Assessment of Process Technologies for SFR Metallic Fuel Fabrication

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1. Introduction

In order to meet the rising energy demand and the emission of greenhouse gas, the generation IV International Forum is undertaking the development of innovative nuclear energy system with the goals, safety, economics, resource utilization, waste management, proliferation resistance and physical protection (PR&PP) [1]. The sodium-cooled Fast reactor (SFR) system is among the six systems selected for Gen-IV promising systems and expected to be deployed in 2020. Since 1997, R&D on SFR has been actively launched as a part of the national long-term nuclear R&D program. And the Korea Advanced Liquid Metal Reactor (KALIMER) developed in Korea was chosen as a GEN-IV SFR reference reactor. In the end of 2008, the 255th Atomic Energy Commission finalized the SFR R&D roadmap to construct the demonstration reactor by 2028 [2]. International collaborative research is under way on fuel developments within Advanced Fuel Project for Gen-IV SFR with the closed fuel cycle of full actinide recycling, while TRU bearing metallic fuel, U-TRU-Zr alloy fuel, was selected and is being developed at KAERI in conjunction with a pyroprocessing technology. In this paper, in order to develop the process requirements and design the process technology for the fabrication of TRU bearing metallic fuel, the fabrication process flow and key process technologies were assessed and evaluated.

2. Assessment of U-TRU-Zr metal fuel fabrication

2.1 Features of metal fuel fabrication

Fig. 1 shows the specifications and dimensions of U-TRU-Zr fuel bundle which is under development at KAERI. The composition of the fuel is U-20%TRU-10%Zr. As shown in figure, a fuel bundle is composed of a nose piece and a handling socket in the end, and a duct in the middle part which contains 271 fuel pins assembled inside it [3]. Each fuel pin has a lower end plug, a fuel slug, an upper gas plenum, and an upper end plug. The outside of fuel is wrapped with a wire. In inside of fuel pin, the gap between fuel slug and fuel cladding is filled with sodium (Na). In principle, a closed fuel cycle is based on recycling a used fuel discharged from a reactor, which means the handling of high radioactive materials. Since americium is a strong gamma emitter, and curium a high neutron emitter, the fabrication of TRU bearing metallic fuel needs to be performed in a remote manner in a shielded hot-cell with sufficient radiation protection as shown in Fig. 2. Moreover, all the fabrication works should be done in an inert atmosphere, because of the high reactivity of the handling materials like Uranium (U), Plutonium (Pu), and Sodium (Na) metals. At the same time, other issues, which is totally different from the conventional fresh fuel fabrication, should be considered from the viewpoint of criticality safety, safeguards, and PR&PP, etc.

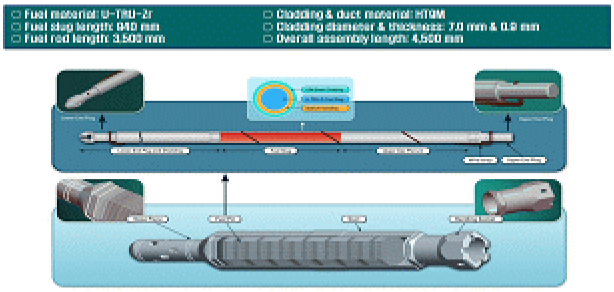

Fig. 1. U-TRU-Zr metal fuel for SFR

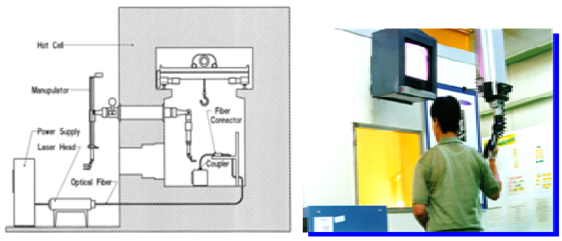

Fig. 2. Remote operation in a shielded hot cell

2.2 Assessment of Fabrication Process Flow

Based on background knowledge on the metal fuel fabrication of the Experimental Breeder Reactor II (EBR-II) and the Integral Fast Reactor (IFR), the assessment was conducted on the process technology and process flows for the fabrication of U-TRU-Zr fuel bundle [4]. To produce a final product, a fuel bundle, there are 3 major process field, a head-end process, an electro-treatment process, and a fuel fabrication process. A head-end process consists of disassembling of used fuel bundle, extraction and removing of bonded Na. An electro-treatment process is composed of electrorefining and winning, and TRU-ingot producing. A fuel fabrication process is based on fuel slug fabrication, fuel pin fabrication, and fuel bundle fabrication. In this study, the electro-treatment process is not assessed and will be discussed in pyroprocessing because it is the same as that of pyroprocessing. Thus, the conceptual process flow for U-TRU-Zr fuel fabrication can be proposed as shown in Fig. 3.

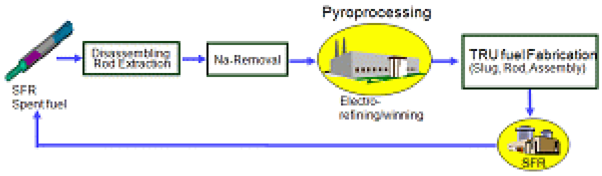

Fig. 3. Conceptual process flow for SFR metallic fuel fabrication

2.3 Assessment of Process Technology

Considering the available commercial technology and the developed fabrication process flow, the applicable process technologies are as follows;

2.3.1 Assessment of fuel slug fabrication Process

For the fabrication of fuel slug, the key technology is a casting process. Many casting methods such as centrifuge casting, gravity casting, and continuous casting as well as injection casting which was used for IFR fuel, could be proposed. Considering the high volatility of americium (Am) and process simplification in a hot-cell, the gravity casting and continuous casting were evaluated as the most promising process for fabricating fuel slug. But, from the viewpoint of reducing the radioactive wastes such as crushed molds, a continuous casting is better than the gravity casting, and needs a continued research for the demonstration.

2.3.2 Assessment of fuel pin fabrication Process

For the fabrication of fuel pin, the end plug welding is a crucial process. The sealing of end plug to cladding tube should be hermetically perfect to prevent a leakage of fission gases and to maintain a good reactor performance. There are lots of commercialized sealing methods such as gas tungsten arc welding (GTAW), electron beam welding (EBW), and laser beam welding (LBW) as a sort of fusion welding and resistance upset butt welding, percussion welding, and flash welding as a sort of solid state welding. Among them, a resistance upset butt welding method is now used for the endcap welding of PWR fuel element and CANDU fuel rod in a commercial basis. The end plug welding should be selected and developed in consideration of weldability, weld joint design, production efficiency, etc. In the case of GTAW, the equipment is simple and the welding procedures are not complicated, but the weld defects like undercut or pin-hole occur occasionally due to the features of fusion welding. For EBW, the equipment is very expensive and needs high vacuum, which means it has a difficulty in handling in a hot cell. In the case of resistance upset butt welding, the weld quality is good, but the weld components are too complicated to handle in a hot cell. Considering the micro-welding of end plug of TRU fuel pin, remote operation and maintenance in a hot cell, and production efficiency, a laser beam welding (LBW) method using optical fiber for transmission of power is evaluated as the most promising process.

3. Conclusions

Considering remote operation and maintenance in a shielded hot cell, the major process technologies for TRU bearing fuel fabrication were assessed in terms of fabrication process flow and availability of commercial technology. As a result of this assessment, the design requirements and conceptual design for TRU bearing fuel fabrication facility could be established. These activities are at an early stage of a long term R&D roadmap and continued activities are still required.

ACKNOWLEDGEMENTS

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