

## Development of Leak-Before-Broken Material for Double – Walled Once Through Steam Generators in Lead – Bismuth Cooled Fast Reactors

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### 1. Abstract

Among the various types of liquid metal cooled fast reactor, lead cooled fast reactor (LFR) can take a closed fuel cycle to manage fertile fuel and actinide efficiently. LFR can adapt an External Boiling Bayonet Steam Generator (EBSSG) system instead of conventional once-through high pressure steam generator. While EBSSG designs have proven extensive operating experiences in submarine reactors of the Former Soviet Union, their complex tube geometries invite life-limiting disadvantages ranging from vibration-led fatigue, oxide particles sedimentation and increased resistance to natural circulation under accident conditions. Therefore, LFR with the External Boiling Bayonet Steam Generator has advantages in terms of thermal efficiency and safety during operation.

However, the External Boiling Bayonet Steam Generator has thermal vibration issues at the nozzle because of a huge heat exchanger inside once-through steam boiler which consists of additional steam blowers. Furthermore, this vibration can lower the heat transfer efficiency of heat exchanger due to the adhesion phenomenon of impurities from lead coolant.

And then, fatigue failure as well as environmental corrosion may occur at the shell side of heat exchanger, which leads the coolant leakage accident. To assure the overall performance of steam generator, those structural material degradation issues on the thermal vibration should be solved.

In the paper, we present innovative design concepts for durable, maintainable and accident-tolerant double-walled once-through steam generators (DWOTSG) that can fulfill requirements for non-refueling and hermetically-sealed 40 years life micro-modular LFR: Micro-Uranus. The newly designed tube for steam generator is consisted of double walled layers. In order to assure Leak-Before-Break (LBB), the inter-tubular gap is filled with engineered materials for leak detection and conductivity enhancement. Tube materials are also designed to assure prolonged corrosion resistance and oxide deposition control on heavy-liquid metal side. Exceptional corrosion resistance over 40 year-life can be delivered by Functionally Graded Composite (FGC) tubes with substrate made of internationally certified fast reactor fuel cladding materials. Oxide deposition and thermal degradation can

be controlled by advanced flow channel structure and maintenance designs. The LBB characteristics, corrosion resistance, thermal-hydraulic performance of the innovative designs will be presented using fracture mechanics, oxidation and heat transfer models. <sup>[1]</sup>

### 2. Introduction

The concept of the 4th generation reactor is expected to reduce the burden of disposal of spent fuel and create a huge national resource as a new concept reactor that enables long-term supply of electricity. As a Small Modular Reactor (SMR) that complements large-scale commercial reactors. SMR is suitable for environments where large-scale commercial reactors are difficult to construct. During the accident, SMR has good Colling capacity using natural convection, it is becoming more complete and stable technology than the large-scale commercial reactors.

Among the various types of liquid metal cooled fast reactor, LFR has some good characteristics; high thermal conductivity and low Prandtl number. Due to the low Prandtl number, the propagation of heat by conduction is faster and dominant than the momentum diffusion of molecules inside the fluid. Since the lead coolant has a very low neutron absorption cross section and decelerating capacity. It is suitable for designing fast reactor.

Therefore, it has a high boiling melting point, it operates without pressurizing the primary system of pressurized water reactor. It also has high operating temperature and high efficiency of power production.

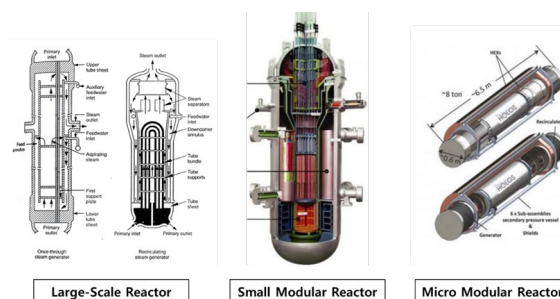


Fig 1. Comparative Schematic Diagram of Large, Small and Micro Modular Reactor

Among the liquid metal cooled reactors, the lead and lead-bismuth type in the form of a tank has reactivity and high-density characteristics with the

water/air of the coolant as compared with the sodium cooled fast reactors.

