5th Joint IAEA-GIF Technical Meeting/Workshop on
Safety of Sodium-Cooled Fast Reactors

Provision of Safety Design Criteria for Generation-IV Sodium-cooled Fast Reactor System implementation in BN-1200 reactor design

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Contents

- BN-1200 design
- Safety design criteria for Generation-IV sodium-cooled fast reactor system
- BN-1200:
  - Safety criteria
  - Safety concept
  - Engineered safety provisions
  - Safety analysis and assessment
- Conclusion

BN-1200 design

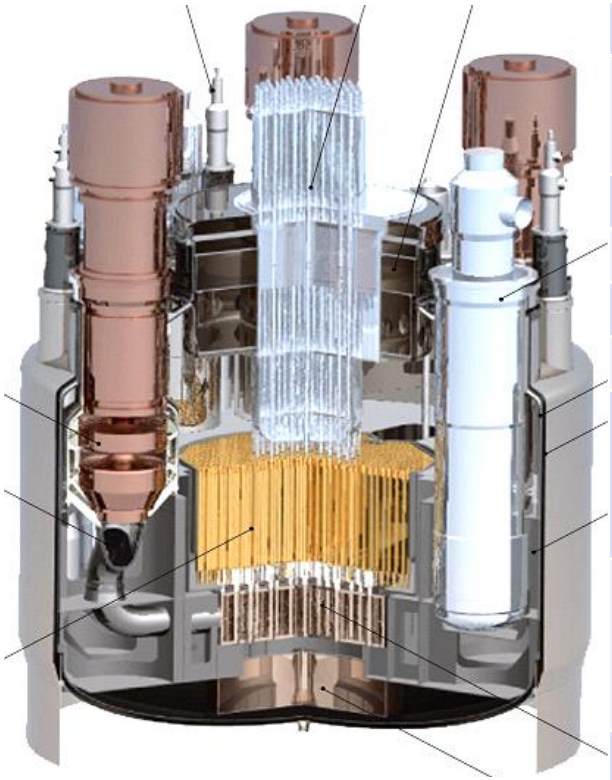
The BN-1200 next generation sodium-cooled fast reactor is developed in accordance with Federal Target Programme "A New Generation of Nuclear Power Technologies for 2010-2015 and Prospectively until 2020"

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

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

BN-1200 reactor is considered as sodium-cooled fast reactor design for serial construction

Key BN-1200 parameters



Parameter	Value
Thermal power, MW	2800
Electric power, MW	1220
Capacity factor, %	90
Efficiency, %: –brutto –netto	 43.5 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 Live steam temperature, °C Feedwater temperature, °C	17.0 510 275

Safety Design Criteria for Generation-IV Sodium-cooled Fast Reactor System

GEN IV International Forum

SDC-TF/2013/01

May 1, 2013

Safety Design Criteria
for
Generation IV Sodium-cooled Fast Reactor System

Prepared by:

The Safety Design Criteria Task Force (SDC-TF)

Of the Generation IV International Forum

- **Developed by the GIF Safety Design Criteria Task Force in 2013**
- **Include:**
  - ➢ Safety approach to the SFR as a Generation-IV reactor system
  - ➢ Management of safety in design
  - ➢ Principal technical criteria
  - ➢ General plant design
  - ➢ Design of specific plant systems
- **SDC analysis indicates that:**
  - ➢ Criteria correspond to the IAEA Specific Safety Requirements SSR-2/1 Safety of Nuclear Power Plants: Design
  - ➢ Criteria correspond to the Russian national regulatory NPP safety requirements (OPB-88/97, NP-082-07) in accordance with BN-1200 design is developed

Safety criteria

- **Radiation safety:** allowable radiation doses at nuclear power plant site:
  - **Normal operation:** less 20 mkSv per year at and beyond site boundary
  - **Anticipated operational occurrences:** 100 mkSv per year at and beyond site boundary
  - **Design-basis accidents:** not greater than 1 mSv for first year after accident at site boundary excluding any protective measures beyond site boundary
  - **Beyond design-basis accidents:** not greater than 50 mGy beyond site boundary at early accident stage (first 10 days) and not greater than 50 mSv for first year after accident (population evacuation and resettlement are excluded)

