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Principles of Inherent Self-Protection Realized in the Project of Small Size Modular Reactor SVBR-100

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CONTENT

INTRODUCTION (1)

- During the historically short period, use of nuclear power (NP) was followed by a number of low probability accidents of various extent of severity, which caused strong exhausts of radioactivity into the environment and/or considerable economical losses.

- The initial events for these accidents are very unlike. These are such as personnel’s errors, technical failures, extremal external impacts. However, there is a common cause of the severe consequences of all these accidents, which are the result of releasing the various types of potential energy accumulated in different materials, first of all, in the reactor facility (RF) coolant.

- Because of those accidents, in many countries the population trust in the NPP safety was lost. Therefore, in order to win the population confidence, it is necessary to make corrections in the long-term strategy of NP development.

INTRODUCTION (2)

- **The RF coolant much determines the RF design as well as safety and economic characteristics of the NPP power-unit.**
  Each of coolants used or proposed for usage possesses its own advantages and drawbacks, their significance is determined by the reactor purpose and external conditions.

- **Heavy liquid metal coolant (HLMC) is used in reactor facility SVBR-100 (Lead-Bismuth Fast Reactor with 100 MWe of equivalent electric power). In HLMC there is no stored potential energy, which as being released in events of accidents can cause damage in protection barriers and strong exhausts of radioactivity and/or economical losses.**

- **That is potential energy of coolant compression and chemical energy of interaction with water, air, zirconium.**

INTRODUCTION (3)

- **The factor of hazard reactivity accidents (prompt neutron runaway) must be minimized as early as at the reactor design phase.**
- **Catastrophic consequences of such accident caused by damage of protection barriers and radioactivity exhaust into the environment will be only observed provided growth in coolant temperature caused by power increase results in inadmissibly high increase of pressure (Chernobyl).**
- **Possible melting of the core that is a severe accident itself. However it will not result in catastrophic exhaust of radioactivity into the environment without high increase of coolant pressure and damaging of protective barriers.**

INTRODUCTION (4)

- For the coolants considered below (water, sodium and HLMC), which boiling point under the atmospheric pressure is 100 ºC, ~ 900 ºC and ~ 1700 ºC, correspondingly, growth in pressure will be the least for coolants with the highest temperature of boiling.
- Elimination of prompt neutron runaway is possible by coupling the technical means provided in the control and protective system with negative feedbacks. On the contrary potential (non-nuclear) energy stored in the RF coolant is an inherent property of coolant material and cannot be changed by engineering solutions.

EFFECT OF STORED POTENTIAL ENERGY ON SAFETY AND ECONOMY (1)

The hazard from the RF is determined by two factors:

1) **Radiation potential accumulated**, i.e., total radioactivity (more exactly, radiotoxicity) contained in the reactor facility;
   That factor does not depend strongly on the RF type, because total radioactivity contained in the RF is determined by amount of fission products, i.e. by energy production.

2) Amount of radiotoxicity release into the environment for different initial events. That factor depends strongly on the RF type and is determined mainly by potential energy accumulated in the RF materials (first of all, it is coolant compression energy and chemical energy).

EFFECT OF STORED POTENTIAL ENERGY ON SAFETY AND ECONOMY (2)

Comparison of potential energy for different coolants

Coolant	Water	Sodium	HLMC
Parameters	P = 16 MPa T = 300 ºC	T = 500 ºC	T = 500 ºC
Maximal potential energy, GJ/m^3, including:	~ 21,9	~ 10	~ 1,09
Thermal energy / potential compression energy	~ 0.90 / ~ 0.15	~ 0.6 / None	~ 1.09 / None
Potential chemical energy of interaction	With zirconium: ~ 11.4	With water: ~ 5.1 With air: ~ 9.3	None
Potential energy of interaction of escape hydrogen with air	~ 9.6	~ 4.3	None
Potential compression energy and chemical energy	~ 21	~ 9.4	None

EFFECT OF STORED POTENTIAL ENERGY ON SAFETY AND ECONOMY (3)

