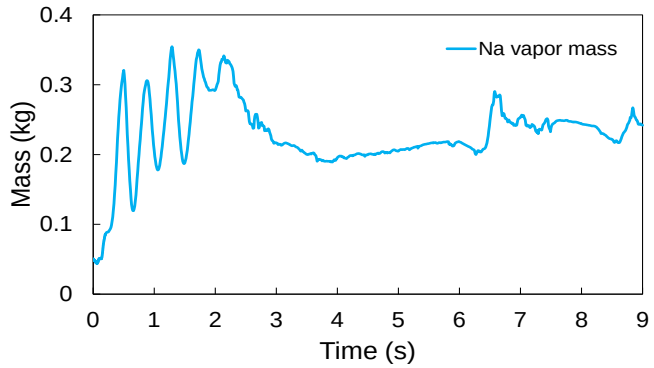
CRP on Radioactive Release from Prototype SFR under Severe Accident Conditions (2016- 2020): Expansion Phase

Click to play SIMMER-IV Video
(provided by JAEA)









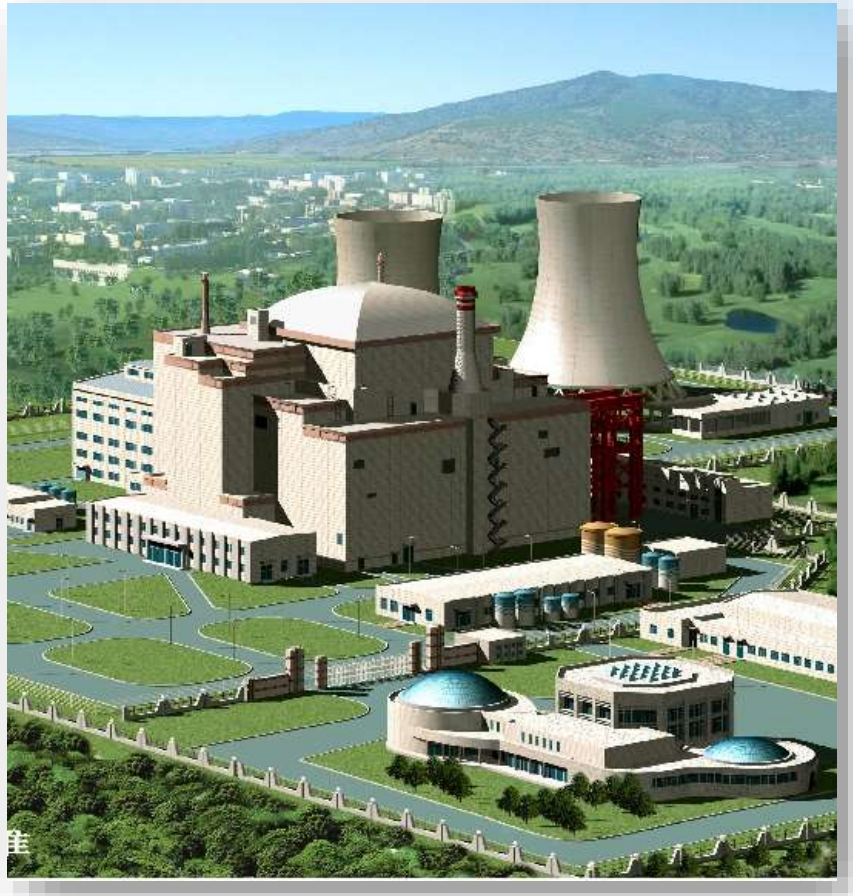
WP-1. *Sodium Bubble Expansion Phase*

New CRP: **Neutronics Benchmark of CEFR Start-Up Tests**

中国原子能科学研究院
中核集团 CHINA INSTITUTE OF ATOMIC ENERGY

IAEA

- China Experimental Fast Reactor
  - Sodium-cooled fast reactor with nominal power of 65MW(th), 20MW(e)
  - Reached the first criticality in 2010
  - Generated electricity at 40% full power and was connected firstly to the grid in July 2011
  - Generated electricity at 100% power in December 2015 and operated for more than 40 effective full power days

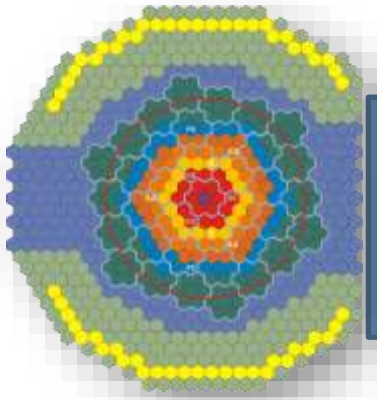


1st, Kick-Off RCM: June 2018, Vienna

CEFR Start-Up: Tests and Simulations

Experiments

1. Fuel loading and criticality	2. Measurement of control rod worth	3. Reactivity effects measurement	4. Irradiation test of foils
Net criticality	Net criticality core	**Temperature reactivity coefficient**	**Reaction rate distribution**
250℃(cold state)	**Operation loading core (250℃)**	Pressure reactivity effect	Cross-section ratio
360℃ (hot standby)	Operation loading core (300℃)	Flowrate reactivity effect	Neutron spectrum
Nuclear heating start point		**Sodium void reactivity effect**	Absolute nuclear power
		Core SA exchange reactivity effect	



