Review of Euratom projects on design, safety assessment, R&D and licensing for ESNII/Gen-IV fast neutron systems

K. Mikityuk (PSI), L. Ammirabile (JRC), M. Forni (ENEA),
J. Jagielski (NCBJ), N. Girault (IRSN), A. Horvath (MTA EK),
J.-L. Kloosterman (TU DELFT), M. Tarantino (ENEA), A. Vasile (CEA),

Introduction

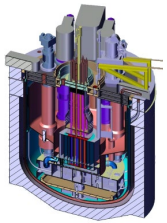
European Sustainable Nuclear Industrial Initiative (**ESNII**) considers:

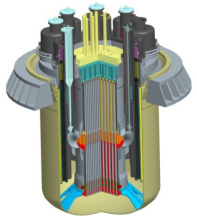
- Reference solution: Sodium Fast Reactor **ASTRID**;
- 1st alternative: Lead-cooled Fast Reactor **ALFRED** supported by LBE facility **MYRRHA**;
- 2nd alternative: Gas-cooled Fast Reactor **ALLEGRO**.

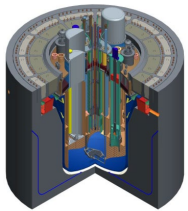
In addition:

- Gen-IV Molten Salt Fast Reactor **MSFR** (mentioned in SRA Annex as an attractive long-term option);.
- Gen-IV European Sodium Fast Reactor **ESFR** and Swedish Advanced Lead Reactor **SEALER**.

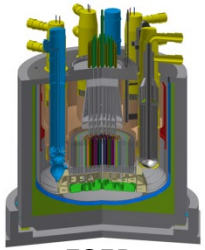
Since late 2011 EU framework programs supported **nine projects** on these systems.


ASTRID

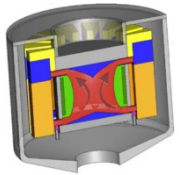

ALFRED


MYRRHA


ALLEGRO

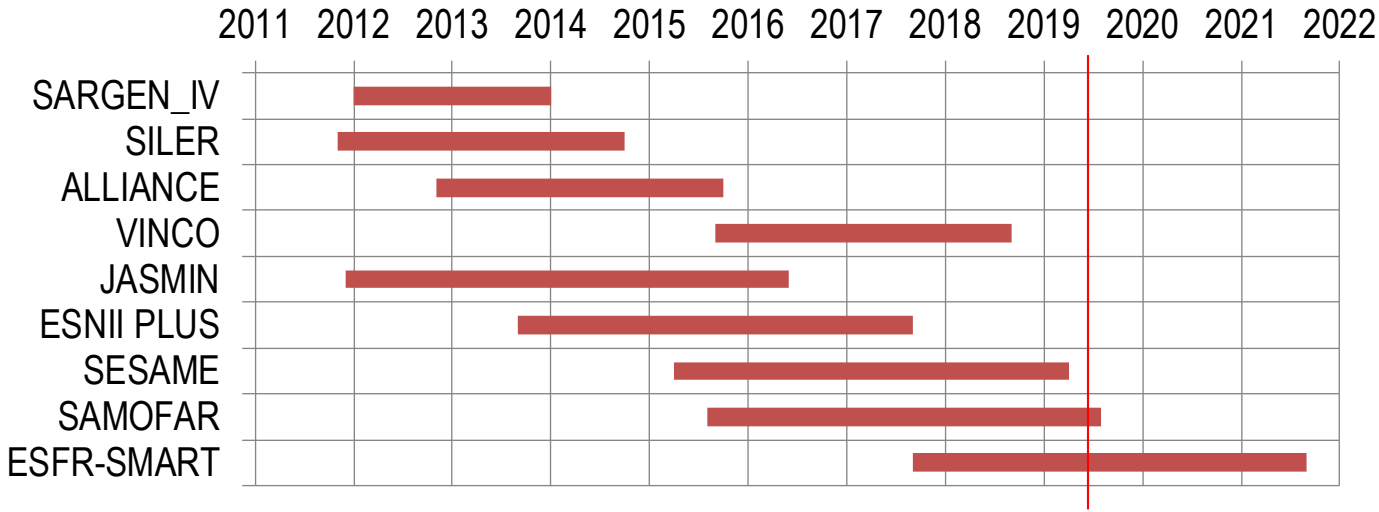

ESFR


SEALER


MSFR

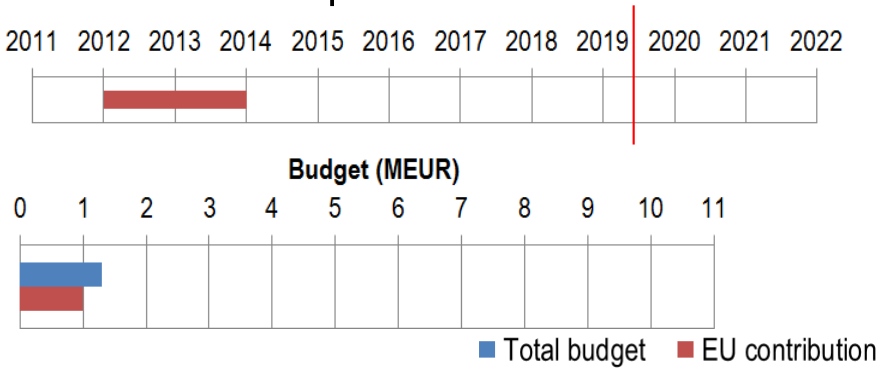
Outlook

- Introduction
- 9 EU projects: fact sheet; main goals; selected results
- Summary