- **Probabilistic safety goals:**
  - **Cumulative severe accident probability for one nuclear plant unit for one year should not exceed 10^{-6}.** Severe accident is beyond design-basis accident with fuel damage exceeding maximum design margin
  - **Cumulative large early release probability for one nuclear plant unit for one year should not exceed 10^{-7}.** Large early release is a release of radioactive materials to environment during accident at NPP when public protection measures beyond emergency planning zone boundary are required

Proven engineering practices

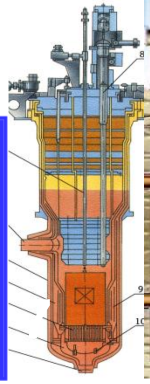
- 50 years of successful design and operating experience
- BN-800 reactor commissioning at final stage
- Opportunity for commercial fast reactor construction: BN-1200

Experimental reactors

Power reactors

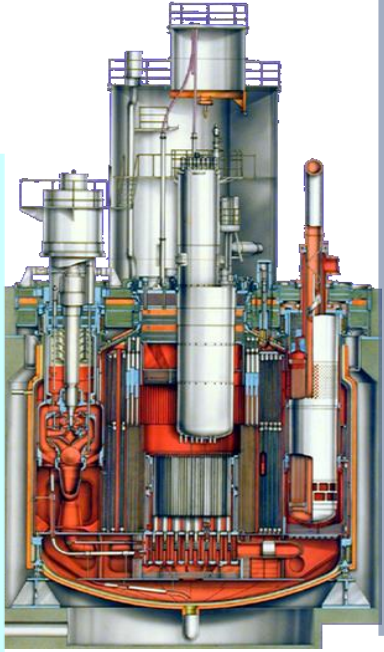
BR-5/10
1959

BOR-60
1969



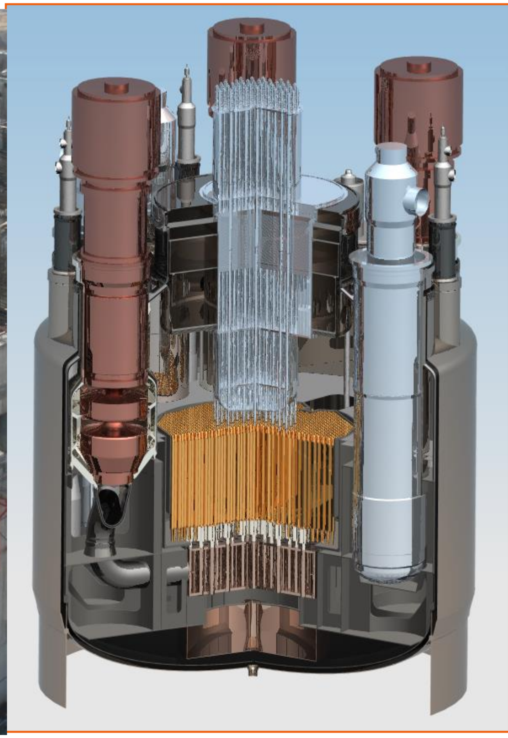
BN-350
1973

BN-600
1980



BN-800
Commissioning

BN-1200
Development



Safety concept

- **BN-1200 reactor safety is ensured through consistently implementing the defense-in-depth concept based on:**
  - **Physical barriers** in confining radioactive material at specified locations
  - **System of technical and organizational measures** aimed at preventing harmful effects of radiation on people and the environment, and ensuring adequate protection from harmful effects and mitigation of the consequences in the event that prevention fails

- **Physical barriers include:**
  - Fuel composition
  - Fuel cladding
  - Primary circuit boundary: reactor vessel, intermediate heat exchangers tubes, piping
  - Plant containment

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 ($dK/dN = -2,6*10^{-6}$ MW^{-1}) and core materials temperature ($dK/dT = -2,3*10^{-5}$ $°C^{-1}$)	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 insertion 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

