4th Joint IAEA-GIF Technical Meeting/Workshop on
Safety of Sodium-Cooled Fast Reactors

# Requirements and approaches to BN-1200 safety provision

**Boris A. Vasilyev[1)], Sergey F. Shepelev[1)], Igor A. Bylov[1)]**

**Vladimir M. Poplavskiy[2)], Iurii M. Ashurko[2)]**

[1)] JSC "OKBM Afrikantov", Nizhny Novgorod, Russia
[2)] FSUE "SSC RF-IPPE named after A. I. Leypunsky" , Obninsk, Russia

IAEA HQ, Vienna , Austria, 10-11 June 2014

# Contents

- BN-1200 design
- Safety requirements
- Inherent safety features
- Passive safety systems
- Design engineering solutions to increase safety
- Approaches to severe accidents analysis
- Conclusion

# BN-1200 design

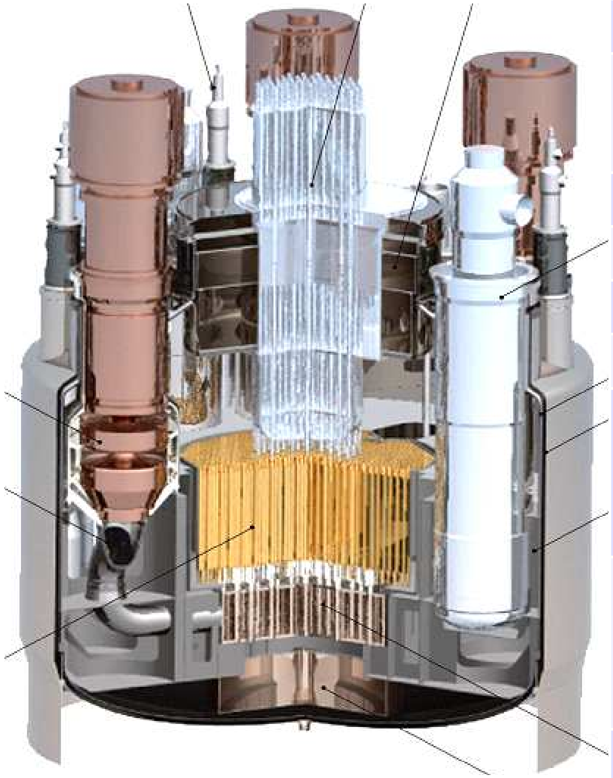
The BN-1200 next generation sodium-cooled fast reactor is being developed in accordance with Federal Target Programme "A New Generation of Nuclear Power Technologies for 2010-2015 and Prospectively until 2020"

The BN-1200 is next generation reactor plant which should meet all Generation IV systems goals in:

- *Sustainability that meets clean air objectives and provides long-term availability of systems and effective fuel utilisation for worldwide energy production*
- *Safety*
- *Economics*
- *Proliferation resistance and physical protection*

**BN-1200 reactor is developing as sodium-cooled fast reactors design for serial construction**

# Key BN-1200 parameters



| Parameter | Value |
|---|---|
| Thermal power, MW | 2800 |
| Electric power, MW | 1220 |
| Capacity factor, % | 90 |
| Efficiency, %:<br>–brutto<br>–netto | <br>43.5<br>40.7 |
| Cooling circuits number | 3 |
| Primary and secondary circuits coolant | Sodium |
| 3rd circuit coolant | Water/steam |
| Desing lifetime, years | 60 |
| Sodium temperature in the primary circuit at core inlet/outlet, °C | 410/550 |
| Sodium temperature in the secondary circuit at SG inlet/outlet, °C | 355/527 |
| Live steam pressure, MPa<br>Live steam temperature, °C<br>Feedwater temperature, °C | 17.0<br>510<br>275 |

# Safety requirements

**BN-1200 design should meet the following safety requirements:**

- *Current regulatory safety requirements for operating nuclear power plants*
- *Core damage frequency should not exceed $10^{-6}$ 1/reactor·year*
- *Large early release frequency should not exceed $10^{-7}$ 1/reactor·year*
- *Elimination of accidents with consequences requiring the need for offsite public evacuation*