1. SARGEN_IV: fact sheet

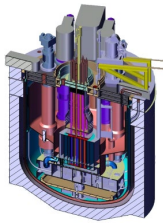
Name: Proposal for a harmonized European methodology for the safety assessment of innovative reactors with fast neutron spectrum planned to be built in Europe

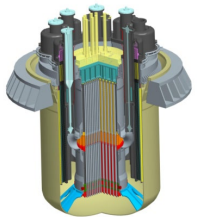


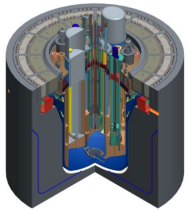
Domains:

- Design
- R&D
- Safety
- Licensing

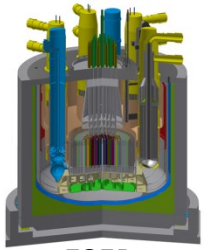
Partners: 22
Countries: 13
Coordinator: IRSN


ASTRID

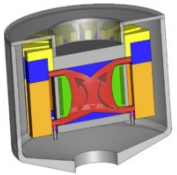

ALFRED


MYRRHA


ALLEGRO


ESFR


SEALER


MSFR

1. SARGEN_IV: main goals

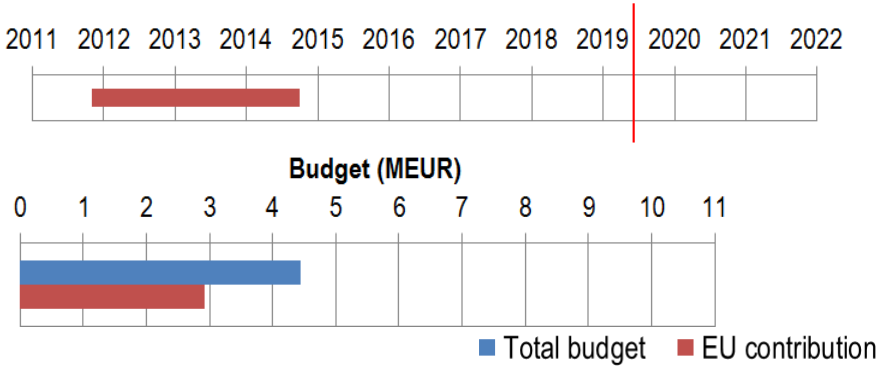
- Identify critical safety features of selected Generation-IV concepts, relying on the outcomes from existing FP7 projects.
- Develop and provide safety assessment methodology relying on legacy from international organizations, national practices, etc.
- Identify open issues in safety area to provide a roadmap and preliminary deployment plan for fast reactor safety-related R&D.

1. SARGEN_IV: selected results

- Safety issues identified for ESNII systems.
- List of initiating events identified and categorised according to their occurrence frequency.
- Commonly agreed methodology for safety assessment of ESNII systems developed.

2. SILER: fact sheet

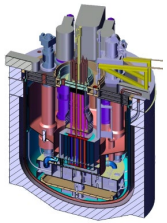
Name: Seismic-Initiated Events Risk Mitigation in Lead-cooled Reactors

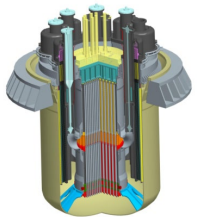


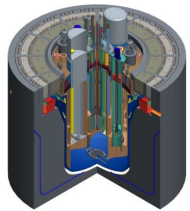
Domains:
- Design
- R&D
- Safety
- Licensing

R&D areas:
- TH & CFD
- Neutronics
- Fuel
- Seismic
- Multiphysics

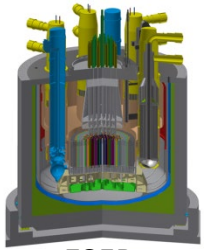
Partners: 18
Countries: 9
Coordinator: ENEA


ASTRID

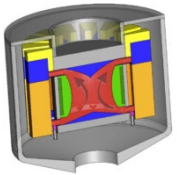

ALFRED


MYRRHA


ALLEGRO


ESFR


SEALER


MSFR

2. SILER: main goal

– Develop and experimentally qualify seismic isolators for lead-cooled reactors (but applicable to any other nuclear plant).

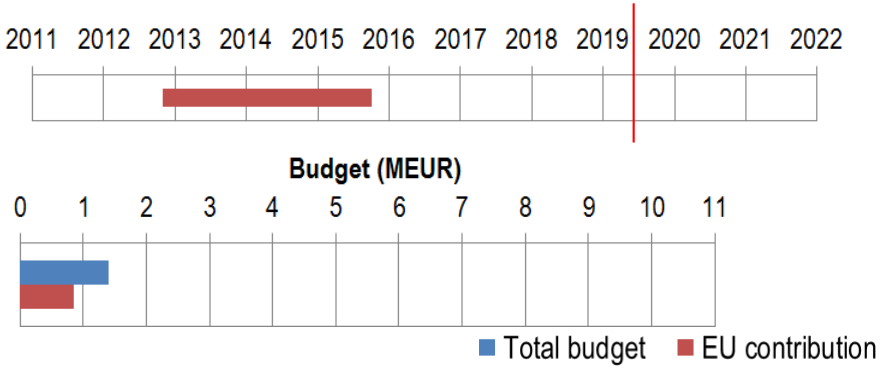
2. SILER: selected results

- Two isolators for ELSY and MYRRHA (High Damping Rubber Bearings and Lead Rubber Bearings, respectively) designed, manufactured and tested in different sizes up to the full scale.
- Prototype subjected to 3D dynamic tests under the real service loads up to failure.
- Cost-benefit analysis of seismic isolation adoption conducted.

