ГОСУДАРСТВЕННАЯ КОРПОРАЦИЯ ПО АТОМНОЙ ЭНЕРГИИ «РОСАТОМ»

REVIEW OF SFR SAFETY RELATED OPERATIONAL EXPERIENCE IN RUSSIA

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Submitted to the IAEA-GIF Workshop on Operational and Safety Aspects of Sodium Cooled Fast Reactors,

Vienna, Austria, 23-25 June 2010

SFR OPERATIONAL EXPERIENCE

More than 140-reactor-year SFR operation experience has been gained in Russia:

- About 44-year operation of research fast reactor BR-5/BR-10 (1959-2002, IPPE, Obninsk);
- More than 40 years of experimental fast reactor BOR-60 operation (since1969, RIAR, Dimitrovgrad);
- More than 26 years of prototype BN-350 reactor facility operation (1972-1999, Shevchenko/Aktau, Kazakhstan);
- More than 30 years of BN-600 industrial power unit operation (since 1980, Beloyarsk NPP, Zarechny).

SODIUM LEAKS EXPERIENCE

One of the specific features of SFRs is chemical activity of sodium coolant in relation to air and water.

It results in an increased attention of regulatory authorities to all events related to sodium coolant leaks.

Sodium leaks are subdivided into two types:

- *Loss of tightness of sodium equipment with sodium release outside of the sodium loops and its potential burning in the air;*
- *Loss of heat exchange tubes integrity in steam generators (SG) with subsequent water/steam-sodium interaction.*

Over the entire period of Russian SFRs operation sufficient experience has been gained both on external sodium leaks and SG leaks.

These leaks predominantly took place at the initial stages of SFRs operation at the period of sodium technology mastering and rejection of latent defects in sodium equipment.

LIST OF EXTERNAL LEAKS IN RUSSIAN SFRs

Cause of leakage	Reactor facility			
	BR-5/BR-10	BN-350	BN-600	Total
Pipe burning-through by electric heater	2	-	-	2
Failure of pump-vessel level indicator sensor	6	-	-	6
Sodium valve failure	7	-	2	9
Improper procedure of sodium unfreezing	2	6	4	12
Manufacturing defect	1	-	3	4
Crack formation on pipeline	1	-	6	7
Flange joint defect	-	2	5	7
Intercircuit leak in SG	-	2	-	2
Mechanical formation of hole by personnel	-	4	2	6
SG sodium valve seal	-	1	5	6
Unknown cause (possibly corrosion)	-	1	-	1
Total	19	15	27	61

EXTERNAL SODIUM LEAKS IN BN-600

27 sodium leaks occurred during BN-600 reactor operation. Most of these leaks were small:

- *In 21 cases the amount of leaked sodium did not exceed 10kg.*

In 6 cases only the amount of leaked sodium was 30, 50, 300, 600, 650 and 1000 kg:

- *In the first three cases the leaks were caused by flange joint defects in the sodium reception system.*

Sodium burning was observed in 14 cases.

All leaks were timely detected by the detection systems or operators and localized.

There was not a single case of exceeding the permissible safety limits.

The latest external sodium leak in BN-600 occurred in May 1994.

EXPERIENCE WITH LEAKS IN STEAM GENERATORS (1/2)

The statistics of SG leaks for the reactor facilities is as follows:

- *1 leak — BOR-60*
- *14 leaks — BN-350*
- *12 leaks — BN-600*
- *27 leaks — in total.*

As a result of numerous leaks at the initial stage of BN-350 operation due to insufficient manufacturing quality of Fild's heat exchange tubes used in SG evaporators the problem of ensuring SG reliability was fairly acute:

- *So, during the first two years of BN-350 operation (1973-75) 8 leaks occurred including three "large" ones.*
- *Altogether for the entire period of operation there were 12 leaks in the SG with Fild's tubes.*
- *A fairly fast self-development of small SG leaks to the level of large leaks was revealed.*
- *It required upgrading the SG leak protection system and increasing their performance.*

EXPERIENCE WITH LEAKS IN STEAM GENERATORS (2/2)

The experience gained on BN-350 SG leaks further influenced the change-over from integral-type to sectional-modular SGs used in BN-600 and BN-800 designs.