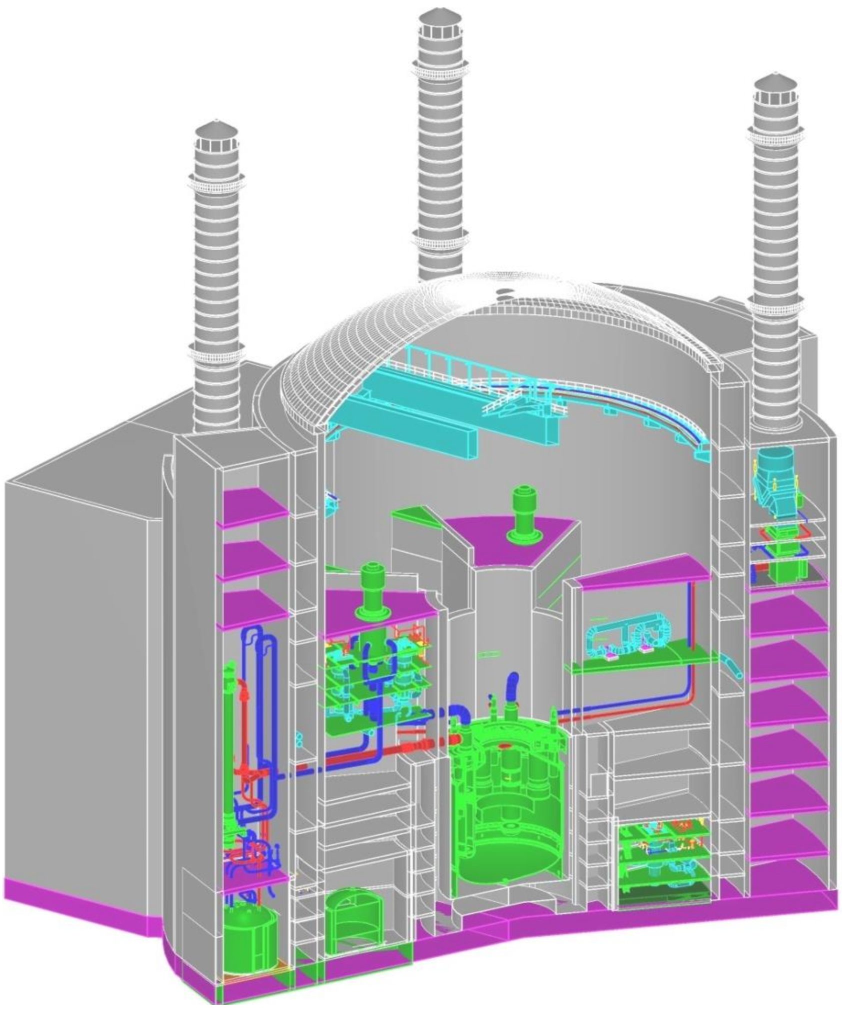
- Hydraulically suspended absorber rods
- Absorber rods with temperature-triggered action
- Decay heat removal system with air heat exchangers
- Leak-tight above-reactor premise
- Guard vessel
- Core catcher of a heat-resistant metal at the bottom of the reactor vessel

External hazards consideration

- **Design basis impacts:**
  - maximum design-basis earthquake: magnitude 7 on the MSK-64 scale
  - design-basis earthquake: magnitude 6 on the MSK-64 scale
  - 20 tons aircraft crash on the reactor building
  - external pressure wave with front pressure 30 kPa

- **Beyond design basis impacts:**
  - 400 tons commercial aircraft crash on the reactor building considering fuel ignition
  - earthquake with horizontal ground acceleration 40% more than maximum design-basis earthquake