Full scale pipeline expansion joint during seismic tests at the ELSA laboratory of the JRC of Ispra

3. ALLIANCE: fact sheet

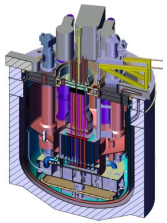
Name: Preparation of ALLEGRO – Implementing Advanced Nuclear Fuel Cycle in Central Europe

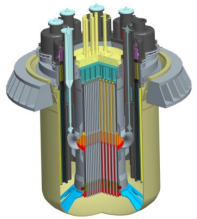


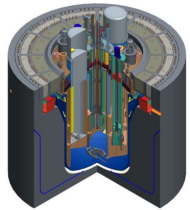
Domains:
- Design
- R&D
- Safety
- Licensing

R&D areas:
- TH & CFD
- Neutronics
- Fuel
- Seismic
- Multiphysics

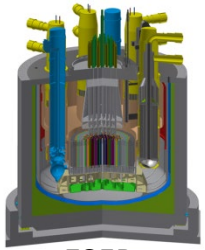
Partners: 9
Countries: 6
Coordinator: MTA EK


ASTRID

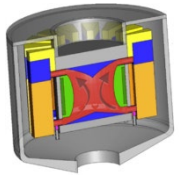

ALFRED


MYRRHA


ALLEGRO


ESFR


SEALER


MSFR

3. ALLIANCE: main goal

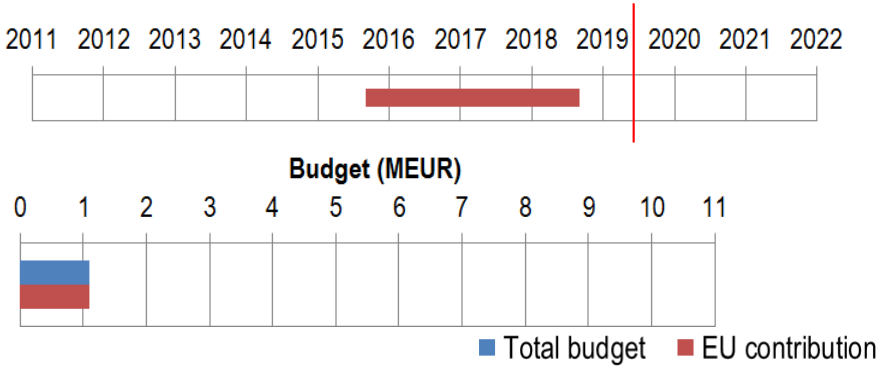
– Continue elaboration of basic documents needed for high level decisions and licensing of ALLEGRO Gas-cooled Fast Reactor demonstrator.

3. ALLIANCE: selected results

- New strategy for developing ALLEGRO reactor prepared and accepted by partners.
- New systematic Roadmap prepared to cover all design, safety and experimental aspects.
- Different governance models for ALLEGRO implementation discussed.

4. VINCO: fact sheet

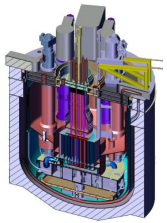
Name: Visegrad Initiative for Nuclear COoperation

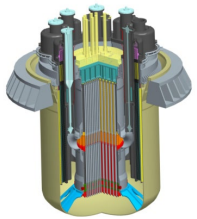


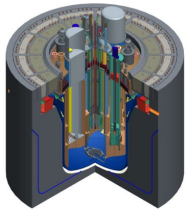
Domains:
- Design
- R&D
- Safety
- Licensing

R&D areas:
- TH & CFD
- Neutronics
- Fuel
- Seismic
- Multiphysics

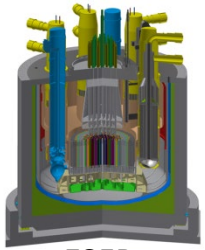
Partners: 6
Countries: 5
Coordinator: NCBJ


ASTRID

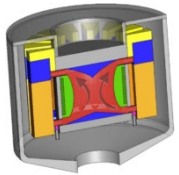

ALFRED


MYRRHA


ALLEGRO


ESFR


SEALER

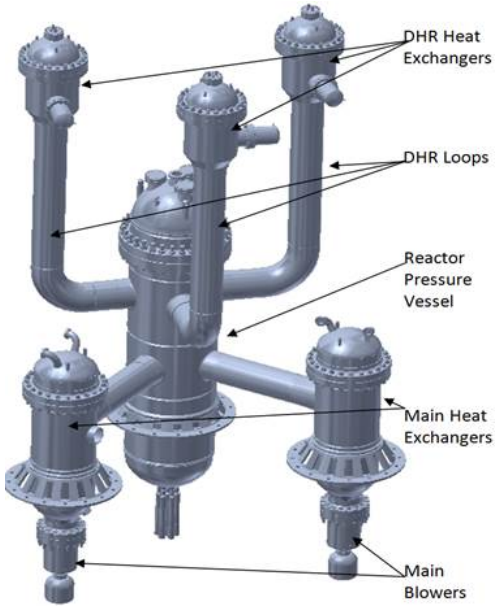

MSFR

4. VINCO: main goals

- Develop principles of cooperation and rules of access to existing and planned infrastructure.
- Identify specific objectives of R&D activities in cooperating countries.
- Describe and analyze existing research, training and educational equipment and capabilities.
- Determine investment priorities in cooperating countries.
- Set up joint research, educational and training projects.