- **Upgrade of safety for NPPs based on traditional type RFs (with high margin of potential energy accumulated in coolant) requires increase of the number of safety systems and defense-in-depth barriers, which reduce the probability of arising severe accidents and weight of their consequences.**
- **While assessing that probability, the failures of the basic equipment, safety systems, protection barriers, and personnel's errors are considered as random events.**
- **However, even low probability of the severe accident (10^{-7} and lower) does not eliminate an opportunity of its happening. So, the level of social acceptability of the NP is reduced.**

EFFECT OF STORED POTENTIAL ENERGY ON SAFETY AND ECONOMY (4)

- For the risk of radioactivity release from different type RFs being at a similar, socially acceptable level, the number of safety systems and defense-in-depth barriers, which strongly determine the NPP technical and economical characteristics, can be reduced with decrease of potential energy accumulated in coolant, which selection determines the RF design.
- At this point, it is important that the high safety level at a low value of potential energy stored in coolant can be achieved, mainly, due to elimination of the causes of severe accidents, i.e., deterministically.

EFFECT OF STORED POTENTIAL ENERGY ON SAFETY AND ECONOMY (5)

- Therefore, the most expedient way to upgrade the NPP safety and at the same time improve the economic characteristics is use of the RF, in which the value of stored potential energy is the lowest and in which the inherent self-protection and passive safety properties can be realized to the maximal extent.
- For example, that is the RF based on modular fast reactor SVBR-100 with heavy liquid metal coolant –
  eutectic lead-bismuth alloy.

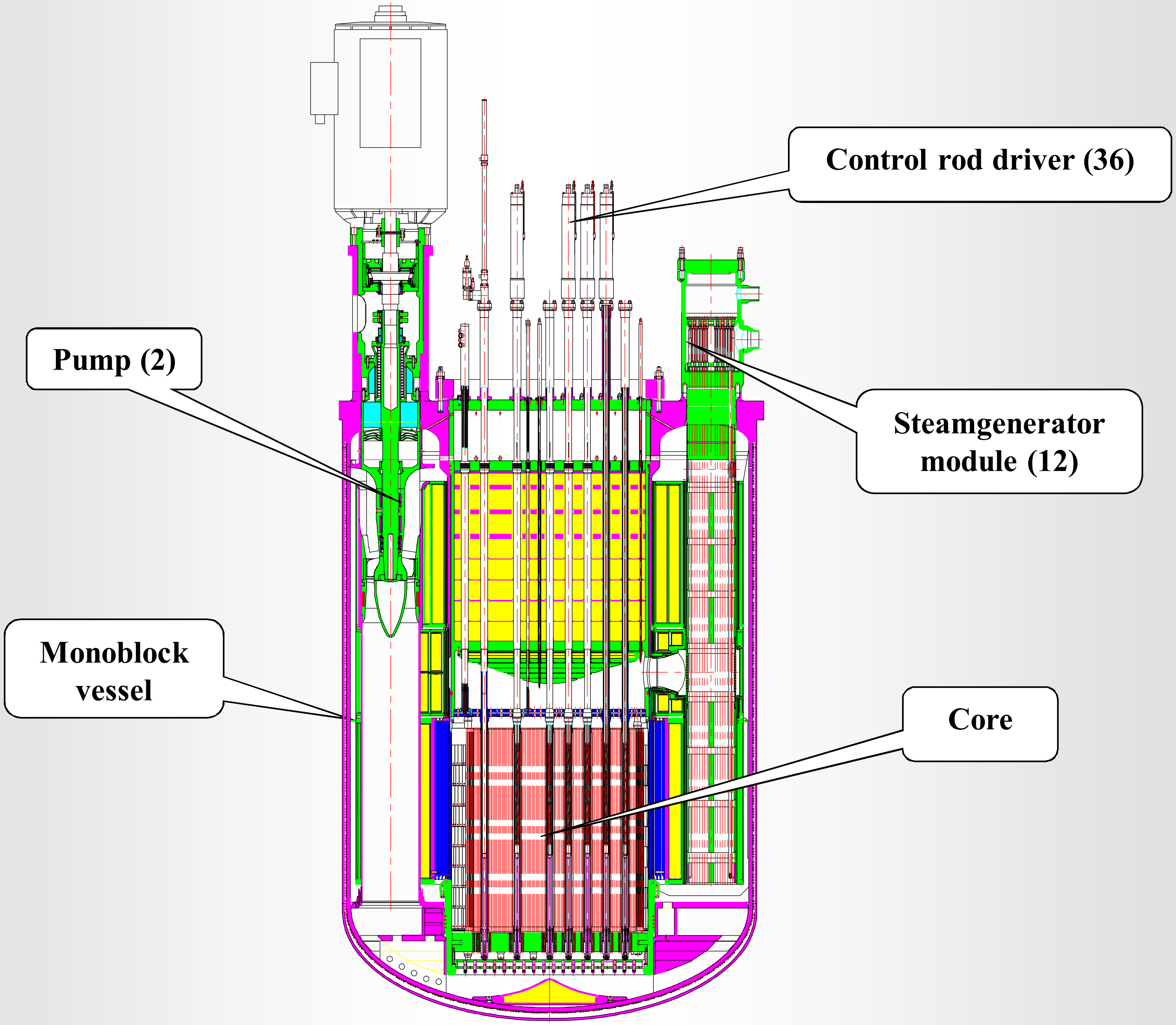
EFFECT OF STORED POTENTIAL ENERGY ON SAFETY AND ECONOMY (6)

