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Refueling System Design for Protoype Gen-IV Sodium-cooled Fast Reactor

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1. Introduction

Generation IV (Gen-IV) reactors aim a number of design goals including improved safety, sustainability, efficiency, cost, and proliferation resistance [1, 2]. A Sodium-cooled Fast Reactor (SFR) is one of Gen-IV reactors, and SFRs are in development progress for up to the commercialization level. One of key elements to fulfill Gen-IV goals is a refueling system. An efficient but reliable refueling method can make not only constructional but also operational costs low. But the design task of a refueling system, nevertheless, sees hurdles in order to satisfy all the design criteria due to a number of constraints such as opacity of sodium coolant, unique working environment in sodium and inert gas environment, a moving path across the pressure boundary, radiation risk, tight construction layout, and so forth. In this paper, we briefly review refueling components of the Prototype Gen-IV Sodium-cooled Fast Reactor (PGSFR), and its refueling system type.

2. PGSFR Refueling System

SFR research in Korea has set out to demonstrate advancements of a Gen-IV nuclear reactor by PGSFR. The PGSFR construction by 2028 had been planned with a specific design safety analysis report by 2017, and its approval by 2020 [3]. The Korea Atomic Energy Research Institute (KAERI) has been carrying out the design and validation tasks of PGSFR including the primary heat transfer system, steam generator and fuel development. PGSFR is a pool-type reactor with two intermediate heat transport system loops with two steam generators. Its thermal and electric output is 392.2 MWt and 150 MWe, respectively, with 112 drive U-Zr FAs at its initial burning cycle and U-TRU-Zr later on [3]. The thermal/electric output size of PGSFR can be compared with an experimental reactor, FFTF [4], which thermal capacity is 400 MWt with 76 drive FAs, and max. decay heat of pulled-out spent FAs from the reactor vessel (RV) is 10 kW.

2.1. PGSFR Refueling System Overview and Procedure

The overall concept of the PGSFR refueling system is illustrated in Fig. 1. The refueling system consists of in- and ex-vessel components. Dual rotatable plugs (DRP), in-vessel transfer machine (IVTM), fuel transfer port (FTP) are grouped in the in-vessel components, and ex-vessel transfer elements include fuel transfer basket (FTB), fuel transfer cask (FTC), fuel transfer adapter (FTA) and ex-vessel transportation machine (EVTM).

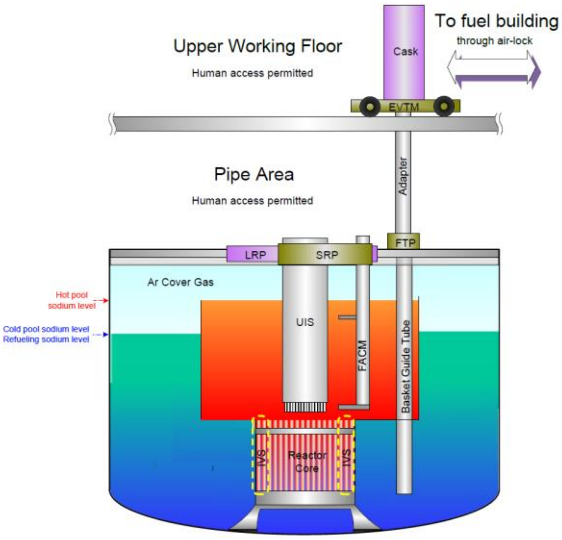


Fig. 1 The overview of the PGSFR refueling system with only IVS

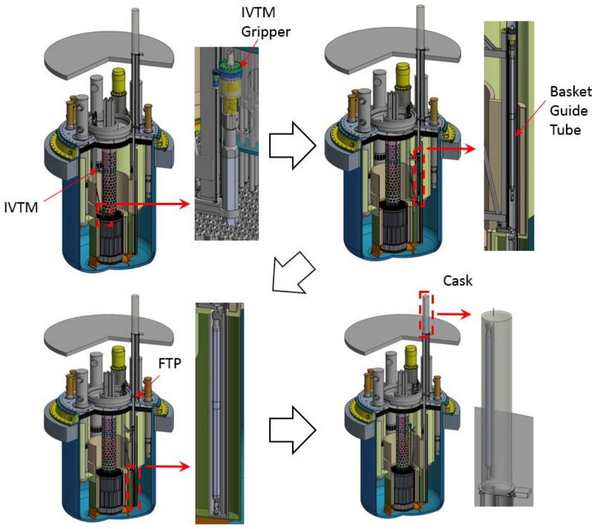
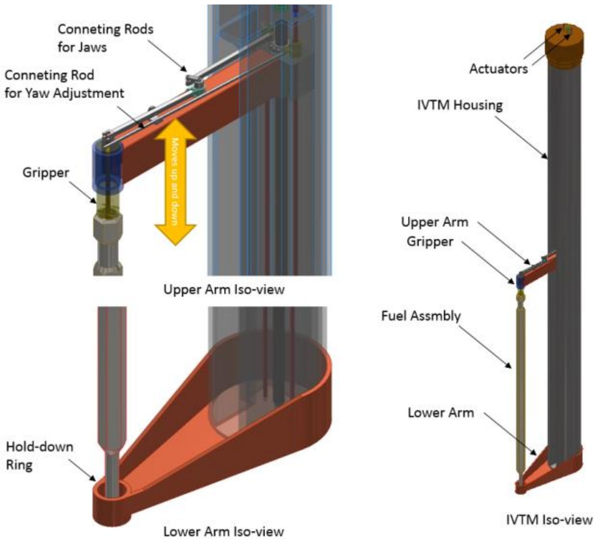