Planned duration: 2018 – 2022

Set up simplified model of CEFR core	Perform blind neutronics calculations independently	Comparison with experimental data, models update	**Refined Simulations; Publications of the results**

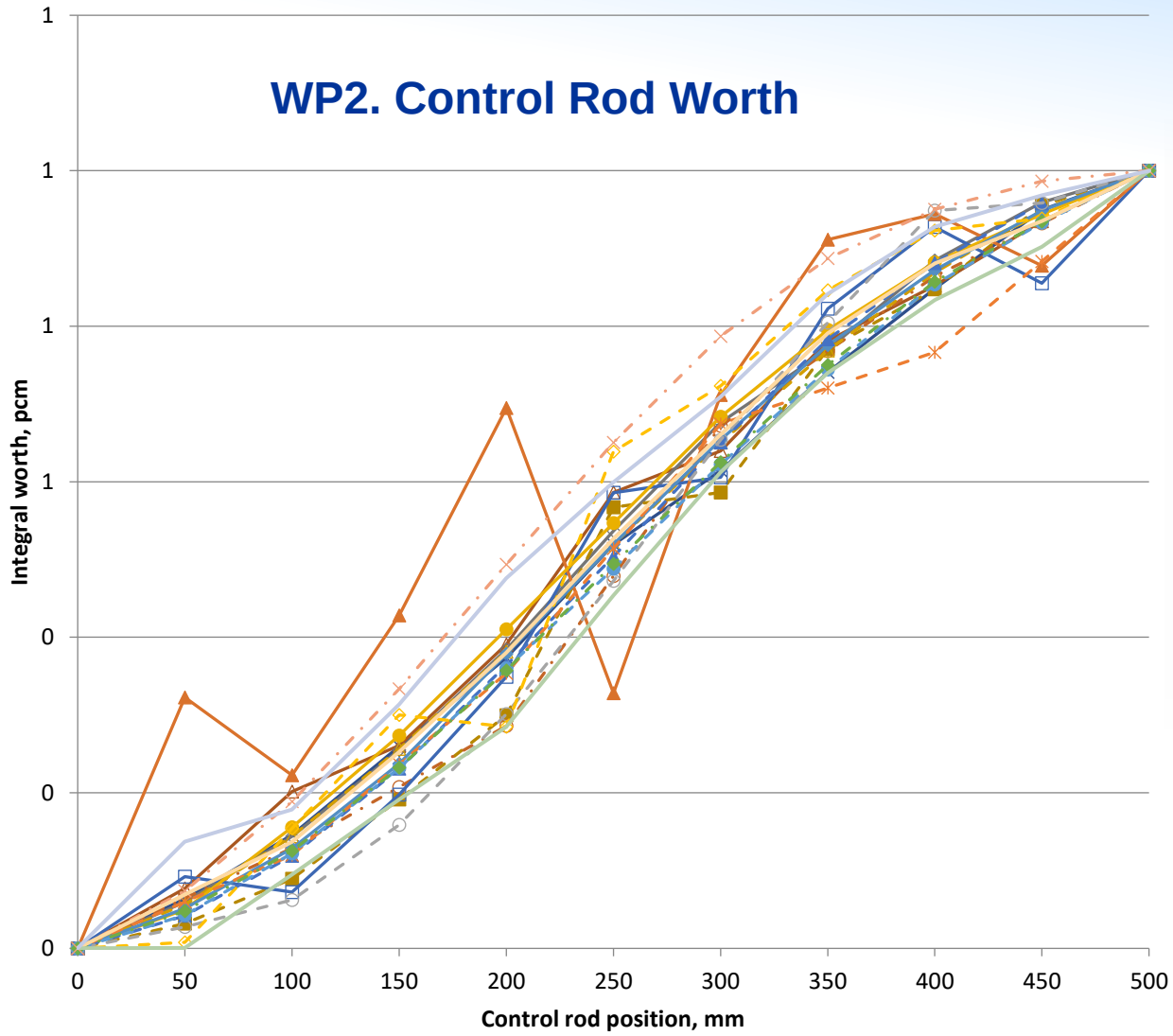
Kick-off RCM: 11-14 June 2018 (27 Participants from 17 MSs)

