14. Lars Hallstadius , Steven Johnson, Ed Lahoda, Cladding for high performance fuel, Progress in Nuclear Energy 57 (2012) 71-76.
15. Kurt A. Terrani, Accident tolerant fuel cladding development: Promise, status, and challenges, Journal of Nuclear Materials 501 (2018) 13-30
16. Michau, A.; Maskrot, H.; Gazal, Y.; Maury, F.; Duguet, T.; Boichot, R.; Pons, M.; Brachet, J.-C.; Monsifrot, E.; Schuster, F. Inner surface protection of nuclear fuel cladding, towards a full-length treatment by DLI-MOCVD, an optimized coating process. In Proceedings of the TopFuel 2018, Prague, Czech Republic, 30 September–4 October 2018; Available online: https://www.researchgate.net/publication/328073036 (accessed on 4 October 2018).
17. Edsinger, K.; Murty, K.L. LWR Pellet-Cladding Interactions : Materials Solutions to SCC. JOM 2001, 9–13.
18. Chen, H.; Wang, X.; Zhang, R. Application and Development Progress of Cr-Based Surface Coatings in Nuclear Fuel Element :1. Selection, Preparation, and Characteristics of Coating Materials. coatings-MDPI 2020.
19. Michau, A.; Gazal, Y.; Addou, F.; Maury, F.; Duguet, T.; Boichot, R.; Pons, M.; Monsifrot, E.; Maskrot, H.; Schuster, F. Scale up of a DLI-MOCVD process for the internal treatment of a batch of 16 nuclear fuel cladding segments with a CrCx protective coating. Surf. Coat. Technol. 2019, 375, 894–902, doi:10.1016/j.surfcoat.2019.06.101.

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# COMPARISON OF COOLED LIQUID METALLIC REACTORS (SODIUM AND LEAD)

A breeder reactor is a nuclear reactor that generates more fissionable material than it consumes. This unique reactor is meant to increase the amount of nuclear fuel available for electric power generation. A breeder reactor uses either uranium-238 or thorium, both of which are abundant. A conventional nuclear reactor can only use the readily fissionable but scarce isotope uranium-235 for fuel [1].

**Types**

**1. Thermal breeder reactors**

Thorium-232 is used as the basic fuel, or fertile material, in another breeder, the thermal breeder reactor. This isotope is converted to fissionable uranium-233, which can cause a chain reaction. Ordinary water is used as a coolant to dissipate the heat created by the continuous succession of fission reactions in the thermal breeder, whose technology is far simpler than that of the liquid-metal fast breeder.

**2. Fast breeder reactors**

Liquid-metal fast breeder reactors that use artificial radioactive decay to convert uranium-238 into the fissionable isotope plutonium-239 then the plutonium-239 is bombarded with high-speed neutrons. A plutonium nucleus separates into two fission pieces when it absorbs a free neutron. This fission produces heat and neutrons, which then divide other plutonium nuclei, releasing more neutrons. When this process is repeated several times, it forms a self-sustaining chain reaction, giving a constant source of energy, primarily in the form of heat, which is carried from the reactor core to a series of heat exchangers by a liquid sodium coolant. This system uses heat to generate steam, which is used to operate a turbine that drives an electric generator.

The fission chain reaction in a fast neutron reactor (FNR) is begun by fast neutrons (carrying energies more than 1 MeV on average) rather than thermal neutrons utilized in thermal neutron reactors. This eliminates the requirement for a neutron medium (Moderator), but it does require a fuel with a higher fissile content than a thermal neutron reactor's fuel.

*Sodium-Cooled Liquid-Metal Reactor*

A sodium-cooled fast reactor is a fast neutron reactor cooled by liquid sodium, with BN being the most important of these reactors.

The BN-reactor is a type of sodium-cooled fast breeder reactor developed by OKBM Afrikantov in Russia.

There are numerous types of BN-Reactors: BN-350, 600, 800, and 1200.

BN's new technology platform is built around a closed nuclear fuel cycle. This indicates that using MOX fuel will allow the nuclear power industry to make use of uranium that isn't currently used in fuel synthesis, so expanding its resource feedstock. Furthermore, by "afterburning" long-lived isotopes, the BN-800 reactor may recover spent nuclear fuel from other nuclear power plants, reducing radioactive waste.

