IAEA
International Atomic Energy Agency

HLMC-2018

5th Conference on Heavy Liquid Metal Coolants In Nuclear Technologies

8 – 10 October 2018, Obninsk, Russian Federation

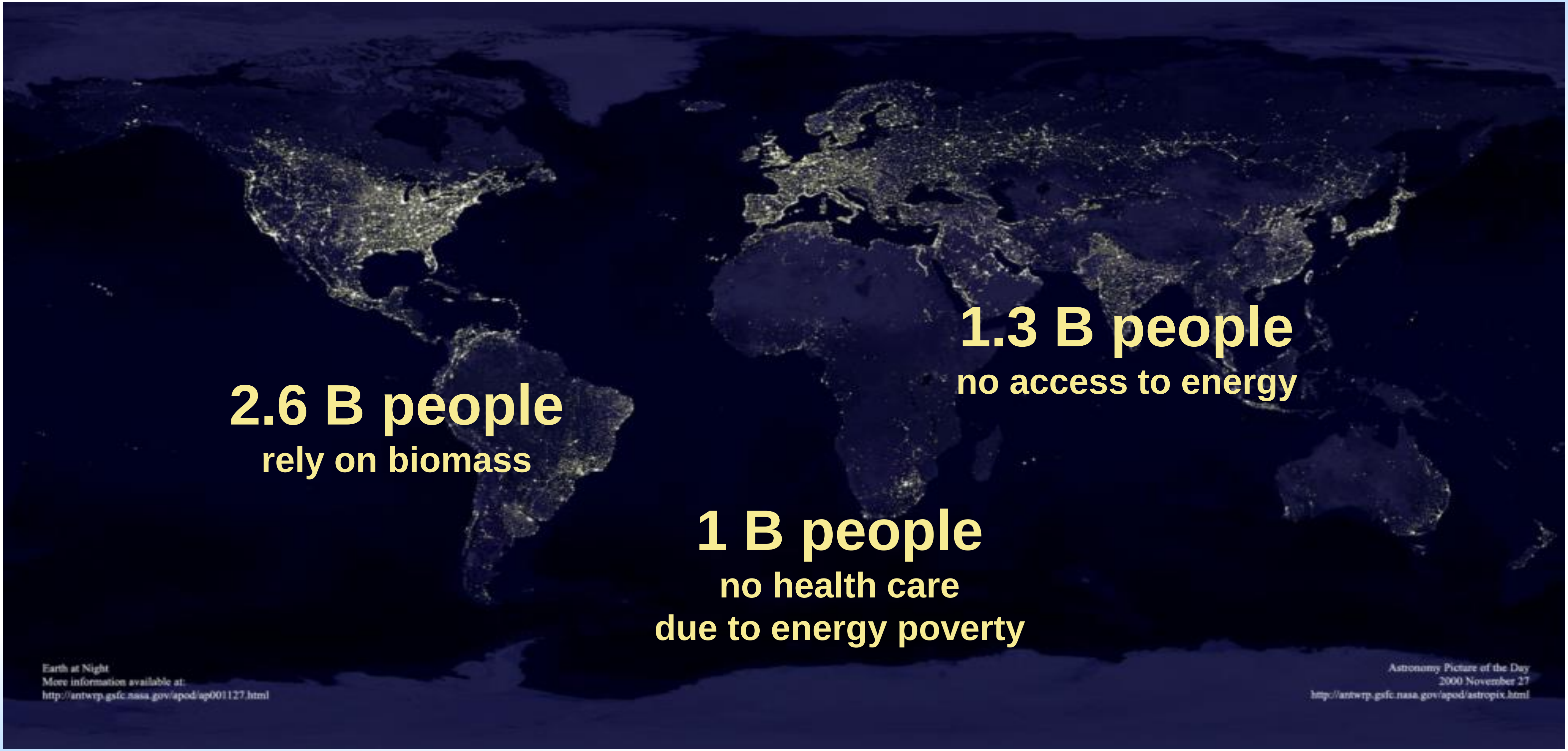
Overview of **IAEA Activities in Field of Fast Reactor Technology Development:** *Current State and Future Vision*

Vladimir Kriventsev, *Mikhail Khoroshev, Chirayu Batra*
Fast Reactor Technology Development Team
Nuclear Power Technology Development Section
Division of Nuclear Power
Department of Nuclear Energy
International Atomic Energy Agency - **IAEA**

FastRTeam

FR@IAEA.org

Energy 2017



2.6 B people
rely on biomass
1.3 B people
no access to energy
1 B people
no health care
due to energy poverty
Earth at Night
More information available at:
http://antwrp.gsfc.nasa.gov/apod/ap001127.html
Astronomy Picture of the Day
2000 November 27
http://antwrp.gsfc.nasa.gov/apod/astropix.html

IAEA
International Atomic Energy Agency

IAEA goals, mandate and assistance to the IAEA Member States

The IAEA in Numbers

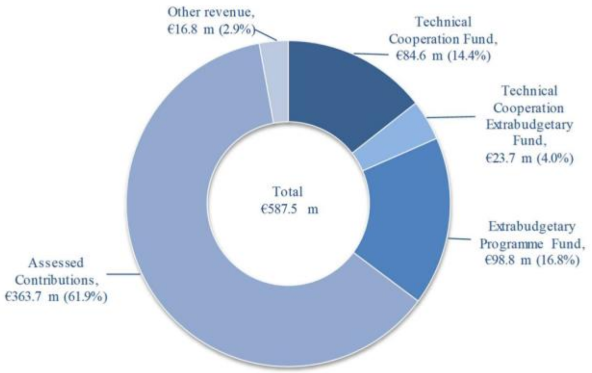
Founded in 1957: **62 Years** of international service

170 Member States (as of April 2018)

~2500 Professional and support staff

Regular Budget (2017) ~ €363M

Extra-budgetary (voluntary) ~ €98M



Technical Cooperation Fund contributions **~ €85M** in 2017

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: Atoms for Peace and *Development*

Nuclear Technology & Applications

Nuclear Safety & Security

Safeguards & Verification

Nuclear Energy

Nuclear Sciences & Applications

Technical Cooperation

Nuclear Safety & Security

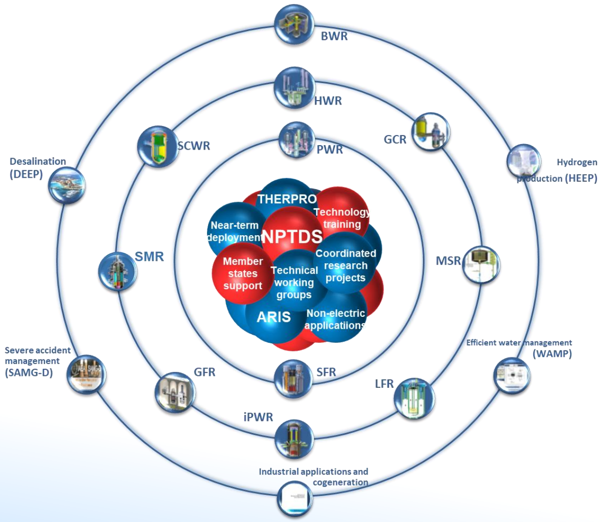
Safeguards

IAEA Fast Reactor Technology Development Team

"Atoms for Peace and Development"

Nuclear Power Technology **Development** Section **NPTDS**

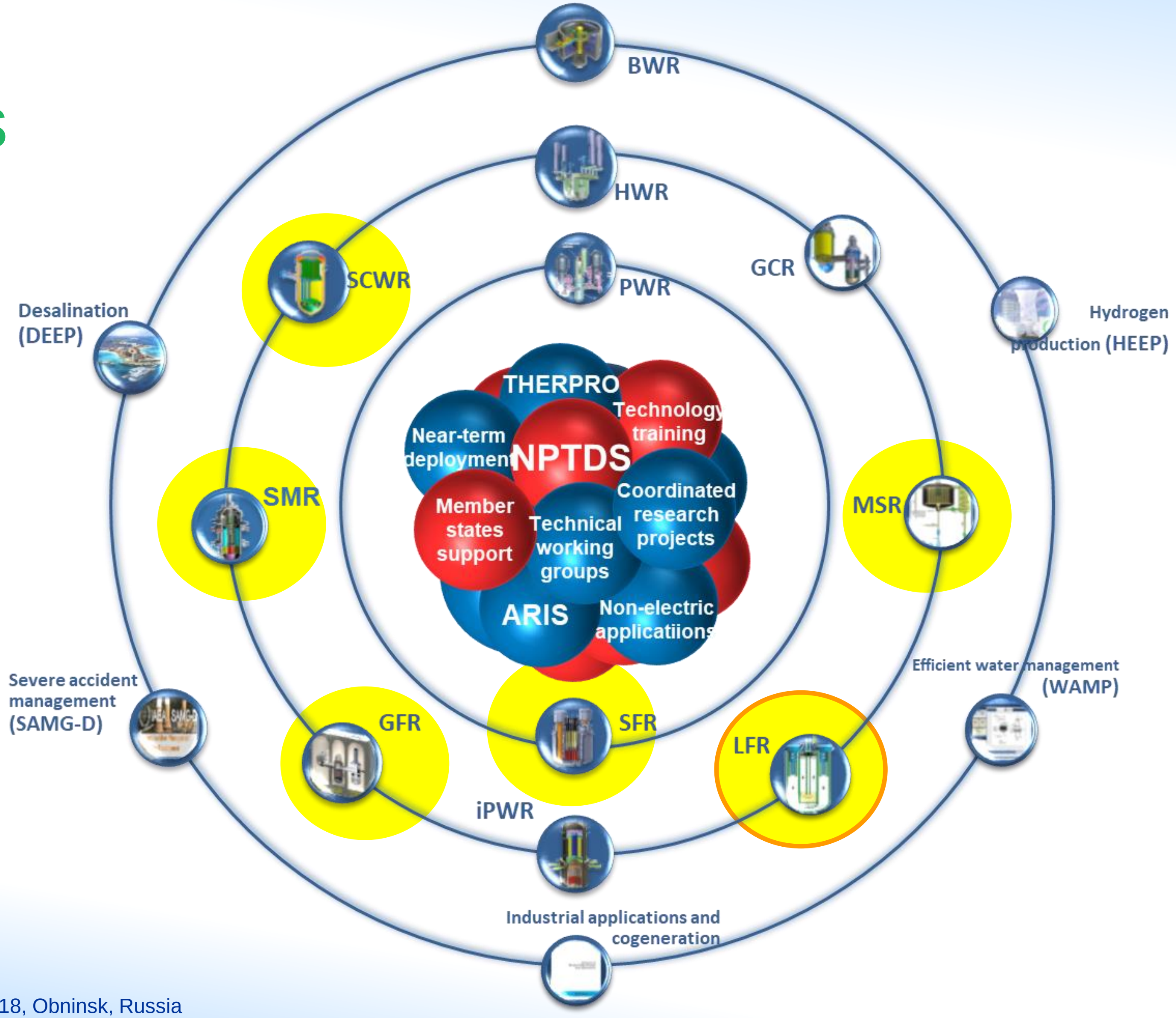
Fast Reactor Technology **Development** Team



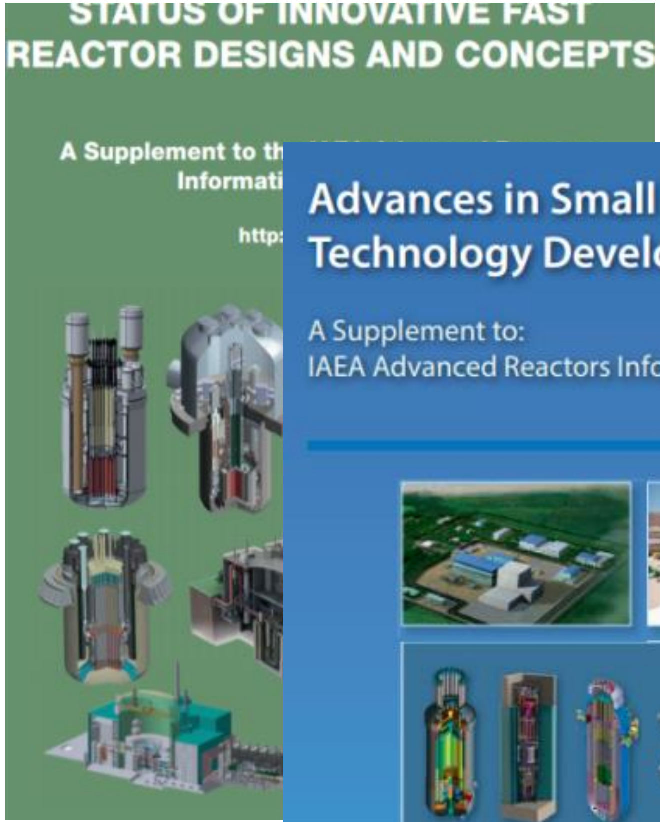
FastRTeam

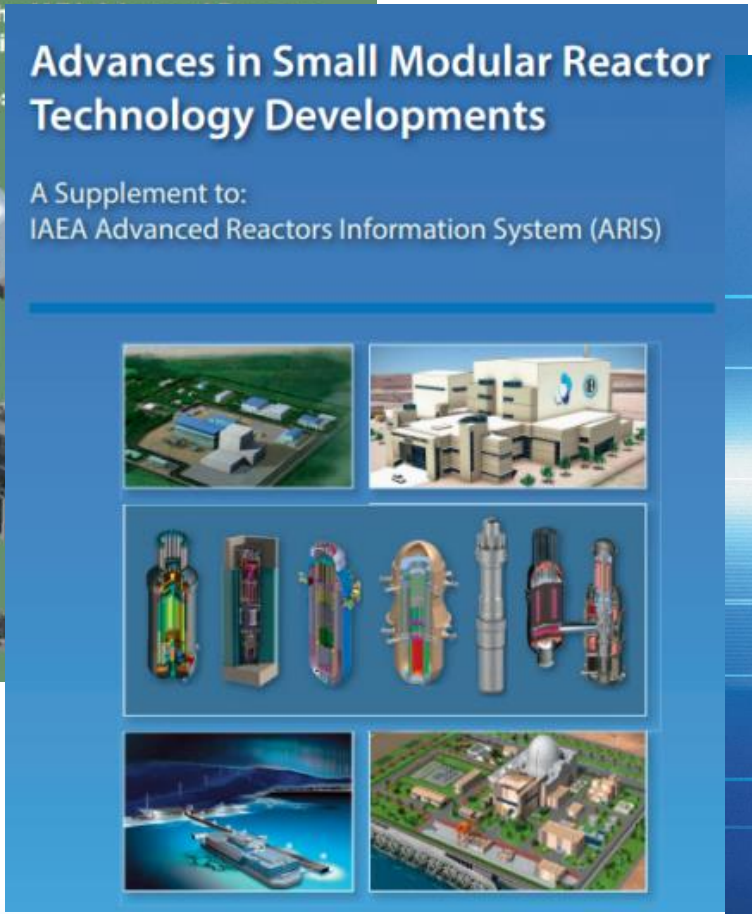
Nuclear Power Technology Development

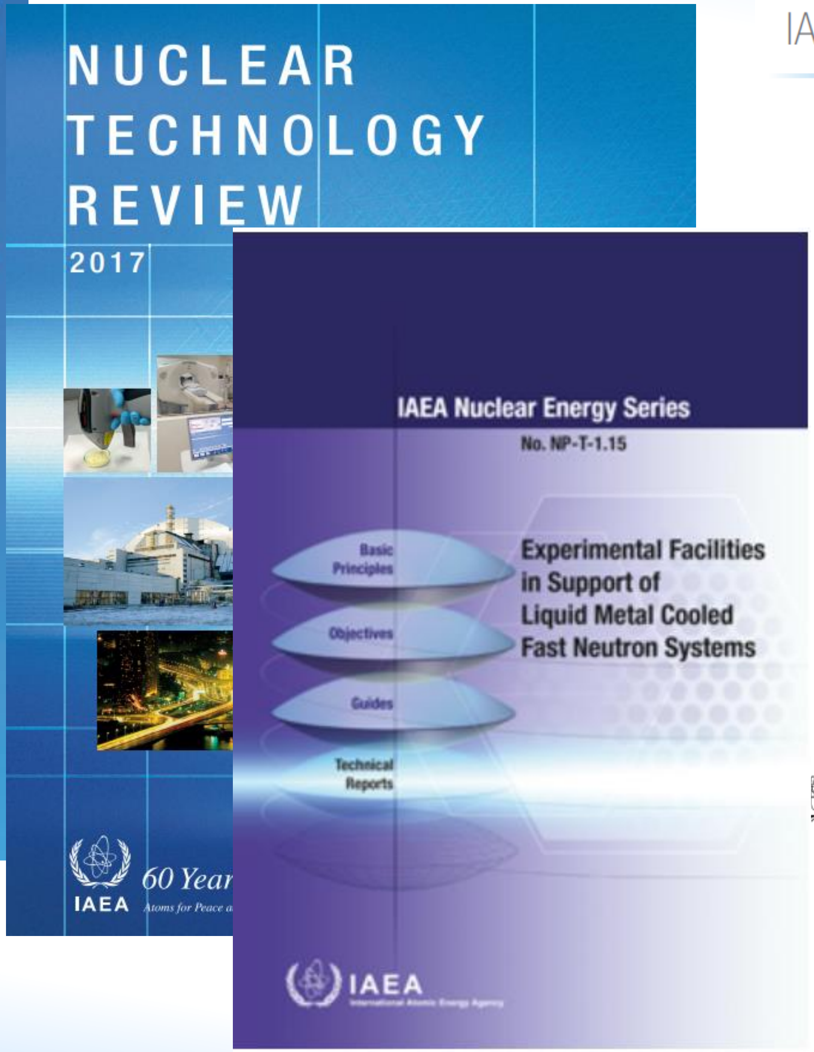
NPTDS:
Tasks & Activities



Innovation & Technology Development







IAEA

International Atomic Energy Agency

Fast Reactor Technology Development Team:

Advanced Technology for
Innovative Nuclear Energy Systems

IAEA Technical Working Group on Fast Reactors (TWG-FR)

IAEA

"The Driving Force…"

- Provide advice and guidance
- Forum for information exchange and knowledge sharing
- Link between IAEA activities and national communities
- Provide advice in planning and implementing of CRPs
- Develop and review selected documents
- Contribute to status report, technical meetings, topical conferences
- Identify important topics for SAGNE
- Encourage participation of young professionals in IAEA activities

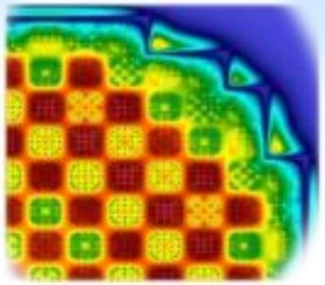
Members of the IAEA Technical Working Group on Fast Reactors	
Full Members	
Belarus	**Brazil**
China	**France**
Germany	**India**
Italy	**Japan**
Kazakhstan	**Korea, republic of**
Netherlands	**Russian Federation**
Slovakia	**Sweden**
Switzerland	**Ukraine**
UK	**USA**
European Commission	***OECD/NEA***
Observers	
Argentina	Belgium
Czech Republic	Mexico
Romania	Spain
Generation-IV International Forum (GIF)	

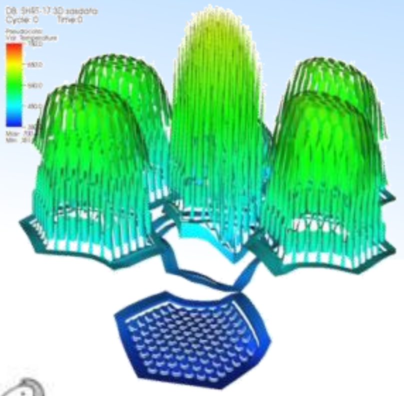
51st TWG-FR Meeting, Hefei, 21-25 May 2018

Fast Reactors: Key Activities

Modelling and Simulations

- Coordinated Research Projects (CRPs)
  - ***EBR-II*** *(Shutdown Heat Removal Tests)*
  - ***NAPRO*** **(Sodium properties)**
  - ***PSFR*** Source Term
  - ***CEFR*** Start-Up Tests: **NEW**
  - ***FFTF*** ULOF Test: **NEW**





Knowledge Preservation

- Fast reactor knowledge preservation portal **(*FRKP*)**
- Liquid metal cooled fast neutron system database (***LMFNS***)

Education and Training

- **SFR Simulator** for Educational Purposes
- **ICTP-IAEA Workshops** on the Physics and Technology of **Innovative Nuclear Energy Systems**

Safety

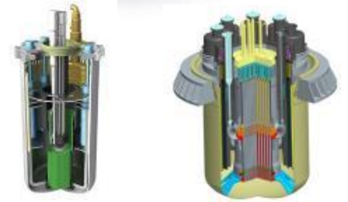
- Joint **IAEA-GIF** Workshops on LMFR Safety
- **Passive Shutdown Systems** for Fast Neutron Systems – NES Publication

Technology Support

- ***NAPRO***: CRP
- ***LMFNS*** Catalogue

Information Exchange

International Cooperation

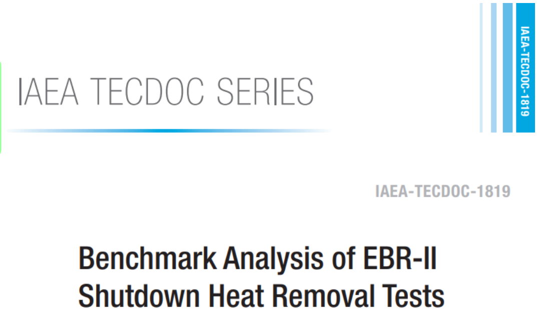


Fast Reactors: *Coordinated Research Projects*

CRPs on Fast Reactors Technology

CRP recently completed

- BN-600 MOX Core Benchmark
- Analytical and Experimental Benchmark Analysis of ADS
- PHENIX – EOL Tests
- MONJU – Na Natural Convection
- **EBR-II** Shutdown Heat Removal Tests (published in 2017)


IAEA TECDOC SERIES

IAEA-TECDOC-1819

IAEA-TECDOC-1819

Benchmark Analysis of EBR-II Shutdown Heat Removal Tests

CRP currently on-going

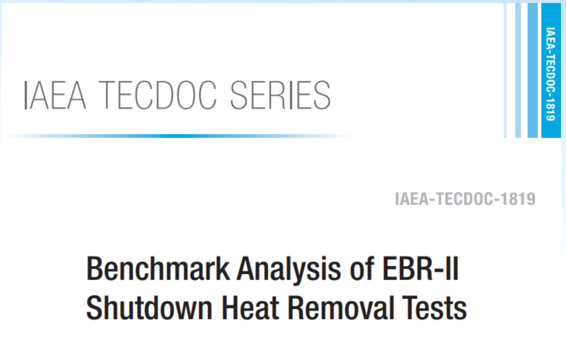
- **NAPRO** – Na Properties and Safe Operations of Exp. Facilities
- **PSFR Source Term** – Radioactive Release Under Severe Accident Conditions

New CRPs

- MONJU – Turbine Trip Test
- **Neutronics Benchmark of CEFR Start-Up Tests** (28 participants)
- Benchmark Analysis of **FFTF** Loss of Flow Without Scram Test (25 participants)

IAEA Benchmarks / CRPs on FRs

- **Completed:**
  - **EBR-II** Shutdown Heat Removal Tests
    Completed and Published


IAEA TECDOC SERIES

IAEA-TECDOC-1819

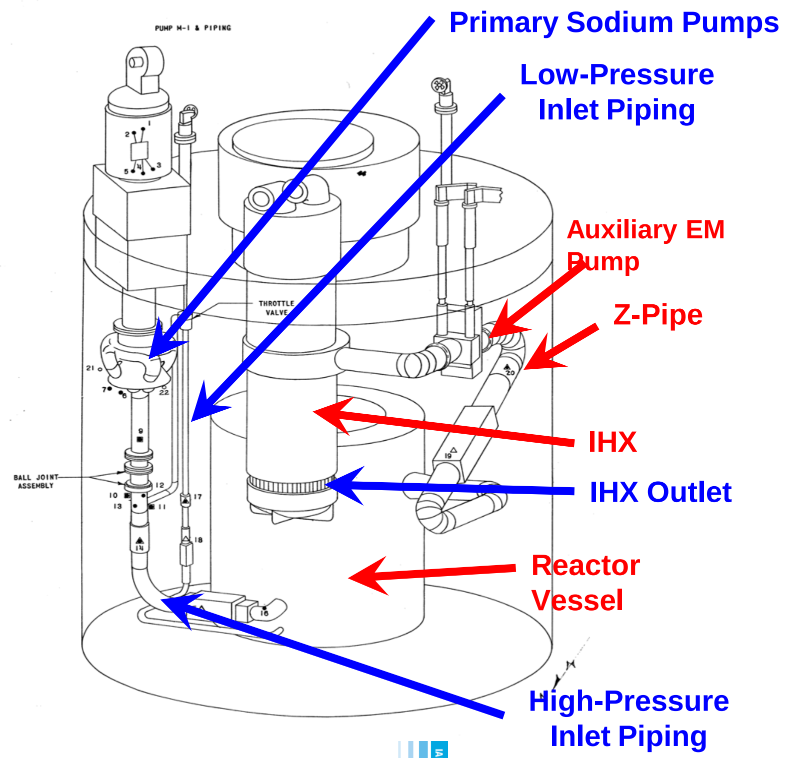
IAEA-TECDOC-1819

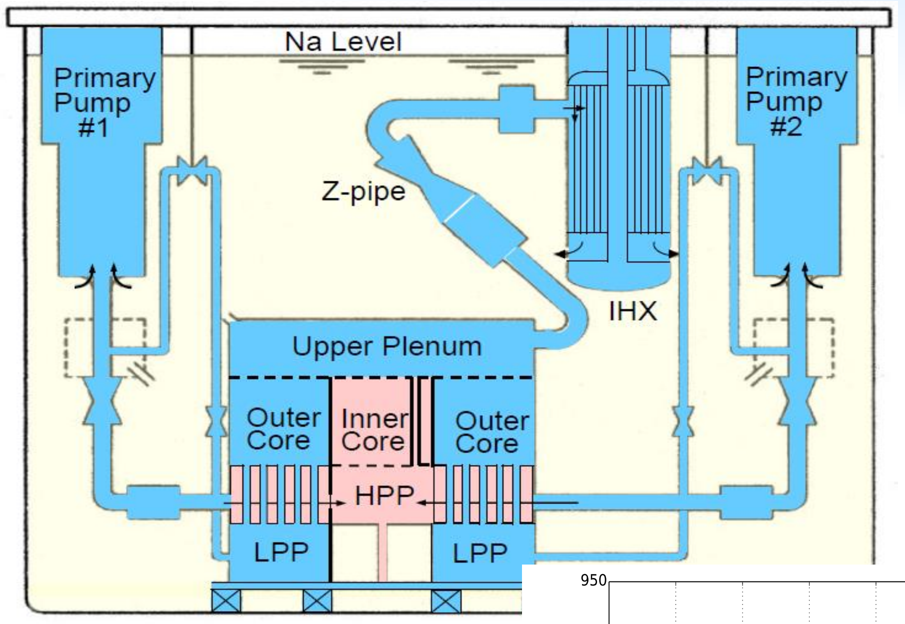
Benchmark Analysis of EBR-II
Shutdown Heat Removal Tests