2nd RCM: 28 October – 1 November, Beijing

CRP: **Neutronics Benchmark of CEFR Start-Up Tests**

2nd RCM: *Comparing 'Blind' Simulations vs. Experiment*

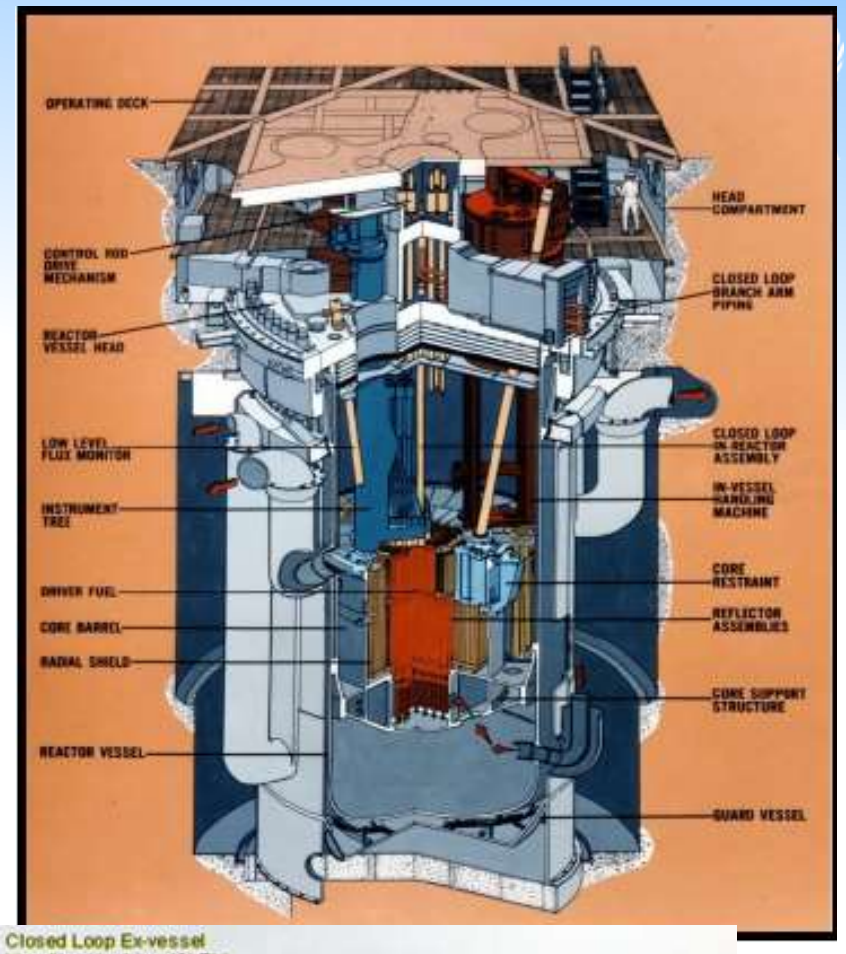
WP1	Net criticality
WP2	Control Rod Worth
WP3	Temperature reactivity coefficient
WP4	Sodium void reactivity effect
WP5	Core S/A exchange reactivity effect
WP6	Irradiation test of foils



2nd **RCM:** November 2019 (27 Participants from 17 MSs)

CRP: **Benchmark Analysis of FFTF Loss of Flow Without Scram Test**

- FFTF Reactor:
  - 400 MW(th) sodium cooled fast test reactor
  - Mixed UO2-PuO2 (MOX) fuel
  - Loop type plant, axial and radial reflectors
  - Prototypic size
    - ~1m^3 core volume
    - ~91 cm high, ~120 cm diameter
  - Series of Passive Safety Tests
    - Demonstrated passive safety of SFRs
    - Demonstrated efficacy of negative reactivity insertion safety devises (GEMs)



CRP: **Benchmark Analysis of FFTF Loss of Flow Without Scram Test**

2nd Virtual Meeting: *Update & End of Blind phase*

- Completed the blind phase, no more updates to the blind phase results now
- Refined phase calculations started
- 2nd RCM planned for Feb 2021 – Online or postponed to Nov 2021
- Refined phase results to be completed by June 2021
- FR21 special session with 5 papers o benchmark (May 2021)
- First draft TECDOC in 2022