**In any technically credible situation, the following requirements must be implemented:**

- *Removal of decay heat generated by the reactor while maintaining its structural integrity*
- *Localization of the majority of radioactive products escaping from the reactor in the event of potential accidents within a special above-reactor premise*
- *The reactor should go subcritical while maintaining acceptable temperature conditions of its components*

**Implementation of all of these requirements should ensure achievement of the objective of precluding offsite public evacuation**

# Inherent safety features (I)

| Characteristic | Effect produced |
|---|---|
| Large heat capacity of integral reactor design (all primary circuit equipment contained inside the reactor vessel) | Low heat-up rate of sodium in the primary circuit (20°C an hour) in case of complete loss of cooling after emergency shutdown |
| Placement of all systems containing radioactive sodium within the reactor vessel | Exclusion of radioactive sodium release into rooms from external piping |
| Low corrosive and erosive effect produced by sodium upon structural materials | Exclusion of fuel rod overheating as a consequence of clogging of the fuel assembly open flow area and breach of reactor vessel as a result of corrosion |
| High boiling temperature of sodium: 883°C at atmospheric pressure | Low, approximately 0.15 MPa, absolute pressure in the reactor gas cavity (sodium boiling temperature 930°C); absence of coolant phase transitions in case of primary circuit depressurization with reliable core cooling |

# Inherent safety features (II)

| Characteristic | Effect produced |
|---|---|
| Effective containment of iodine and caesium isotopes by sodium (confirmed by BN-600 operational experience) | Practically full preclusion of any release of the most hazardous gaseous and air-borne fission product isotopes into the environment during normal operation and accidents |
| Stable negative reactivity coefficient for reactor power ($dK/dN = -2{,}6 \cdot 10^{-6}\ MW^{-1}$) and core materials temperature ($dK/dT = -2{,}3 \cdot 10^{-5}\ °C^{-1}$) | Limited reactor power increase in case of unauthorised introduction of positive reactivity, power drop in case of unauthorised reactor heat-up |
| Introduction of negative reactivity in the event of sodium boiling as a consequence of presence of the top sodium cavity in the fuel assemblies | Reactor power drop in case of core overheating accident to sodium boiling temperature |
| Design of control and protection rods drive system that precludes simultaneous withdrawal of more than one rod from the core | Exclusion of unauthorised introduction of excessive positive reactivity and dangerous reactor power excursion |