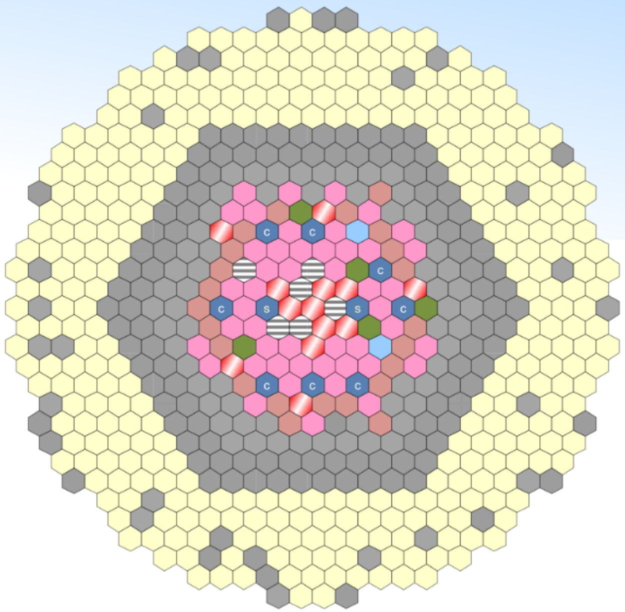
- **Ongoing:**
  - **NAPRO** – Na Properties and Safe Operations of Exp. Facilities
  - **PSFR Source Term** – Radioactive Release Under Severe Accident Conditions
- **New Benchmarks** (started in 2018):
  Good Opportunity for Verification & Validation of Safety Analysis Codes
  - **Neutronics Benchmark of CEFR Start-Up Tests**
    (26 participant organizations from 17 countries)
    - ***Most recent*** *data on Sodium-cooled Fast Reactor*
    - ***Neutronics*** *Codes Benchmarking*
    - **Kick-off RCM: 11-14 June 2018**
  - **Benchmark Analysis of FFTF Loss-of-Flow Without Scram Test**
    (25 participant organizations from 13 countries)
    - ***Coupled*** *neutronics, thermal hydraulics, material behavior and system codes*
    - *Essential Benchmark for* ***Safety Analysis*** *(validation of models and assessment of simulation codes)*
    - **Kick-off RCM: 22-25 October 2018**

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

IAEA





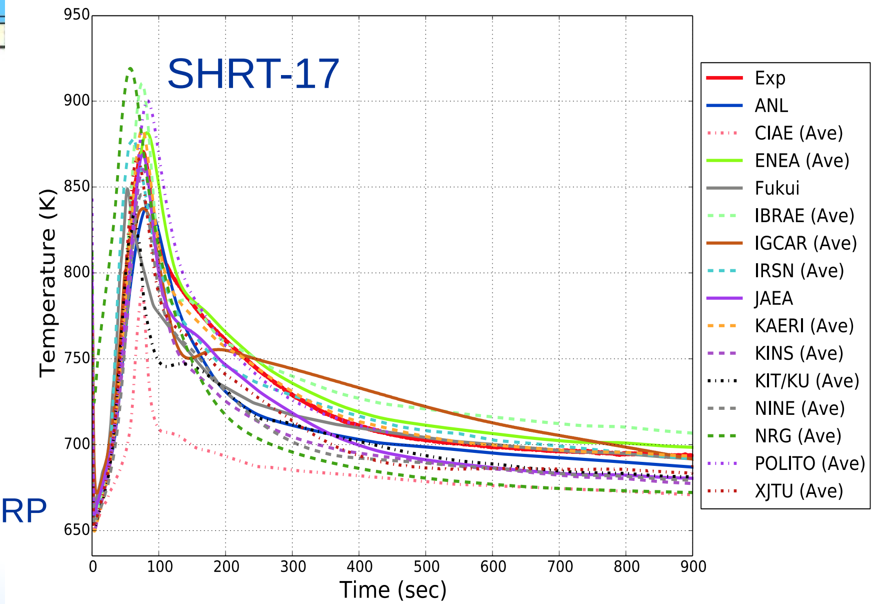


IAEA TECDOC SERIES

IAEA-TECDOC-1819

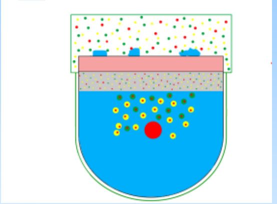
Benchmark Analysis of EBR-II Shutdown Heat Removal Tests

- 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
- Neutronics benchmark was an added dimension to the CRP

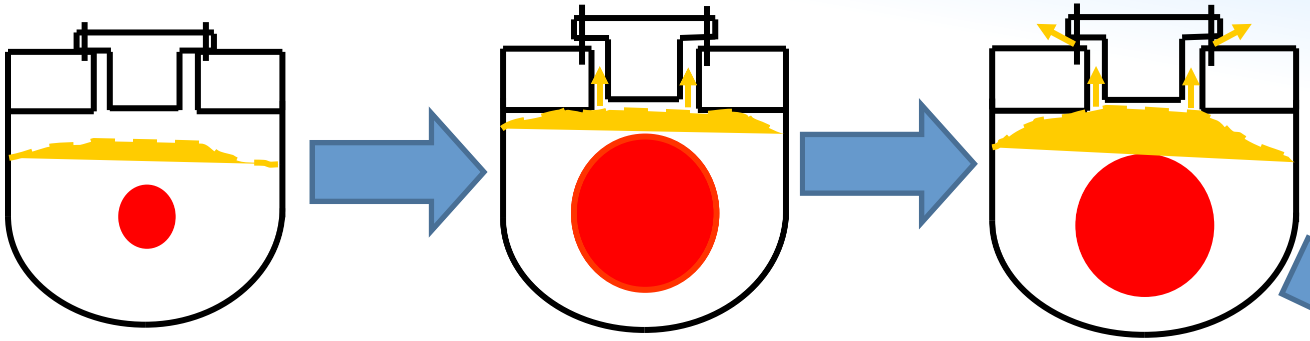


FastRTeam

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

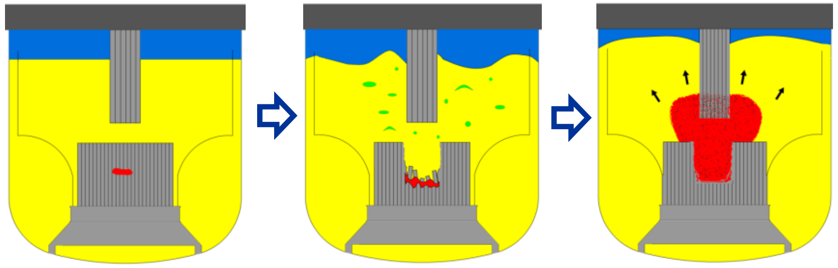


CDA development and propagation in pool type SFR

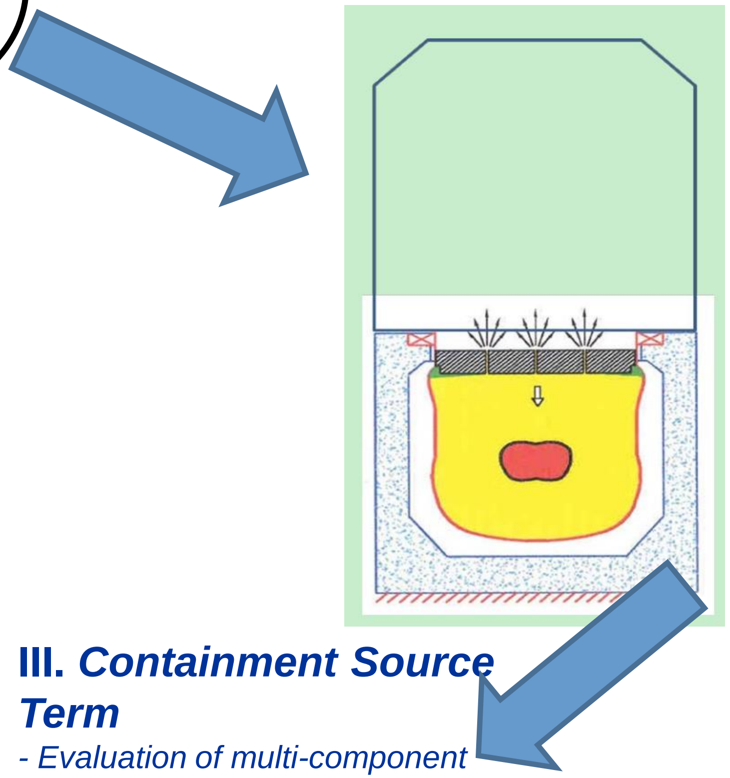


Initiation
(neutronics),
*and **Transition***
(fuel relocation)
Phases
Core Melt/Bubble is formed

I. *Expansion Phase*
Core bubble expands in sub-cooled sodium



II. *Quasi-static Phase*
Release of sodium to the Reactor Containment Building (RCB)

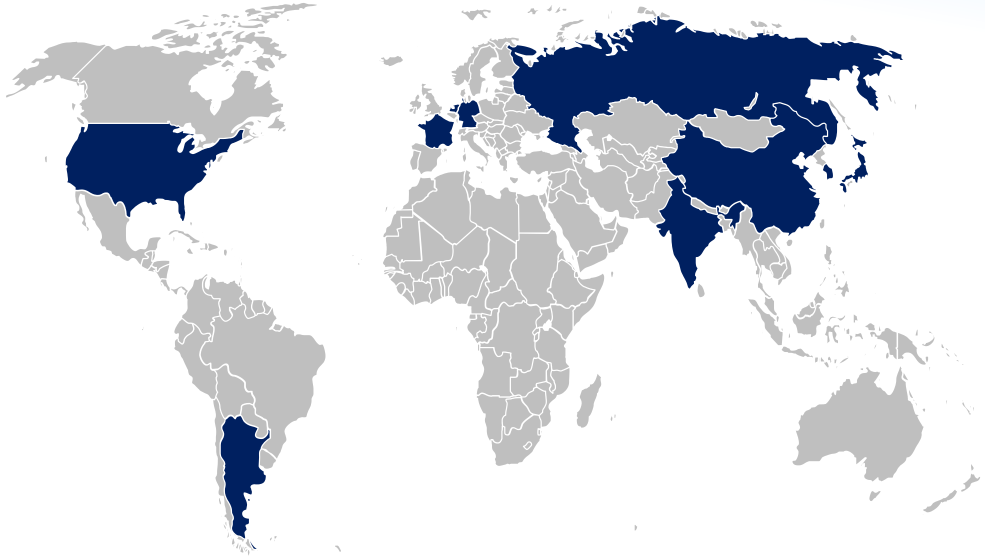


Reference design for the safety analysis:
500 MWe pool type PFBR

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

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*

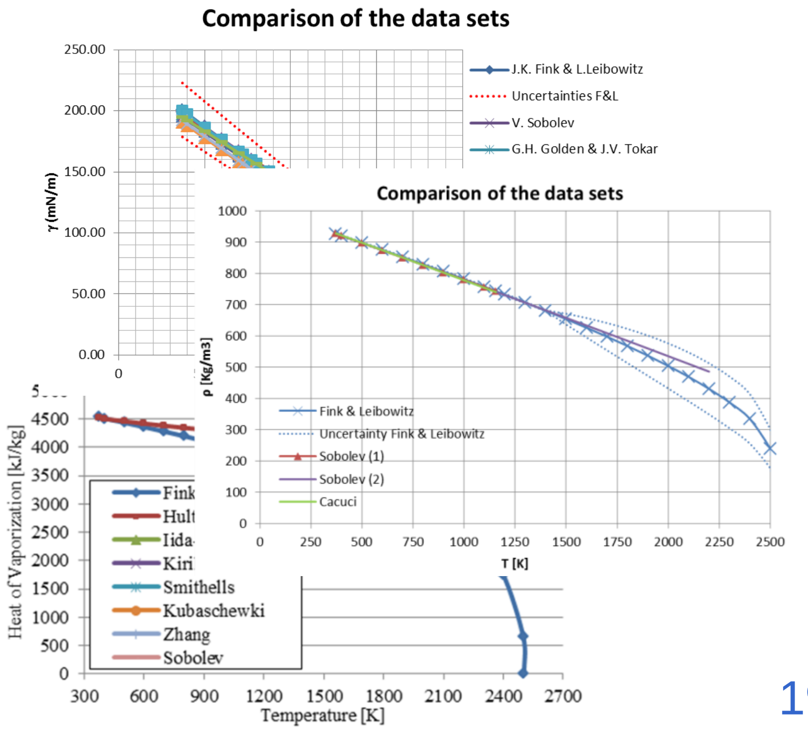
NAPRO CRP: Sodium properties and safe operation of experimental facilities in support of SFRs (2013-2018)



“Sodium properties and safe operation of experimental facilities in support of the development and deployment of SFR”

Argentina (CNEA)	China (CIAE)
France (CEA)	India (IGCAR)
Germany (KIT, HZDR)	Japan (JAEA)
Korea, Republic of (KAERI)	Netherlands (NRG)
Russian Federation (IPPE)	USA (ANL)

- **WP1**: Collection and assessment of sodium properties: harmonization of international data and correlations
- **WP2**: Design rules and best practice for Na exp. facilities
- **WP3**: Guidelines for the safe operation of Na exp. facilities
- 4th RCM in Vienna, 12 -14 June 2017
- Two TECDOCs and one NES to be published
  - TECDOC: Sodium Coolant Handbook: Physical and Chemical Properties (2018)
  - TECDOC: Sodium Coolant Handbook: Thermal-Hydraulic Correlations (2018)
  - NES: Design, Operation and Safety of Sodium Experimental Facilities (2019)



New CRP: **Neutronics Benchmark of CEFR Start-Up Tests (2018-2022)**

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

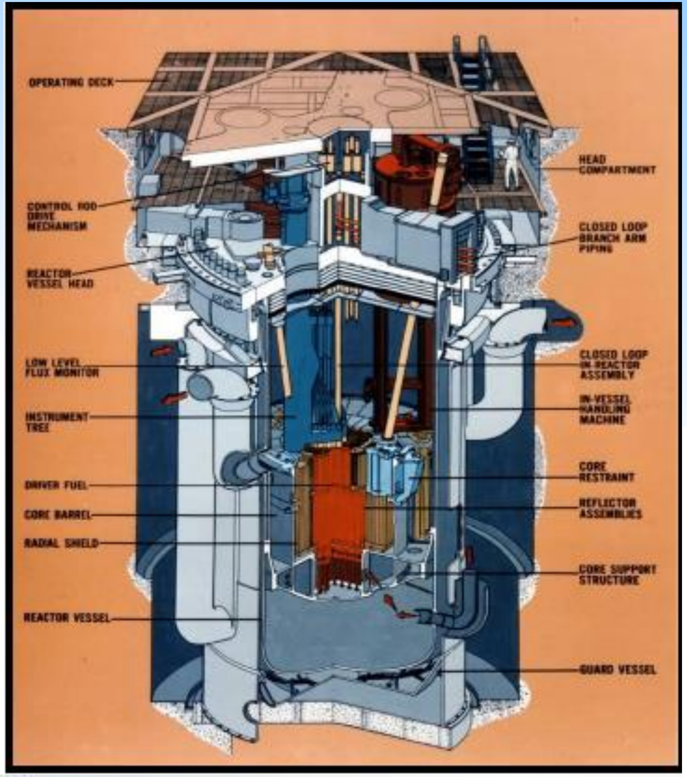
IAEA

- 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

CIAE at 1st RCM, June 2018, Vienna

New CRP: **Benchmark Analysis of FFTF Loss of Flow Without Scram Test** (2018-2022)

- 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)



PNNL/ANL at Consultants' Meeting
November 2017, Vienna

New IAEA CRPs: Participants

CEFR Start-Up Tests

Country	Organization(s)
Belgium	SCK•CEN
China	CIAE, INEST, SNERDI, XJTU
France	CEA
Germany	KIT, HZDR, GRS
Hungary	BME, EK
India	IGCAR
Italy	NINE/UNIPI
Japan	JAEA
Rep. of Korea	KAERI, UNIST
Mexico	ININ
Romania	RATEN
Russia	IPPE, IBRAE, SSL, Kurchatov Inst.
Slovakia	VUJE
Switzerland	PSI
Ukraine	KIPT
UK	Cambridge
USA	ANL, NRC
17 Countries	**28 Organizations**

FFTF ULOF Test

Country	Organization(s)
China	CIAE, NCEPU, INEST, XJTU
France	CEA
Germany	KIT, HZDR
India	IGCAR, ISSSA
Italy	NINE, Sapienza
Japan	JAEA
Rep. of Korea	KAERI
Netherlands	NRG
Russia	IPPE, IBRAE
Spain	CIEMAT
Sweden	KTH
Switzerland	PSI
USA	ANL, PNNL, TerraPower, NRC, TAMU
13 Countries	**25 Organizations**

Proposal of New CRP on Benchmarking Assessment of LOF Transient Test Conducted in Clear-S HML Pool Facility

- *Proposed by FDS/INEST, China at 51st TWG-FR Meeting in May 2018*

Table I. IMain parameters for CLEAR-S facility.

	Items	CLEAR-S
Operating coolant parameters	Coolant	LBE
	Heating power, MW	2.5
	Temperature, °C	250–550
	Inventory, tons	200
	Total mass flow rate, m^3/h	30–100
Fuel assembly simulator (FPS)	Structure	61 pins, wire wrapped
	Number	7
Main vessel	Design pressure, MPa	2
	Diameter, mm	200(
	Height, mm	650(
	Structural material	AISI 31

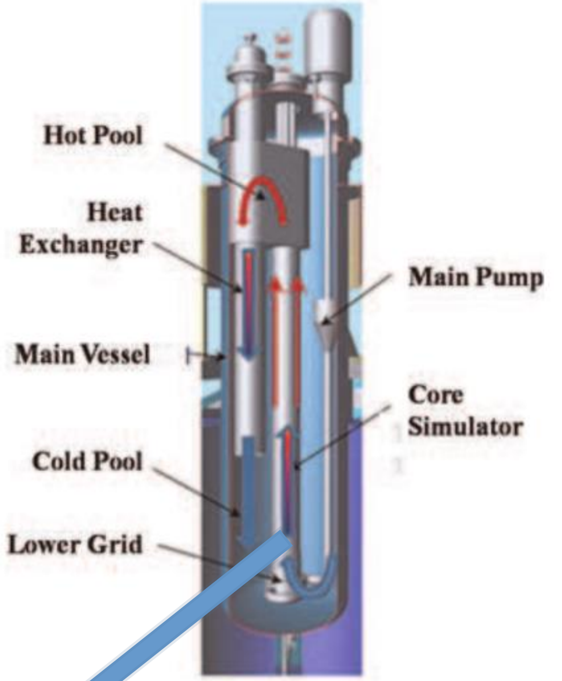


Figure 2. General layout of the primary coolant system.

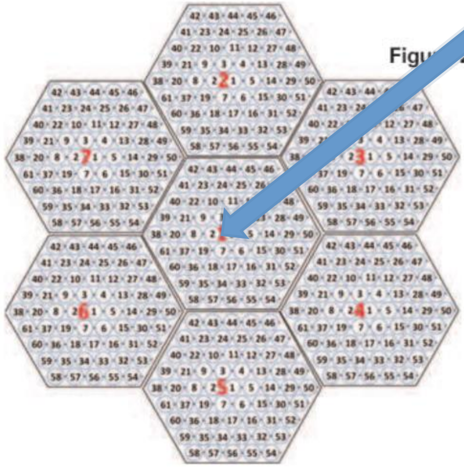


Figure 4. Cross section of fuel assembly simulator.

Y. Wu, CLEAR-S: an integrated non-nuclear test facility for China lead-based research reactor, *Int. J. Energy Res. 2016,* **40**(14), pp.1951–1956

CRP Starting Date: *To be discussed and approved by TWG-FR*

New Studies on Lead/LBE: Technical Meeting on Structural Materials for Heavy Liquid Metal Cooled Fast Reactors

IAEA

- *Proposed by Romania and Italy at 51st TWG-FR Meeting in May 2018*

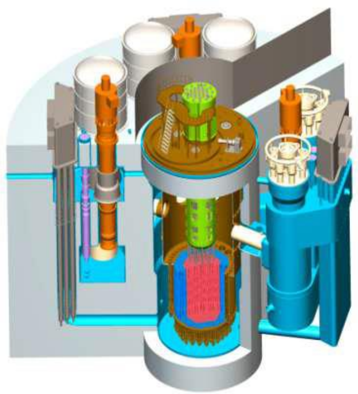
- *TM Topics:*
  - *HLM Compatibility with Structural Materials: phenomena, modelling and operational experience;*
  - *Corrosion Mitigation Measures: coating and surface engineering, environmental conditioning, etc.;*
  - *Development of Structural Materials Resistant to HLM Corrosion;*
  - *HLM Structural Materials and Coatings under Irradiation: testing and characterization, impact of neutron-induced radiation damage, etc.; and*
  - *Qualification Programmes of Structural Materials for HLM Fast Reactors.*

Action	Date
Announcement and Call for Papers	October 2018
Abstract submission Deadline	1 April 2019
*TWG-FR selects **15-20** abstracts at its 52nd Meeting*	*May 2019*
Full paper submission deadline; Starting peer-review	September 2019
Technical Meeting in Vienna	**15 - 17 October 2019**
Final Papers Deadline; Draft TM Report	December 2019
Publication of the IAEA TECDOC (or NES)	2021

FastRTeam

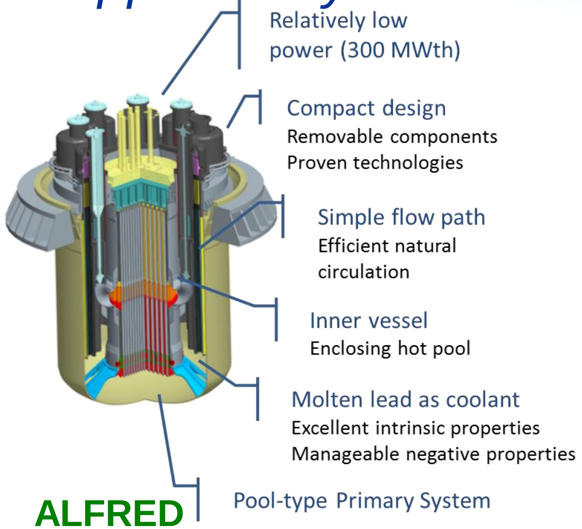
New Studies on Fast Reactors: Technical Meeting on Benefits and Challenges of Fast Reactors of SMR Type

- *Proposed by Italy and supported by TWG-FR at 51st Meeting in May 2018*

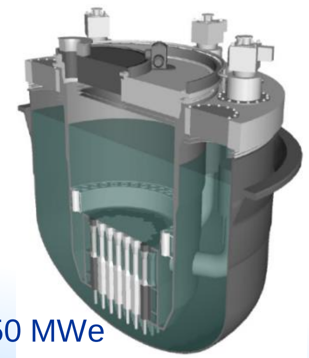


BREST-OD-300
NIKIET/Proryv

SEALER
LeadCold

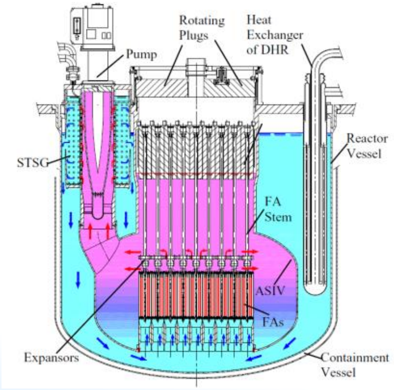


ALFRED
EU / ENEA / Ansaldo Nucleare

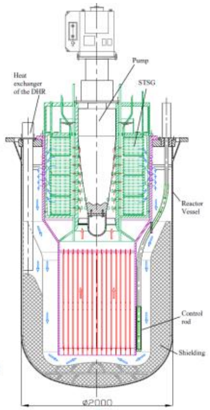


450 MWe

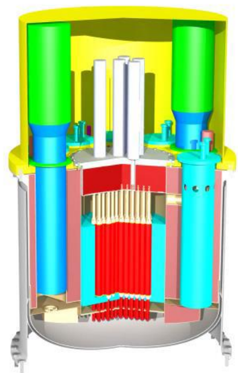
LFR Concept
Westinghouse



LFR-AS-200



LFR-10
Hydromine



CLEAR-M10
FDS/INEST

Action	Date
Announcement and Call for Papers	October 2018
Abstract submission Deadline	1 April 2019
*TWG-FR selects **15-20** abstracts at its 52nd Meeting*	*May 2019*
Full paper submission deadline; Starting peer-review	August 2019
Technical Meeting in Italy	**24 - 27 September 2019**
Final Papers Deadline; Draft TM Report	December 2019
Publication of the IAEA TECDOC (or NES)	2021

IAEA LMFNS Database

Experimental Facilities in Support of
Liquid Metal cooled Fast Neutron Systems

https://nucleus.iaea.org/sites/lmfns

includes data on 150 experimental facilities under design, construction or operation

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

LMFNS Experimental Facilities Database

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

IAEA

Includes an overview as well as detailed information on **150** experimental facilities under design, construction or operation

19 institutions from 14 IAEA Member States contributed

from Russian Federation:
11 for **SFRs**
10 for **LFRs**

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

- A comprehensive Catalogue providing detailed information on experimental facilities currently designed, under construction or operating
- Facilities Designed to support the development and deployment of innovative liquid metal-cooled (sodium, lead and lead-bismuth) fast neutron systems (LMFNS), both critical and subcritical
- Identifies existing or future operational experimental facilities able to support innovative LMFNS
- Expected to facilitate cooperation using existing and planned experimental facilities for LMFNS, and enhance their utilization by providing end-users with detailed information
- Encourages international collaborations

FastRTeam

IAEA NES Publication: Experimental Facilities in Support of Liquid Metal Cooled Fast Neutron Systems

- Inputs received from 14 countries and EU
- 151 facilities reviewed and accepted:
  - Na-based facilities: 79 (11 from Russia)
  - Pb-based facilities: 72 (10 from Russia)
- NES document – 50 pages overview and ~1000 pages on CD
  published last week
  online since 2016

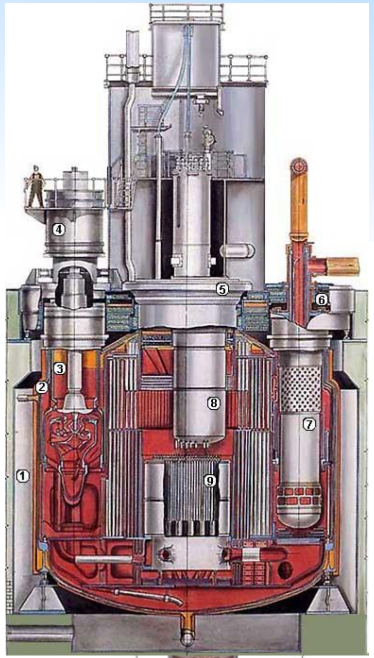
FR17 in Yekaterinburg, June 2017

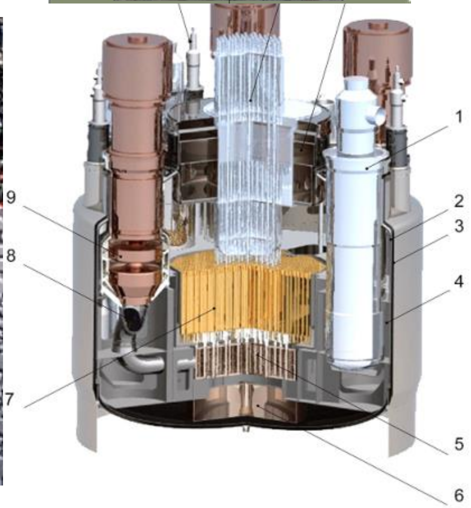
600+ *Participants*
29 *Countries*
6 *Intl. Organizations*
488 *Contributions*