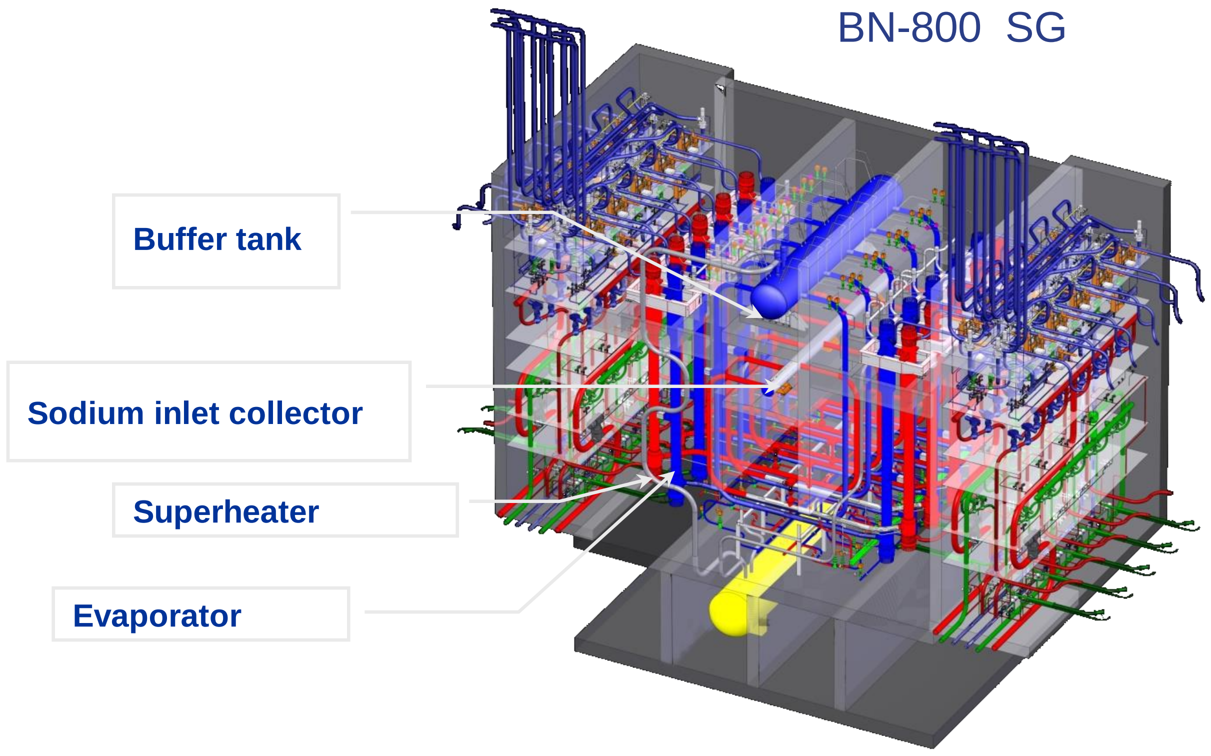
Design engineering solutions to increase safety

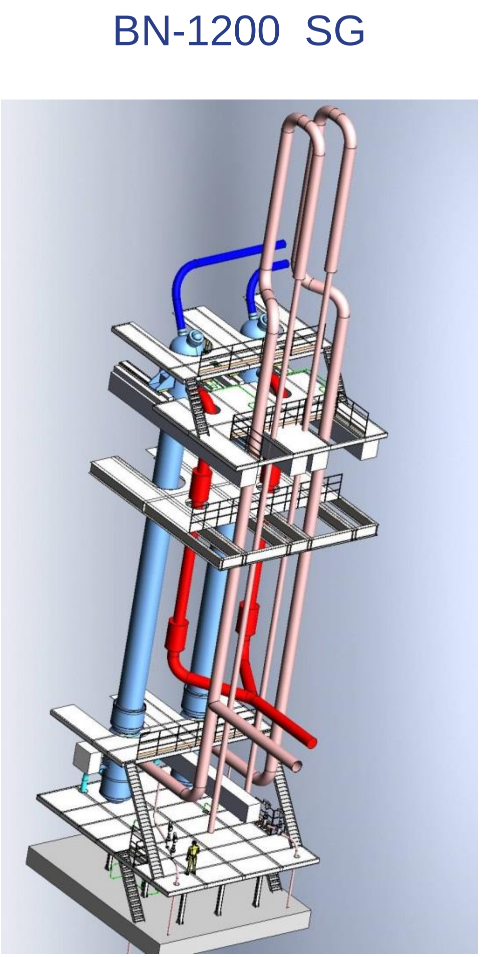


To practically exclude radioactive sodium leaks into reactor rooms and accordingly prevent any sodium fires associated with generation of air-borne radioactivity following engineering solutions are adopted in BN-1200 design :