- Those RFs cannot amplify the external impacts. Therefore, the scale of damages will be only determined by energy of the external impact, the exhaust of radioactivity being localized.
- Such type RFs will possess the robustness properties, which will ensure their enhanced stability not only in events of single failures of the equipment and personnel’s errors, but also in events of malevolent actions, that is especially viable for NP development in the countries where the threat of terrorism is very high.
- For those type RFs the accident similar to that occurred at NPP Fukushima will not cause radioactivity exhaust beyond the NPP fence.

INHERENT SELF-PROTECTION AND PASSIVE SAFETY OF RF SVBR-100 (1)

- The main effect in providing a high safety level of the SVBR-100 RF is achieved due to use of fast neutron reactor, heavy liquid-metal coolant, and integral design of the reactor, with total elimination of pipelines with radioactive coolant beyond the monoblock vessel.
- The reactor possesses a negative void reactivity effect and negative feedbacks, the efficiency of the strongest absorbing rod does not exceed 1 $. And that coupled with technical realization of the control and protection system (CPS) eliminates prompt neutron runaway of the reactor.
- The high boiling point of coolant heightens reliability of heat removal from the core, and safety due to lack of the heat transfer crisis. Also, being coupled with a provided safeguard casing of the monoblock, that eliminates loss of coolant accidents (LOCA) and high pressure radioactive exhausts.

REACTOR MONOBLOCK SVBR-100



INHERENT SELF-PROTECTION AND PASSIVE SAFETY OF RF SVBR-100 (2)

- The low pressure in the primary circuit reduces the risk of its tightness failure and makes possible lessening the thickness of reactor vessel's walls and diminishing the limitations imposed on the rate of temperature change according to thermal-cycling strength conditions.

- The RF components do not contain materials releasing hydrogen as a result of thermal and radiation effects and chemical reactions with coolant, water and air. Therefore, in an event of tightness failure in the primary circuit the likelihood of chemical explosions and fires is virtually eliminated.

- The circulation scheme of lead-bismuth coolant (LBC) provides elimination of water/steam ingress into the core in an event of steam generator (SG) leak due to effective gravitational separation of steam on a free LBC level in the monoblock.