- *4 Opening*
- *11 Keynotes*
- *11 Panels*
- *12 YGE*
- *243 Orals*
- *206 Posters*

FR21:
June 2021 in Vienna

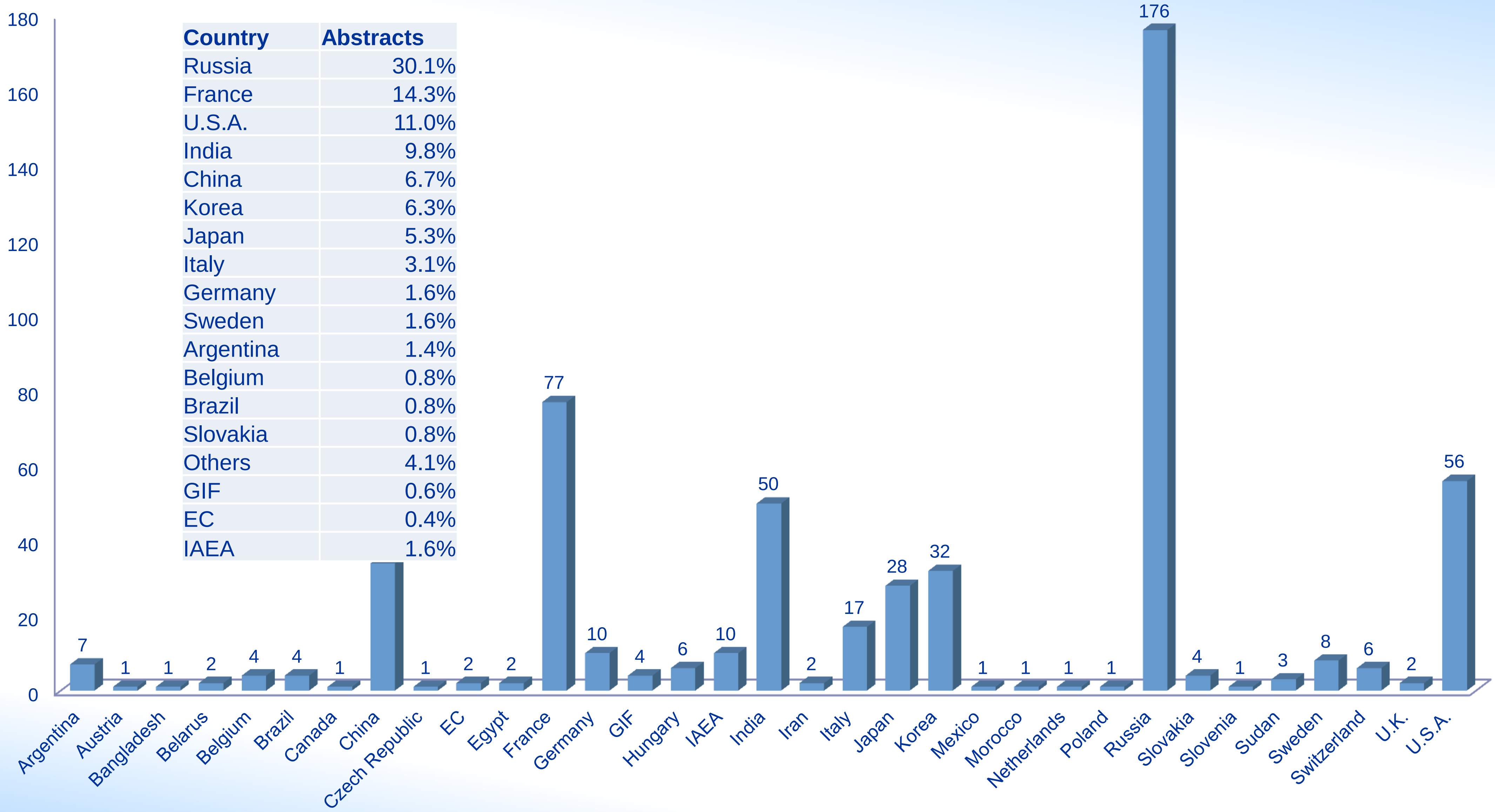
BN-600





BN-1200

FR17 Abstracts: Distribution by Countries



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Italy	3.1%
Germany	1.6%
Sweden	1.6%
Argentina	1.4%
Belgium	0.8%
Brazil	0.8%
Slovakia	0.8%
Others	4.1%
GIF	0.6%
EC	0.4%
IAEA	1.6%

FR17 Panel: Small and Medium Sized Fast Reactors

IAEA

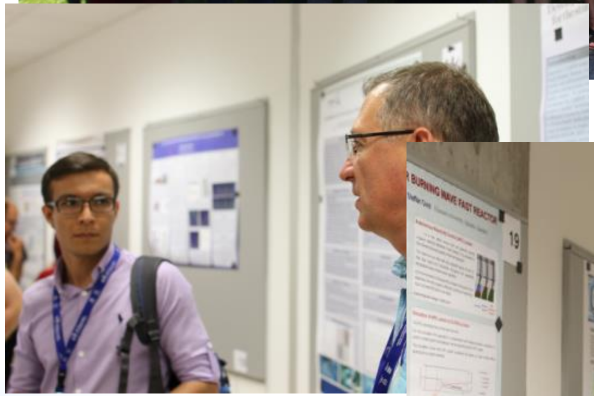
Panel II		**10:20-12:00**		**Small and Medium Sized Fast Reactors**	
Venue: Plenary Hall					
Moderator: **S. Monti**				*Wednesday 28 June 2017*	
Time	Id	Presenter	Country	Title	
10:20		S. Monti	IAEA	Introduction to the Panel	
10:25	CN245-566 PPT-566	Y. Kim	Korea, Rep. of	Feasibility and Challenges for Self-sustainable Long-Life SMR without Refuelling	B&BR (SFR)
10:35	CN245-592 PPT-592	G. Toshinsky	Russia	SVBR-100: Option for developing countries	SVBR-100 (LBE FR)
10:45	CN245-593 PPT-593	G. Grasso	Italy	A safe and competitive lead-cooled small modular fast reactor concept for a short-term deployment	ALFRED (LFR)
10:55	CN245-594 PPT-594	J. Krepel	Switzerland	Eligibility of Small Molten Salt Fast Reactor (S-MSFR)	Fast MSR
11:05	CN245-595 PPT-595	S. Qvist	Sweden	Small and fast reactors for arctic regions	SEALER (LFR)
11:15		***General Discussion***			
			Break 12:00 – 13:30		

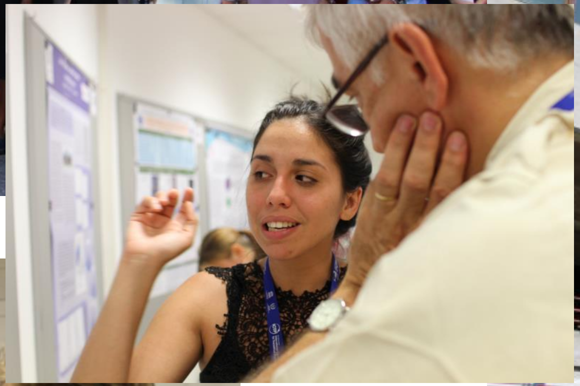
LFR Session and Panel Discussion at 2017 Winter ANS Meeting

- **~ 15 Presentations on LFRs at the ANS Winter 2017**
- **Special Session**: Solutions for **Near-Term Deployment** of Lead-Cooled Fast Reactor Technology
- **Panel Discussion**
  - Panelists:
    - **Luciano Cinotti** (Hydromine Nuclear Energy)
    - Fausto Franceschini **Paolo Ferroni** (Westinghouse)
    - Alessandro Alemberti **Michel Frignani** (Ansaldo Nucleare)
    - **Mariano Tarantino** (ENEA)
    - **Janne Wallenius** (KTH)
    - Vadim Lemekhov (NIKIET)
  - Topics
    - National strategies on LFR development: Comparison of approaches and synergies
    - LFR deployment: maturity and design options for near-term deployment
    - Plant Size: Viability of SMR LFRs
    - Cooperation between industry and research centres at national and international levels
    - Licensing framework: Experiences of early dialogues with regulators
    - ADS Option: Still on the table?

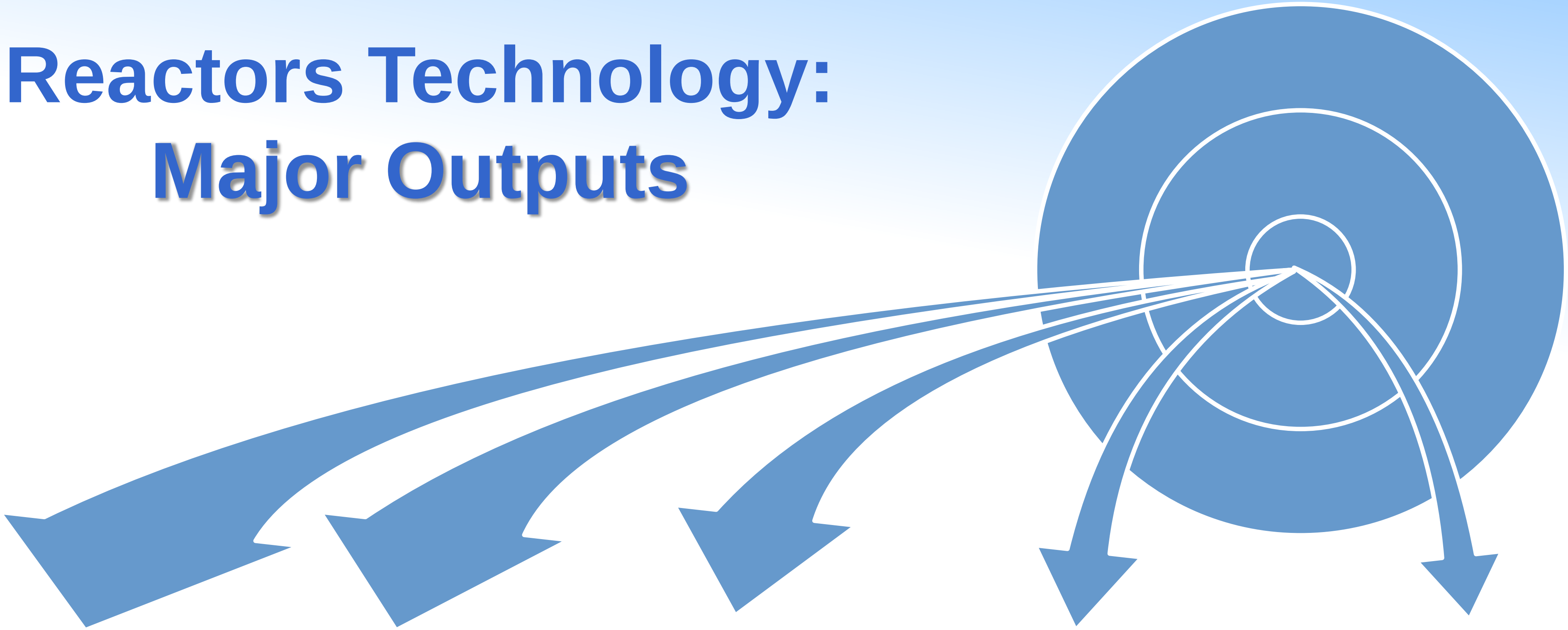
Joint ICTP-IAEA Workshops on Innovative Nuclear Energy Systems

- In **2016** and in August **2018** Trieste, Italy

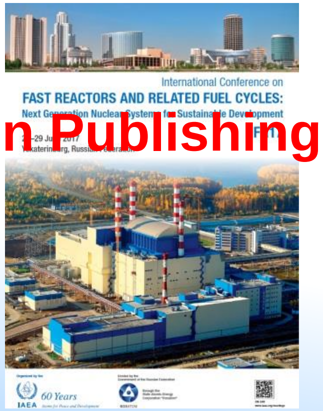




Fast Reactors Technology: Major Outputs



FR 17 Conference	NES on PSS for FRs	LMFNS Compendium	TECDOC on EBR- II Benchmark	Handbook on Sodium Properties



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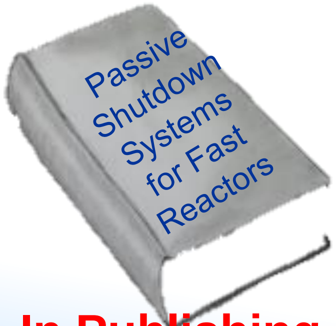

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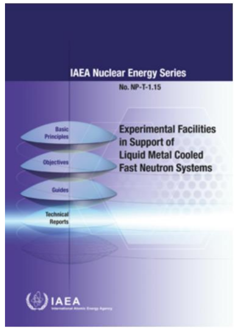
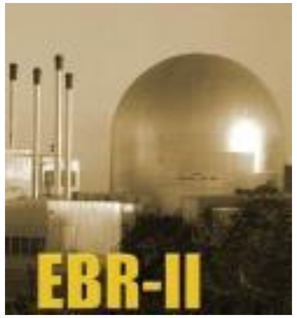


Published 2018
Online since 2016

Published 2017



TECDOC-1
In Review

TECDOC-2
Draft

Main IAEA Activities on Fast Reactor Technology in 2017-2018 and future plans

- FR17 Conference in Yekaterinburg (2017)
- CRPs/Benchmarks/Studies
  - **NAPRO CRP** (2013 - 2018)
  - 3 Ongoing CRPs:
    - **PSFR Source Term** (2016 - 2020)
    - **CEFR Start-Up Tests** (2018 - 2022)
    - **FFTF ULOF Test** (2018 - 2022)
  - 2 CRPs proposed:
    - Modelling of Total Instantaneous Blockage of SFR F/A
    - Benchmarking LOF transient test in CLEAR-S HML Pool Facility
  - Study on **Passive Shutdown Systems** for Fast Reactors (completed in 2017)
  - Technical Meeting (TM) on **Structural Materials for HLM** Reactors (2019)
  - TM on Benefits and Challenges of SMR FRs Type (2019)
  - TM Economical (or Industrial) Optimization of Liquid Metal cooled Fast Reactor Designs (2020)
  - TM Proliferation Resistant Features of Fast Reactors and Related Fuel Cycles (2020)

- Technical Working Group on Fast Reactors
  - 50th TWG-FR Meeting in Vienna, May 2017
  - 51st TWG-FR Meeting in Hefei, China, 21-25 May 2018
  - 52nd TWG-FR Meeting in Romania, 20-24 May 2019
- GIF-IAEA Workshops on Safety of SFR/LMFR
  - 7th GIF-IAEA Workshop on LMFR Safety: 27-29 March 2018
    - Review of GIF Report on Safety Design Guidelines on Safety Approach & Design Conditions for GEN-IV SFRs
  - 8th GIF-IAEA Workshop on LMFR Safety: 20-21 March 2019
- LMFNS Experimental Facilities Database
- Training Courses and Workshops
  - Joint ICTP-IAEA Workshops on the Physics and Technology of Innovative Nuclear Energy Systems (2016, 2018 in Trieste, Italy)

IAEA
International Atomic Energy Agency

FastRTeam

Спасибо!

Contact FR Team: FR@IAEA.org

Heavy Liquid Metal Coolants in Nuclear Power

Toshinsky G.I. (toshinsky@ippe.ru)
JSC “SSC RF-IPPE”

The Fifth Conference
“Heavy Liquid Metal Coolants in Nuclear Technologies” (HLMC-2018)
October 8-10, 2018, Obninsk, Russia

Table of Contents

Introduction (1)

- Water cooled reactors of the PWR (VVER) type, which are the basis of nuclear power (NP) and which way of evolutionary development is long, are safe in operating and meet the current safety requirements. While operating in an open nuclear fuel cycle (NFC), their competitiveness in electricity costs will be retained for long as compared with that of coal generating.
- That is conditioned by low existing costs of natural uranium and absence of their tendency to grow in the nearest and extended-range future, as well as low contribution of the cost of fresh fuel and storage of spent nuclear fuel (SNF) in the cost of produced electricity. Along with that, the upper point of evolutionary development of the existing VVER (PWR) technology has been obtained, and it is possible that in the future that technology cannot provide their competitiveness at the world market.

Introduction (2)

- The further progress in nuclear power technologies (NPT) can be only obtained under considerable increase of the temperature level in the primary circuit coolant and generated steam parameters, and, therefore, heightening of the thermodynamic cycle efficiency.
- As applied to VVER (PWR) type reactors, that can be achieved by use of the water coolant with supercritical parameters (supercritical-water-cooled reactor (SCWR)). However, at that point the conflict between increasing safety requirements and economics requirements is not eliminated.

Introduction (3)

- **The highlighted conflict that is peculiar to reactor facilities (RF), which use coolants with large amounts of accumulated potential energy (compression energy, chemical energy), is shown in the following: rise in safety requirements due to noticeable increase of NPP power-units is inevitably resulting in growth of the number of safety systems and their power capacity, increase of the number of defence barriers.**
- **Thus, the capital and operating costs are growing and the NPP competitiveness is lowering. For comparison, under operating parameters in water coolant and heavy liquid metal coolants (HLMC) the values of accumulated potential energy (compression and chemical energy) are 20 and 0 GJ/m^3 correspondingly.**

1 Safety and Economics (1)

- The problem of NPP safety assurance that sharpened after happening of the Chernobyl disaster has become strongly acute after the accident occurred at NPP Fukushima 1. As a result, in certain countries it caused abatement of the confidence of the population and politicians, who are voicing the population opinion, to the NP safety. Thus, it caused slowing down of the paces of NP development.
- At the same time, further increase of safety requirements (the value of possibility of the severe accident requiring population evacuation is one of the vital quantity criteria for NPPs with traditional type reactors) can result in loss of competitiveness of the NP based on water cooled reactors.

1 Safety and Economics (2)

- To reduce the specific capital costs and cost of produced electricity, it is required to increase a unit capacity of reactors, which, in its turn, is leading to the growing total cost of NPP construction and rise in construction terms. Thus, the financial risks are growing.
- An example is experience in construction of power-units EPR-1650 in Finland (Olkiluoto Nuclear Power Plant) and France (Flamanville Nuclear Power Plant) with power of 1650 MWe. Their construction terms have increased almost twice, and the cost has raised by a factor of two or three. Thus, the profitableness of the Project is sharply reduced that, depending on the tariff, can cause unprofitability of the Project.

1 Safety and Economics (3)

- **Along with that, in future the NP role will be very important as it makes possible generating of electricity and thermal power without limitations in fuel resources, exhausts of harmful substances into the environment and consumption of oxygen, which are resulting in global changes of the earth climate.**
- **Development of the renewable energy sources (RES) demonstrating the noticeable progress in technical and economical parameters can only replace a comparatively low part of fuel and energy resources. Moreover, it is only possible to develop the RES under providing of the governmental support covering their still low efficiency.**

1 Safety and Economics (4)

- The Global Agreement on Climate, that was accepted by 196 parties on 12.12.2015 and signed on 22.04.2016 at UN Climate Change Conference held in Paris and purposed to replace the Kyoto Protocol, will come into force in 2021 and does not specify the concrete ways of lowering of carbon exhausts into the atmosphere. It does not provide establishment of the mandatory tax on carbon exhaust as well.
- Moreover, the nuclear option is not provided in the Agreement, and that is conditioned mainly by radiophobia of the population, whose opinion is accounted by politicians. Along with that, upon large-scale development of the NP, it is assuring the opportunity of considerable lowering of carbon exhausts into the atmosphere.

2 Ways of Lowering of Population's Radiophobia (1)

- **The progressive part of nuclear community is beginning to understand little by little that in the foreseeable future by use of HLMCs it will be possible to eliminate in principle the severe accidents requiring population evacuation. It is confirmed by a growing number of research and development works on HLMC cooled reactors carried out abroad. At the First International Conference HLMC-98 the Russian experts presented a great number of reports on HLMC technology including those on operating experience in reactors with lead-bismuth coolant (LBC) at nuclear submarines (NS). Twelve (12) foreign participants took part in work of Conference HLMC-98. In 2013 forty seven (47) foreign participants took part in work of the Fourth Conference HLMC-2013.**

2 Ways of Lowering of Population's Radiophobia (2)

- **In 2018 the USA acceded to works on HLMC cooled reactors within the Generation IV International Forum (GIF) Framework Agreement for International Collaboration on Research and Development of Generation IV Nuclear Energy Systems. The Belgian Nuclear Research Centre (SCK•CEN) organized work of Heavy Metal Summer School on June 12-16, 2017. The Global Symposium on Lead and Lead Alloy Cooled Nuclear Energy Science and Technology (GLANST-2017) was held in Seoul (Republic of Korea) in September 2017. The International Symposium on Lead-Cooled Fast Reactor Technology Development was held in Shenzhen (China) on March 14-16, 2018. On March 9h, 2018 the initiative of building China Industry Innovation Alliance of Lead-based Reactor (CIIALER) was lunched in the Industrial Strategy Symposium of Lead-Based Reactor held in Hefei, Anhui Province, China. The CIIALER includes the representatives from over 100 enterprises. As for publications on the HLMC subjects in peer-reviewed journals, in 2018 their number can be compared with those on sodium coolant.**

2 Ways of Lowering of Population's Radiophobia (3)

- **The conclusion made up in the report of Massachusetts Institute of Technology (MIT) predicated a noticeable role of HLMC in the future NP:**

"If the corrosion resistant characteristics

of these alloys are confirmed for realistic reactor conditions and assuming that there are no other unexpected challenges, LFRs (Lead-Cooled Fast Reactor) could become

an attractive alternative to SFRs (Sodium-Cooled Fast Reactor)".

2 Ways of Lowering of Population's Radiophobia (4)

- Use of HLMC in FRs provides the reactor with crucial properties of inherent self-protection regarding to the severest accidents requiring population evacuation. That is conditioned by HLMC nature properties, namely: high boiling point and chemical inertness in events of contacting with water and air. In the HLMC cooled reactors there is no potential energy accumulated in coolant (coolant compression energy, chemical interaction energy), which upon the certain initial events can cause destruction of defence barriers and catastrophic exhaust of radioactivity.
- Use of HLMC is forming the backgrounds for simplification of the RF design due to elimination of the certain safety systems, which are necessary in the RFs with other coolants. Thus, it is possible to construct the NPPs on the basis of FRs with HLMC, which are not only safer, but more efficient, as compared with NPPs based on traditional type reactors.

2 Ways of Lowering of Population's Radiophobia (5)

- Though now there is no currency equivalent for the safety level, its enhancement is providing the competitive advantages under the similar technical and economical parameters of different type NPP projects and is lowering the financial risks for the NPP owner in the process of operation.
- Moreover, deterministic elimination of the necessity of population evacuation in events of severe accidents is assuring the higher level of population confidence that can be crucial upon selection of the NPP project for construction (e.g. absence of pressure in the reactor, lack of hydrogen release means that explosion cannot occur and so on). It is more clearly understood by the people, who consider the events on the basis of their own experience, but not on the results of probabilistic safety analyses.

2 Ways of Lowering of Population’s Radiophobia (6)

- For the population the possibility of catastrophic consequences of the nuclear accident is much more important than the low probability of its realization. Nevertheless, in accordance with the reliably received statistical data, the man-caused risks caused by operation of industrial enterprises and their fuel-energy infrastructure are many orders greater than the corresponding risks from the NP.
- From the standpoint of the nuclear community and educated part of the population, that perception of the NP is not reasonable. However, that factor should be taken into consideration as an objective one and the high safety level of the NPP should be validated for the population, whose opinion is crucial and final, by “transparent” arguments without use of probabilistic analysis methods, if possible.

3 The Role of FRs with HLMC in the Future Large-scale NP (1)

- Today it is generally recognized that the factor of FRs will be determining in the future large-scale NP. It is conditioned by the fact that only in fast neutron reactors we can obtain the breeding ratio (BR) that is equal or exceeds one. That makes possible involving of ^{238}U (widespread heavy uranium isotope) instead of ^{235}U (rare light uranium isotope) in electric power generating at the NPP.
- Due to the highlighted fact, the source of raw fuel for the NP can be extended approximately by a factor of one hundred thus providing the people by energy for many thousands years without carbon exhausts into the atmosphere and destruction of oxygen. To realize that opportunity, the FRs must operate in the closed NFC with recycling of built up plutonium.

3 The Role of FRs with HLMC in the Future Large-scale NP (2)

- Along with that, despite such unchallengeable advantage over the operating water cooled thermal reactors (TR), the FRs are not developed widely. Moreover, in reality the time for their economically expedient implementation in the NP is being constantly postponed.
- For instance, in the USA, where the park of TRs is the largest (about 100 GWe), it is not planned to implement FRs in the current century due to considerable increase of the natural uranium cost that can result in loss in competitiveness of the NPPs based on TRs with heat power plants (HPP) using fossil fuel.

3 The Role of FRs with HLMC in the Future Large-scale NP (3)

- **The main reason is that FRs are much more expensive than TRs. That is conditioned by the fact that everywhere the sodium was selected as coolant as possessing the best heat-transfer properties, which allowed providing of intensive heat removal in the core and high rate of excess plutonium buildup.**
- **The highlighted requirement to FRs was a determining factor in the last seventies because of the existing external conditions, when the resources of cheap nature uranium were explored in small scales and the pace of electric power development and especially NP development was high.**

The required doubling time of plutonium (and consequently the time of doubling of the number of NPP power units) was ten years and less.

3 The Role of FRs with HLMC in the Future Large-scale NP (4)

- **The lower economical parameters of FRs are resulting from additional expenditures for safety caused by nature properties of sodium, namely: extremely high chemical activity when contacting with water and air that is possible in accidental situations. Those expenditures include an intermediate sodium circuit between the radioactive sodium primary circuit and steam-water circuit, the necessity of casing of sodium pipelines, more complicated technology of SNF handling, and special measures on fire-prevention safety.**
- **In the result, the future large-scale NP is necessarily planned as a dual-component one, namely: in the closed NFC the more expensive sodium fast reactors (BN) "are feeding" the cheaper TRs by their excess plutonium.**

3 The Role of FRs with HLMC in the Future Large-scale NP (5)

- At present in most countries, which are developing the NP, there are no external factors highlighted above. For that reason, now the BN reactors are not without alternative ones. The exception is those countries, where aggressive development of the NP is planned and resources of cheap nature uranium are not large (e.g. India, China).
- That fact should be taken into account upon coming to a decision on the issue concerning construction of reactor BN-1200 in Russia that will make possible retaining of competence and skilled potential in sodium technology. Moreover, that makes possible keeping of “running order” for the functioning NPT based on FRs operating in the closed NFC, which can be demanded in events of unforeseeable failures in the process of implementation of FRs with HLMCs.