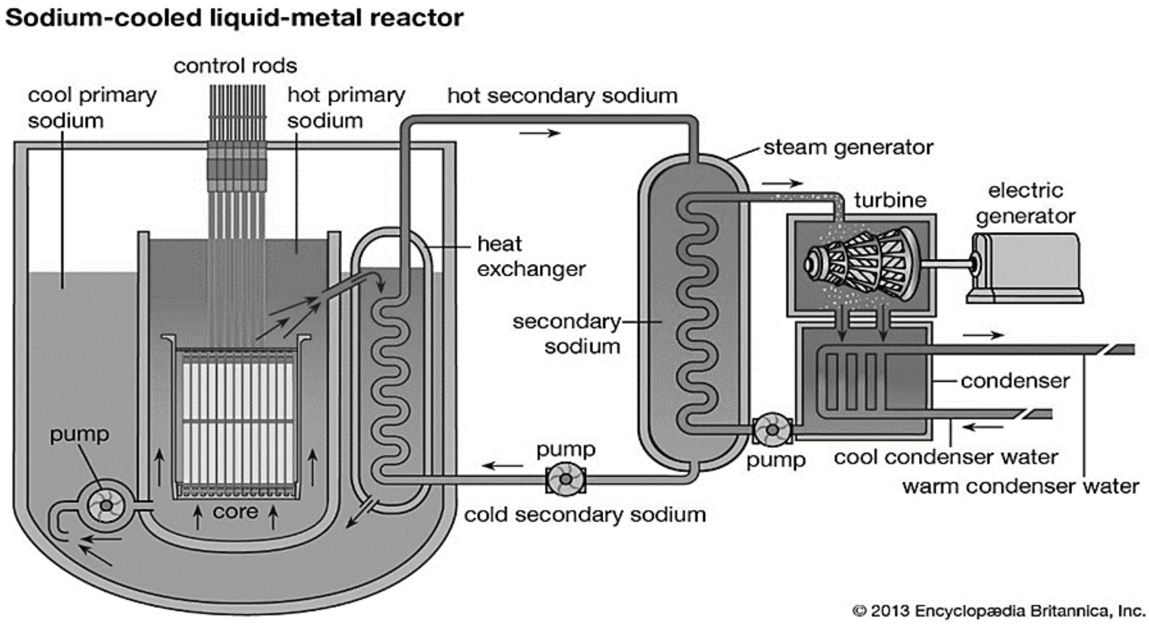


*Fig. 1. Sodium-Cooled Liquid-Metal Reactor*

Unlike traditional enriched uranium nuclear fuel, MOX fuel pellets are made up of a mixture of nuclear fuel cycle derivatives, including plutonium oxide generated in commercial reactors and depleted uranium oxide derived from defluorination of depleted uranium hexafluoride (UF6), also known as secondary tailings from uranium enrichment plants.

*Lead-Cooled Liquid-Metal Reactor*

LFRs are advanced fourth-generation reactors with a fast neutron spectrum, high temperature operation, and cooling by molten lead or lead eutectic bismuth (LBE), both of which permit low pressure operation and have good thermodynamic attributes. It is generally inert when it comes to contact with air or water since it is very inert.

It will be used for a variety of things, including power generation, hydrogen synthesis, and process heat.

Because it operates in the fast neutron spectrum and uses a closed fuel cycle for efficient conversion of enriched uranium, the LFR has superior material management capabilities. It can also be utilized as a burner/breeder with thorium arrays for consuming actinides from waste LWR fuels. The LFR's increased safety is due to the use of molten lead as a comparatively innocuous, low-pressure coolant. Lead is abundant and so available, even if a large number of reactors are deployed, in terms of long-term sustainability. Most notably, the LFR fuel cycle's conversion capabilities, like those of other fast systems, greatly improve fuel sustainability. LFR designs have considerable potential in terms of safety, design simplification, proliferation resistance, and economic performance since they integrate a liquid coolant with a very high margin for boiling and benign contact with air or water.

The European lead-cooled ELFR system, the Russian BREST-OD-300 system, and the US-designed SSTAR system concept are the system concepts featured in the Fourth Generation International Forum (GIF) System Research Plan (SRP) plans. The BREST-OD-300 system is what I'm going to talk about.

The project's name is revealed by the abbreviation OD, which stands for "Experimental and Demonstration" in Russian. "BREST-OD-300" is an abbreviation of the Russian term for a fast neutron reactor with a lead coolant.

It is a breeder reactor that can burn long-term radioactive waste and employs nitride uranium-plutonium fuel. High-boiling, radiation-resistant, low-activated, and at atmospheric pressure, lead is chosen as a coolant.

*The BREST-300 and BREST-1200* are the two designs that are being considered (1200 MWe). Passive safety and a closed fuel cycle are two of the BREST reactor's primary features [2].