4. VINCO: selected results

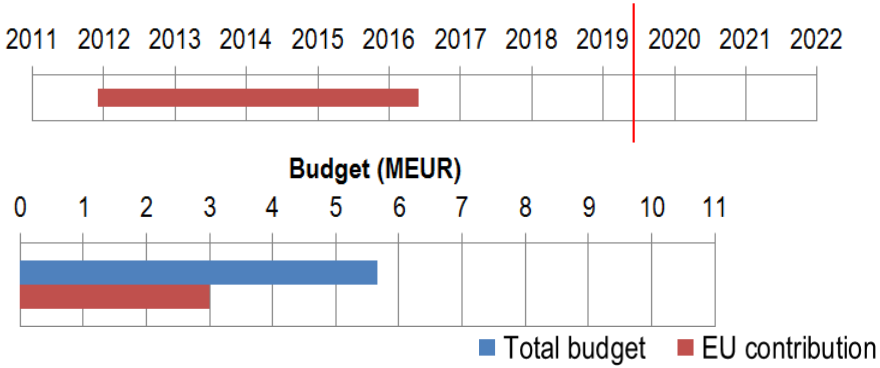
- Possible international cooperation schemes in V4 countries identified
- Neutronic and thermal-hydraulic benchmarks conducted.
- School, workshops and exchange visits organized.



Schematic drawing of the ALLEGRO Reactor (courtesy of Petr Darilek, VUJE)

5. JASMIN: fact sheet

Name: Joint Advanced Severe accidents Modelling and Integration for Na-cooled fast neutron reactors



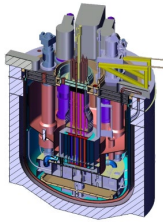
Domains:

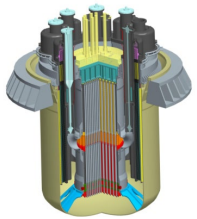
- Design
- R&D
- Safety
- Licensing

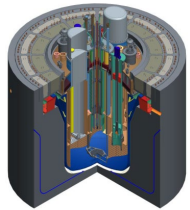
R&D areas:

- TH & CFD
- Neutronics
- Fuel
- Source term
- Multiphysics

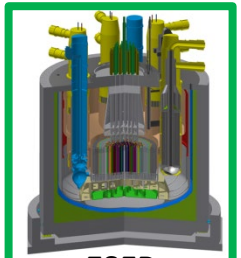
Partners: 9
Countries: 5
Coordinator: IRSN


ASTRID

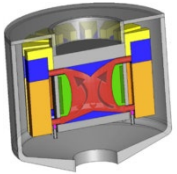

ALFRED


MYRRHA


ALLEGRO


ESFR


SEALER


MSFR

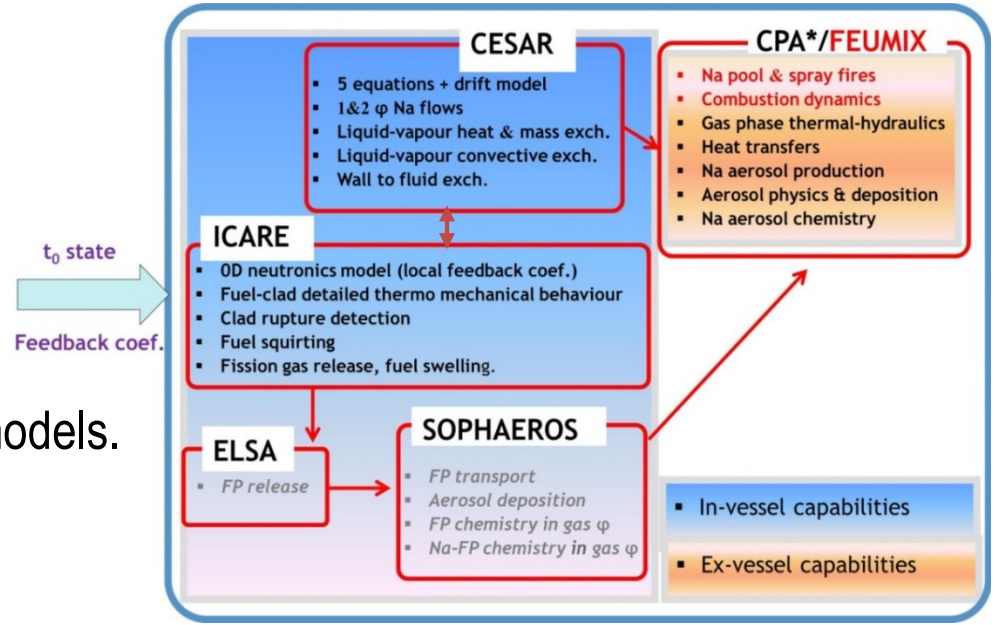
5. JASMIN: main goal

– Enhance current capability of analysis of severe accidents in SFRs by developing a new European simulation code, ASTEC-Na from existing ASTEC platform developed by IRSN and GRS for LWRs