3 The Role of FRs with HLMC in the Future Large-scale NP (6)

- **Use of HLMCs as FR coolants, which heat-transfer properties are much worse as compared with those of sodium, does not allow obtaining of short doubling time of plutonium. However, due to the HLMC natural properties such as chemical inertness and very high boiling point, the application of HLMCs is forming the backgrounds for construction of FRs with a very high level of inherent self-protection, which deterministically eliminates the severe accidents requiring the population evacuation.**
- **At that point, the FRs are not burdened with additional expenditures for safety required for both water cooled TRs and BN reactors. Due to that fact, after the presented technology has been demonstrated, it is possible to consider as an option the one-component structure of the future large-scale NP based on FRs with HLMCs.**

3 The Role of FRs with HLMC in the Future Large-scale NP (7)

- Along with that the cost of produced electric energy, which is within the design basis and determining the level of NPT competitiveness, is depending not only on the values of specific capital costs of NPP construction, but those of the corresponding fuel cycle.
- Under existing low costs of natural uranium and absence of their tendency to grow in the nearest future, as well as low contribution of the costs of uranium fuel manufacturing and SNF storage in the electricity cost that is within the design basis, closing of the NFC will result in heightening of that parameter and lowering of the NFT competitiveness.
- For that reason, at the initial stage of implementation of HLMC cooled FRs in the NP (under their technological readiness and lower values of specific capital costs as compared with those of TRs. However, for the present it is only an assumption confirmed on paper), it is possible that operation of the FRs, which use uranium fuel and operate in an open NFC with postponed reprocessing of SNF, can be economically efficient.

3 The Role of FRs with HLMC in the Future Large-scale NP (8)

- That is expedient for the reasons of nonproliferation especially when construction of such reactors is realized in the non-nuclear countries, bearing in mind that uranium enrichment does not exceed 20 %. At that point, it is possible to utilize step-by-step the SNF of TRs as makeup fuel in the closed NFC of FRs when closing of the NFC is becoming economically justified.
- In conditions of limited opportunities of usage of natural uranium and deficiency in existing resources of extracted plutonium for launching of FRs with HLMC, the necessary pace of growing power capacities of FRs with HLMCs can be provided by including of the corresponding number of fast plutonium breeder-reactors with sodium coolant in the NP structure.

3 The Role of FRs with HLMC in the Future Large-scale NP (9)

- In this case at the stage of the growing implemented power capacities the NP structure will become tri-component, namely:
  1) the cheaper FRs with HLMC operating in the closed NFC in a mode of fuel self-providing;
  2) the TRs operating in the open NFC, which use partially the uranium fuel and partially the plutonium one, and the SNF is sent to the closed NFC of FRs;
  3) the breeder-reactors with sodium coolant, which operate in the closed NFC and supply the TRs by excess plutonium.
- The optimum relationship between the reactor types will be determined by their technical-economical parameters and economical parameters of the corresponding fuel cycles.
- When a stable level of summarized power capacity of NPPs is obtained, a mode of fuel self-providing with breeding ratio (BR) that equals to 1 will be quite sufficient. And that is provided by HLMCs cooled FRs operating in the closed NFC with gradual changeover to a one-component structure of the NP.

3 The Role of FRs with HLMC in the Future Large-scale NP (10)

- There is a one more feature of the HLMCs cooled FRs, namely: the harder neutron spectrum caused by weak moderation of neutrons on lead and bismuth nuclei as compared with FRs cooled by other coolants. That is resulting in heightening of the efficiency of transmutation of minor actinides (MA), which possess the threshold dependence of microscopic fission section on power both in critical and sub-critical FRs (ADS).
- As a result, while FRs are operating in the closed NFC, in a certain time the concentration of MA nuclei (neptunium, americium, curium) upon their recycling is reaching saturation as the velocity of their loss caused by fission is becoming equal to the velocity of their formation.

3 The Role of FRs with HLMC in the Future Large-scale NP (11)

- **At that point, the specific radioactivity of MA (counting on one GW-y of produced power) will decrease with increasing of cumulative energy-generating. So, it makes easier finding the solution to the problem of MA handling at the back-end stage of the NFC as long-lived isotopes of MA define the radiotoxicity of wastes, which must be sent to the final burial.**
- **The harder neutron spectrum is also leading to diminishing of the positive constituent of voiding reactivity effect by making it negative for small power capacity FRs with high neutron leakage. And that is important for safety.**

3 The Role of FRs with HLMC in the Future Large-scale NP (12)

- **In Russia lead-bismuth coolant (LBC) with Bi and Pb eutectic content that has been mastered in conditions of operating nuclear submarines (NS) reactors is considered as HLMC. LBC is used in designing of reactor SVBR-100 oriented to construction of small and medium power modular nuclear power plants (NPP).**

In addition, lead coolant (LC) that has not been mastered yet, but that is used in designed reactor BREST-OD-300 is considered as a stage in construction of commercial power unit BR-1200 with lead coolant.

3 The Role of FRs with HLMC in the Future Large-scale NP (13)

- The melting temperature of LBC is much lower (124 °C) as compared with that of lead (327 °C) that is convenient in operation. For that reason, it was selected as primary circuit coolant in reactor SVBR-100 despite of its higher polonium radioactivity (by four orders greater).
- The measures for providing of radiation safety, which were developed upon mastering of that technology regarding to NSs, were efficient. That is proved by the fact that in an event of accidental coolant leaks, the radiation dose of the military and civilian personnel, who took part in eliminating of consequences, did not exceed the permitted sanitary level. Of course, polonium is a source of potential radiation hazard, and that should be accounted in the process of development and operation of NPP projects based on LBC cooled RFs.

4 Small and Medium Power Modular Reactors with HLMC (1)

- In recent years many countries are showing a growing interest in development of small and medium power (SMR) modular NPPs, which also include the NPPs based on RF SVBR-100. Less capital expenditures and shorter terms of construction are required for NPPs based on RF SVBR-100. Thus, the investment risks are lowering and attraction of private investments is becoming more possible.
- Actually, there are no any nuclear power sources in that power niche, though heat power plants (HPP) and heat electric plants (HEP) of such power capacity are producing the major part of electricity and virtually the whole quantity of thermal energy. However, at this point they are the main pollutants of the environment.

4 Small and Medium Power Modular Reactors with HLMC (2)

- Among over twenty SMR projects developed in different countries, the evolutionary projects based on traditional water technologies are the major ones. On consideration of the near future commercialization, the most real option is a project of floating NPP based on RF KLT-40C and further development of that project on the basis of advanced RF RITM-200.
- Within the SMR projects developed abroad there are some projects with HLMC. These are the following projects with LBC: CLEAR (Chinese People's Republic), PEACER and URANUS (Korea), HYPERION (USA), ENHS (USA), MYRRHA with accelerator (EU); with lead coolant: SSTAR (USA), ALFRED (Ansaldo, Italy), SEALER (Sweden). Recently Westinghouse Electric Company LLC has acceded to development works on HLMC cooled reactors.

4 Small and Medium Power Modular Reactors with HLMC (3)

- **The high safety level resulting from natural properties of HLMC (such as extremely high boiling point eliminating the necessity to provide excess pressure, chemical inertness in events of contacting with water and air) is eliminating the opportunity of explosions and fires in the reactor, which are followed by high radioactivity exhausts.**
- **Thus, it is assuring tolerance to the equipment failures, personnel's errors and malevolent actions that is especially viable when the NPPs are located in countries with a high level of terroristic threats.**
- **High safety of SMRs with HLMC makes possible their location in the centers of power consumption or close to the regions with realization of raw and mineral mining. Thus, there is no necessity in construction of expensive extended electric transmission lines. Moreover, the losses caused by transmitting of electricity to the long distances and transport expenditures for long-distance transportations of raw materials are reduced as well.**

4 Small and Medium Power Modular Reactors with HLMC (4)

- However, small and medium power NPPs, which should replace the HPPs, must meet the higher safety requirements, as, bearing in mind their function of heat supply, they must be located in close proximity to the cities.
- Besides meeting of the high safety requirements and level of technological readiness, the major restriction on the way of wide implementation of those NPPs in power engineering is difficulty in obtaining of the required value of LCOE (Levelized Cost of Energy) to the total amount of produced energy.
- The indicated index is introduced in International Project INPRO for the purpose to compare the competitiveness of nuclear and alternative energy sources.

4 Small and Medium Power Modular Reactors with HLMC (5)

- The highlighted difficulty is caused by a common law of increasing of the value of specific capital expenditures in construction of NPPs with lowering of power capacity of the plant, in contrast to HPPs on fossil fuel, for which the value of LCOE is mainly determined by fuel costs.
- At the same time, upon discounting, the capital expenditures made prior to starting of NPP implementation in commercial operation are growing, especially when the terms of construction are increasing and the current annual incomes from sales of power are decreasing.
- Due to a high level of inherent self-protection and with account of serial production, just the SMRs with HLMC, which are not burdened with large expenditures on safety providing, possess the advantages of modularity, are entirely factory manufactured and transported to the NPP site in readiness, have great opportunities to obtain the required values of LCOE, as compared with other types of RFs.

Conclusion (1)

1. **The highlighted difficulty is caused by a common law of increasing of the value of specific capital expenditures in construction of NPPs with lowering of power capacity of the plant, in contrast to HPPs on fossil fuel, for which the value of LCOE is mainly determined by fuel costs.**
2. **Slowdown of the paces of NP development and extension of economically available resources of natural uranium enable to consider the FRs with HLMC, which operate in the closed NFC in a mode of self-providing, as an option for the future NP. Those FRs cannot provide the short plutonium doubling time that is possible to obtain in the mastered fast sodium reactors. However, due to the natural properties of HLMC, in those FRs it is possible simultaneously to enhance safety and improve technical-economical parameters.**

Conclusion (2)

3. In the RFs with HLMC the amount of accumulated potential energy is minimal that makes possible realization of inherent self-protection and passive safety properties to a maximal extent and elimination of the reasons of severe accidents requiring the population evacuation. Those RFs are not intensifiers of external impacts and, therefore, the scale of destructions will be only determined by the energy of outside impacts.

4. Those type RFs will possess the robustness properties, which will provide their high sustainability not only in events of single failures of the equipment and personnel errors, but in events of deliberate ill-intentioned actions. Such properties of RFs with HLMC will make it possible to overcome the population radiophobia that has grown after the accident occurred at NPP Fukushima 1. And that is very important for establishing of large-scale NP and sustainable development.

Conclusion (3)

5. **The RFs with HLMC, which require a stage for their mastering when real experience in conditions of the operating NPP will be gained, can be used as follows:**
   1) **for construction of power units of large unit power, which cover a base part of load;**
   2) **for construction of SMRs operating in local or regional power systems and generating thermal power along with electricity. Such NPPs will make possible replacement of coal HPPs, which are the major pollutants of the environment.**

THANK YOU VERY MUCH

FOR YOUR ATTENTION

SVBR-100 Project for SMR market

V.V.Petrochenko, S.A.Grigoriev, A.V.Dedul,
O.G.Komlev, A.V. Kondaurov, G.I.Toshinsky

Heavy Metal Liquid Coolants in Nuclear Technology
October 9-11, 2018 Obninsk, Russia

CONTENT*)

*) These materials were prepared for presentation at Heavy Metal Liquid Coolants in Nuclear Technology Conference (HLMC-2018) (October 09-11, 2018, Obninsk, Russia), and shall not be considered as an offer and doesn't lead to any obligations to AKME-engineering

PROJECT STATUS

GOALS AND MILESTONES

Goals	• Development of small modular multifunctional nuclear reactor module (SVBR-100, 100 MWe – per unit) technology (including FOAK NPP construction with SVBR-100 reactor unit at the Dimitrovgrad site), and • Commercialization of the technology for domestic and foreign markets
Deliverables	• Ready for location and operation nuclear reactor module, mostly produced and assembled on the factory with possibility to be transported by the railways, vehicles or sea. • Customized NPP project design with capacity corresponding to the local needs (100-500 MW or more), multipurpose applications (electricity, heat, steam, desalinated water), flexible operating modes (load following and weak net systems) that could be placed near industrial and residential areas.
Major milestones	completion of R&D, design and construction documentation, obtaining licenses for location and construction of the first of a kind unit (‘pilot’ unit) SVBR-100 deployment, Dimitrovgrad (Ulyanovsk region, Russia) fist references of industrial operation serial supplies reactor/NPP worldwide

NPP PROJECT WITH SVBR-100 PILOT UNIT CONSTRUCTION

Prototype nuclear plant is to be constructed in Dimitrovgrad, Ulyanovsk region near the Russian State Atomic Reactor Research Institute

FIRST OF A KIND SVBR NPP PARAMETERS:

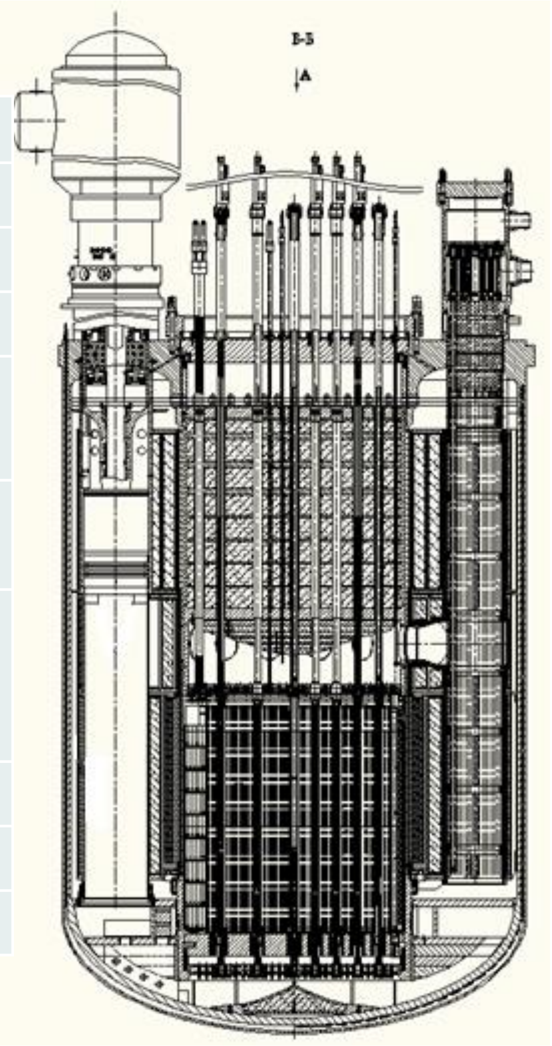
EVENTS BEHIND:

- Positive resolution of public hearing
- Authorized site (signed rental agreement)
- Obtained license a license of RTN for pilot NPP placement

- 1 unit
- co-generation mode
- Installed electric capacity: 100 MW(e)
- Heat capacity: 100 Gcal/h
- Efficiency factor: ~36%
- Working time: 50 years
- ICUF*: ~90%

SVBR-100 REACTOR CHARACTERISTICS

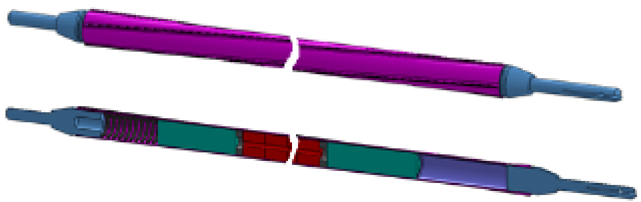
Parameter	Value
Reactor thermal power, MWt	280
Pressure of generated steam (saturated), MPa	7
Steam flow rate, t/hour	580
Primary circuit coolant:	44,5% Pb + 55,5% Bi
Temperature of primary circuit coolant at core inlet/outlet, °C	335 / 477
Fuel: type average enrichment on U-235,% maximal enrichment on U-235,%	UO_2 16,7 19,5
Core lifetime, eff. hours	50 000
Time between refueling, year (one-stage refueling)	7
Dimensions of reactor vessel (diameter/height), m	4,40 / 12,4



REACTOR DESIGN STATUS (1/3)

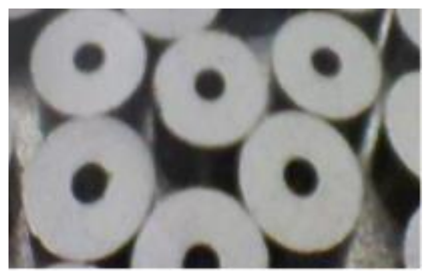
Basic design documentation for the core elements, main circulation pump, primary coolant system and reloading equipment were issued.

- Ribbed fuel element cladding
- Modified uranium oxide
- Impermeable fuel element design



Modified uranium oxide:
- Increased density
- enhanced thermal conductivity
- These material properties were justified by BOR-60 and IVV-2 reactor experiments as well as by comprehensive tests conducted by Kurchatov center

Pilot batch of full scale cladding (fuel element, external reactor neutron sources) was manufactured by 2013



Fuel pellets were manufactured by fabrication plant

Full scale fuel elements were manufactured by fabrication plant

Model neutron sources (successfully tested in BOR-60)

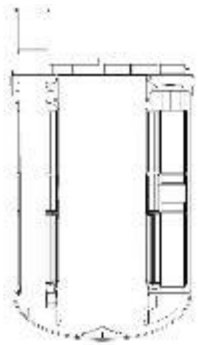
Absorber rod models for testing in BOR-60

REACTOR DESIGN STATUS (2/3)

Basic design documentation includes all key design decisions for SVBR-100 reactor

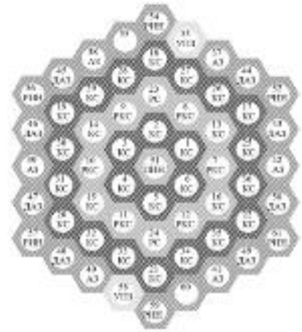
Reactor

- Reactor vessel with in vessel structures is intended for equipment placement and forms a coolant circulation circuit



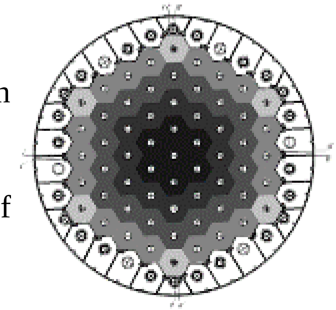
Core

- Average fuel burnup ~65 MWt days/ U kg
- Core lifetime, not less than 50000 eff. hours.



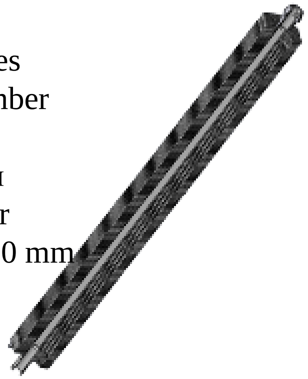
Reflector

- Reduce of neutron leakage
- Core boundary
- Thirty elements of five types



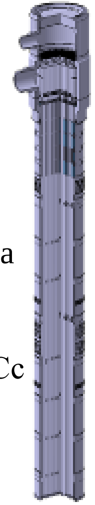
Fuel Assembly

- Fuel UO_2
- 61 fuel bundles
- Fuel rods number ~200
- Height ~2,4 м
- Dimension for "wrench" ~200 mm



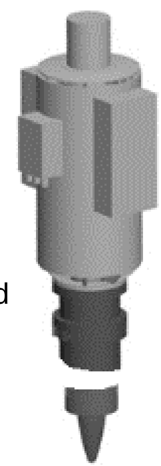
Steam generator module

- Bayonet tubes type heat exchanger
- Pressure - 7 MPa
- Temperature of steam-water mixture ~290 °Cc



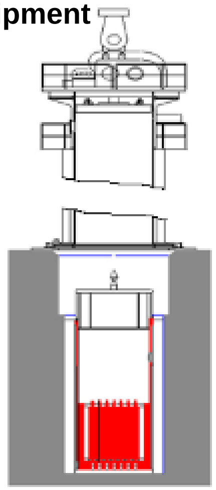
MCPU

- The discharge part is installed in the reactor vessel
- The electric motor is located on the reactor cover



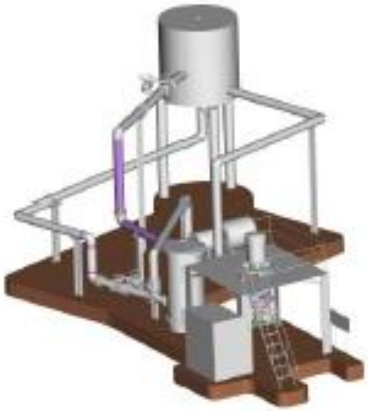
Refueling equipment

- Core assembly installation into reactor
- Control rods installation
- Dismantling of control rods drives
- Unloading of SF bundles from the reactor
- The reactor block load/removal



REACTOR DESIGN STATUS (3/3)

Basic design of the primary circulation pump with electric drive and control system was developed



- The model flow section of the primary pump was tested on water
- The necessary flow characteristics are obtained

The test facilities for the elements of the primary pump and full-scale pump testing

- The first stage of large hydraulic test facility was put into operation
- The first stage of the model bearing block testing was performed

PROJECT REVIEW

Project documentation were reviewed by national regulators (Rostechnadzor, SEC NRS, Rosprirodnadzor) for the following points:

- Sufficiency of the regulatory framework for FOAK NPP licensing
- Sufficiency of R&D program and safety concept
- Licensing

Industrial expertize followed by considerations of SC Rosatom’s Scientific and Technical Councils on the topics:

- Optimization possibilities for FOAK NPP
- Sufficiency of R&D program and safety concept
- Possibilities to get competitiveness

- Regulatory framework is sufficient for FOAK NPP licensing (with some regulations to be reviewed)
- Some additions for R&D program and safety concept were suggested
- Some recommendations for FOAK NPP optimization and provision of NOAK NPP competitiveness were formulated
- The absence of technical obstacles for further development of the Project was stated
- License for the FOAK NPP placement was granted

WORLD POWER SYSTEM DEVELOPMENT TRENDS. CONSEQUENCES FOR NUCLEAR POWER

SOURCES OF INFORMATION

World Energy Outlook, **International Energy Agency**, 16 November 2017.

BP Statistical Review of World Energy, 67th edition, June 2018.

New Energy Outlook 2018, **Bloomberg NEF**, 2018.

Shell Scenarios SKY, Meeting the Goals of the Paris Agreement, Shell International B.V., 2018

International Energy Outlook, **US Energy Information Administration**, September 14, 2017.

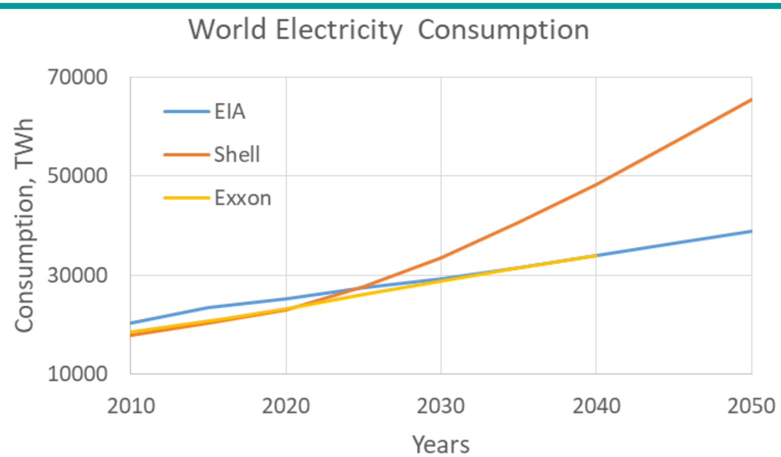
2018 Outlook for Energy: A View to 2040, **ExxonMobil**, 2018.

IRENA (2018), Global Energy Transformation: A roadmap to 2050, International Renewable Energy Agency, Abu Dhabi.

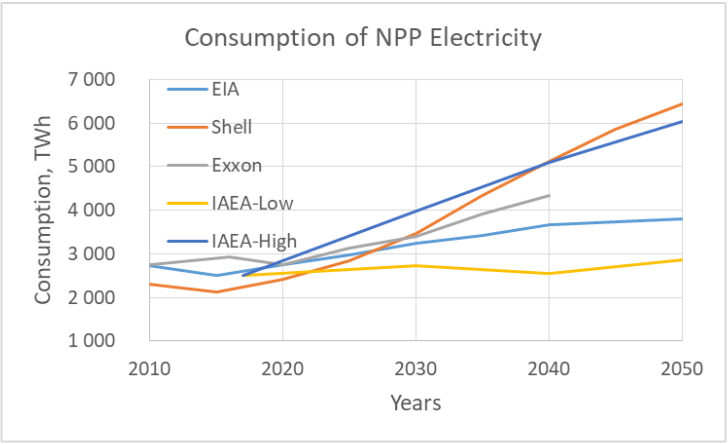
National Renewable Energy Laboratory. (2012). Renewable Electricity Futures Study. Hand, M.M.; Baldwin, S.; DeMeo, E.; Reilly, J.M.; Mai, T.; Arent, D.; Porro, G.; Meshek, M.; Sandor, D. eds. 4 vols. NREL/TP-6A20-52409. Golden, CO: National Renewable Energy Laboratory.

Renewables 2018, Global Status Report, **Renewable Energy Policy Network** for the 21st Century, REN21, 2018.