Fig: Peak Cladding Temperature

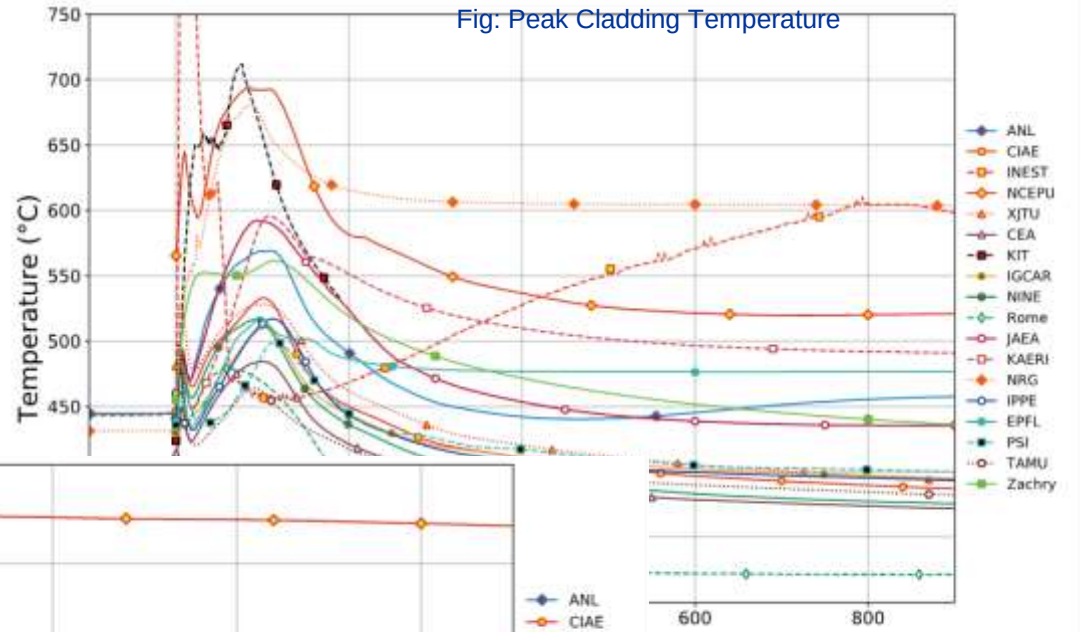
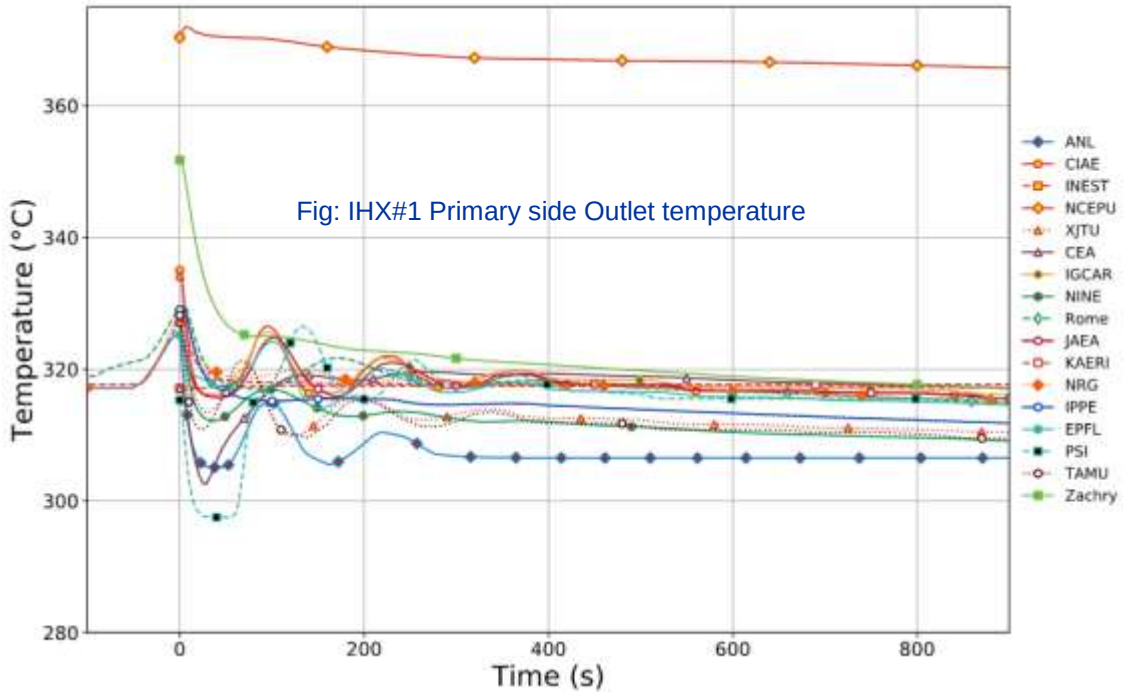


Fig: IHX#1 Primary side Outlet temperature



Fast Reactors Safety: Joint GIF-IAEA Workshops on Safety of LMFRs

A decade of cooperation

1st : June 2010
2nd : Dec 2011
3rd : Feb. 2013
4th : June 2014
5th : June 2015

6th GIF-IAEA Workshop on Safety of SFR

November 2016

7th Joint GIF-IAEA Workshop on LMFR Safety

March 2018

- Final Review of GIF Report on Safety Design Guidelines on Safety Approach & Design Conditions for GEN-IV SFRs

8th GIF-IAEA Workshop on LMFR Safety

20-22 March 2019

- Discussion of GIF Report on “Safety Design Guidelines on Structures, Systems and Components for Gen-IV SFRs”

9th GIF-IAEA Workshop on LMFR Safety

18-20 March 2020 >> postponed>> March 2021

- Review of GIF Report on “Safety Design Guidelines on Structures, Systems and Components for Gen-IV SFRs”

Online Catalogue on LMFNS Experimental Facilities

Experimental Facilities in support of Development and Deployment of Liquid Metal cooled Fast Neutron Systems