# Passive safety systems

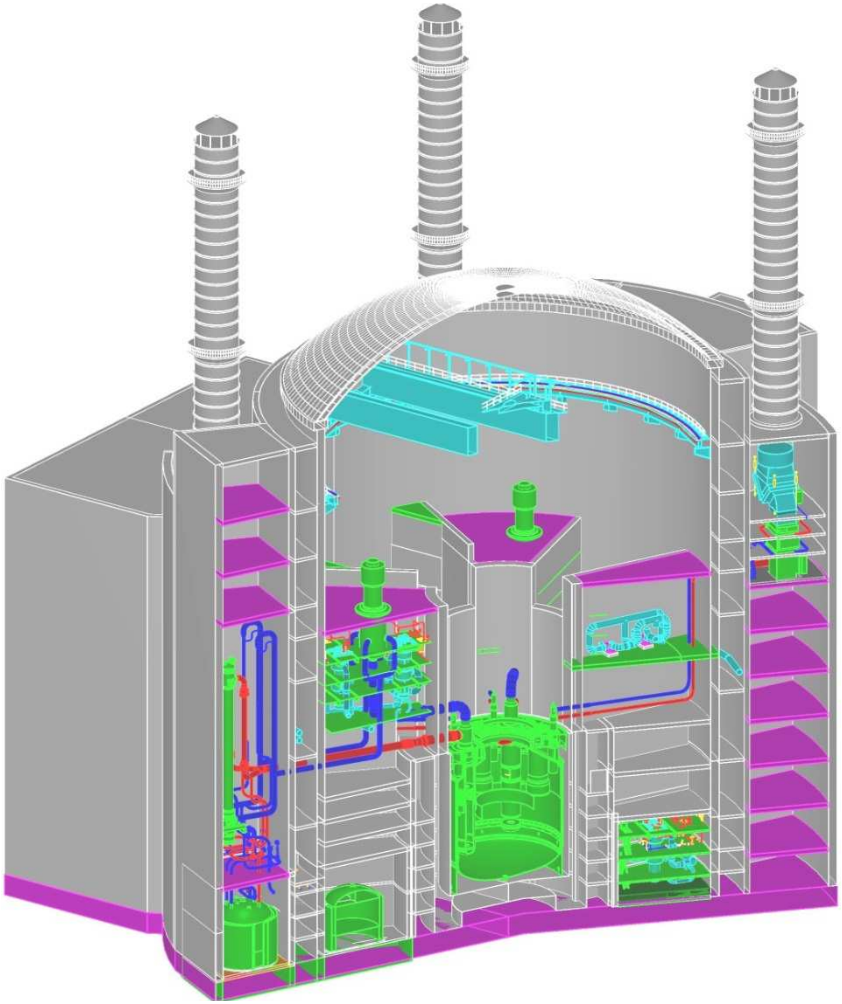
**In addition to the inherent safety features BN-1200 design includes number of passive safety devices and passive safety systems**

- Hydraulically suspended absorber rods
- Absorber rods with temperature-triggered action
- Decay heat removal system with air heat exchangers
- Leak-tight above-reactor premise
- Guard vessel
- Core catcher of a heat-resistant metal at the bottom of the reactor vessel

# Decay heat removal system

- **TISEY** testing facility modelling DHRS channel was constructed in OKBM Afrikantov
- DHRS effectiveness was confirmed by experimental researches for natural circulation in transient and steady conditions
- DHRS parameters and operating conditions were ensured by calculations
- Full-scale check valve model manufacturing has been prepared
- Preparation for full-scale check valve model testing in sodium is conducting

# Design engineering solutions to increase safety



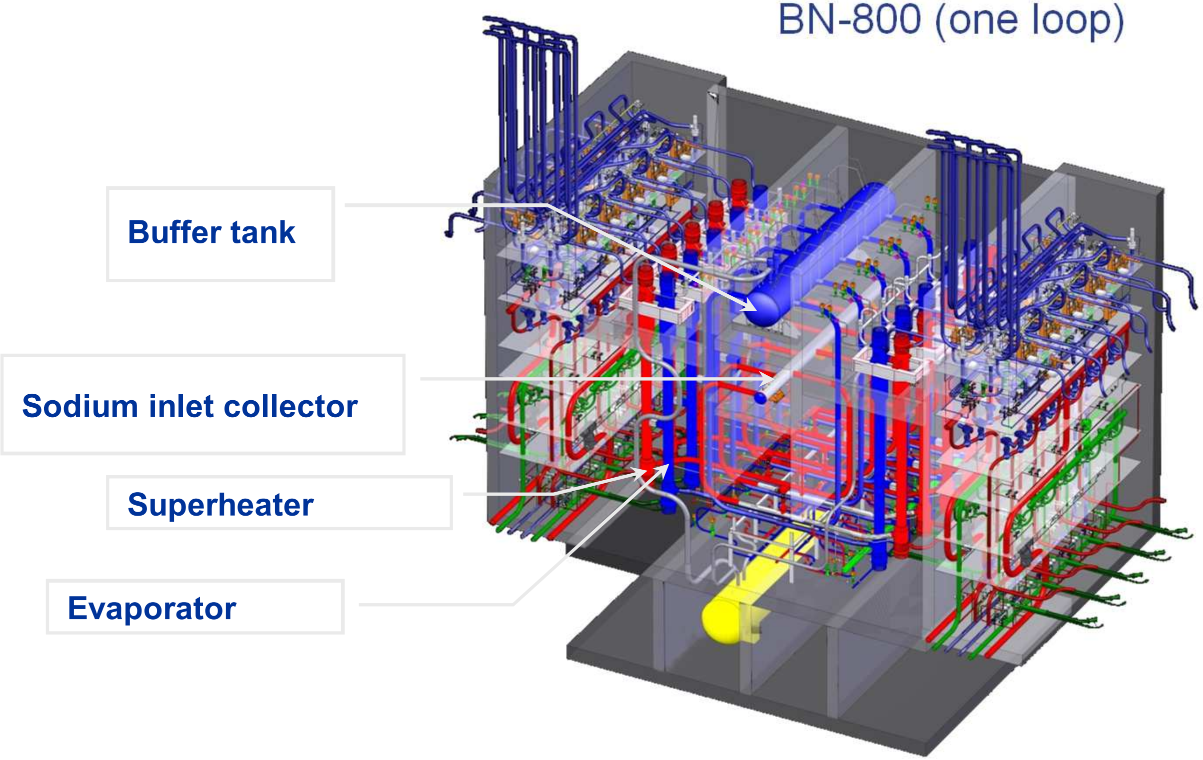
To practically exclude radioactive sodium leaks into reactor rooms and accordingly prevent any sodium fires associated with generation of air-borne radioactivity following engineering solutions are adopted in BN-1200 design :