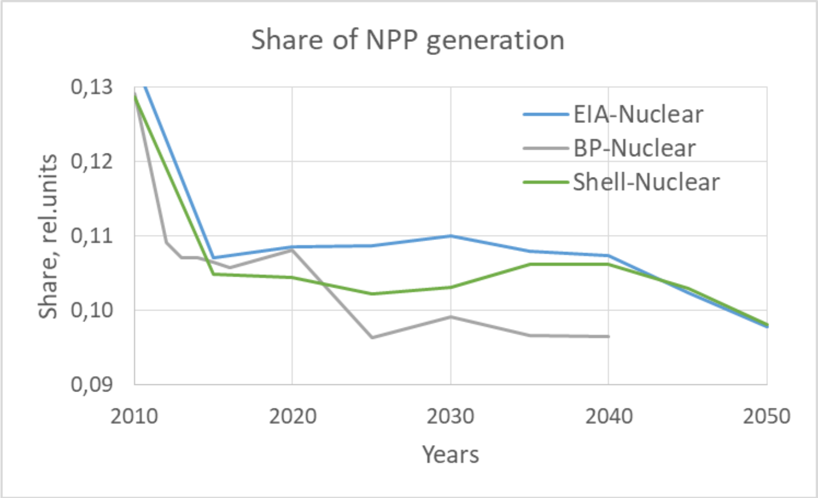
ELECTRICITY PRODUCTION



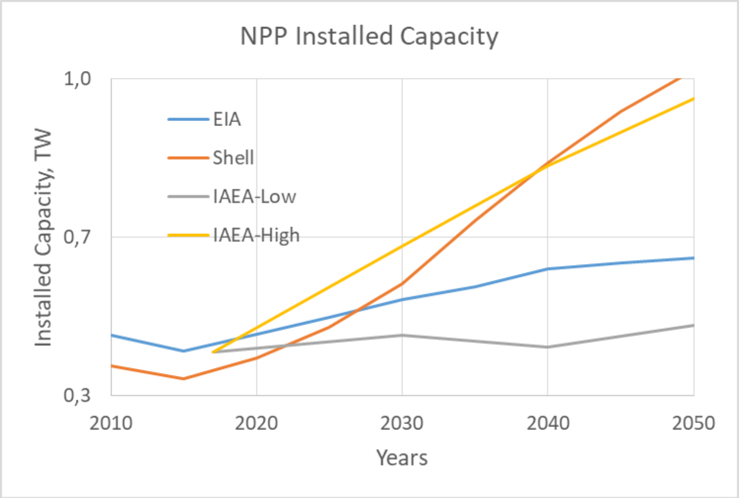
Electricity consumption increases



Indefinite Nuclear Power development

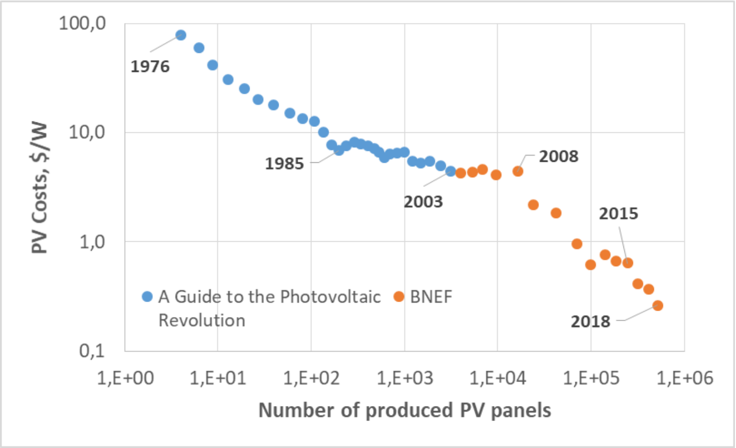


Nuclear Power does not generate proper share of electricity (as it could be able according to energy stored in U and Th)

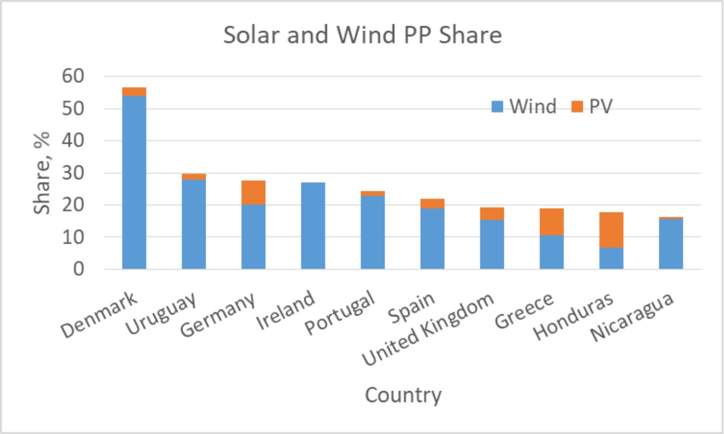


Nevertheless, future Nuclear Power will be Large scale one

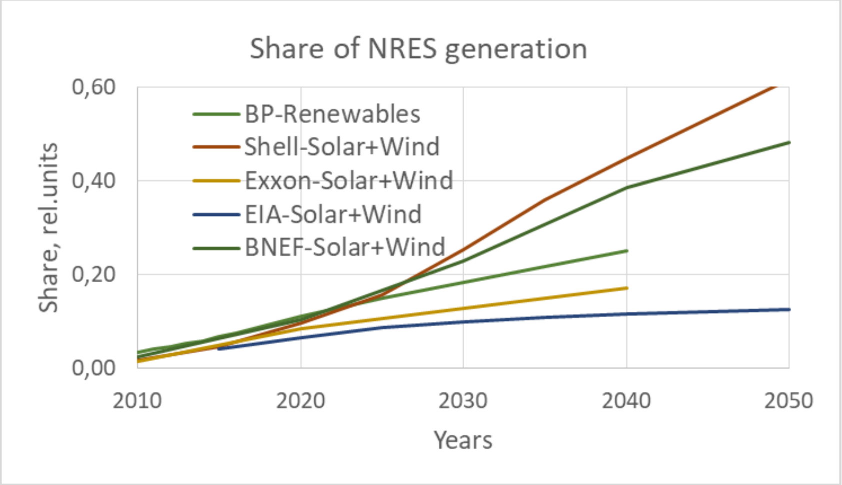
CHANGE IN ELECTRICITY GENERATION MIX



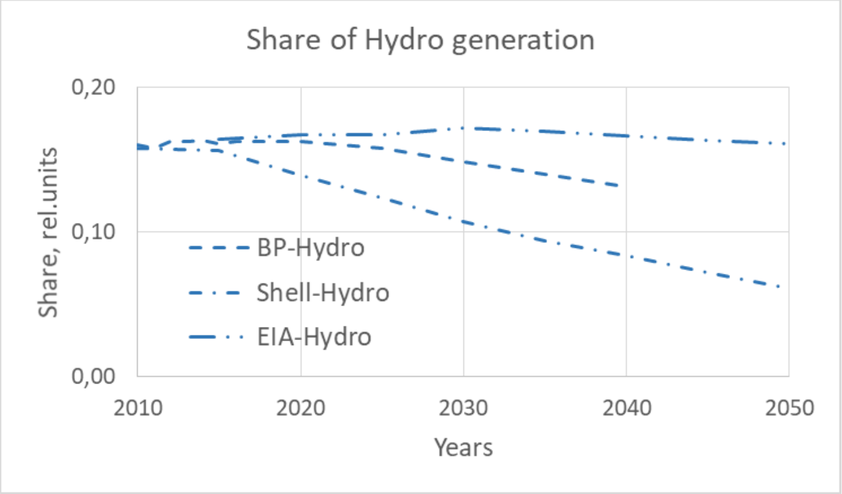
Significant Cost Reduction of RES



Large RES generated Electricity Share

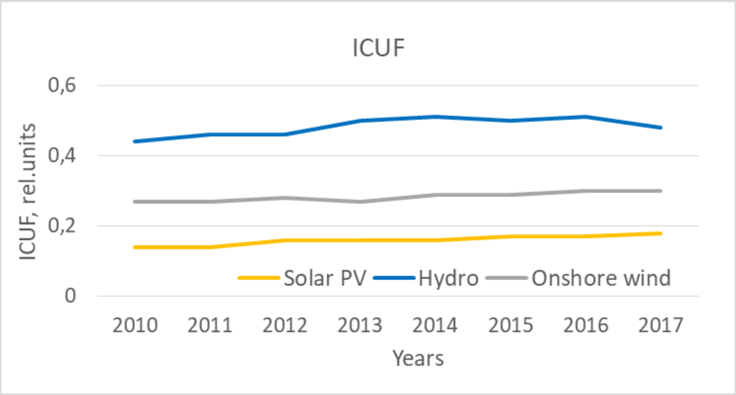


RES Share should be about 50% to meet Paris Climate Agreements

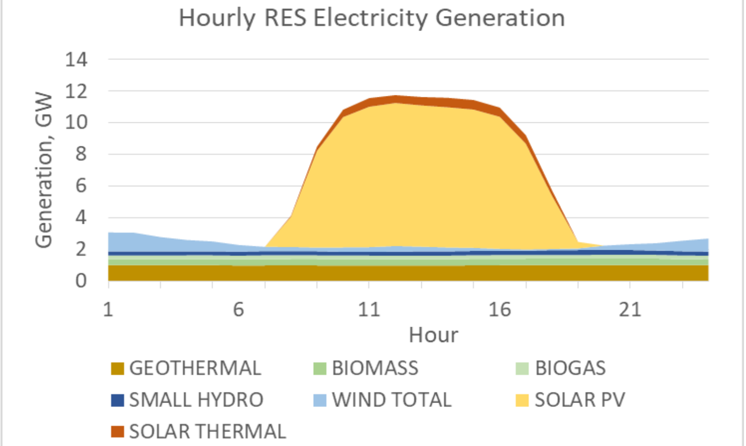


Hydro Share will not rise significantly

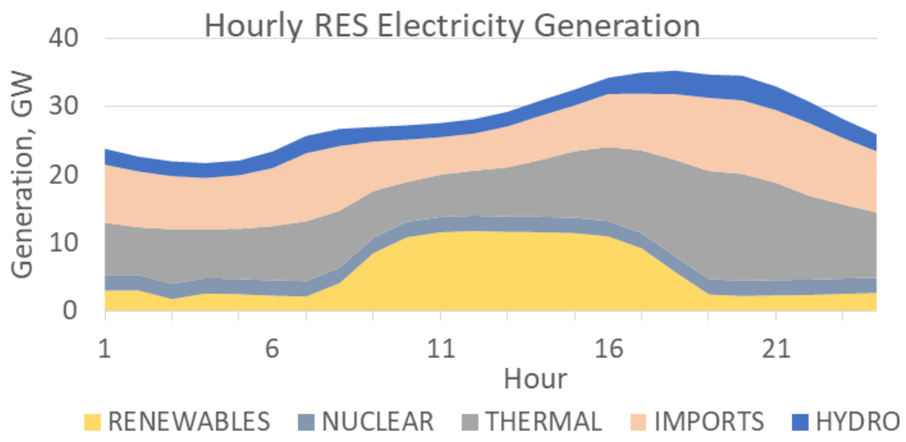
RES FEATURES THAT AFFECT POWER GENERATION MIX



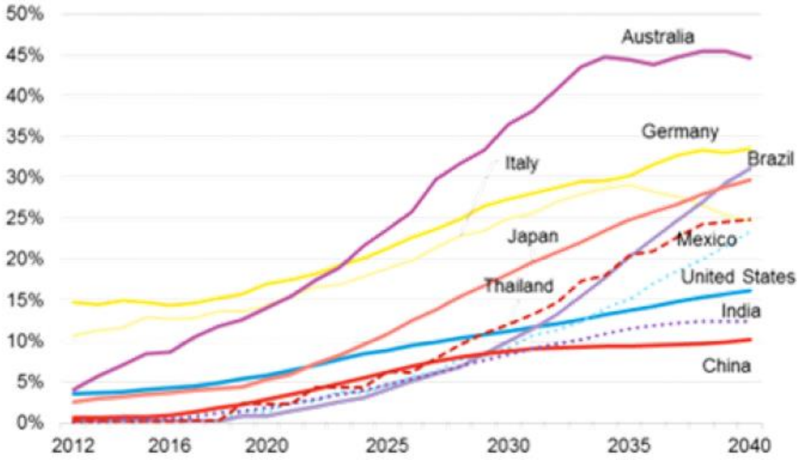
Rather Low installed Capacity Utilization Factor for RES



Variability and uncertainty for RES

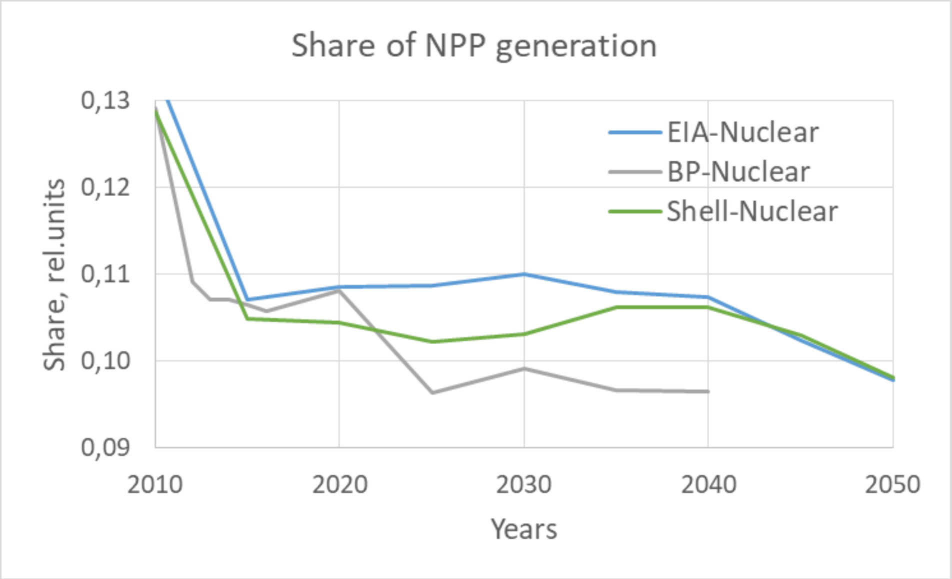


Flexibility of Power System is provided by imports and Thermal PP



Decentralization of Power System

NEXT GENERATION REQUIREMENTS AND SVBR NPP

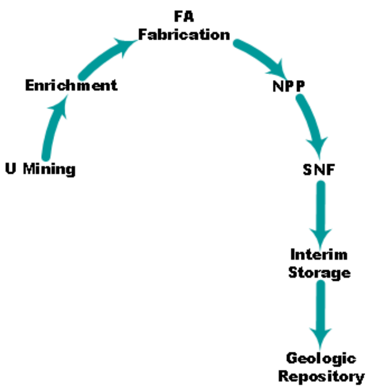


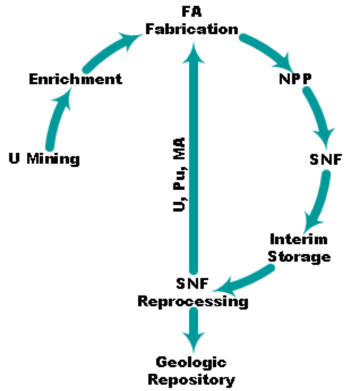
MEETING GEN-IV REQUIREMENTS

Generation IV goals	SVBR-100 solution
Sustainability	
… sustainable energy generation … and effective fuel utilization…	Fast spectrum reactor, U-Pu и U-Th closed fuel cycle, high fuel bur-up, different fuel types (oxide, nitride, carbide)
… minimize and manage their nuclear waste …	
Safety and reliability	
… excel in safety and reliability …	Absence of severe consequences under realizable accidents Inherent safety features Passive safety systems Design based accidents do not lead to core damage Emergency response area is bounded by NPP site
… very low likelihood and degree of reactor core damage …	
… nuclear energy systems will eliminate the need for offsite emergency response	
Economics	
… a clear life-cycle cost advantage over other energy sources	Life cycle cost (LCOE) is comparable to large-scale NPP (60-70 $/MWh, discount rate 7%)
… a level of financial risk comparable to other energy projects	Operation experience of prototypes and FOAK development
Proliferation resistance and physical protection	
… a very unattractive … for diversion or theft of weapons-usable materials, and provide … protection against acts of terrorism	235-U enrichment is less than 20% Sensitive neutronics of small reactor core Long core life time Impossibility to get prompt criticality Impossibility to withdraw all available reactivity

MEETING GEN-IV REQUIREMENTS. FUEL CYCLE

OPEN OR CLOSED NFC





ABILITY TO USE A NUMBER OF NF TYPES

$(U\text{-}Pu)O_2$

UN

$(U\text{-}Th)O_2$

UO_2

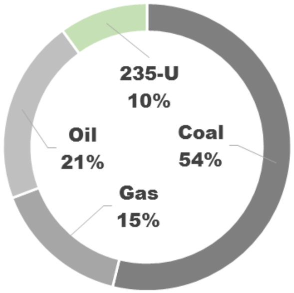
(U-Pu)N

UC

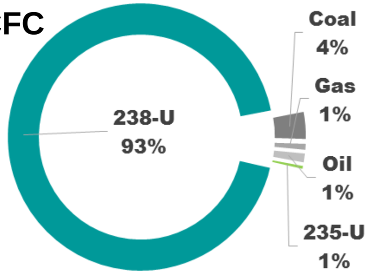
$(U\text{-}Pu\text{-}MA)O_2$

(U-Th)N

SUSTAINABLE ENERGY PRODUCTION

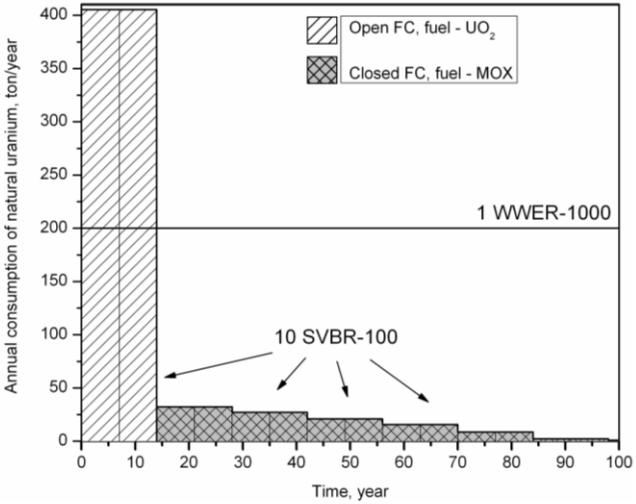


CFC



Lifetime number	1-2	3-4	…	13-14	15-16
Enrichment of added U, %	16	18	…	1,4	0,7
Used natural uranium, t	284	23	…	1,5	0,5
Breeding ratio	0,84	0,85	…	0,97	0,99

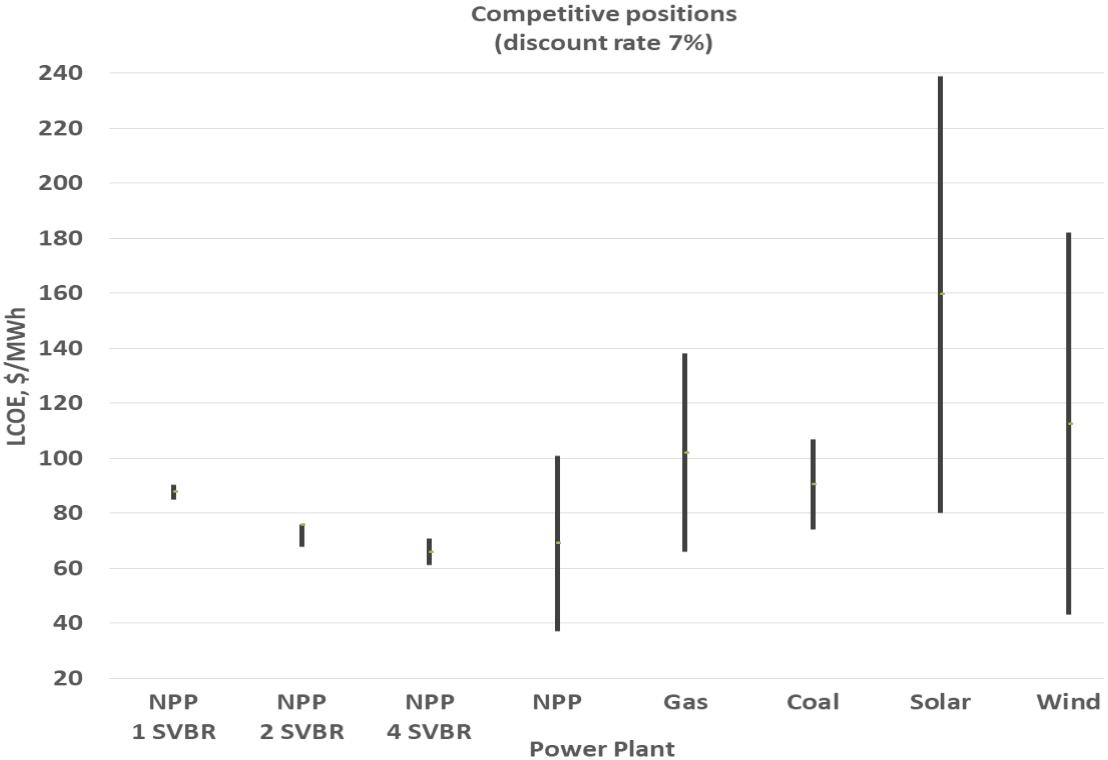
U CONSUMPTION



MEETING GEN-IV REQUIREMENTS. SAFETY

	TMI	Chernobyl	Fukushima	SVBR	SVBR design features
Coolant evaporation	●			Not possible	t_b = 1670ºC
Inability to remove Fuel afterheat	●		●	Not possible	Heat removal by natural circulation of LBC with heat transfer to tank water + 72 hours of non-interference
Growth of temperature in the reactor core	●		●	Not possible	
Fuel rods zirconium casing interaction with water		●	●	Not possible	No zirconium (steel casing)
Hydrogen extraction & explosion		●	●	Not possible in significant quantities	No zirconium (steel casing)

MEETING GEN-IV REQUIREMENTS. COMPETITIVENESS



Parameter	NOAK		
	1 RU	2 RU	4 RU
Construction time, month	42-45	45-48*	51-57*
LCOE, $ / MWh	85	68	61

* Construction and commissioning of the second (and each subsequent) reactor into operation on a separate schedule (at least 9 months).

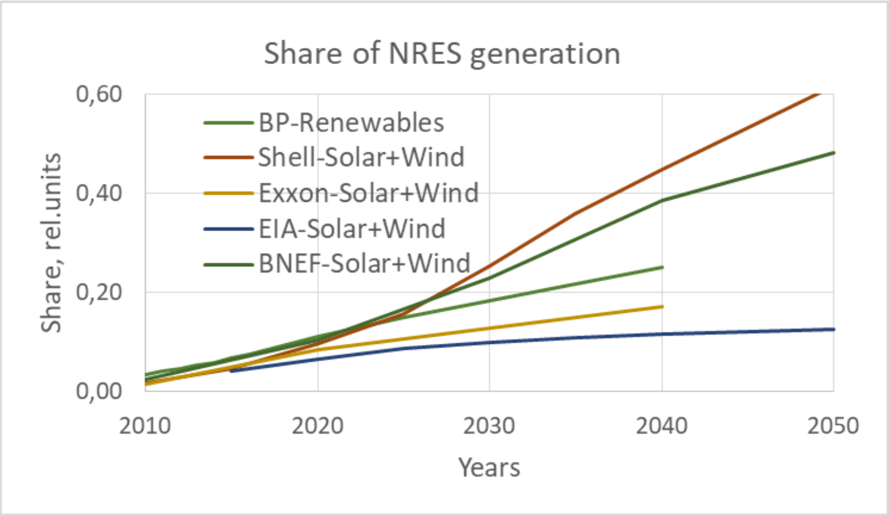
Figure shows LCOE ranges from the report *) for

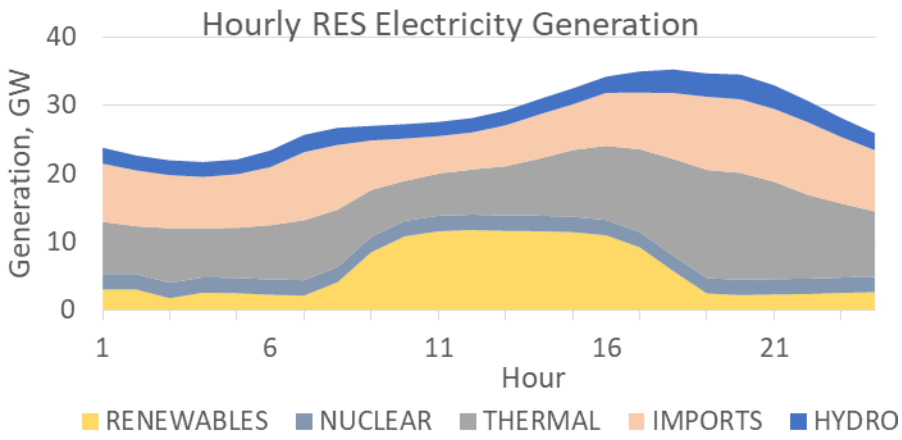
- the large capacity NPP (denoted as “NPP”),
- natural gas-fired power plants (denoted as “Gas”),
- coal-fired power plants (denoted as “Coal”),
- solar power plants (denoted as “Solar”)
- on-shore wind power plants (denoted as “Wind”)

Minimal LCOE values of SVBR NPP on this figure present LCOE values for SVBR NOAK NPP operated in combined heat and power mode
Maximal LCOE values present LCOE values for SVBR NOAK NPP operated in power mode

*) LCOE data and model assumptions were accepted from «Projected Costs of Generating Electricity», IEA, NEA, OECD, ISBN 978-92-64-24443-6, 2015

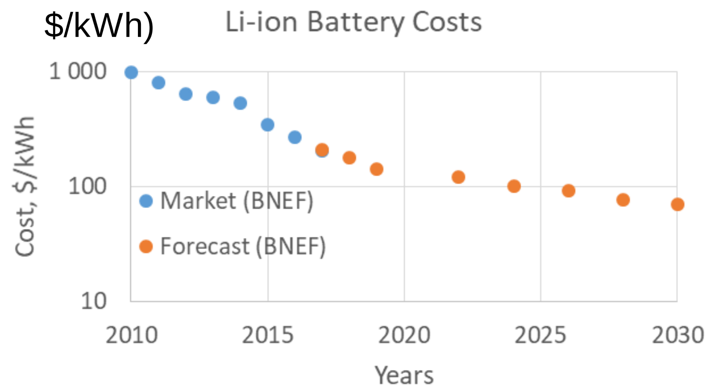
POWER SYSTEM INTEGRATION. POSSIBILITIES FOR SVBR NPP





POSSIBILITIES TO PROVIDE POWER SYSTEM FLEXIBILITY

- Grid infrastructure development
  - High cost
- Energy storage utilization
  - Limited use (pumped hydro), High cost (~ 300 $/kWh)



- Demand side integration
  - Limited use

Necessity in Dispatchable generation

- Dispatchable generation
  - Hydro (lead to decline installed capacity utilization factor)
  - Fossil fuel PP (decline decarbonization efficiency)

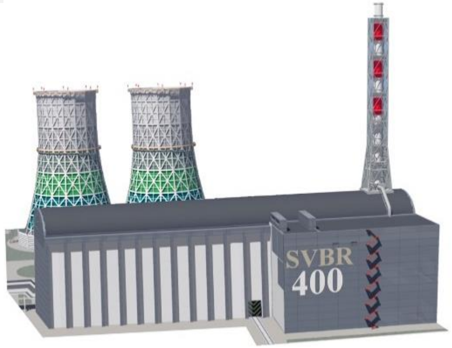
NPP with abilities:

- Load follow operational mode
- To operate in decentralized power system
- Multipurpose application

- Up to 2% $N_{НОМ}$/min
- Weak grids
- Heat, des.water, steam
- Energy cluster

MULTIPURPOSE APPLICATION

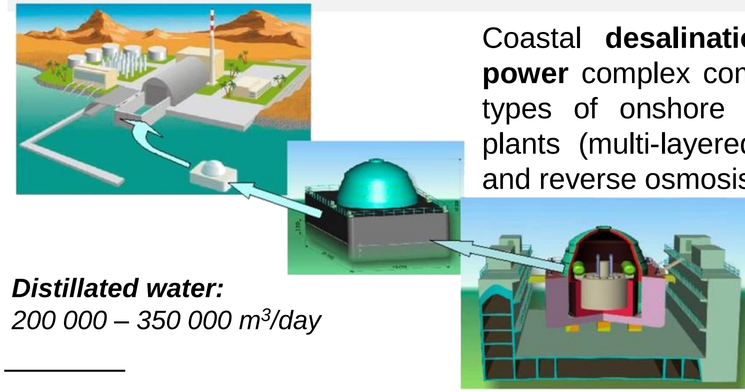
FLEXIBLE CAPACITY FOR LOCAL AND REMOTE AREAS: GRADUAL BUILD-UP



Construction of **small and medium dual application** complexes (power and heat) in local and remote areas with poor energy infrastructure

Preliminary design of dual application complex was developed by Atomenergoproekt, OKB "GIDROPRESS" and IPPE

DESALINATION



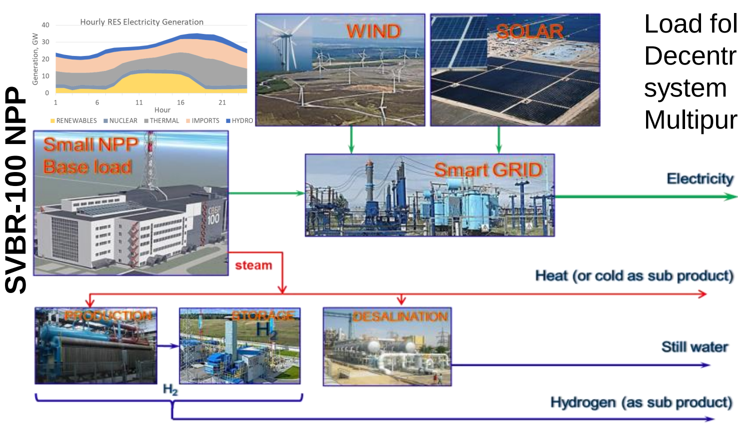
Coastal **desalination nuclear power** complex comprising two types of onshore desalination plants (multi-layered distillation and reverse osmosis).