- 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

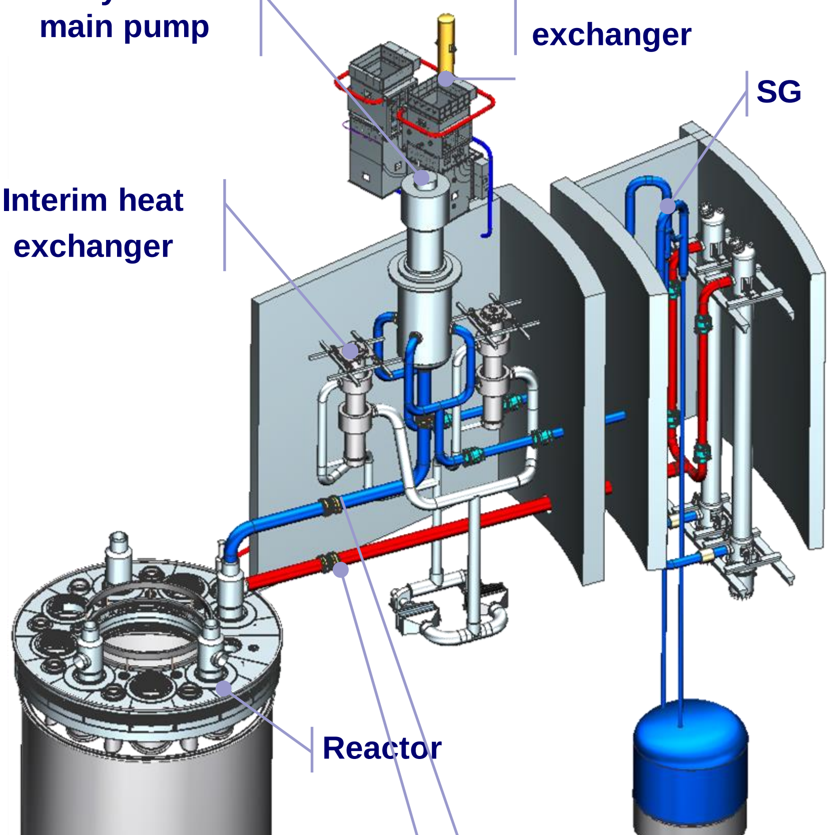
Design engineering solutions to increase safety: measures to minimize possibilities of non-radioactive sodium leaks (1)





Applying of shell-type steam generators (8 modules) instead of module-type steam generators BN-600 (72 modules) and 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

Safety analysis and assessment (I)

To assess safety deterministic and probabilistic safety analyses shall be done for all operational conditions

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

Following postulated initiating events are taking into account:

- **Main reactor vessel leakage: Decrease of coolant level inside reactor caused by leakage into space between main and guard vessel shall not lead to break of sodium circulation in primary circuit**
- **Steam generator leakage: The total cross section rupture of one steam generator tube is considered as postulated initiating event. Additional damage of tubes surrounding ruptured tube can be considered as beyond design-basis event**
- **Total instantaneous blockage of a fuel subassembly: Sodium boiling and fuel rods damage (cladding and fuel melting) in one fuel assembly without propagation of damage in the remaining volume of the core**

Safety analysis and assessment (II)

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**

Conclusions

- **BN-1200 reactor design provides** Safety Design Criteria for Generation-IV Sodium-cooled Fast Reactor System implementation

- Sodium-cooled fast reactors design and operating experience accumulated in Russia confirms technology maturity and ability for **developing BN-1200 as sodium-cooled fast reactor design for serial construction**

- **BN-1200 reactor design safety** provisions due to optimal combination of proven and new solutions allow to consider this design as design of **Generation IV systems**

Thank you for attention!