5. JASMIN: selected results

– New models for ASTEC-Na code developed, verified and validated

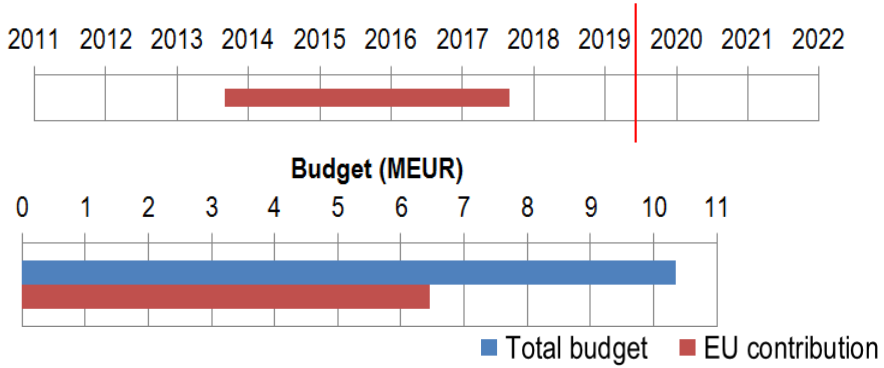
- Thermal-hydraulic models.
- Fuel thermomechanical models.
- Fission gas behaviour models.
- Point kinetics models.
- Sodium pool fires and aerosolisation models.
- ...



ASTEC-Na calculation scheme and modelling capabilities

6. ESNII Plus: fact sheet

Name: Preparing ESNII for HORIZON 2020



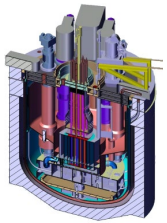
Domains:

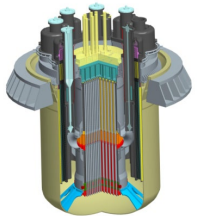
- Design
- R&D
- Safety
- Licensing

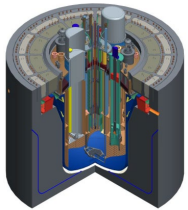
R&D areas:

- TH & CFD / Instrumentation
- Neutronics
- Fuel
- Seismic
- Multiphysics

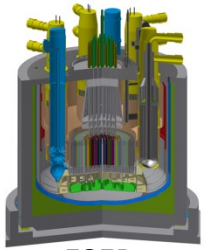
Partners: 36
Countries: 16
Coordinator: CEA


ASTRID

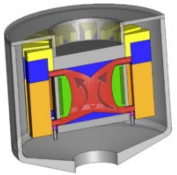

ALFRED


MYRRHA


ALLEGRO


ESFR


SEALER


MSFR

6. ESNII Plus: main goals

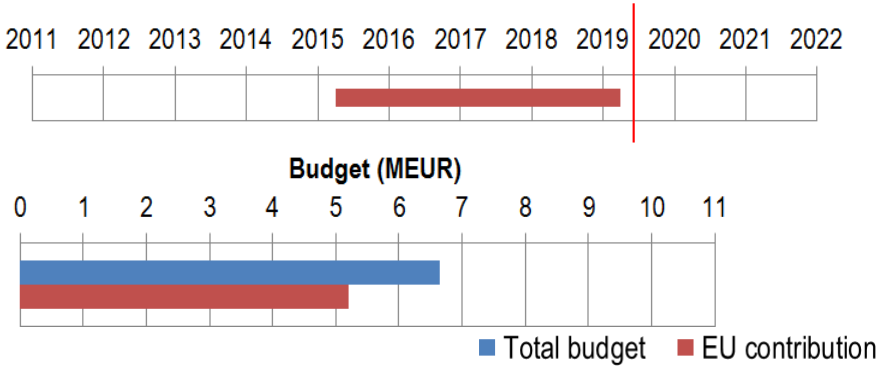
- Develop a broad strategic approach to advanced fission systems in Europe in support of European Sustainable Industrial Initiative (ESNII) within the SET-Plan
- Do R&D in support to the ESNII demonstrators

6. ESNII Plus: selected results

- Coordination between ESNII, EC and national programs analysed and topics for joint programming identified.
- Challenges for future financial and legal models for ESNII identified.
- Irradiation infrastructure in Europe reviewed.
- Siting and licensing requirements for the new generation of fast reactors analysed.
- Existing supply chain reviewed to support deployment strategy for fast reactors.
- Potential of small modular and cogeneration fast reactors investigated.
- Benchmarks on core physics for ESNII systems conducted.
- MOX fuel properties measurements implemented.
- R&D on seismic isolators and selected instrumentation performed.

7. SESAME: fact sheet

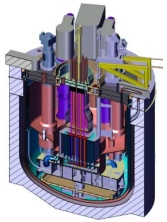
Name: Thermal Hydraulics Simulations and Experiments for the Safety Assessment of Metal Cooled Reactors

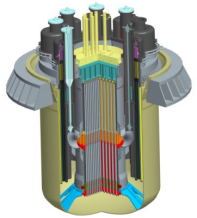


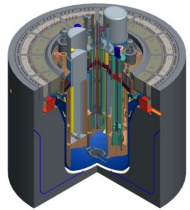
Domains:
- Design
- R&D
- Safety
- Licensing

R&D areas:
- TH & CFD
- Neutronics
- Fuel
- Seismic
- Multiphysics

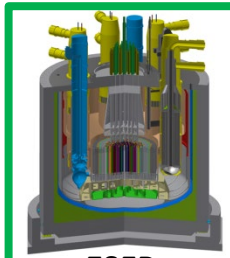
Partners: 23
Countries: 9
Coordinator: ENEA