Distilled water:
200 000 – 350 000 m³/day

Shore-based nuclear desalination power complex based on a transportable reactor unit with a SVBR-75/100 reactor, Atomic Energy. 2005. T. 99. № 6

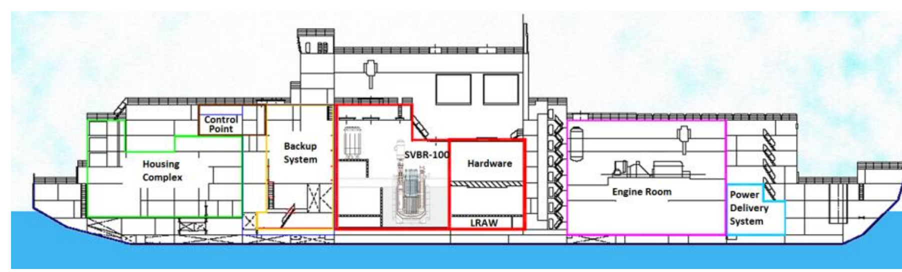
HYBRID (CLUSTER FORMAT)

SELF-SUFFICIENT ENERGY SYSTEMS WITH NUCLEAR OPTION AS BASE LOAD GENERATOR



Load follow mode
Decentralized power system
Multipurpose application

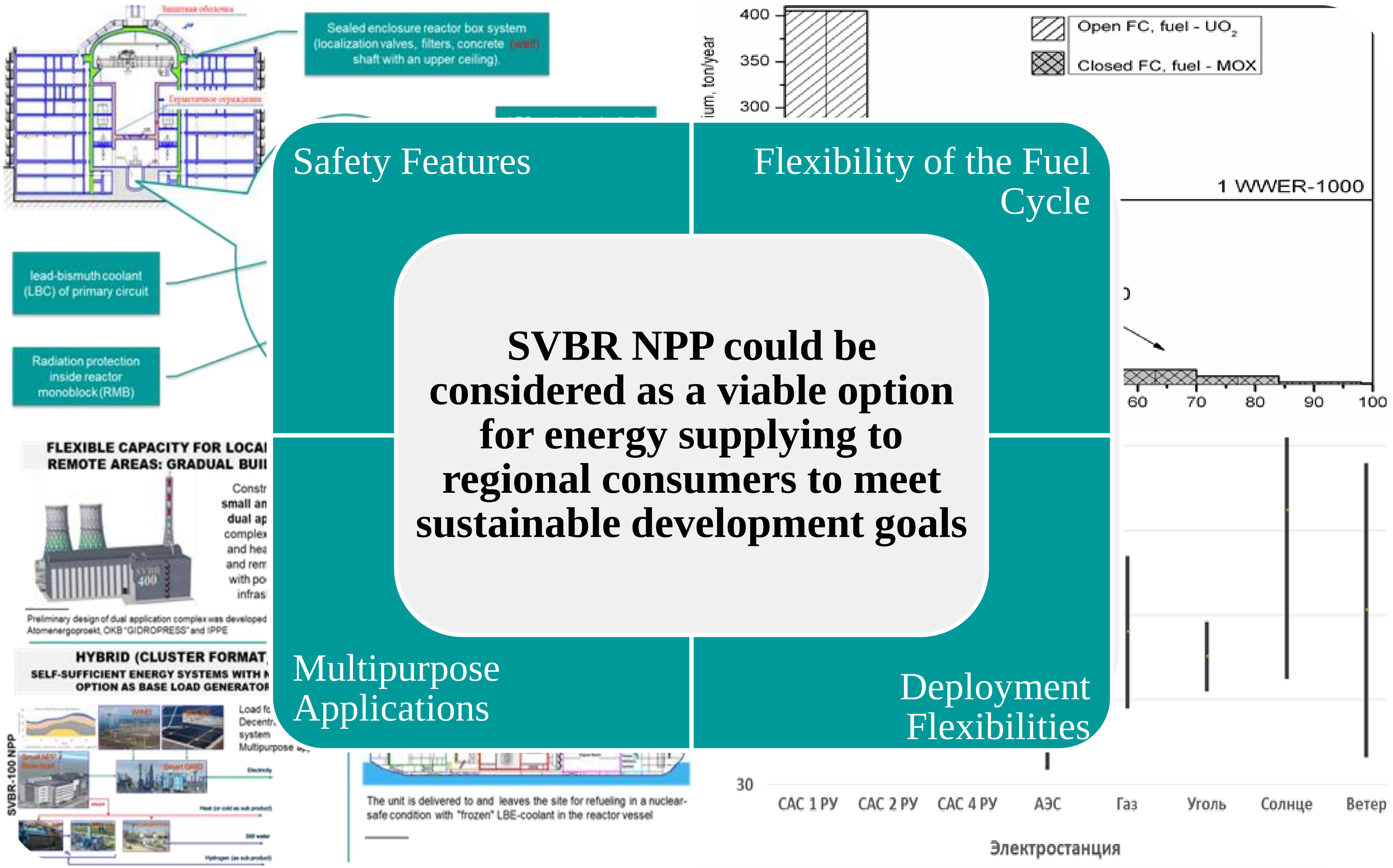
FLOATING POWER UNIT WITH SVBR-100



The unit is delivered to and leaves the site for refueling in a nuclear-safe condition with "frozen" LBE-coolant in the reactor vessel

Preliminary design of 50 MW Floating power unit "CRUIZ-50" was developed by Malashit, OKB "GIDROPRESS" and IPPE

CONCLUSION



SVBR NPP could be considered as a viable option for energy supplying to regional consumers to meet sustainable development goals

Generation-IV Lead Fast Reactor Activities

Alessandro Alemberti

EURATOM / Ansaldo Nucleare

on behalf of

GIF - LFR

provisional System Steering Committee

Outline

- ***The Lead cooled Fast Reactors in GIF***
- ***Activities of the LFR provisional SSC (pSSC)***
- ***Status of LFR R&D activities in MoU Countries***

The Lead-cooled Fast Reactor in GIF

GIF LFR provisional System Steering Committee

MoU Signatories	*Observers*
EURATOM	*People's Republic of China*
Japan	*United States of America*
Republic of Korea	
Russian Federation	

There has recently been a change in the membership of the GIF LFR pSSC.

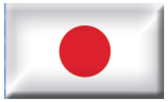
The Lead-cooled Fast Reactor in GIF

GIF LFR provisional System Steering Committee

MoU Signatories

EURATOM

Japan



Republic of Korea

Russian Federation

United States of America

Observers

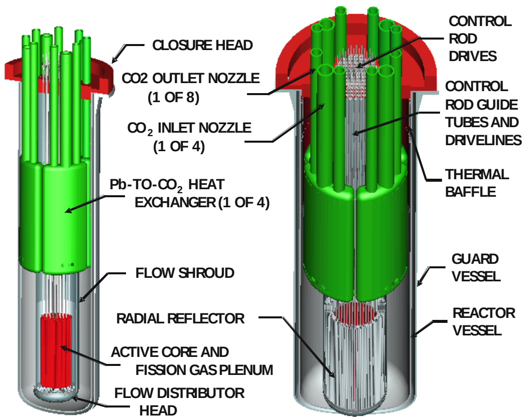
People's Republic of China

signed on 8 February 2018

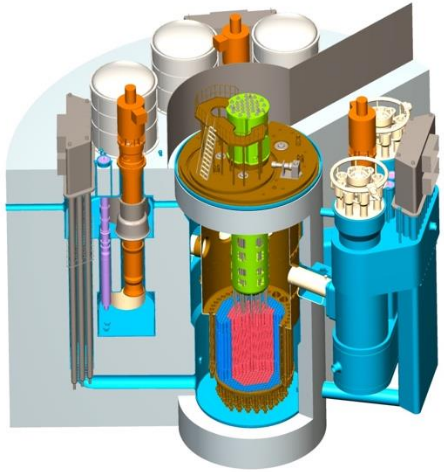
The Lead-cooled Fast Reactor in GIF

Reference systems for the GIF LFR pSSC activities

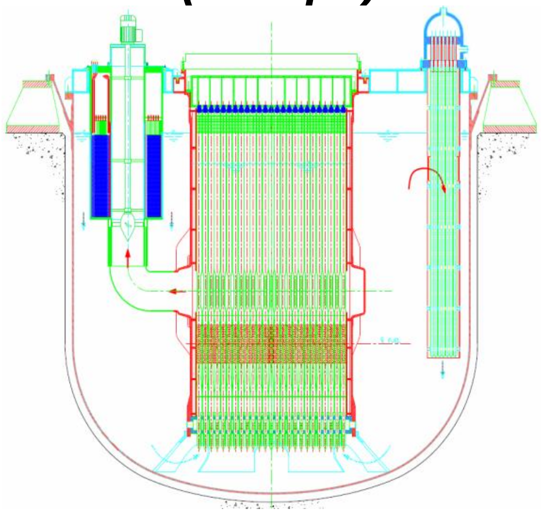
SSTAR	***BREST-OD-300***	***ELFR***
(USA)	***(Russia)***	***(Europe)***



Small-sized, battery type reactor with long core life



Medium-sized, «pools-in-loop» type reactor with associated closed fuel cycle facilities



Large-sized, integral type reactor for closing of the fuel cycle

Key design parameters of the GIF LFR Reference Systems

Parameters	ELFR	BREST-OD-300	SSTAR
Core thermal power [MW_{th}]	1 500	700	45
Electrical power [MW_e]	**600**	**300**	**20**
Primary system type	**Pool**	**Pool**	**Pool**
Core inlet T [°C]	400	420	420
Core outlet T [°C]	480	535	567
Secondary cycle	**Superheated steam**	**Superheated steam**	**Supercritical CO_2**
Net efficiency [%]	42	43.5	44
Turbine inlet pressure [bar]	180	170	200
Feed temperature [°C]	335	340	402
Turbine inlet T [°C]	450	505	553
Fuel	**MOX**	**nitride**	**nitride**

pSSC Main activities

- **LFR System Safety Assessment (SSA):**

  SSA was thoroughly revised taking into account comments received from RSWG

- **LFR Safety Design Criteria (SDC):**

  SDC were thoroughly revised following comments received from RSWG and US
  Document was also updated following the IAEA SSR 2/1 (rev. 1) version (2016)

- **LFR Safety Design Guidelines (SDG):**

  LFR SDG will be developed after SDC finalization

- **Contribution to the 2018 update of the GIF R&D Outlook Report**

- **White Paper on the LFR PRPP aspects is currently being updated**

- **LFR pSSC active in the GIF Task Force on Research Infrastructures**

- **Several papers at the GIF Symposium 2018 (PARIS 16-17 Oct. 2018)**

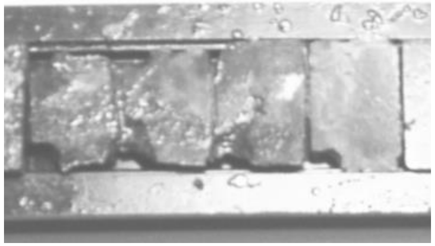
- **LFR White Paper on safety:**

  Final version of the White Paper on safety available to the public on GIF web-site

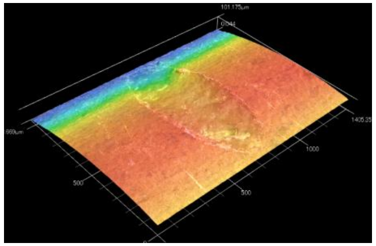
Status of LFR R&D activities in MoU Countries/Entities

Japan

Japanese activity centered on Heavy liquid metal technology



Severe corrosion-erosion
In flowing Pb-Bi



Fretting corrosion

➢ **<u>Material compatibility</u>**

Corrosion-Erosion, Oxidation corrosion, Fretting corrosion

Excellent corrosion resistance
of Al-rich steel in flowing Pb-Bi

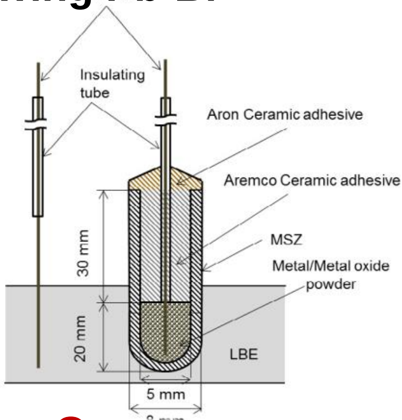
➢ **<u>Development of corrosion resistance materials</u>**

Al-rich steel, Ceramic materials, Ceramic coatings

➢ **<u>Development of oxygen control system</u>**

Oxygen sensor, Gas injection system, Mass exchanger, Electrochemical impedance spectroscopy

High-purity Pb alloy

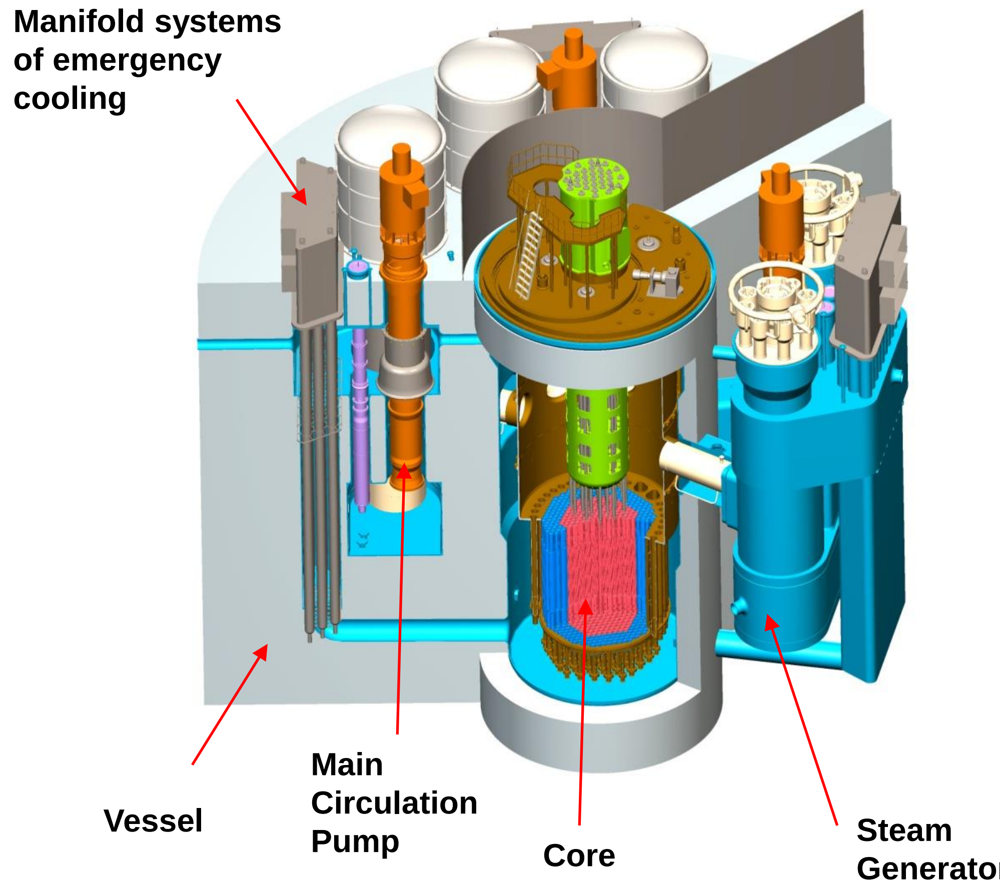


Oxygen sensor

The BREST-OD-300 Lead-cooled Fast Reactor

GIF Road Map based on BREST schedule/advancement

- Power: 700 MW_{th}, 300 MW_e
- Core diameter: 2.4 m
- Core height: 1.1 m
- Core fuel: (U+Pu+MA)N
- Fuel inventory: 20.6 t
- Coolant temperature (inlet/outlet): 420˚C/535˚C
- Maximum cladding temperature: 650˚C
- Efficiency: 43.5%
- Core breeding ratio (CBR): ~ 1



Key technical attributes include multi-layer metal-concrete reactor vessel, and collocated fuel manufacturing and reprocessing

Republic of Korea

Summary

New Focus	• Demonstrate load-following capability for marine propulsion & hybrid power • Materials R&D to eliminate refueling during MMR lifetime (>30 years)
Physical model establishment	• URANUS load-follow has been modeled by MARS-LBE and TraSSAM
Experimental investigation	• PILLAR, URANUS mock-up, is designed with hydrodynamic scaling law (1/200) • System integral behaviors especially in pool configuration are tested
Numerical validation and modeling	• MARS-LBE is validated with natural circulation experimental results on PILLAR for steady state and transient conditions
Analytical model development & assessment	• TraSSAM, a reactor dynamics simulation model for passive SMR has been developed and validated against MARS-LBE • Transient analysis results show that URANUS, the passive LBE-cooled SMR can follow 50% power increase in 4 minute with full stability

Future work

Experimental investigation	• Comparison of very fast transient experiment and model • Ramp rate vs. nuclear fuel and steam generator water-level stability: EdF PWR power changes 80% in 30% (the worst case limit for URANUS)
Further study on passive SMR simulation model	• Balance of plant (BOP) design and Fuller Simulation • Al-containing Corrosion-resistant Alloy under Development • Pilgering of Functionally Graded Composite in Progress

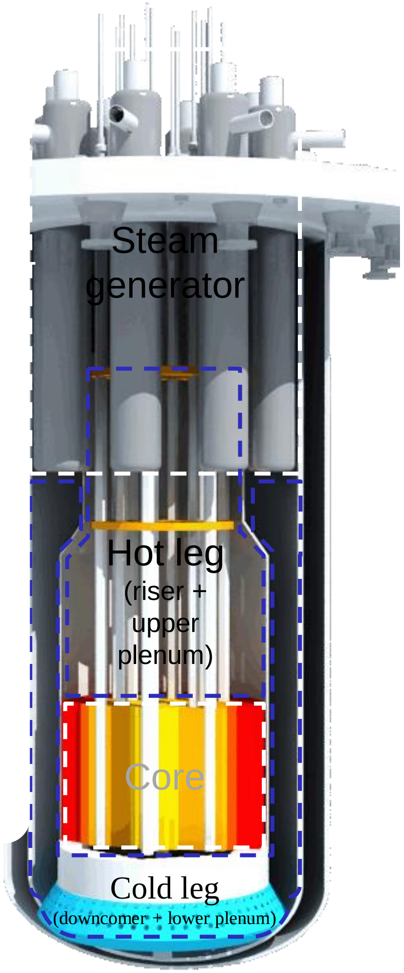
LWR

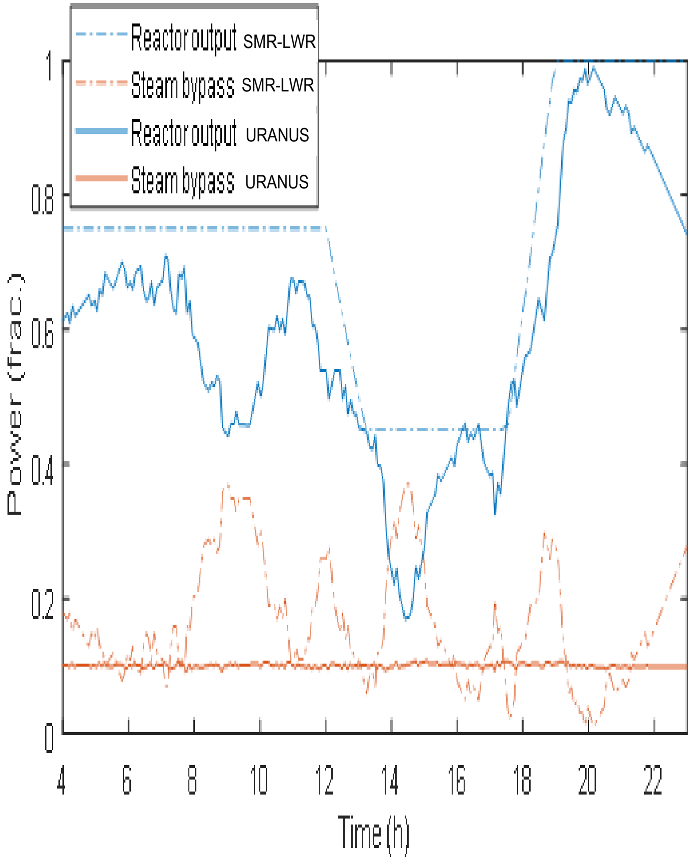
Micro Modular Reactor state-space model : TraSSAM

- ***MMR: divided into four lumps/calculation nodes***

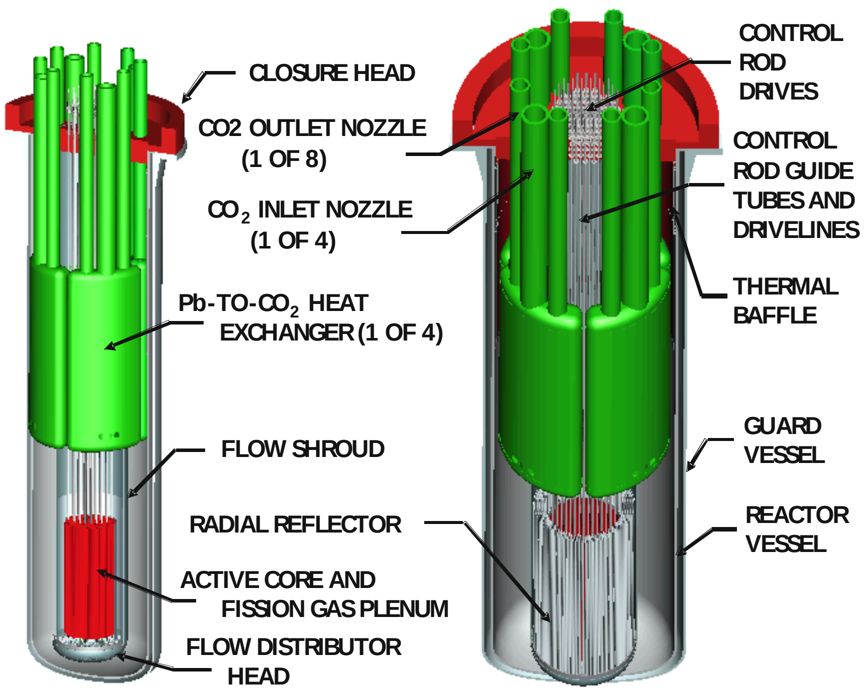
- **Three-region moving boundary S/G formulation**
  - **Flow inside the OTSG**
  - **Subcooled feedwater**
  - **No axial heat conduction**
  - **Secondary pressure constant**
  - **Two-phase region in thermal equilibrium**

- **Critical flow assumption on steam outlet**
  - **Steam flow rate is proportional to steam pressure**





The Small Secure Transportable Autonomous Reactor (SSTAR)



SSTAR is a small natural convection fast reactor of 20 MW_e / 45 MW_{th}, that can be scaled up to 180 MW_e / 400 MW_{th}

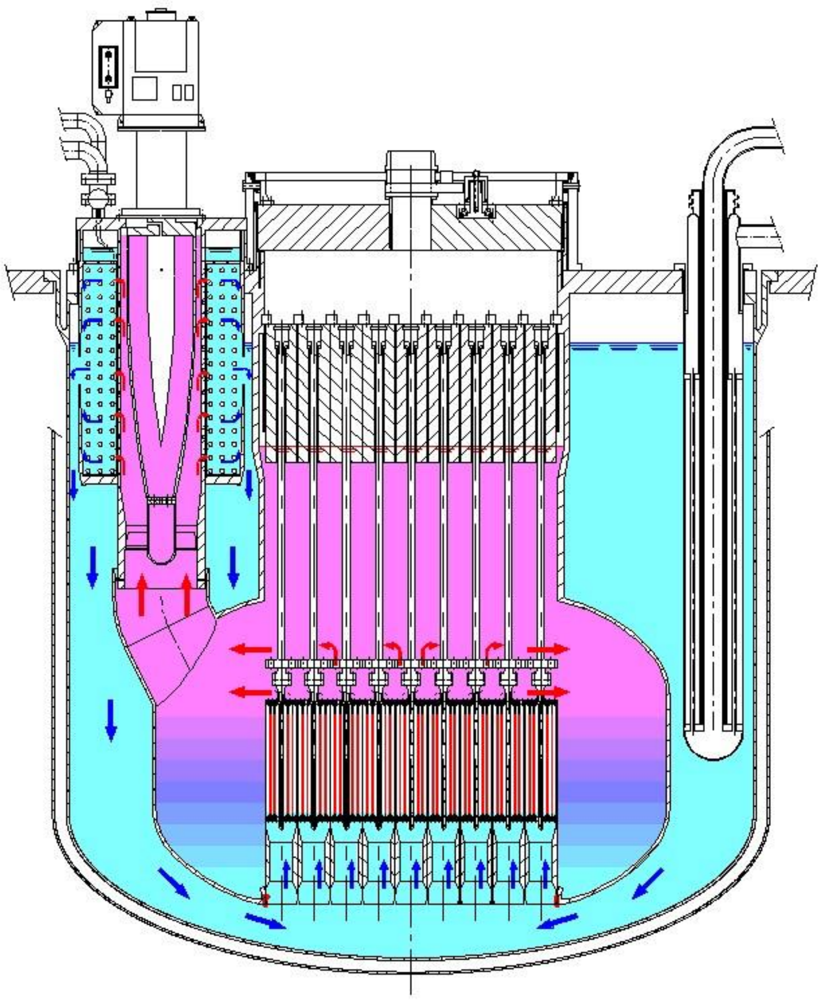
The compact active core is removed by the supplier as a single cassette and replaced by a fresh core (increased proliferation resistance)

Key attributes include advanced power conversion system (S-CO_2), use of natural convection cooling and a long-life core in a small, modular system

New Developments

- **The SSTAR system remains a legacy system**, little additional work being done since completion of its conceptual design
- **More recent developments include the US industrial involvement in three LFR initiatives:**
  - **Hydromine AS-200**
  - **Westinghouse LFR**
  - **Columbia Basin Consulting Group (CBCG) LBE-cooled SMR**
- Additionally, an ongoing **US-EU INERI project** is considering the possible role of a **small LFR in powering an assured microgrid**
- Most important, the **signature of the LFR-SSC MoU by DOE took place in February 2018**

Hydromine's AS-200 concept



The Hydromine AS-200 concept is a **highly compact 200 MW_e** LFR achieved primarily by elimination of components

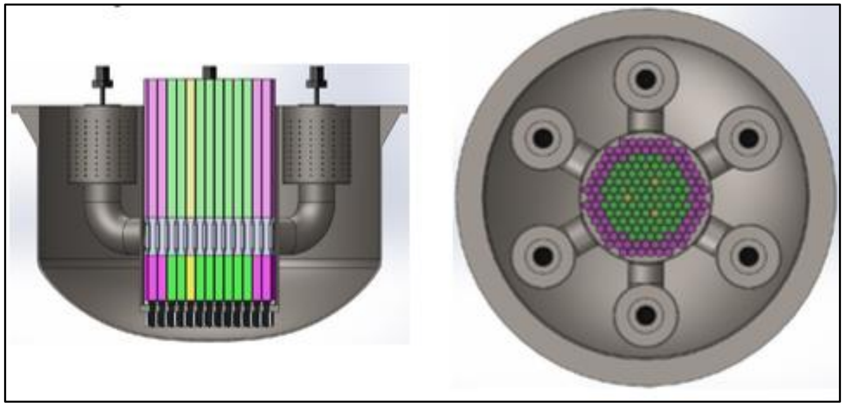
- ~ 4 times more compact than the Superphénix (SPX-1) SFR
- ~ 2-3 times more compact than than the best SFR projects
- ~ 3-5 times more compact than previous LFR projects

