Development of Sacrificial Material for the Eu-APR1400 Core Catcher

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1. Introduction

To increase and diversify the export marker of the Korean nuclear reactor design, we developed the Eu-APR1400 reactor design based on the APR1400 reactor design, satisfying the European nuclear design requirements including the European Utility Requirements (EUR) and the Finnish requirements of YVL. As recommended by both requirements, the so-called core-catcher molten core ex-vessel cooling facility was developed to manage a severe accident at the Eu-APR1400 reactor involving a core meltdown and to mitigate its consequences.

Usually, sacrificial material (SM), which controls the melt properties and modifies melt conditions favorable to corium retention, can be employed to protect the core catcher body from the molten core and increase its cooling capability. The EPR reactor design (by Areva, France) core catcher consists of the initial corium retention space, the transportation channel and the wide spreading room for core melt cooling[1]. The EPR used two kinds of SM to protect the initial core retention space from core melt and to spread the core melt across the wide spreading room using the different compositions. The VVER (Russia) ensures melt localization in a water-cooled vessel located directly beneath the reactor. SM is used to remove the thermal focusing effect by the layer inversion process between metallic and oxidic melts.[2]

The functional requirements for the SM determined for the present core catcher are (1) melting spreading improvement, (2) focusing effect prevention, (3) hydrogen explosion prevention, (4) FP (fission product) release decreasing, and (5) melt recriticality exclusion.

The rest of the paper is organized as follows. The next section provides detailed descriptions of the composition of the present SM, which satisfies its functional requirements. Following this, the manufacturing process of the SM is presented.

2. Requirements to Sacrificial Materials

The entire set of requirements for the SM at different stages of the core catcher functioning may be broken into four groups.

1. In the standby mode (before an accident), i.e., during the normal operation of a nuclear power plant (NPP), the SM should manifest the following:

- Long-term mechanical strength that will allow the structure to safely exist for 60 years - the entire NPP service life - as a self-bearing structure subjected to vibrations and thermocycling;
- Chemical inertness to atmospheric forces under possible thermocycling within a 20-100°C range (permissible temperatures in the space below the reactor);
- No noticeable material activation in the neutron flow under normal operation.

2. During the first stage of the core catcher operation, SM should ensure the following:

- Intensive chemical interaction with the molten core oxidic part that should cause a liquidus temperature decrease, which thus increases efficient cooling of the system down to lower temperatures, and decreases the melt temperature and reduces the melt density to its inversion with the metallic part of the molten core. The latter should prevent heat fluxes focusing on the water-cooled surface of the heat exchangers in the zone of molten steel upper layer and create favorable conditions for melt flooding;
- Intensive chemical interaction with the molten core metallic part to cause oxidation of the most potent reducers (capable of active hydrogen formation when interacting with steam) in its composition;
- Dilution of the melt containing fission products for reducing the density of energy release from the FP and ensuring nuclear subcriticality of the system;
- A reduction of both the initial peak and long-term melt temperature at the expense of the SM's own cooling capacity;
- The absence of equilibrium or gravity stratification (segregation) of the melt forming from the interaction of the SM with the molten core oxidic part;
- Minimization of quantities of gases, steam and aerosols (radioactive ones included) released at the interaction of the SM with molten core and after melt flooding;
- Reduction by different ways of the quantity of the most dangerous radioactive components released into the gaseous phase;
- A high degree of resistance of the construction to dynamic mechanical load and thermal shock before the beginning of active chemical interaction of the SM with the metallic and oxidic parts of molten core, i.e., the SM should display high strength, resilience and heat resistance.

3. At the stage of accident-free NPP decommissioning, the SM should ensure the following:

- An easy and safe disassembly of the construction;
- Economic disposal of the material.

4. At the stage of the NPP decommissioning after molten core localization, the SM should ensure:

- The stable existence within a long period of time of the formed solid body with chemical and radiochemical processes running in it, and in the presence of contact with borated water and air;
- A low rate of FP leaching from the ingot.

3. Choice of the Composition of Sacrificial Material for the Eu-APR1400 Core Catcher

The major composition of the present SM is ferric oxide (Fe_2O_3) and aluminum oxide (Al_2O_3). Following these, SrO and CaO are added. In order to avoid the thermal focusing effect by the layer inversion process between the metallic and oxidic melts, a large amount of ferric oxide component is decided. An additional small amount of Gd_2O_3 is included to avoid recriticality of the core melt. The present SM is made by $SrFe_{12}O_{19}$, from SrO and Fe_2O_3, and commercial cement composed of CaO an Al_2O_3 as shown in Fig. 1.

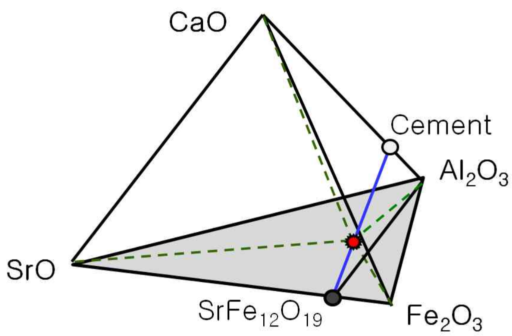

Fig. 1 Schematic of the Sacrificial Material for the Eu-APR1400 Core Catcher

4. Manufacturing Process of Sacrificial Material

The manufacturing process of sacrificial material for the Eu-APR1400 core catcher is shown in Fig. 2

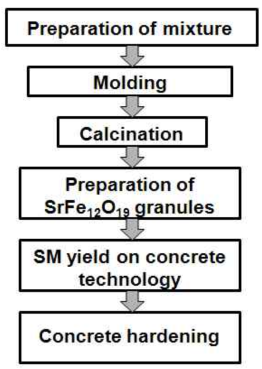

Fig 2 Flow Chart of the Manufacturing of Sacrificial Material

Fig. 3 shows the materials used to make $SrFe_{12}O_{19}$, the main component of SM, which is produced by mixing ferric oxide and SrC03. Fig. 4 shows the commercial cement composed of ferric oxide and CaO, to be mixed with $SrFe_{12}O_{19}$. Finally, the SM is produced by mixing SrFe12O19 and commercial cement with an appropriate ratio.

Fig. 3 Material Composition to Produce $SrFe_{12}O_{19}$

Fig. 4 Cement Component to be Mixed with $SrFe_{12}O_{19}$

5. Conclusions

Based on the requirements for the sacrificial material for an ex-vessel core catcher and the results of the analysis of candidate alternatives, concrete with strontium hexaferrite filler and binder composed of alumina and calcia was selected as the sacrificial material for the EU-APR1400 core catcher.

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