ASTRID

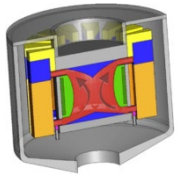

ALFRED


MYRRHA


ALLEGRO

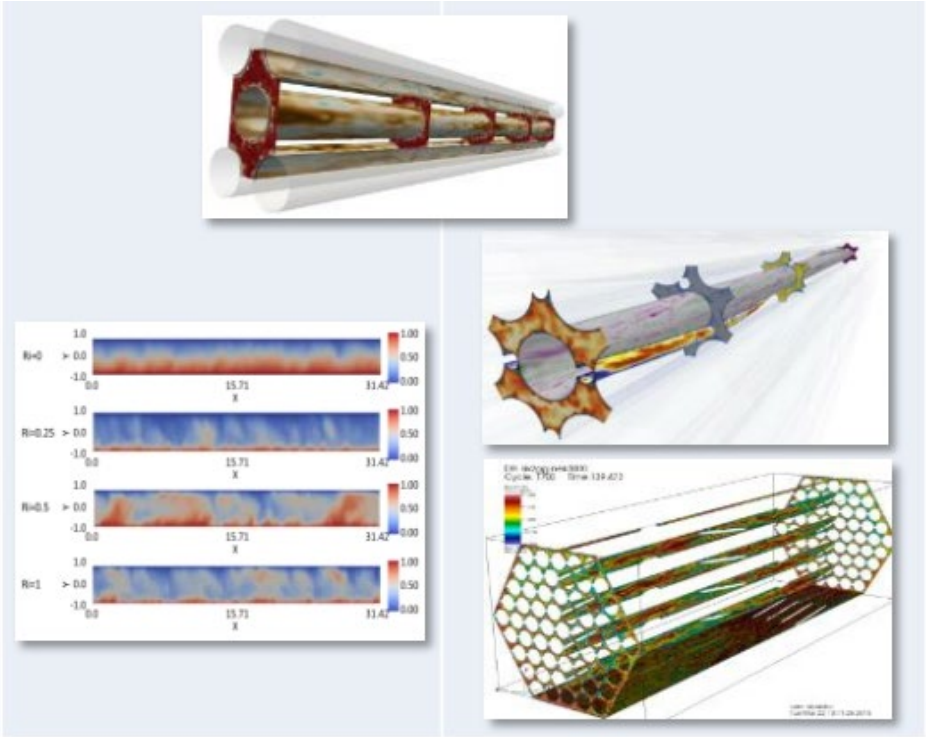

ESFR


SEALER


MSFR

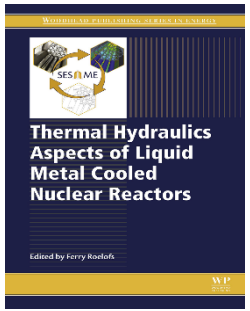
7. SESAME: main goals

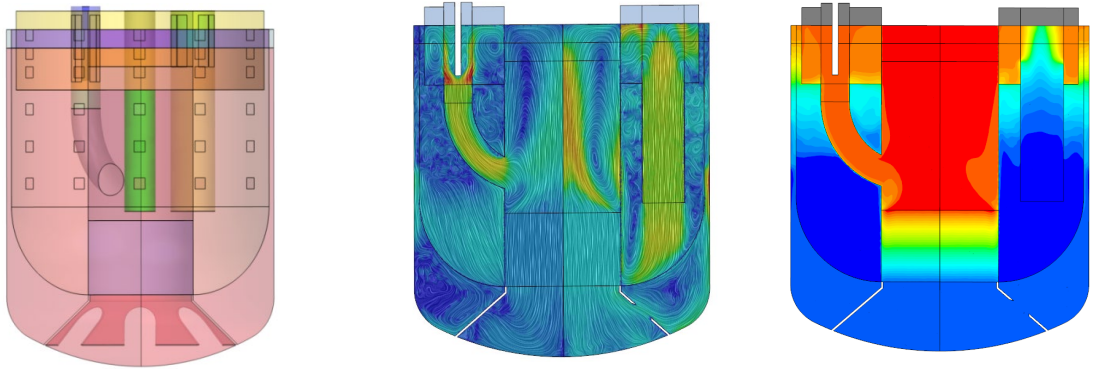
- Develop and validate advanced numerical approaches for design and safety evaluation of advanced reactors.
- Achieve new or extended validation base by creation of new reference data.
- Establish best practice guidelines, Verification & Validation methodologies, and uncertainty quantification methods for liquid metal fast reactor thermal hydraulics.



7. SESAME: selected results

- Validation base was extended for turbulent heat transfer in mixed and natural convection regimes and for geometrically complex cases.
- Combination of experimental data and high fidelity numerical simulations was set-up for wire wrapped fuel assemblies.
- Liquid metal experiments for pool thermal hydraulics performed at different scales.
- Validation data were provided in loop scale for validation of system TH codes.
- Lectures and workshop organized.
- Textbook published.

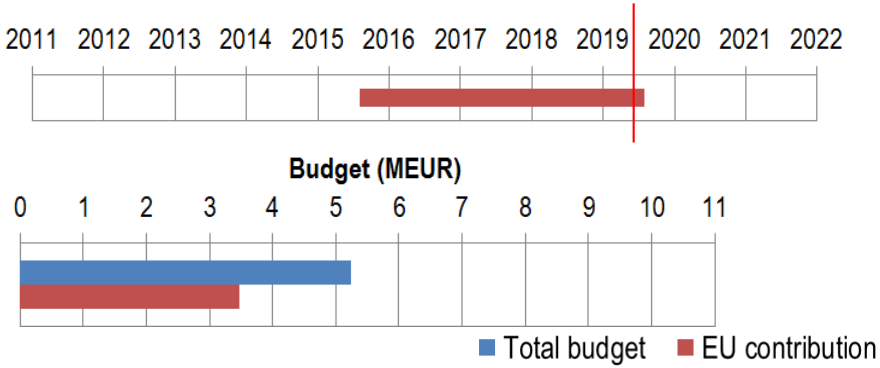




CFD Model of ALFRED Primary System. (Courtesy of CRS4, SESAME Task 3.1.2)