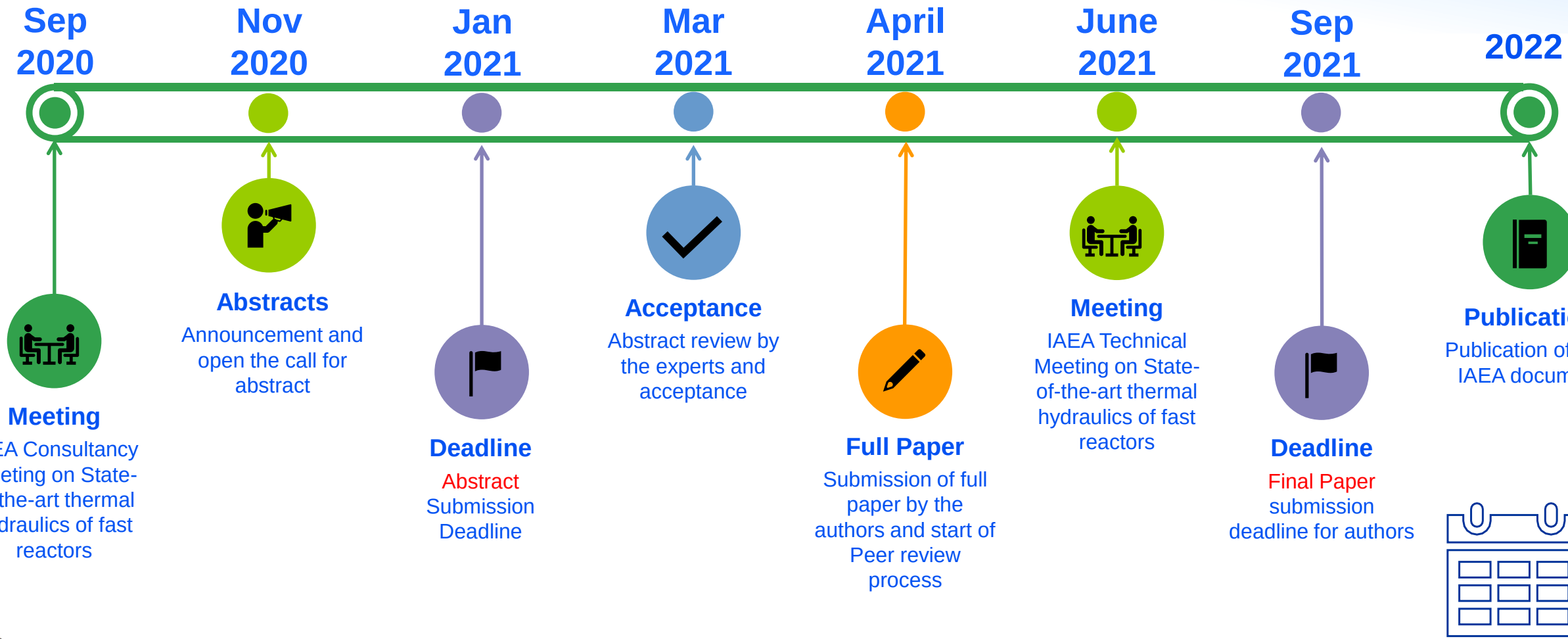
Includes an overview as well as detailed information on
190 experimental facilities under design, construction or operation
19 institutions from 14 IAEA Member States contributed

Freely Available at iaea.org:
Search for "IAEA LMFNS"

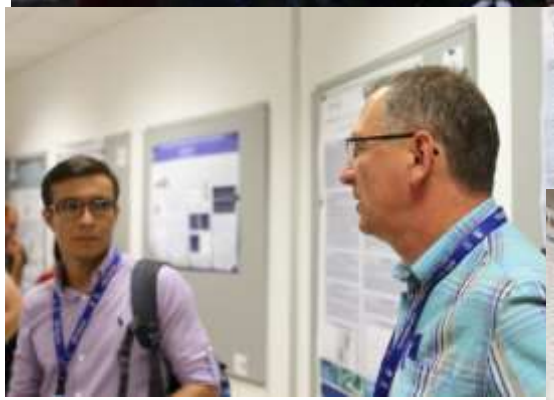
Updated in August 2019:

- Added **38** New Facilities
- Updated Profiles for **41** Facilities

New Technical Meeting on
State-of-the-art Thermal Hydraulics of Fast Reactors



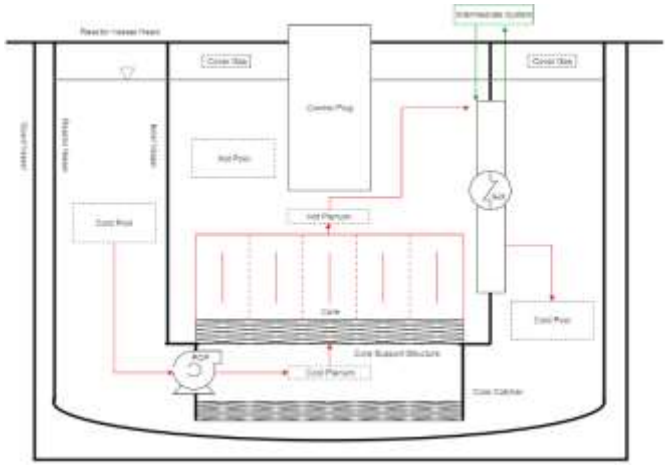
Joint ICTP-IAEA Workshops on Innovative Nuclear Energy Systems