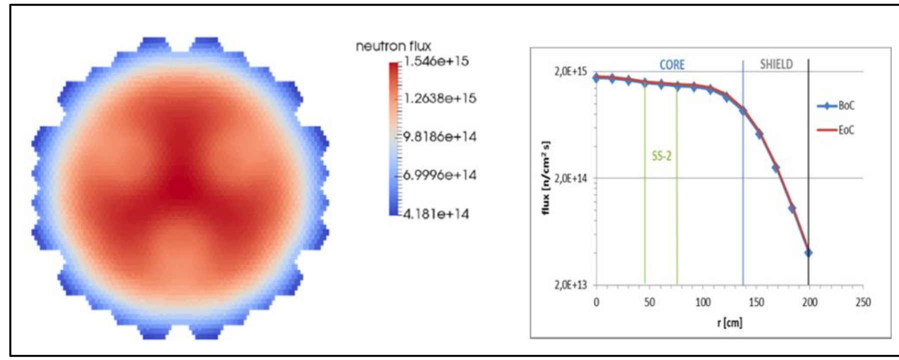
Core power (MWth)	480
Electrical power (MWe)	200
Coolant	Lead
Core inlet/outlet T (°C)	420/530
Primary loop pressure loss (bar)	1.3
Secondary cycle	Superheated steam
Fuel	U or mixed oxide

Westinghouse’s Demonstration LFR (DLFR)

Aims at enhanced passive safety and system compactness

Envisages thermal energy storage system to provide load-following with minimum variations in core thermal power





	Cladding		Core non-cladding component	Other Internals	SG tubes	Pump impeller	Main Vessel
	Base	Coating					
Max operating temp, °C	600		510	510	510	510	390
Fluence	100-150 dpa			5 dpa	N/A	N/A	0.1dpa
Possible material	D9	Al_2O_3	Same as cladding	SS316	SS316 or SS347, possibly coated	400 Series SS + Ti_3SiC_2	SS316

INEST observer of pSSC activities

Institute of Nuclear Energy Safety Technology,CAS
Key Laboratory of Neutronics and Radiation Safety,CAS

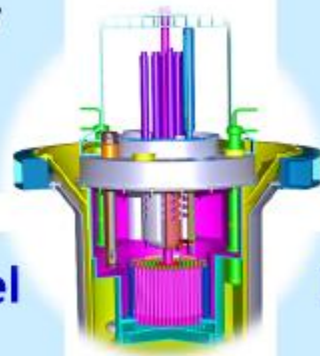
Key Technologies

I. Coolant Technology

- Preparation of lead alloy
- Purification
- Oxygen control

II. Key Components

- HLM pump
- Heat exchanger
- Remote handling



III. Materials and Fuel

- Structure material
- Cladding
- Fuel assembly

IV. Operation and Control

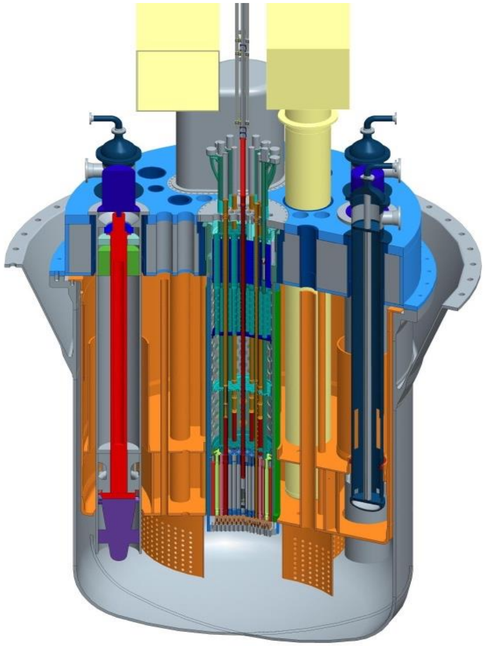
- Digital I&C
- Simulator
- Digital reactor

Most of 1:1 scale testing prototype components have been fabricated

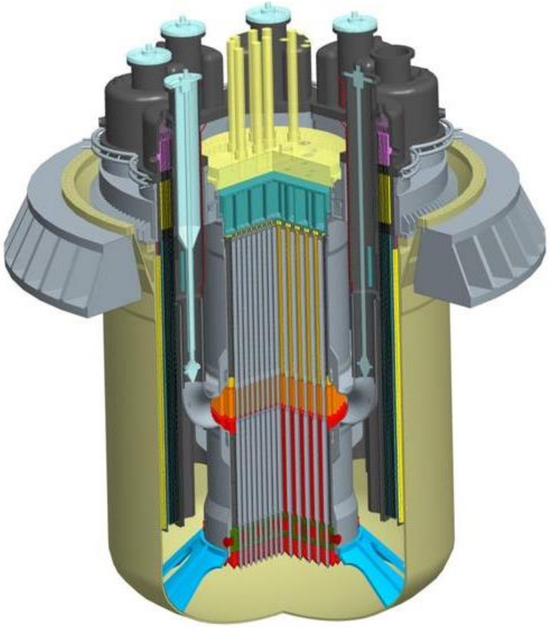
ACTIVITIES ON CLEAR-I, CLEAR-M, CLEAR-A and FISSION/FUSION SYSTEMS

Lead & LBE technology development in Europe

There are presently two main projects in EU (with many synergies):

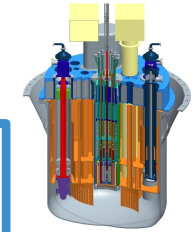


MYRRHA (LBE)
Flexible Irradiation Facility
(Demonstrator of ADS)



ALFRED (LFR)
Advanced Fast Reactor
European Demonstrator

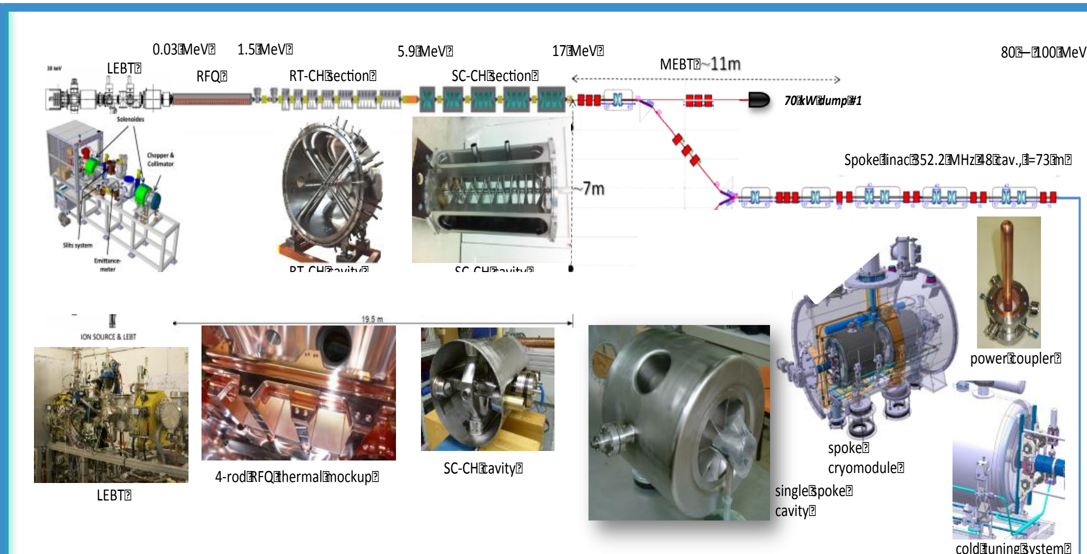
MYRRHA's implements phased approach



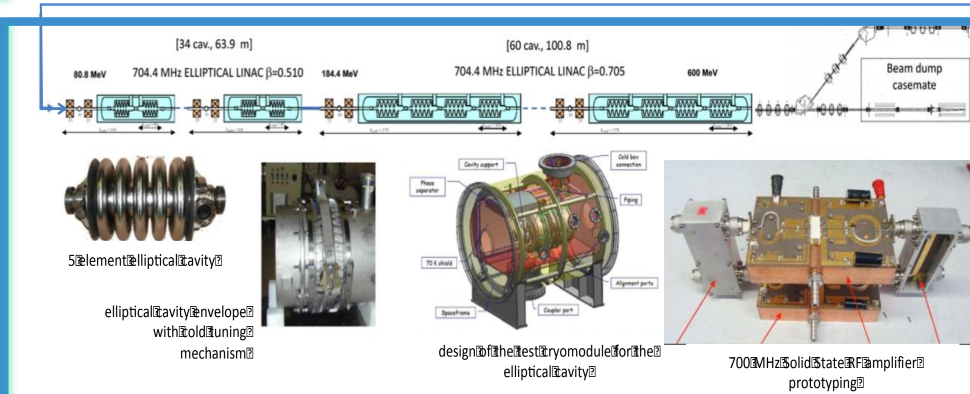
Benefits of phased approach:

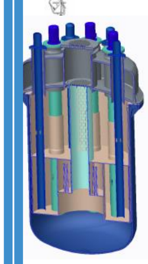
- Phase 1 - construction of 100 MeV accelerator
- Reducing technical risk
- Spreading investment cost
- Allowing to have the first R&D facility available in Mol end of 2024

Phase 1 – 100 MeV



Phase 2 – 600 MeV





Phase 3 – Reactor

BELGIUM Government recently funded PHASE 1 of Myrrha with 558 M€

ALFRED SUPPORT: The FALCON* Consortium

- FALCON Consortium Agreement was established in 2013 to bring LFR technology to industrial maturity
- FALCON recently evolved in the European context.
- Main objectives are:
  - ALFRED as a Major Project in Romania
  - Finalization of ALFRED feasibility study
  - Initiation of construction of supporting R&D facilities
- New members sharing the objective of a rapid deployment of an LFR demonstrator, interested in the R&D supporting infrastructure and in the ALFRED industrial outcomes are welcome to join.

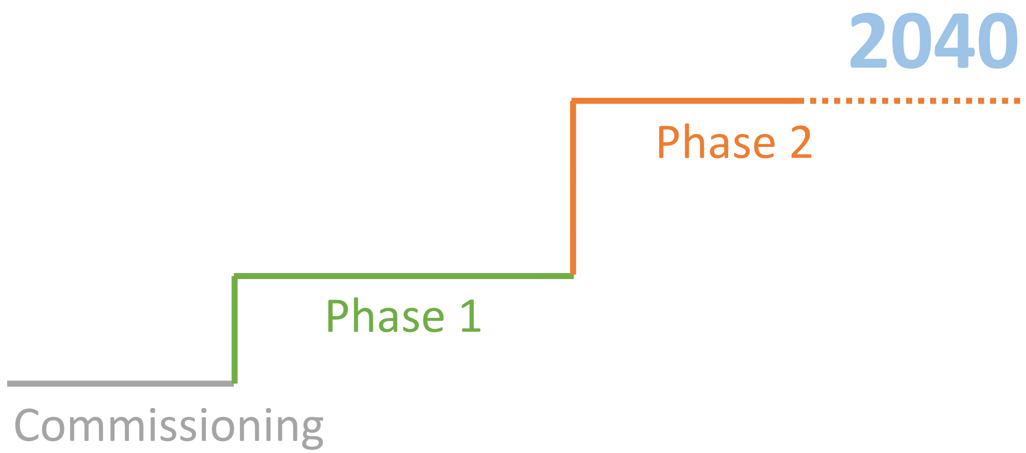
***FALCON** – **F**ostering **AL**fred **CON**struction

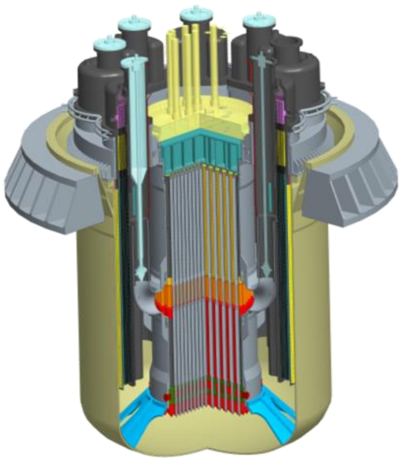
ADVANCED LEAD FAST REACTOR EUROPEAN DEMONSTRATOR – ALFRED PROJECT

Alessandro Alemberti
Ansaldo Nucleare - Italy

September 26, 2018

ALFRED DEMONSTRATOR
to achieve technology maturity



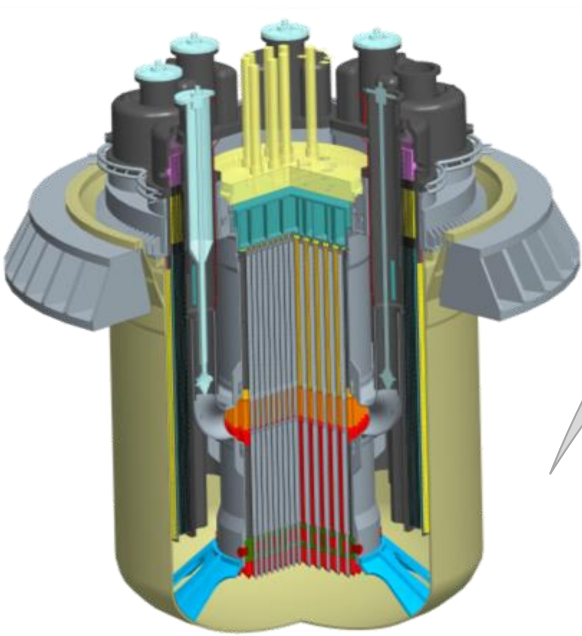


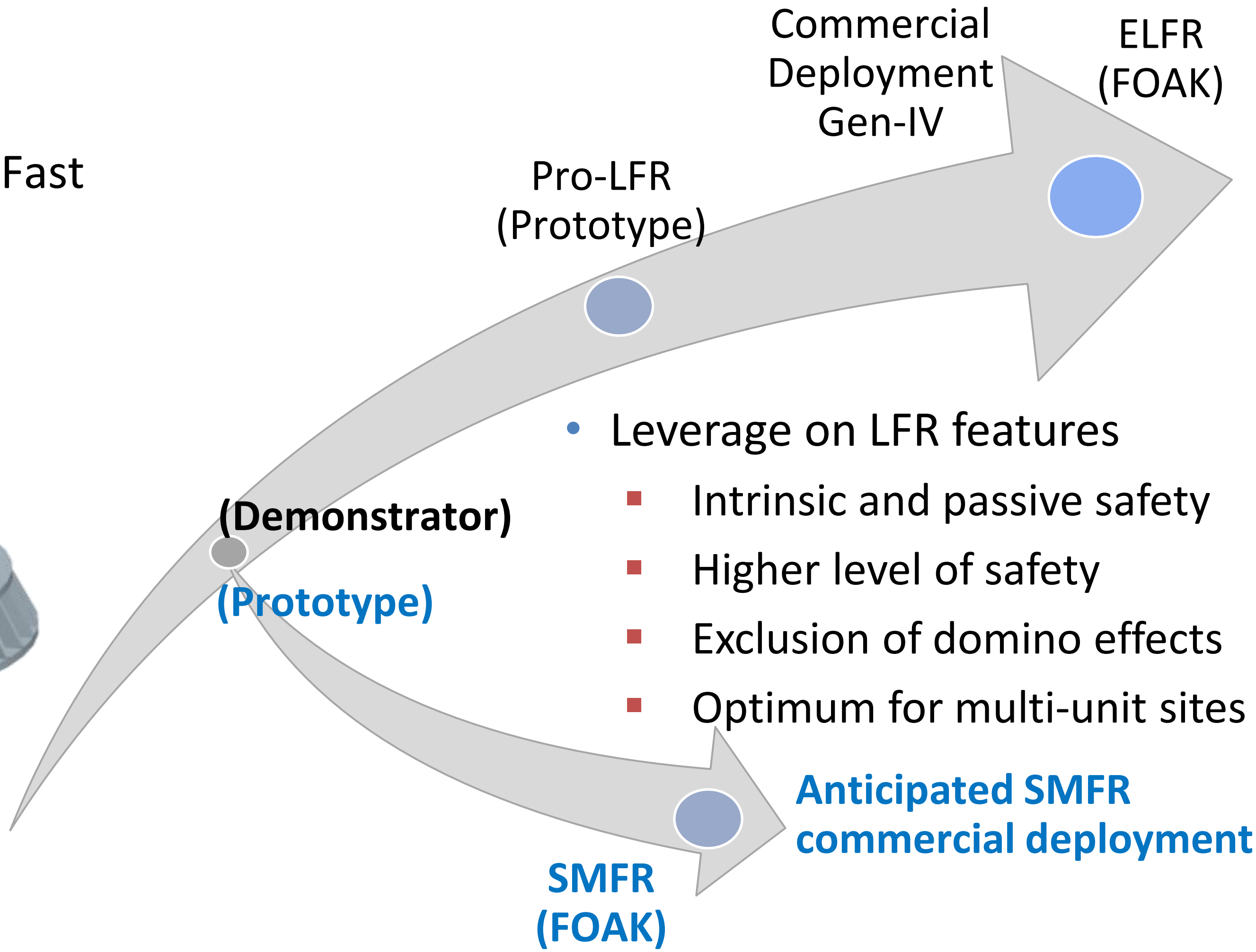
The operation of ALFRED will be based on a stepwise approach:

- phase 1: operation at low power and low-temperature range
  - Using presently existing proven materials working without corrosion protection
- phase 2: operation at full power and high-temperature range
  - Using coated materials fully qualified during phase 1

ALFRED: a LFR Demo with SMR-oriented features

ALFRED
Advanced Lead-cooled Fast Reactor European Demonstrator





- Leverage on LFR features
  - Intrinsic and passive safety
  - Higher level of safety
  - Exclusion of domino effects
  - Optimum for multi-unit sites

TIME WINDOW TARGET – 2035 - 2040

ROSATOM

Joint Stock Company “State Scientific Centre of the Russian Federation – Institute for Physics and Power Engineering named after A. I. Leypunsky”

SSC RF – IPPE

MAINTENANCE OF TECHNOLOGY OF HEAVY LIQUID-METAL COOLANT IN NEW GENERATION REACTOR FACILITIES

Askhadullin R.Sh., Storozhenko A.N., Melnikov V.P., Legkikh A.Yu., Ulyanov V.V. (JSC “SSC RF - IPPE”, Russia)

HLMC-2018, Obninsk, 08.10.2018

РОСАТОМ

НИКИЭТ им.Н.А.Доллежаля

ГОСУДАРСТВЕННАЯ КОРПОРАЦИЯ ПО АТОМНОЙ ЭНЕРГИИ «РОСАТОМ»

ЭНЕРГОБЛОК С РУ БРЕСТ-ОД-300

Лемехов В.В., Моисеев А.В., Бажанов А.А.,

Саркулов М.К., Смирнов В.С., Ярмоленко О.А.,

Лемехов Ю.В., Черепнин Ю.С., Васюхно В.П.,

Афремов Д.А. и др.

и др. участники ПН «Прорыв»

Научный руководитель - ГНЦ РФ-ФЭИ

ГНЦ РФ - ФЭИ,

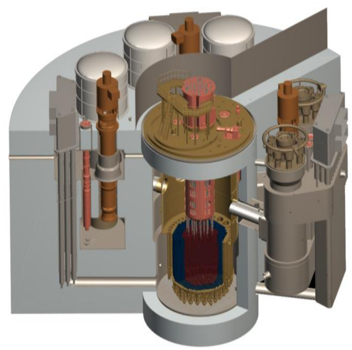
Обнинск, 08-10 октября 2018

Этапы создания коммерческих РУ со свинцовым теплоносителем

Исключение аварий на АЭС, требующих эвакуации, а тем более отселения населения

Коммерческая РУ

БРЕСТ-ОД-300



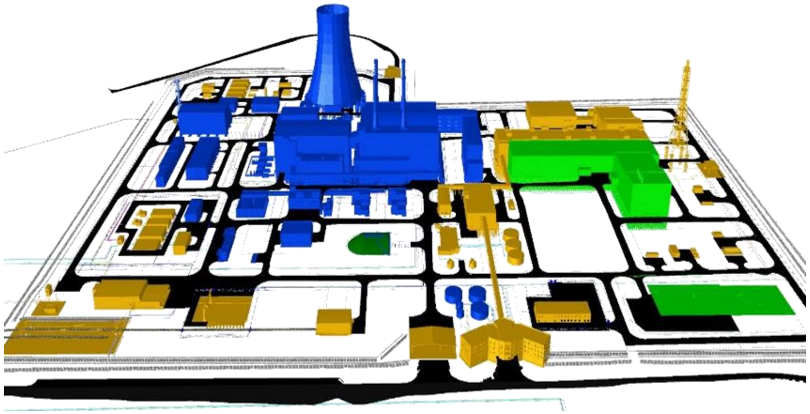
Формирование ЗЯТЦ для полного использования энергетического потенциала природного уранового сырья - <u>Использование Pu ВВЭР на старте</u>

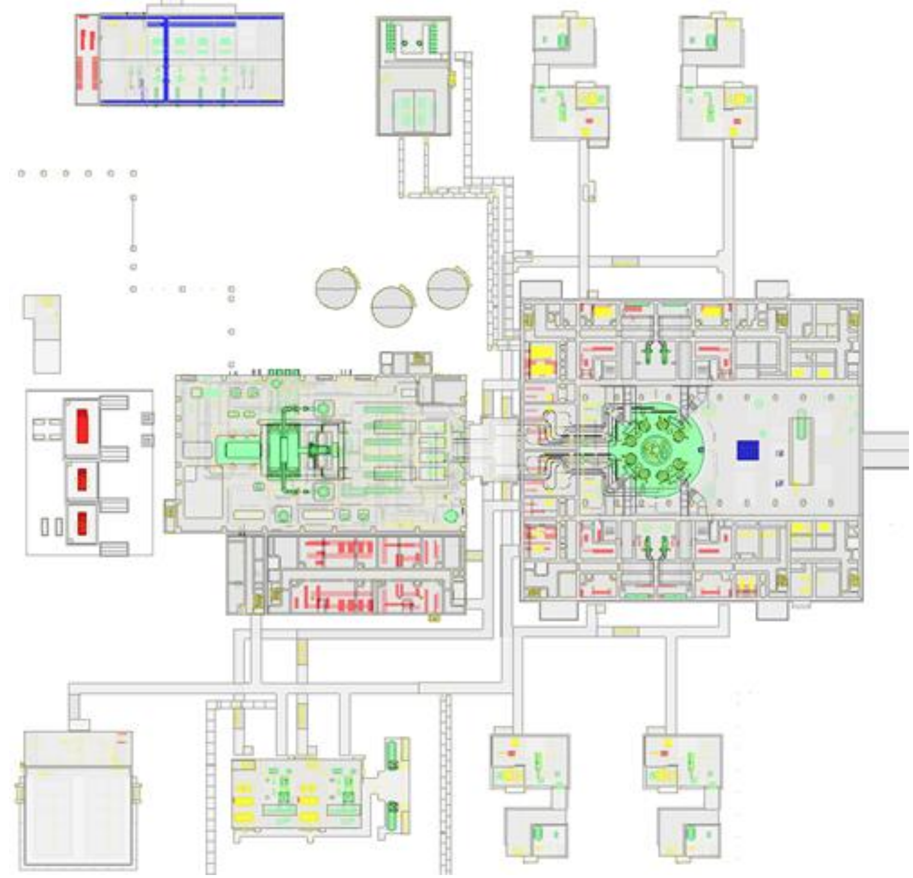
Последовательное приближение к радиационно-эквивалентному (по отношению к природному сырью) захоронению РАО - <u>на этапе эксплуатации после освоения топлива с МА</u>

Обеспечение конкурентоспособности по сравнению с другими видами генерации - <u>демонстрация потенциала технологии</u>

Технологическое укрепление режима нераспространения - <u>отсутствует бланкет</u>

Опытно-демонстрационный энергетический комплекс

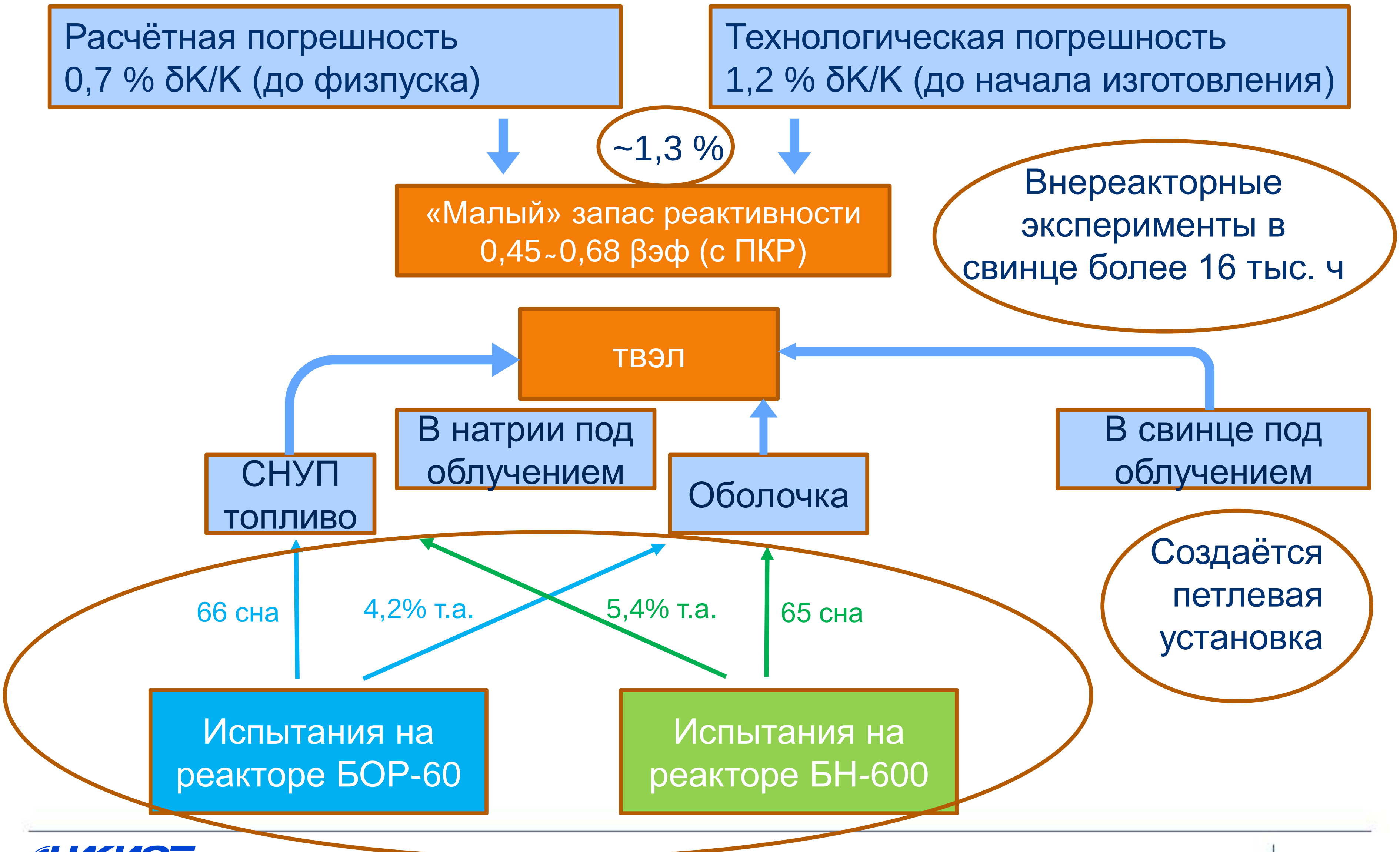




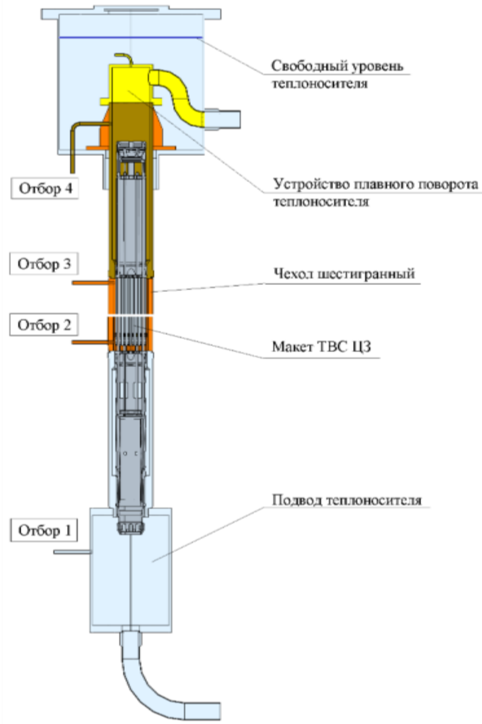
- Здания и сооружения модуля фабрикации и рефабрикации (МФР) - I очередь
- Здания и сооружения энергоблока (ЭБ) с РУ БРЕСТ-ОД-300 - II очередь
- Здания и сооружения модуля переработки (МП) - III очередь
- Перевод (модернизация) МФР на рефабрикацию ЯТ из продуктов переработки ОЯТ РУ БРЕСТ