8. SAMOFAR: fact sheet

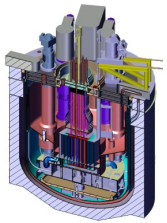
Name: A Paradigm Shift in Reactor Safety with the Molten Salt Fast Reactor

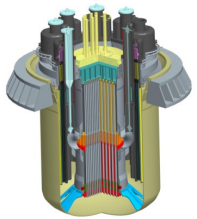


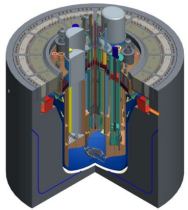
Domains:
- Design
- R&D
- Safety
- Licensing

R&D areas:
- TH & CFD
- Neutronics
- Fuel
- Seismic
- Multiphysics

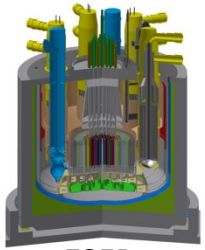
Partners: 10
Countries: 6
Coordinator: TU DELFT


ASTRID

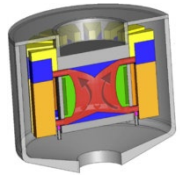

ALFRED


MYRRHA


ALLEGRO


ESFR


SEALER

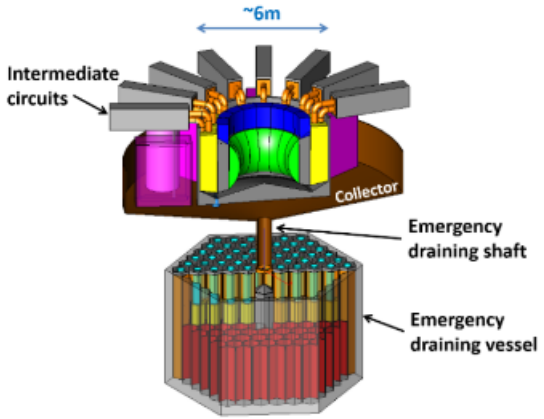

MSFR

8. SAMOFAR: main goals

- Deliver experimental proof of concept of unique safety features of MSFR.
- Provide safety assessment of MSFR for both reactor and chemical plant.
- Update conceptual design of MSFR.
- Create momentum among key stakeholders.

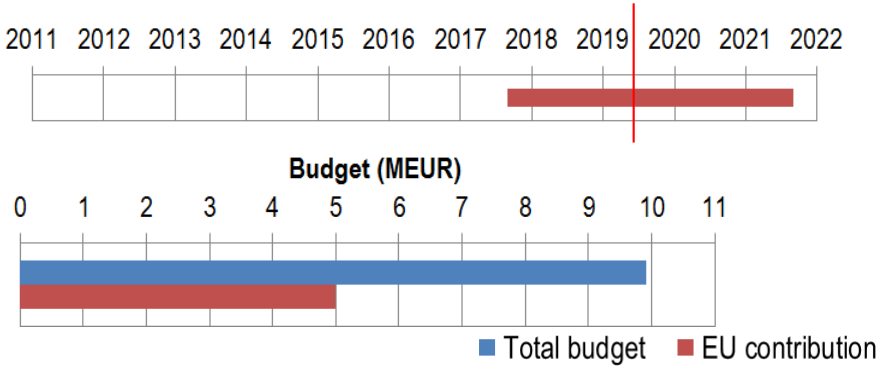
8. SAMOFAR: selected results

- MSFR design including the emergency draining system updated and assessed.
- Plant simulator developed and used to define reactor control strategies and procedures.
- Risk assessment methodology developed based on ISAM.
- Setup constructed to study actinides in molten fluorides and to synthesize actinide fluorides.
- Experiments on fuel salt vaporization revealed retention properties at high temperature.
- Test facility made to measure viscosity of salts.
- DYNASTY and SWATH facilities prepared for TH experiments.
- Transient calculations performed.
- Fuel salt processing scheme updated.
- Thermochemical calculations performed.
- Summer school organized.



9. ESFR-SMART: fact sheet

Name: European Sodium Fast Reactor Safety Measures Assessment and Research Tools

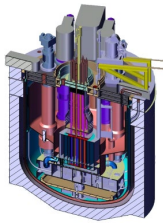


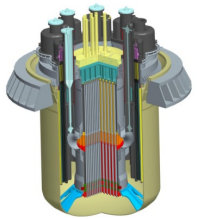
Domains:
- Design
- R&D
- Safety
- Licensing

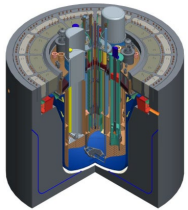
R&D areas:
- TH & CFD
- Neutronics
- Fuel
- Seismic
- Multiphysics

ESFR-SMART
sodium fast reactor safety

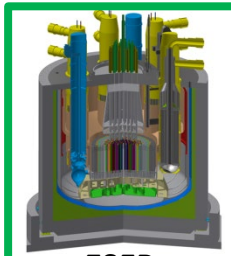
Partners: 19
Countries: 9
Coordinator: PSI