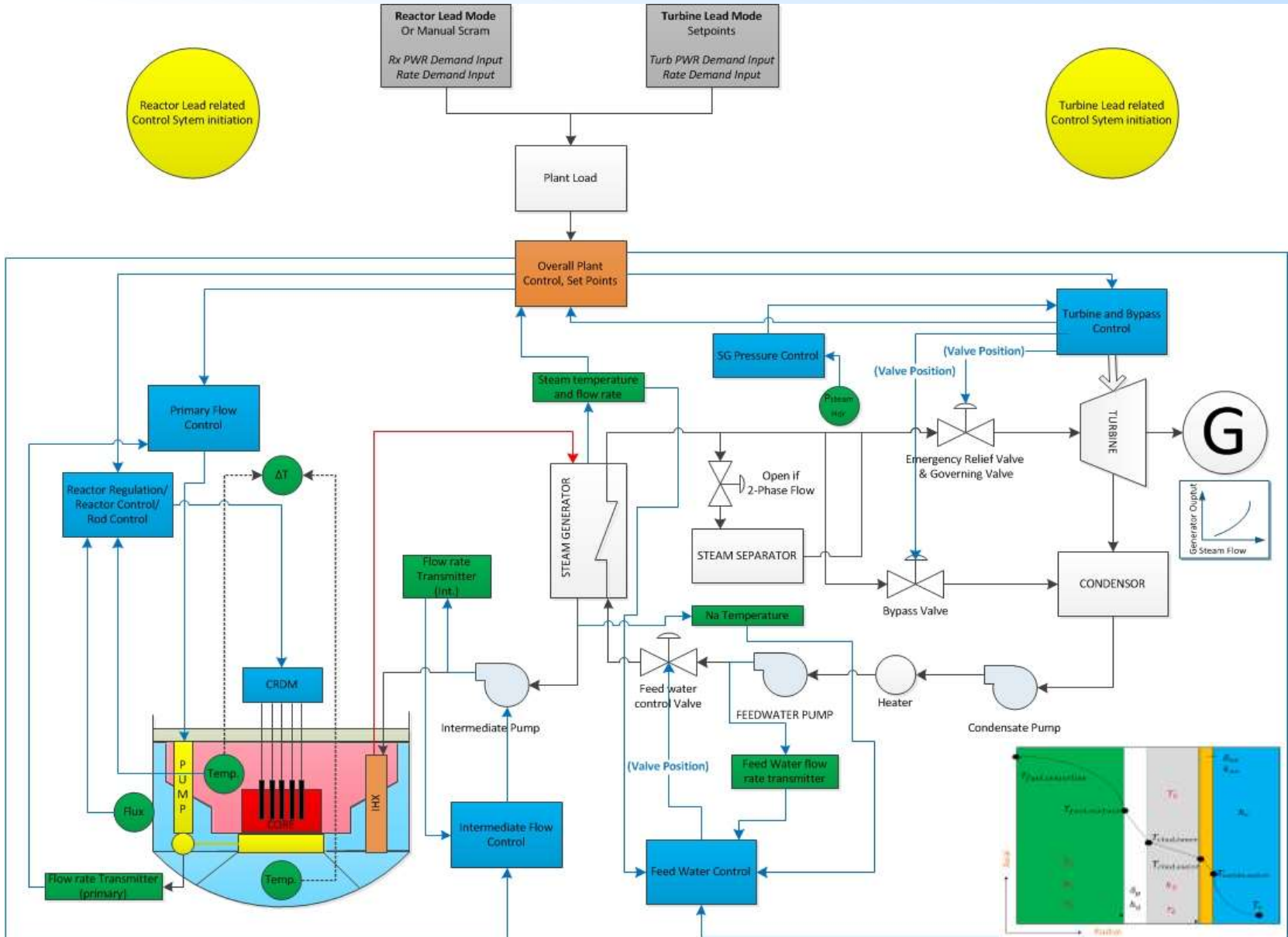


- In **2016** and in August **2018** Trieste, Italy
- Contributed by NPTDS, INPRO, GIF, and other external experts
- Next Workshop: July 2020 >> 2021/22??