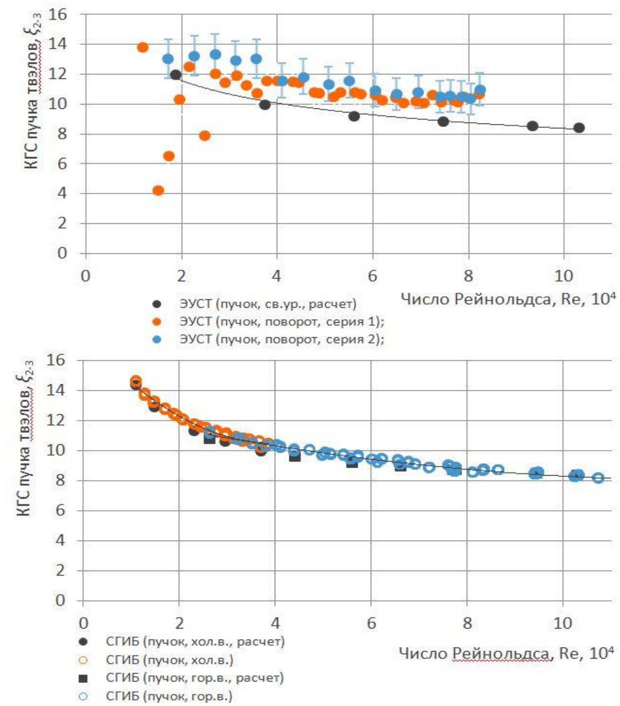
Землетрясение МРЗ/ПЗ 8/7 МСК-64
Тепловая/ эл. мощность 700/300 МВт
Загрузка топлива 20,8 т/ 169 ТВС
Перегрузки 6%/9% т.ат. 7,2/4,8 т

Активная зона (нейтронная физика и топливо)



Активная зона (испытания ТВС)

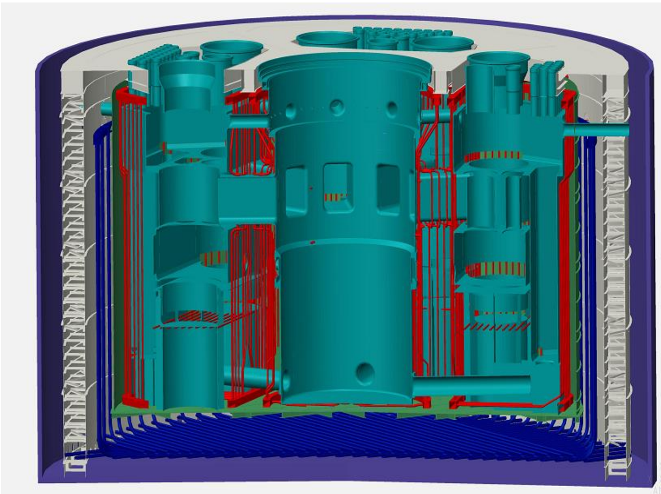




- Изготовлены полномасштабные макеты всех типов тепловыделяющих сборок, проведены механические испытания, получены гидравлические и виброметрические характеристики в воде и жидком свинце

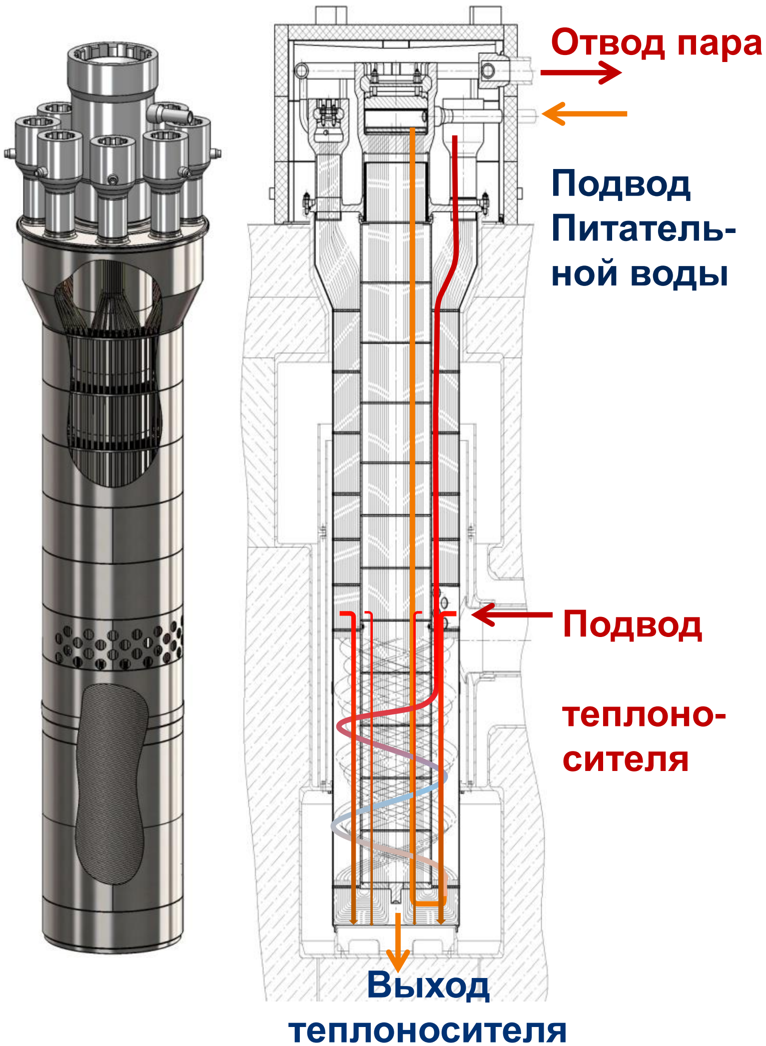
- Для последующего изготовления изделий активной зоны освоено промышленностью большинство полуфабрикатов

Корпус блока реакторного



- Экспериментально получены свойства высокотемпературных бетонов при рабочих температурах и под облучением, показана химическая инертность теплоносителя по отношению к бетонам
- Выпущен обобщающий отчёт по металлическим конструкционным материалам, включая сварные соединения, материалы поставлены на производство
- Верифицированы коды под тепловые и прочностные задачи
- Расчётно и на макетах подтверждена локализующая функция бетона
- Принципиально разработана технология сборки и монтажа

Парогенератор (1/2)



➢Обоснованы требуемые теплогидравлические параметры ПГ. Определена граница устойчивой работы – более 15 % по расходу воды

➢Выпущены обобщающие отчёты со свойствами материалов

➢Расчетно обоснована прочности элементов ПГ во всех эксплуатационных режимах

➢Поставлена на производство теплообменная труба

➢Экспериментально показано отсутствие зависимого отказа при разрыве одной ТОТ

➢Обоснован нейтральный ВХР, позволяющий уменьшить кол-во отложений при эксплуатации ПГ. Разработана технология отмывки теплообменных труб ПГ

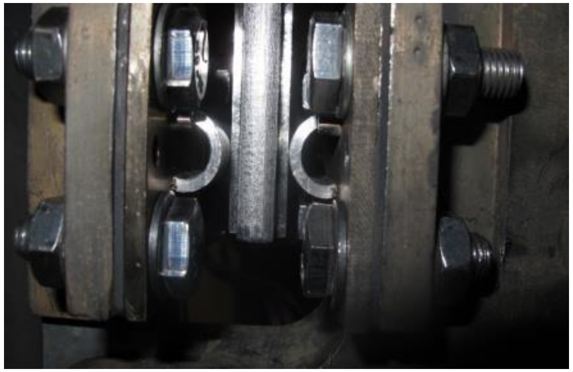
Парогенератор (2/2)

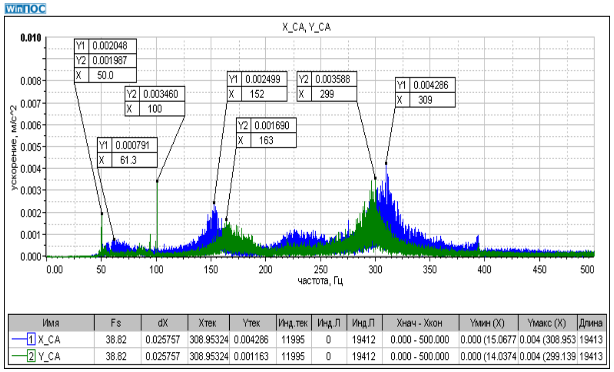
➢Подтверждено выполнение условий термоциклической прочности теплообменных труб и сварных швов приварки к трубной доске

➢Проведены эксперименты, обосновывающие прибавку на коррозию в условиях воды, пара и свинцового теплоносителя

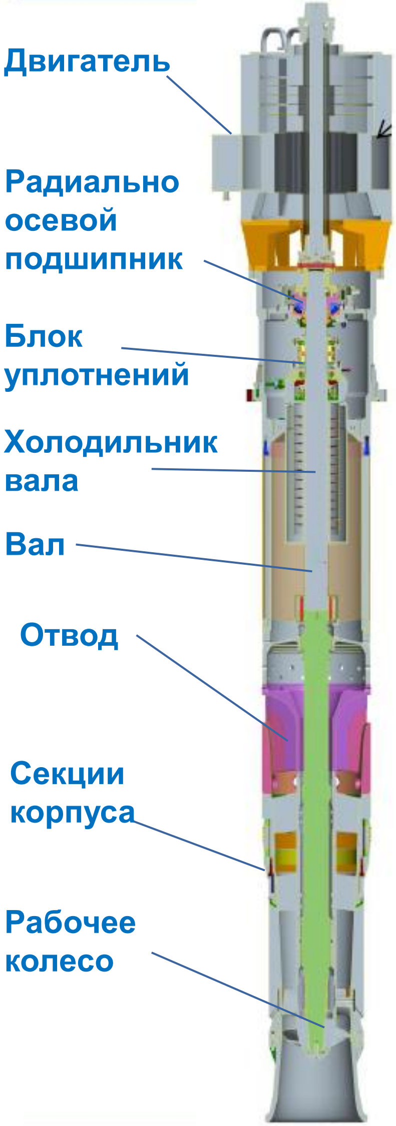
➢Показано незначительное влияние свинца на скорость ползучести в свинце при нагрузках, характерных для парогенератора

➢Проведена серия испытаний трибосопряжения ТОТ-ДГ. Разработана физико-механическая модель. Расчёты по модели подтверждают ресурс 30 лет. Создаётся стенд для натурного изучения вибрационных характеристик

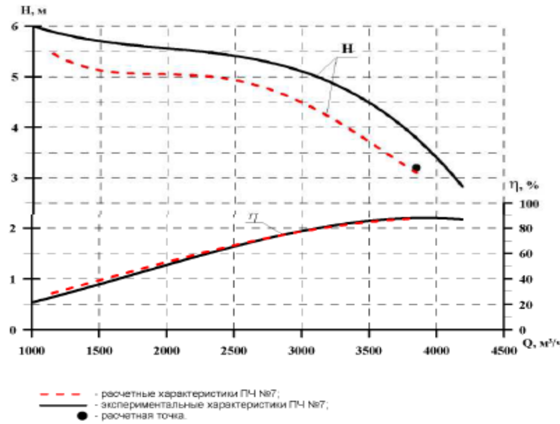




ГЦНА



- Проведена оптимизация проточной части на водяном и свинцовом среднемасштабных стендах
- Получена необходимая характеристика напор-расход для обеспечения работы насоса в диапазоне от 30 до 100 %.

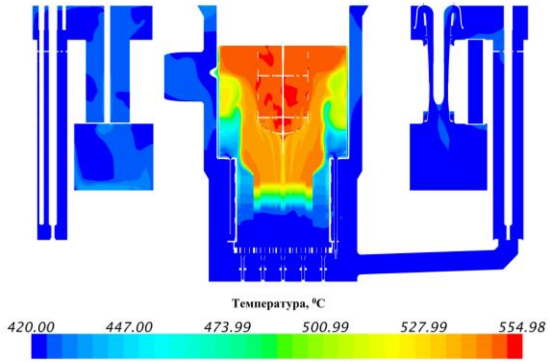


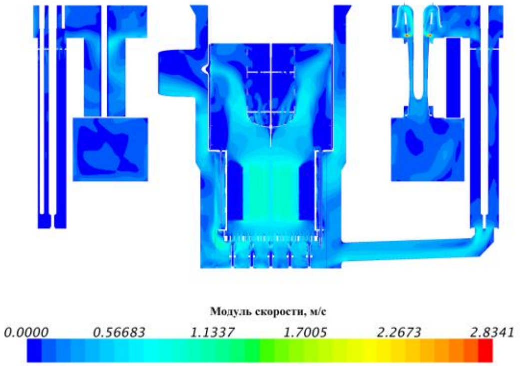
- Разработан и изготовлен нижний радиальный подшипник
- Проводятся ресурсные испытания подшипника на свинце (набранный ресурс 30% от проектного)
- Разработана конструкция торцевого уплотнения по газу. Начато изготовление для стендовой отработки
- Начато изготовление опытного насоса
- Ведётся подготовка к созданию полномасштабного стенда для испытаний ГЦНА на свинце
- Проведены прочностные расчёты по свойствам конструкционных материалов из обобщающих отчётов

Прочие элементы

- Положительно окончены испытания опытного образца привода исполнительного механизма СУЗ
- Изготавливаются и проходят испытания первичные преобразователи параметров первого контура
- Разработан технический проект АСКУ РУ, создан стенд, на котором показана устойчивость работы регуляторов КСУЗ при различных переходных режимах
- Разработана и испытана арматура системы безопасности парогенератора
- Проводятся ресурсные испытания компонентов системы поддержания качества теплоносителя
- Завершается отработка элементов системы контроля герметичности оболочек твэл

Теплогидравлические расчеты в обоснование конструкторских решений и безопасности





Распределение температуры и модуля скорости в вертикальном сечении, проходящем через ось одного из ГЦНА (1-ая секунда переходного процесса потери системного энергоснабжения)

- Проведено расчётное обоснование циркуляции в первом контуре трёхмерными кодами
- Расчёты проведены как для нормальной эксплуатации, так и для нарушений нормальной эксплуатации
- Трёхмерные расчёты, как правило, показывают, что расчёты по канальным кодам в режимах с нарушения нормальной эксплуатации дают консервативные (более высокие) температуры
- Завершается верификация трёхмерных кодов

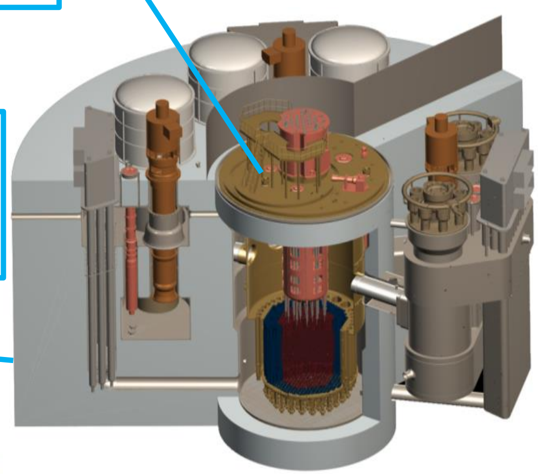
Обоснование радиационной безопасности (1/2)

4,3•10^{8} Бк за первые сутки для множественных отказов с вводом полного запаса реактивности

От активной зоны менее 0,1 мкЗв/ч

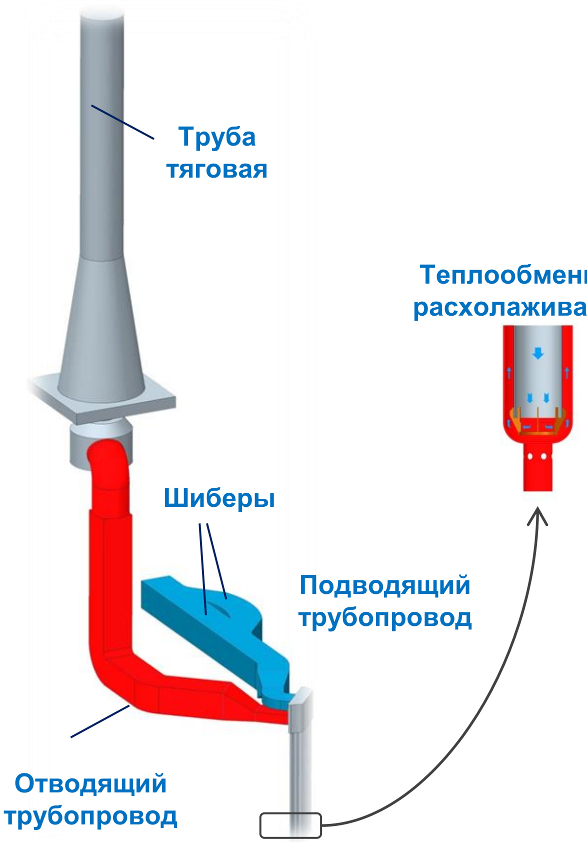
1,5 мЗв за первые 10 сут. при наложении разгерметизации ПГ и системы локализации течи

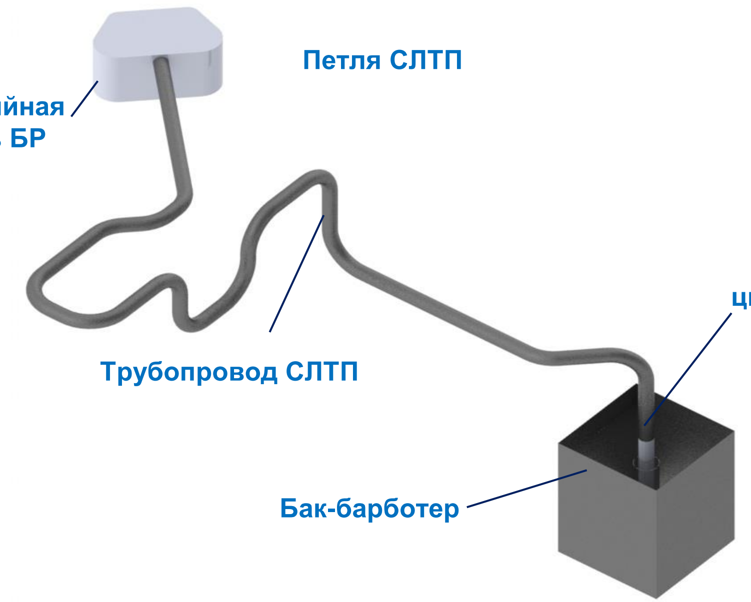
На уровне естественного фона



Активация выемного внутрикорпусного оборудования практически отсутствует (кроме размещаемого в центральной полости).

Обоснование безопасности (2/2)





Благодаря конструктивным решениям по РУ, применению свинцового теплоносителя, обеспечению малого запаса реактивности, пассивным системам безопасности, суммарная вероятность повреждения а.з. от всех ИС на базе 24 ч не более $9 \cdot 10^{-9} \cdot 1$/год.

Нормативные правовые акты и стандартизация

- В основу проекта реакторной установки заложены требования действующих федеральных норм и правил в отношении АЭС: ОПБ, ПБЯ, НРБ и т.д.
- Для обеспечения создания инновационных АЭС процессы разработки проекта, новых ФНП и перспективных программных средств (расчётных кодов) идут практически одновременно
- Специфическими являются правила устройства и безопасной эксплуатации и сопутствующие документы (сварка, правила контроля и т.д.), нормы расчёта на прочность корпуса
- В настоящее время идёт совместная работа с Ростехнадзором по согласованию и вводу в действие основополагающих ФНП на основании которых будет вестись создание РУ.

Расчётные коды

Наименование	Статус	Количество
Нейтронная физика, теплогидравлика оборудования, прочность, ВАБ	Аттестованы	5
Радбезопасность	Имеются положительные заключения секции	2
Остальные	В процессе аттестации	5


Федеральная служба
по экологическому, технологическому и атомному надзору
(Ростехнадзор)

ЭКСПЕРТНЫЙ СОВЕТ ПО АТТЕСТАЦИИ ПРОГРАММНЫХ СРЕДСТВ
ПРИ РОСТЕХНАДЗОРЕ

АТТЕСТАЦИОННЫЙ ПАСПОРТ ПРОГРАММНОГО СРЕДСТВА

Регистрационный номер 426 от 27 февраля 2018 года

Настоящий аттестационный паспорт устанавливает назначение и область применения программного средства

Программа для решения задач нестационарной теплогидравлики применительно к реакторным установкам и экспериментальным стендам с натриевым, свинцовым и свинцово-висмутовым теплоносителями. Версия 1.1 (HYDRA-IBRAE/LM/V1.1),

которые указаны в разделе 2 приложения к настоящему аттестационному паспорту.

Аттестационный паспорт предоставлен

Федеральному государственному бюджетному учреждению науки Институт проблем безопасного развития атомной энергетики Российской академии наук (ИБРАЭ РАН).
Юридический адрес: 115191, Россия, г. Москва, ул. Большая Тульская, д.52.

Настоящий аттестационный паспорт действует при соблюдении условий Приложения, являющегося его неотъемлемой частью.

Срок действия настоящего аттестационного паспорта: до 27 февраля 2023 года

Заместитель директора ФБУ «НТЦ ЯРБ»,
председатель экспертного Совета
по аттестации программных средств
при Ростехнадзоре, канд. техн. наук С.Н. Богдан

ETSON | EUROPEAN TECHNICAL SAFETY ORGANISATIONS NETWORK

HYDRA-IBRAE/LM/V1.1


Федеральная служба
по экологическому, технологическому и атомному надзору
(Ростехнадзор)

ЭКСПЕРТНЫЙ СОВЕТ ПО АТТЕСТАЦИИ ПРОГРАММНЫХ СРЕДСТВ
ПРИ РОСТЕХНАДЗОРЕ

АТТЕСТАЦИОННЫЙ ПАСПОРТ ПРОГРАММНОГО СРЕДСТВА

Регистрационный номер 405 от 08 декабря 2016 года

Настоящий аттестационный паспорт устанавливает назначение и область применения программного средства

«MCU-BR с библиотекой констант MDBBR50»,

которые указаны в разделе 2 Приложения к настоящему аттестационному паспорту.

Аттестационный паспорт предоставлен

Акционерному обществу «Ордена Ленина Научно-исследовательский и конструкторский институт энерготехники им. Н.А. Доллежаля» (АО «НИКИЭТ»),
юридический адрес: 107140, Россия, г. Москва, улица Малая Красносельская, д. 2/8.

Настоящий аттестационный паспорт действует при соблюдении условий Приложения, являющегося его неотъемлемой частью.

Срок действия аттестационного паспорта до 08 декабря 2026 года

Председатель экспертного Совета
по аттестации программных средств
при Ростехнадзоре, к.т.н. С.Н. Богдан

ETSON | EUROPEAN TECHNICAL SAFETY ORGANISATIONS NETWORK

MCU-BR

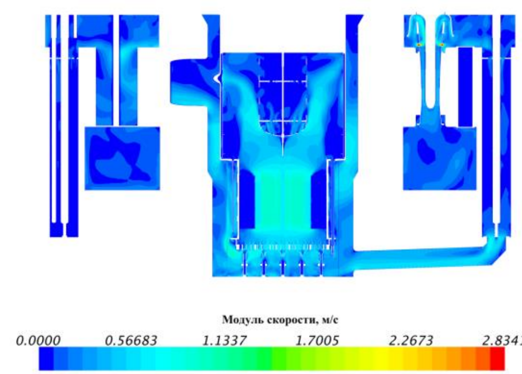
Перспективы РУ со свинцовым теплоносителем

- При разработка РУ БРЕСТ-ОД-300 создаются **технологии**, проводятся эксперименты, находятся современные технические решения для создания оборудования, пригодные в том числе для масштабирования

- **Расчётные коды**, используемые для БРЕСТ-ОД-300, также можно будет применять для расчётов подобных РУ или с небольшим уточнением в случае изменения параметров новых РУ

- **Нормативная база**, в том числе усовершенствованная после получения опыта при прохождении этапов жизненного цикла БРЕСТ-ОД-300, может быть применена для других РУ

- Присущие качества могут быть использованы для других РУ **в достаточно широком диапазоне мощности**



Заключение

1. Технические решения по оборудованию РУ подтверждены положительными результатами экспериментов на макетах оборудования или его компонентов, расчётным обоснованием с учётом влияния свинцового теплоносителя, ведутся испытания опытных образцов.
2. Технические решения по активной зоне подтверждены положительными результатами облучательных экспериментов, гидравлических и вибрационных экспериментов, нейтронно-физических расчетов по аттестованным программным кодам.
3. Проведённые теплогидравлические расчёты с использованием CFD-кодов показали непревышение пределов безопасной эксплуатации по температуре топлива, оболочки твэлов, обеспечение локализующей функции корпуса реакторного блока при нарушениях нормальной эксплуатации с реализацией множественных отказов.
4. Проведённые расчёты радиационной безопасности подтвердили целевые показатели - отсутствие необходимости эвакуации и отселения населения за границей промплощадки при нарушениях нормальной эксплуатации РУ с множественными отказами.
5. Проект энергоблока с РУ БРЕСТ-ОД-300 проходит лицензирование в Ростехнадзоре.
6. Решения, применяемые в РУ БРЕСТ-ОД-300, могут быть использованы в коммерческих РУ большой мощности.

РЕАКТОРНАЯ УСТАНОВКА

БРЕСТ

ЕСТЕСТВЕННОЙ БЕЗОПАСНОСТИ