ASTRID

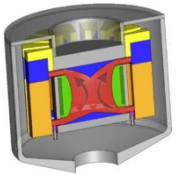

ALFRED


MYRRHA


ALLEGRO


ESFR


SEALER

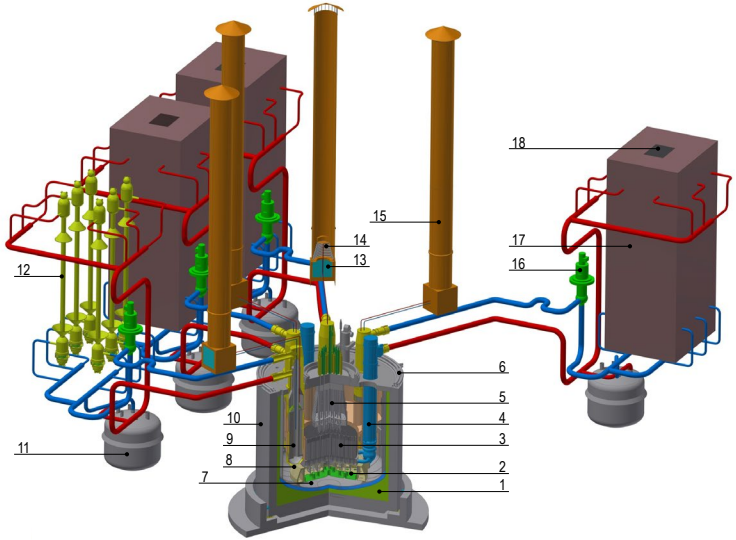

MSFR

9. ESFR-SMART: main goals

- Produce new experimental data to support calibration and validation of computational tools for each DiD level.
- Test and qualify new instrumentations to support their utilization in reactor protection system.
- Perform further calibration and validation of computational tools for each DiD level to support safety assessments of Gen-IV SFRs.
- Select, implement and assess new safety measures for commercial-size ESFR.
- Strengthen and link together new networks (sodium facilities and students).

9. ESFR-SMART: selected results

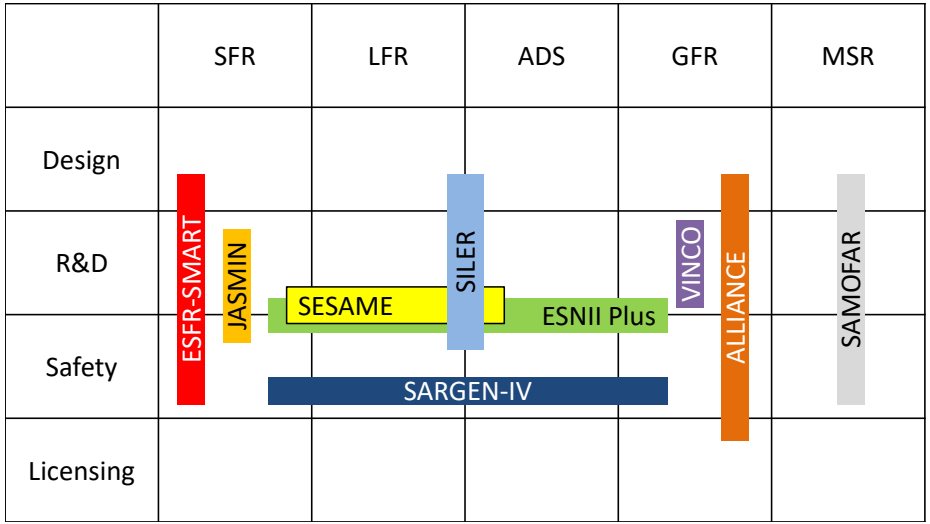
- A set of new safety measures for ESFR was proposed by the end of the 1st year.
- New low-void core performance during base irradiation was evaluated.
- Benchmarking of neutronics, TH, fuel performance and severe accident codes started.
- New experiments launched (CHUG, HAnSOLO, ECFM).



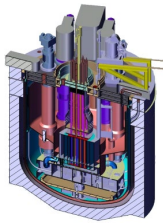
1: Insulation with steel liner
2: Core catcher
3: Core
4: Primary pump
5: Above-core structure
6: Pit cooling system (DHRS-3)
7: Main vessel
8: Strongback
9: IHX
10: Reactor pit
11: Secondary sodium tank
12: Steam generator
13: Window for air circulation (DHRS-1)
14: Sodium-air HX (DHRS-1)
15: Air chimney (DHRS-1)
16: Secondary pump
17: Casing of SGs (DHRS-2)
18: Window for air circulation (DHRS-2)

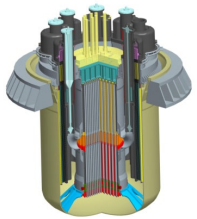
Summary

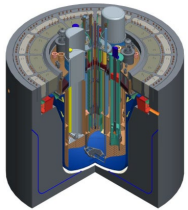
- 9 EU project since late 2011
- 7 ESNII/Gen-IV fast neutron systems
- 45 MEUR of total budget including 28 MEUR of Euratom contribution.
- 64 organizations from 20 countries
- Design, R&D, safety and licensing aspects
- R&D in
  - TH and CFD
  - Fuel
  - Seismic
  - Multiphysics



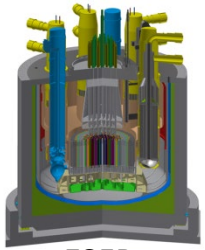
Thank you for your attention


ASTRID

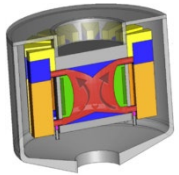

ALFRED


MYRRHA


ALLEGRO


ESFR


SEALER


MSFR