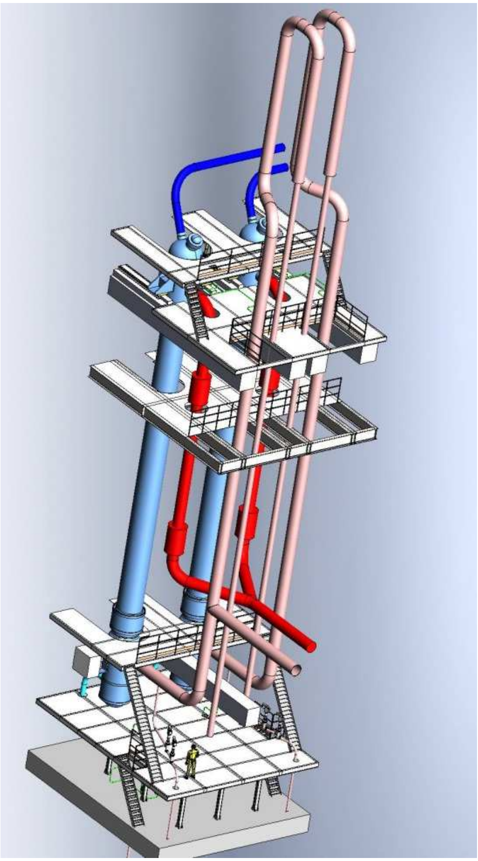
- Placement of all systems containing radioactive sodium within the reactor vessel
- Guard vessel
- Exclusion of the spent fuel assemblies drum – a potential source of accidents involving radioactive sodium

## Design engineering solutions to increase safety: measures to minimize possibilities of non-radioactive sodium leaks (1)

BN-1200 (one loop)