The sectional-modular SGs have demonstrated high performance characteristics during the entire period of BN-600 power unit operation despite the leaks that occurred:

- *Half of them took place within the first year of operation and were caused by the propagation of latent manufacturing defects.*
- *All leaks in BN-600 SGs were eliminated using standard technical means and did not result in emergency situations.*
- *An avalanche-type accident propagation to the heat exchange tubes adjacent to the damaged one like in the case of PFR SG leak were not observed.*

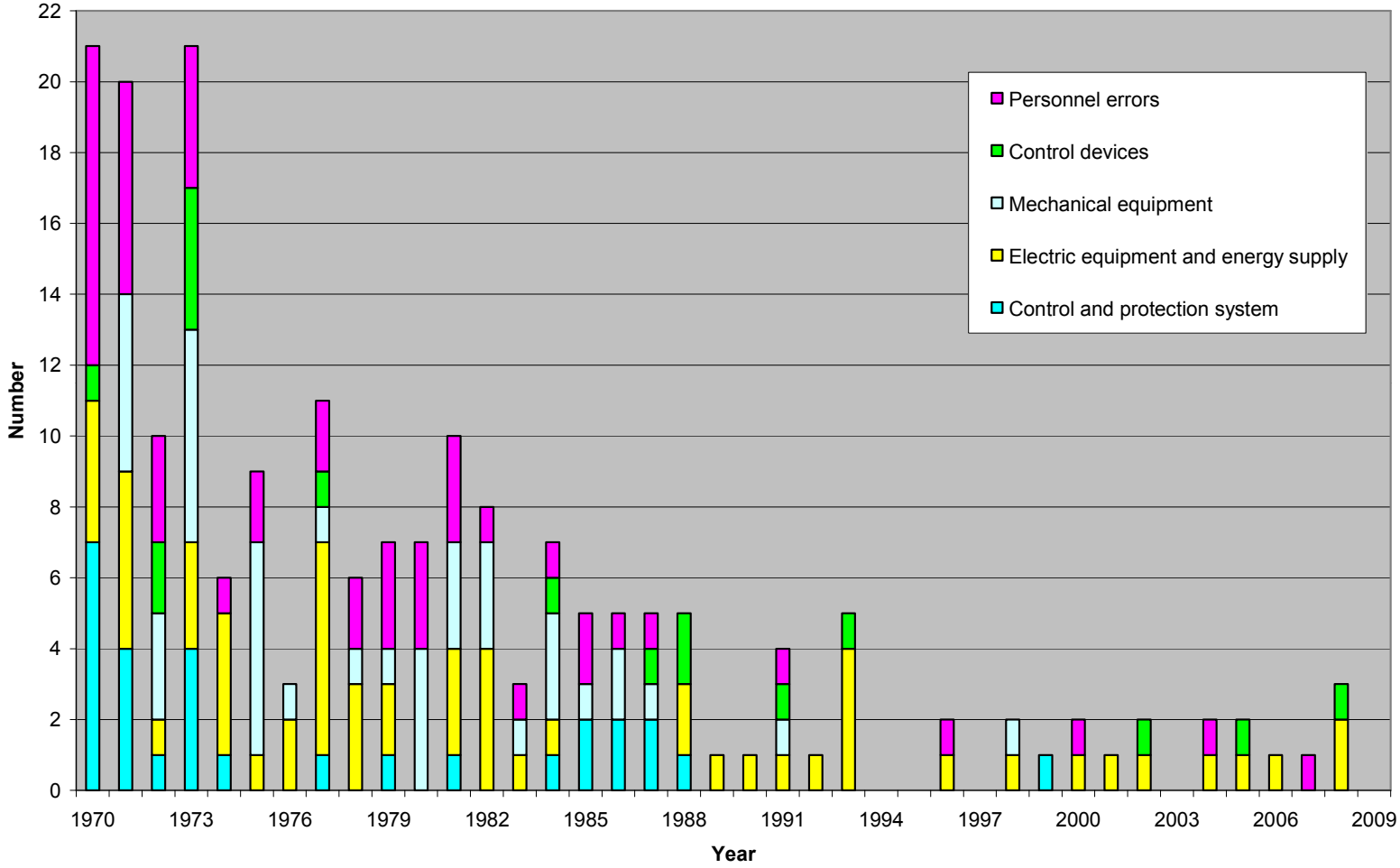
Successful operation of BN-600 sectional-modular SGs has created prerequisites for transition to integral-type SG design.