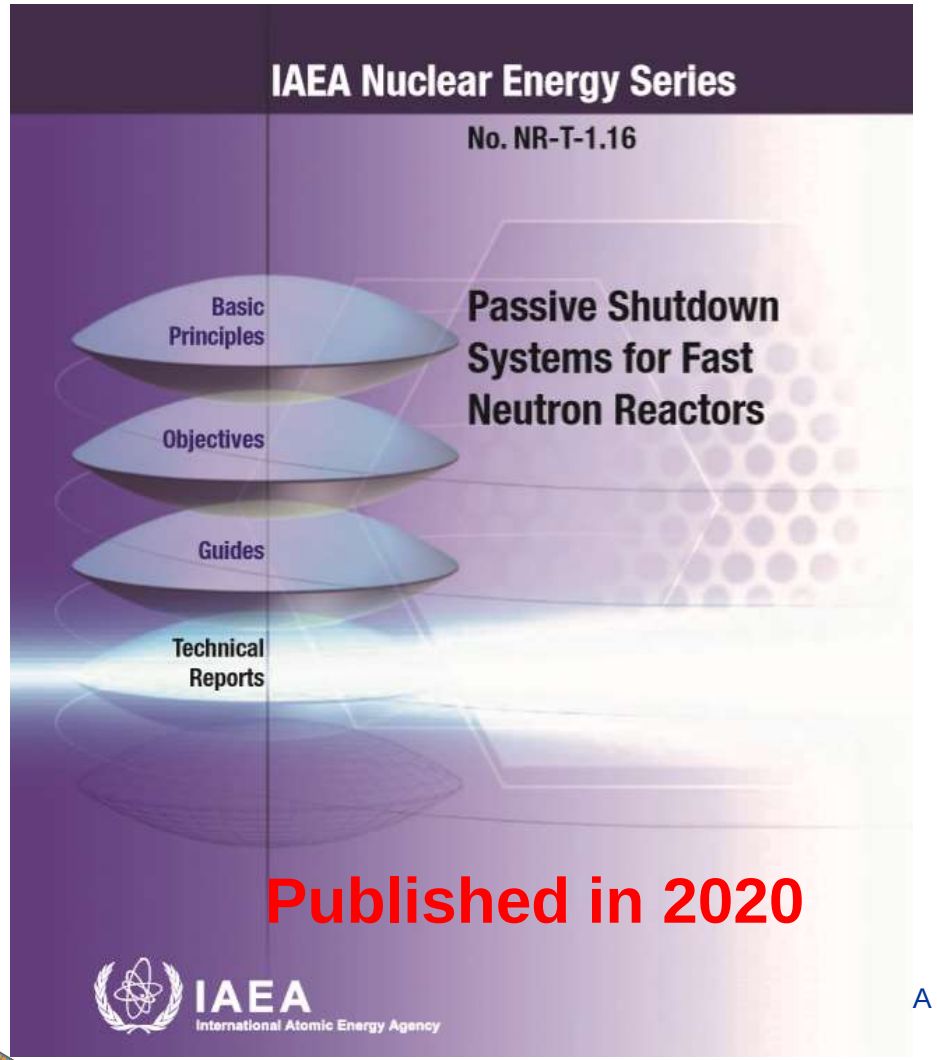
SFR Simulator for Educational Purposes

- Pool type sodium cooled fast reactor simulator for education and training
- 2021: delivered to the IAEA
  in testing now
- end of 2021: distribution to the Member States





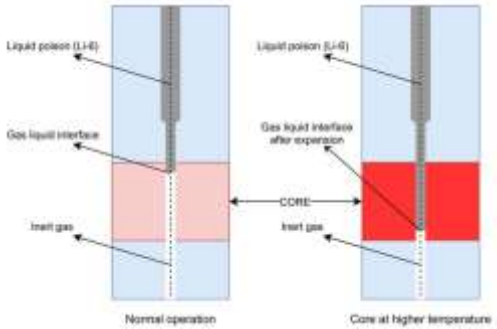
NES: Passive Shutdown Systems for Fast Neutron Reactors



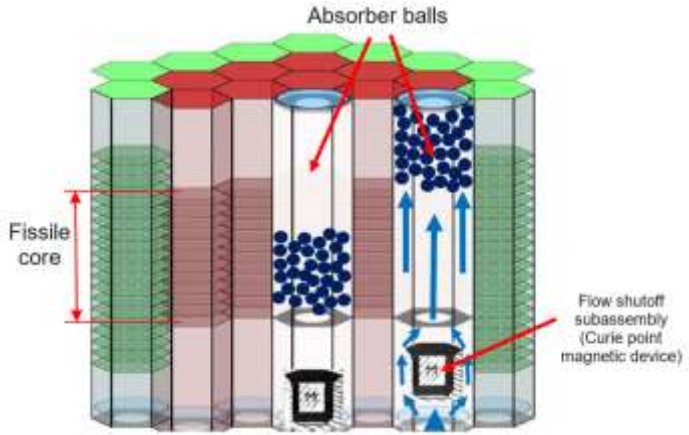
Published in 2020

Click to access: https://www.iaea.org/publications/13386/passive-shutdown-systems-for-fast-neutron-reactors

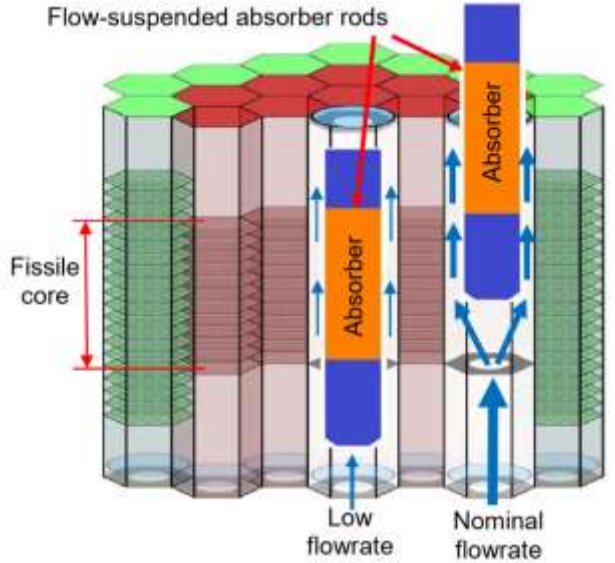
- Lithium expansion modules
- Lithium injection modules
- Curie point latches
- Thermostatic switches
- Lyophobic capillary porous systems
- Flow levitated absorbers
- Cartesian divers
- Levitated absorber particles
- Enhanced thermal elongation of control rod drivelines
- Gas expansion modules
- Autonomous reactivity controls
- Travelling wave reactor thermostats
- Thermo siphon based passive shutdown systems
- Static absorber feedback equipment