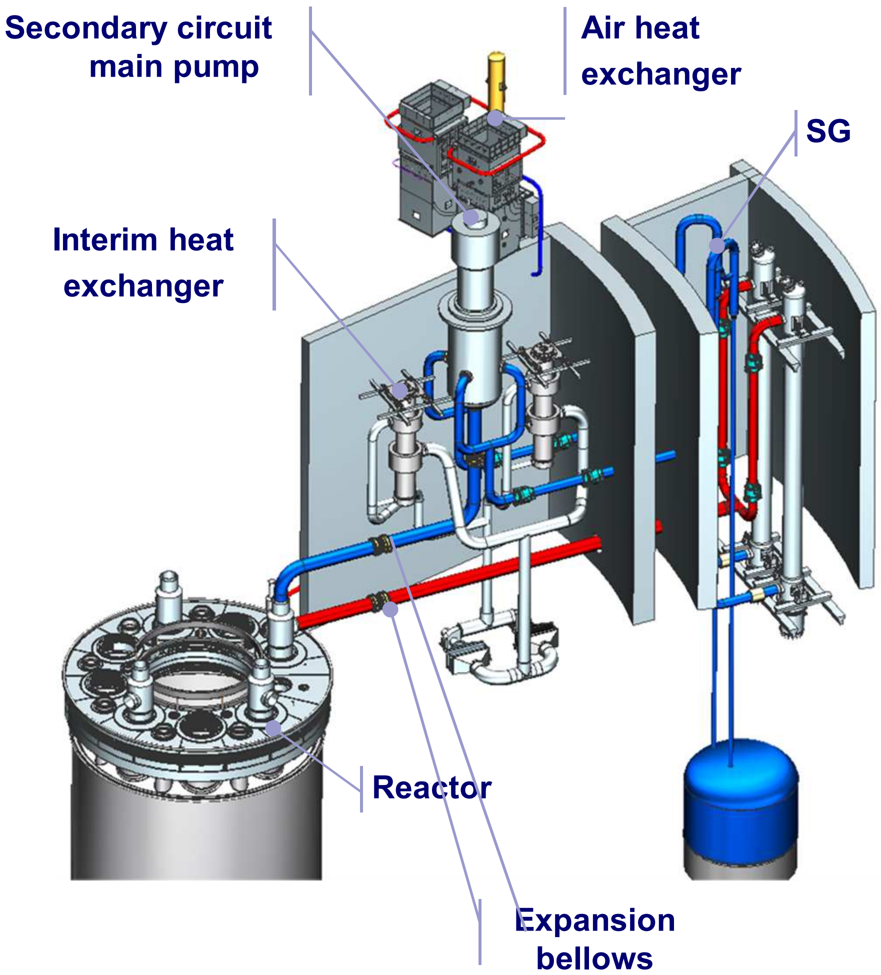
BN-800 (one loop)



**Applying of shell-type steam generators (8 modules) instead of module-type steam generators BN-600 (72 modules) и BN-800 (60 modules) ⇒ substantial decreasing of secondary circuit pipes length**

## Design engineering solutions to increase safety: measures to minimize possibilities of non-radioactive sodium leaks (2)




- Effective prevention and sodium leaks consequences mitigation
- Applying of built-up pipeline shrouds ⇒ sodium leaks localization
- Applying of expansion bellows ⇒ thermal displacement compensation

# Approaches to severe accidents analysis (I)

To assess BN-1200 safety all technically credible even low probability events are taken into consideration

Safety is provided by both technical measures and operational procedures

In addition to regulatory requirements in BN-1200 safety analysis following events are considered:

- *Failure of all active safety systems*
- *Single failures in passive safety systems*

The most severe beyond design basis accidents are analyzed in BN-1200 design as following:

- *Station blackout and reactor shutdown systems failure*
- *Station blackout and emergency heat removal system failure*

# Approaches to severe accidents analysis (II)

**In case of realization of such accidents BN-1200 design includes** :

- *Two passive reactor shutdown systems employing different action principles:*
  - *Hydraulically suspended absorber rods*
  - *Absorber rods with temperature-triggered action*

- *To provide decay heat removal system passive operating additionally to residual heat removal by natural circulation consideration is being given to system operation mode with :*
  - *Air dampers opening without of power sources available*
  - *Air dampers previously slightly opened*

- To assess the level of BN-1200 inherent safety severe accidents with residual risk are analyzed:
  - *Station blackout and failure of all active and passive safety systems*
  - *Unauthorized withdrawal of all control rods without of initiation of all active and passive reactor shutdown systems*

# Conclusion

**Preliminary evaluations of BN-1200 safety indicate that developed inherent safety features and various passive devices and systems in design allow:**

- *To meet the safety requirements to Generation IV nuclear plants*
- *In particular to eliminate the need for offsite public evacuation in case of any technically credible accidents*

***Thank you for attention!***