LIST OF INTERCIRCUIT LEAKS IN THE BN-600 SG MODULES

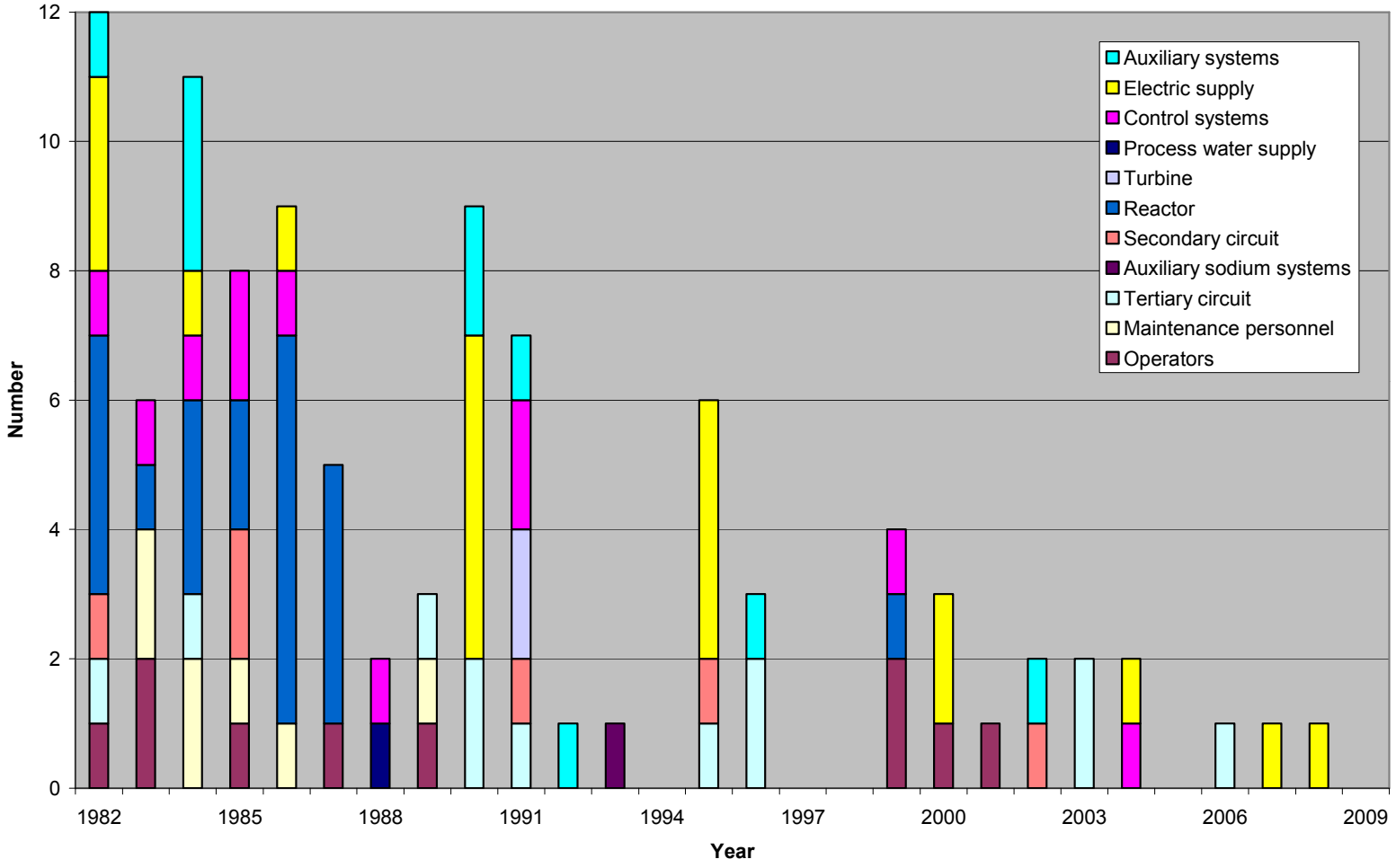
Date	24.06. 1980	04.07. 1980	24.08. 1980	08.09. 1980	20.10. 1980	09.06. 1981	19.01. 1982	22.07. 1983	06.11. 1984	10.11. 1984	24.02. 1985	24.01. 1991
Leak location	RH	SH	RH	SH	SH	SH	SH	SH	E	RH	SH	RH
Leak size	L	L	S	S	S	S	L	S	S	S	S	S