In the case of Pressurized Water Reactor (PWR) type, it is inevitable to replace the nuclear fuel every 7 years. For icebreakers using conventional PWR type, nuclear fuels need to replace about five times during the operation life of 40 years.

During the replacement of the nuclear fuel, it increase the life cycle cost. If lead-bismuth is used, the marine facility can be operated without replacing the fuel during the operation time without replacing the fuel. Therefore, development of a new material or functional graded composite for long term operation about 40 years; of cladding pipes and structure materials is imperative in order to operate the lead-bismuth reactor for the ocean without replacing the long-term nuclear fuel

### 3. Corrosion Issue

There is interaction between material and liquid metals. In the case of it, it causes the corrosion issue. First is dissolution.

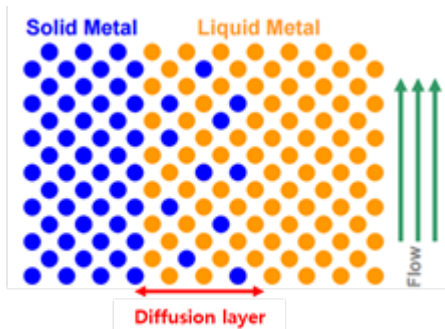


Fig 2. Interaction between solid metal and liquid metal<sup>[3]</sup>

The schematic diagram of dissolution and diffusion is represented the Fig 2. It is kind of solubility that is saturated concentration of solid metal in liquid one. As a result, it falls in bond among atoms in sold metal. Also, it affect the bonding of dissolved atom with atoms of liquid metal.

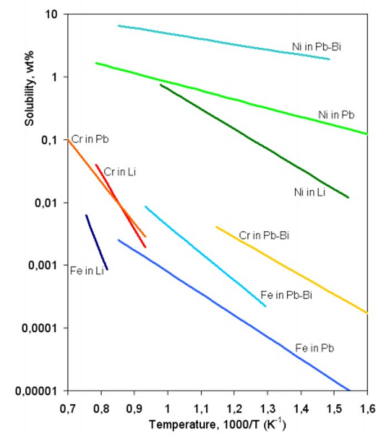


Fig 3. Solubility of atom in liquid metal <sup>[1]</sup>

Therefore, it lead to dissolution if Ni, Cr and Fe from the solid metal by liquid metal. In the Fig 3., it can be checked the solubility of Fe, Cr and Ni in corrosion aggressiveness of liquid metal increases in the following sequence: Pb → Pb – Bi

As the result of dissolution, there are some problems. First, liquid metal penetrates into the material. Second, components of materials (Cr, Fe...) have high affinity to oxygen than Pb or Bi. Oxidation of material surface instead of dissolution of material constitutes by liquid metal.

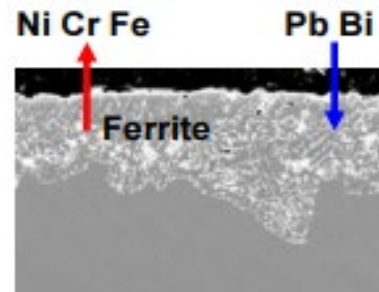


Fig 4. Example of dissolution in Pb – Bi<sup>[2]</sup>

According to Fig 4, there is a dissolution between the liquid metal and the solid metal. Therefore, in order to operate a 40-year-old nuclear reactor, new materials with high corrosion resistance to liquid metals (Pb-Bi, Pb) must be researched and developed.

This research aims to develop materials suitable for operation of 40-years reactors with various corrosion issues as described above.

### 4. Summary and Future work

In the paper, we present innovative design concepts for durable, maintainable and accident-tolerant DWOTSG that can fulfill requirements for non-refueling and hermetically-sealed 40 years life micro-modular LFR: Micro-Uranus.

There are some corrosion issues in liquid metal cooled fast reactor; oxidation, dissolution. As it checked these issues, it aims to develop materials suitable for operation of 40 years with various corrosion issues.

#### **REFERENCES**

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