Lithium expansion module concept



A levitated absorber system for self-actuated shutdown system

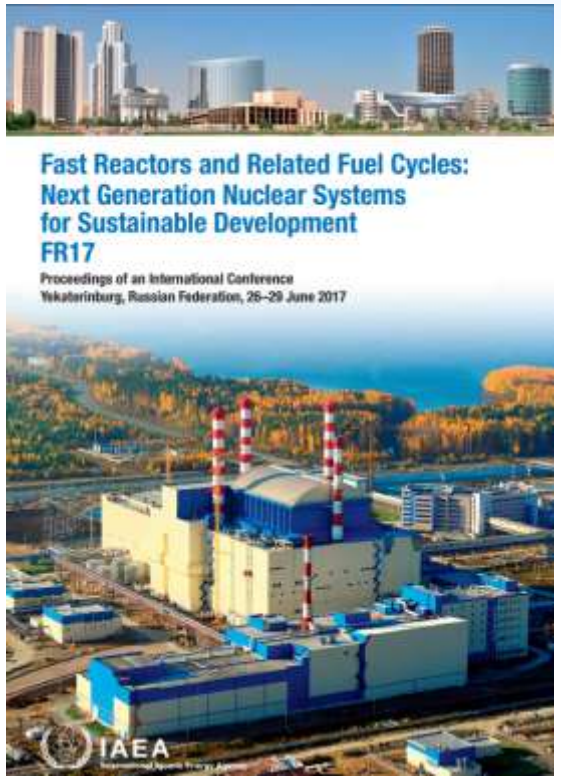


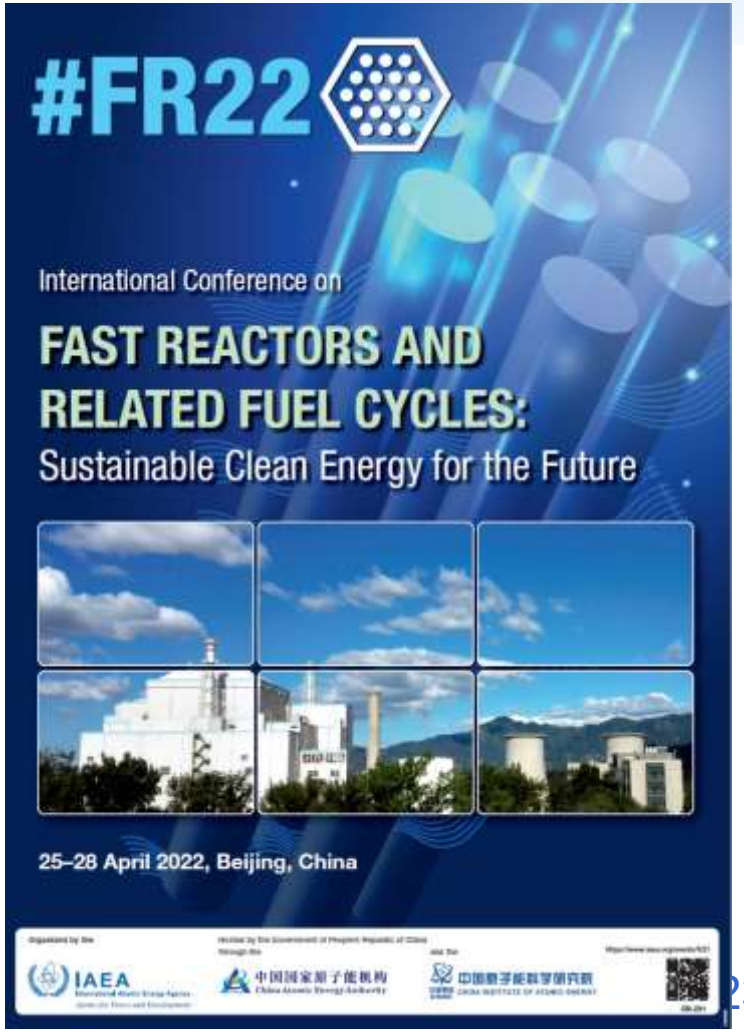
Passive shutdown system with flow levitated rods for BN-800

FR09 >> FR13 >> FR17 >> FR21 Conferences

IAEA International Conferences on
Fast Reactors and Related Fuel Cycles

FR21>>FR22
Beijing
April 2022





FR22: 530 Abstracts accepted

Working at the IAEA

In Fast Reactors Team:

- One Year Internship
- Six Months Temporary Assignment (P2 Professional)

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Thank You!

contact *Vladimir Kriventsev:* FR@IAEA.ORG