INHERENT SELF-PROTECTION AND PASSIVE SAFETY OF RF SVBR-100 (3)

- **Safety systems do not contain elements, which actuation can be blocked in an event of their failure or under impact of human factors:**

- Removal of heat decay is provided passively by natural circulation of LBC in the primary circuit. This is realized by transferring heat over four independent channels in the SG to the secondary circuit water and then to the water tank of the passive heat removal system (PHRS) with removal of generated steam into the atmosphere;

- In an event of large leak in several SG tubes, localization of SG leak is provided passively while increasing the steam pressure in the gas system over 0.5 MPa. This is provided by using a safeguarding membrane and discharging steam into the bubbling device. (It should be highlighted that operating experience has revealed that in an event of small leak in the SG, the RF does not need to be shut down at once).

INHERENT SELF-PROTECTION AND PASSIVE SAFETY OF RF SVBR-100 (4)

- When LBC temperature is increased over a specified value, the rods of the additional emergency protection system, which are mounted in "dry" channels and are without drivers on the reactor lid, actuate passively by gravity due to fusible locks made of the alloy with a corresponding melting temperature and holding the rods in the upper position at normal temperature modes;
- In an event of postulated failure of all four channels of the PHRS, it is provided to flood the reactor vault by water from the tank mounted above and transfer heat via the monoblock vessel, air gap and safeguard casing to the water with further removal of generated steam into the atmosphere.

SPECIFIC FEATURES OF SVBR-100 TECHNOLOGY (1)

- **Technology is based on forty-year (80 reactor-years) experience of development and operation of LBC cooled RFs at NSs and ground facilities-prototypes. In the process of mastering this new technology a series of scientific and technical problems has been solved:**

- providing corrosion resistance of structure materials, control and maintenance of coolant quality (coolant technology);

- providing radiation safety, which was caused by formation of polonium-210 in the process of irradiating bismuth with neutrons;

- multiple “freezing-unfreezing” of LBC while keeping operability of the RF equipment;

- providing of reliability of steam generators.

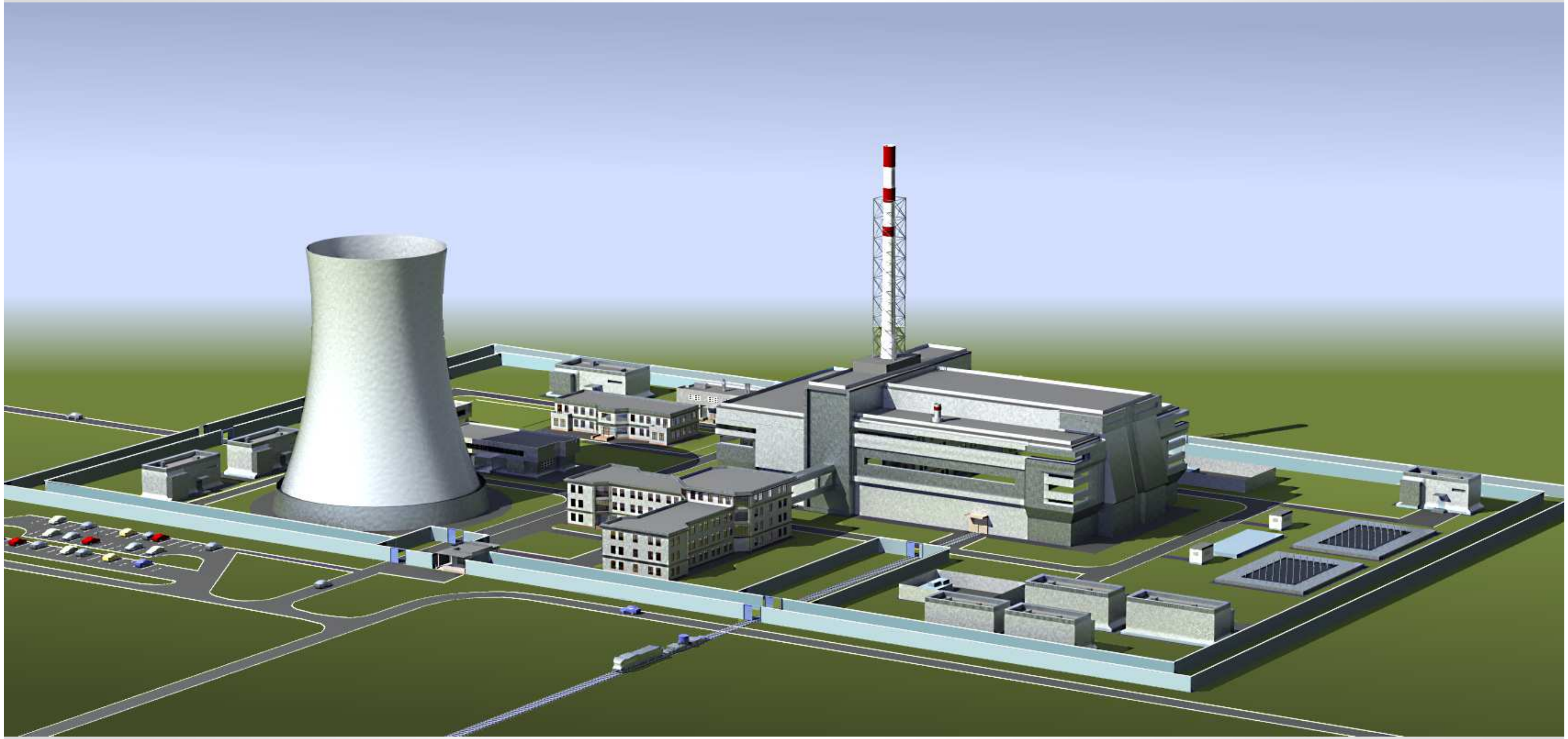
SPECIFIC FEATURES OF SVBR-100 TECHNOLOGY (2)