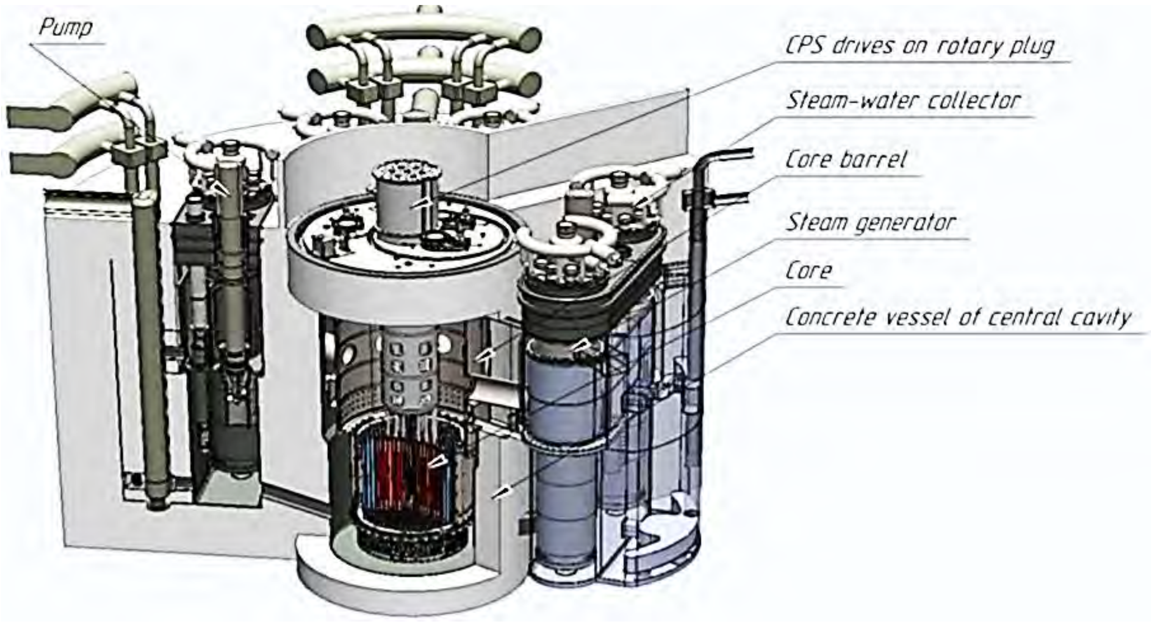


*Fig. 2. Schematic representation of BREST-OD-300*

Table 1

| Name | Description (BREST-300) | Description (BN-800) |
|---|---|---|
| Reactor type | Liquid metal cooled fast reactor | Liquid metal cooled fast reactor |
| Electrical capacity | 300 MW | 864 MW |
| Thermal capacity | 700 MW | 2100 MW |
| Coolant | Lead | Sodium |
| Primary circulation | Forced circulation | Forced circulation |
| System pressure | Low pressure operation | Low pressure operation |
| Core inlet/outlet temperature | 420 / 540°C | 354 / 547°C |
| Fuel material | PuN–UN | MOX fuel ($PuO_2$-$UO_2$/depleted $UO_2$) |

*Parameters of BREST-300 & BN-800 [2, 3]*

**Conclusion**

For a variety of reasons, lead stands out among the coolants available for nuclear reactor systems [4].

1. It has good cooling qualities as a thick liquid, and its nuclear properties (i.e., its low inclination to absorb or slow down neutrons) allow it to easily maintain high neutron energy.

2. The problem of coolant boiling is virtually eliminated due to the extremely high boiling temperature of lead, which is 1749 °C. The large boiling margin provides significant safety benefits, as well as design simplification and enhanced economic performance.

3. Lead's chemical inertness is one of its most essential features as a coolant. In comparison to sodium and water, lead is a safe coolant since it does not promote rapid chemical reactions that could result in energy release in an accident.

REFERENCES

1. Britannica. Breeder reactor // URL: https://www.britannica.com/technology/breeder-reactor (date 06.04.2022)
2. IAEA. BREST-OD-300 // URL: https://aris.iaea.org/PDF/BREST-OD-300.pdf (date 06.04.2022)
3. JSC "Saint Petersburg Research and Design Institute "ATOMENERGOPROEKT". NPP with BN-800. 2011. 20 p
4. GENIVIV. Lead-Cooled Fast Reactor// URL: https://www.gen4.org/gif/jcms/c_42149/lead-cooled-fast-reactor-lfr (date 06.04.2022)

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## MECHANICAL SPECTRAL SHIFT CONTROL FOR VVER-1000 REACTOR

### Introduction

The mechanical spectral shift control (SSC) method has the potential for enhancing the utilization of nuclear fuel along with increasing the fuel cycle in nuclear reactors. The mechanical SSC approach is carried out by variation of the water-to-fuel volume ratio (VM/VF) through inserting displacer rods at the beginning of the cycle (BOC) into water tubes distributed uniformly within the fuel assembly and then withdrawing the displacer rods at the end of the cycle (EOC). In the present analysis, the mechanical SSC design of the VVER-1000 reactor with low enriched uranium (LEU) fuel assembly is applied. The obtained numerical values were compared with the benchmark exercise in which conventional control methods have been applied (600 ppm $H_3BO_3$ and 4.0 wt.% $Gd_2O_3$). The results demonstrated that the fuel discharge burnup has increased by 32% and the conversion ratio (CR) value reached up about 0.8 compared with the reference benchmark mean (BM) values.

The mechanical spectral shift control design concept