Abbreviations: RH – reheater, SH - superheater, E – evaporator, L – large leak, S – small leak

DISTRIBUTION OF UNSCHEDULED BOR-60 SHUTDOWNS BY INITIAL EVENTS AND YEARS



Time distribution of equipment faults and personnel errors during BN-600 power unit commercial operation



MAIN RESULTS OF THE BN-600 OPERATIONAL EXPERIENCE

The absence of sodium leaks in BN-600 during the recent 16 years allows us to assert that the sodium technology has been mastered securely.

Failures occurring in the recent years of BN-600 operation are primarily related to process equipment of the tertiary circuit and power supply systems rather than sodium systems.

The most important results of Russian SFRs operation, in particular BN-600, which demonstrate a capability to ensure safe and reliable SFR operation, are as follows:

- *Sodium coolant technology has been mastered and developed in industrial scale;*
- *Long-term endurance tests of large-size sodium components have been carried out;*
- *SFR equipment operating/servicing modes have been developed and upgraded;*
- *Sodium component replacement and repair technology has been mastered including the main equipment (pumps, steam generators, intermediate heat exchangers, rotating plugs);*
- *Acceptable level of fuel burnup has been achieved.*

POSITIVE FEATURES OF SODIUM COOLANT

Operational experience gained has allowed the following positive sodium coolant properties contributing to provision of SFR safe and reliable operation that were not evident at the beginning of SCFR life to be revealed:

- *A capability to provide stable heat removal from fuel elements under sodium boiling;*
- *Low corrosion activity.*

Thus sodium coolant demonstrated good compatibility with structural materials and low corrosion activity in the operating parameters range mastered for SFRs.

The work performed at BN-600 within the framework of its lifetime extension proved a possibility of SFR operation for as long as 45 years. Looking forward at present consideration is given to the possibility to extend design lifetime of advanced SFRs up to 60 years.

Achieved parameters on operation time and lifetime of SFR equipment without overhaul (as of 2009), h

Type of equipment	BR-5/BR-10	BOR-60	BN-350	BN-600
Non-replaceable equipment: Reactor vessel Primary pipings	 150 000 300 000	 225 000 225 000	 170 000 170 000	 205 000 205 000
Sodium pumps	170 000 electromagnetic	260 000 mechanical	100 000 mechanical	105 000 mechanical
Intermediate heat exchangers	300 000	225 000	170 000	205 000
Steam generators	-	155 000 reverse SG	150 000	125 000 evaporators

ACTIVITIES ON ENHANCEMENT OF BN-600 SAFETY

As to SFR safety aspects it should emphasize that the BN-600 design approaches to safety ensuring, applied technical solutions and safety systems confirmed in general their validity and efficiency.

However, they require further development and improvement in compliance with the requirements of safety regulatory documents in force.

Thus currently the following activities are under way at the BN-600 reactor:

- *Development of a supplementary decay heat removal system through air-sodium heat exchanger (AHX);*
- *Equipping reactor with a second set of protection system devices;*
- *Construction of an emergency control console.*

CONCLUSION

The analysis of SFR safety related operational experience gained in Russia enables us to make a conclusion about industrial application of this reactor technology and, in particular, sodium coolant technology, and it also demonstrates the possibility of ensuring reliable and safe operation of sodium cooled fast reactors on the example of BN-600 power unit operation.

Thank you for your attention !