- **Opportunity to achieve CBR ≥ 1 using MOX fuel and operation in the closed NFC in a mode of fuel self-providing.**
- **Option for reactor module power to be ~100 MWe and fuel lifetime to be 7…10 years.**
- **Opportunity of passive cooling via the reactor monoblock wall.**
- **Opportunity for the factory ready reactor module to be transported to the NPP construction site by railway or some other vehicles.**
- **Opportunity to launch large-scale production at a large number of engineering factories without losses in production of high pressure vessels for pressurized water reactors.**

SPECIFIC FEATURES OF SVBR-100 TECHNOLOGY (3)

- **Construction of power-units of various power multiplied 100 MWe using a standardisated reactor module.**
- **Large-scale production of the standardisated reactor modules in factory readiness will much compensate for economical losses in scale.**
- **Changeover to standard designing and production-line methods of construction and assembly works.**

EXPERIMENTAL- INDUSTRIAL POWER-UNIT WITH RF SVBR-100



CONCLUSION (1)

- From the standpoint of population, the opportunity of catastrophic consequences caused by nuclear accident is much more important than very low possibility of its realization.
- The level of social acceptability of future large-scale NP must be higher.
- Use of the nuclear power technology (NPT) based on RFs, in which the value of stored potential energy of different kinds is minimal, will meet that goal the most efficient.
- Those RFs cannot amplify the external impacts, therefore, the scale of damages will be only determined by the external impact energy, the exhaust of radioactivity being localized.

CONCLUSION (2)

- **Now there are no developed NPTs with such properties.**

- **The NPT based on modular fast reactors SVBR-100 and verified in conditions of NS operating is to the most extent ready to be demonstrated.**

- **Federal target program “New Generation Nuclear Power Technologies for 2010 – 2015 Years and Future Trends up to 2020” stipulates the construction of experimental-industrial power-unit SVBR-100.**

CONCLUSION (3)

- The project is realized within the frameworks of state-private partnership by joint venture JSC “AKME-Engineering” organized on a parity basis by State Atomic Energy Corporation “Rosatom” and Limited Liability Company “Irkutskenergo”.

- The first of a kind power unit with RF SVBR-100 will be commissioned in 2017 near the SSC NIIAR site in Dimitrovgrad (Ulyanovsk region).

- Widespread common use of this NPT, which potentials are very high, is expected to begin in ~ 2020 – 2025. In case of earlier starting, the economic risk will be high; in case it is launched later, much profit will be lost.

Thank you very much for your attention