Fig. 2 PGSFR refueling procedure

When refueling, PGSFR spent fuel assemblies (FAs) are unloaded from the core by a gripper of IVTM with DRP of the RV head, removed from in-vessel storage (IVS) as shown in the top left inset of Fig.2. Spent FAs picked by IVTM are moved to transportation platform where FTB is located (Fig.2 top right). FTB loaded with an FA is pulled from the upper working floor through the basket guide tube (Fig.2 bottom left), and is stored in FTC which is moved by EVTM (Fig.2 bottom right). EVTM with FTC moves to the fuel building for cleaning and storage of the removed FA. Loading a fresh FA similarly follows the reversed steps of the procedure explained.

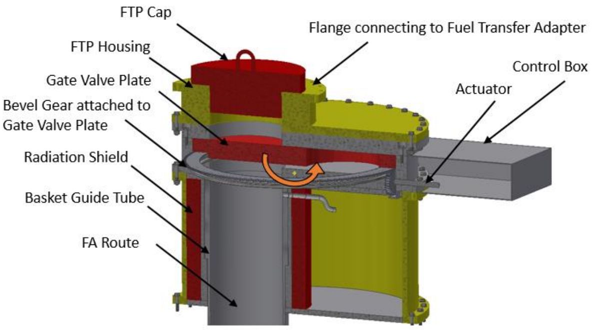


Upper Arm Iso-view

Lower Arm Iso-view

IVTM Iso-view

Fig. 3 PGSFR IVTM module



FTP gate valve operation in half-cut view (Closed)

Fig. 4 FTP configurations: the gate vale is closed.

2.2. PGSFR In-vessel Refueling Components

A fixed arm charge machine (FACM) as shown in Fig.3 was designed as IVTM for PGSFR, being accessible to whole core FAs in combination of rotating small and large rotatable plugs (SRP and LRP, respectively) as DRP, picks up an FA one by one. FACM is basically two upper and lower cantilever beams attached to a main tube frame. FACM has 5 degrees of freedom: gripper jaw open/close, gripper yaw 120° rotation, FACM yaw 360° rotation, gripper up/down, and hold-down movement to spread neighboring FAs from the target FA. Although in-vessel components such as IVTM or rotating plugs let sophisticated reactor design come out, fuels can cross the pressure boundary while maintaining the vessel in a sealed and inert condition.

DRP functions to support IVTM and other primary components such as control rod drive machine and upper internal structure. DRP is composed of SRP and LRP where SRP is offset by 680 mm from the center of LRP. The offset rotation of SRP makes FACM accessible to the whole core area by combination of LRP and FACM rotations. Along with FACM, DRP is also sealed by ledge seal, labyrinth seal, inflatable seal, etc to the adjacent walls of contacts. Argon purging is also actuated between gaps to clear sodium fume. DRP is supported by thrust ball bearings to be freely rotatable.

In the perimeter of the PGSFR reactor core, IVS is located to cool off spent FAs for months prior to transportation. IVS is used for cooling spent FAs in RV, and high decay heat FAs can be modulated before removal. But, IVS inevitably makes the vessel size larger than the one without IVS, and the core and in-vessel design needs extra work due to the IVS.

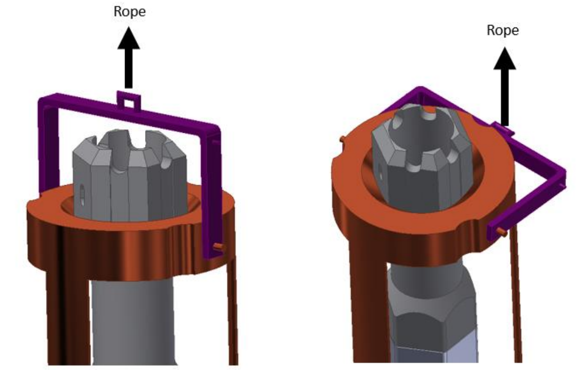
FAs are transferred through FTP (Fig. 4) in which a 170 mm thick gate valve is opened for the FTB pathway. It functions a gateway crossing the pressure boundary out of RV, and thus careful design considerations were taken, e.g., argon gas purging to the port and radiation shields. The figure shows a moment when the gate vale is closed, and it is opened when refueling before installing FTA to the top flange of FTP. FTA, connecting from FTP to the bottom of the EVTM cask, provides an inert FA transfer path separated from a human access area.

2.3. PGSFR Ex-vessel Refueling Components

FTB takes one FA at a time for transportation from the platform in RV to the cask through FTP. FTB is heaved through FTA by the cable installed inside of the cask to be in an inert space. Thus, FTB is inserted only when refueling from the cask but not during the reactor operation. Fig. 5 shows FTB which contains an FA. The cable handle stands upright for transportation by cable tension, but the handle sits by an pushing force due to FTB weight. FTB handle pins on the top of the side are triggered by engraved guides of the basket guide tube.

A spent FA gripped by FACM is moved to the cask that is capable of purging and cooling to treat a fresh/spent FA. Self-motorized EVTM, the cask carriage, provides inert gas, and goes back and forth between the reactor and fuel buildings passing an air-lock gate.

For some reactors employed ex-vessel storage (EVS) where a spent FA brought out of RV is cooled for a temporal period. For the types with IVS and EVS, in summary, it is typical that spent FAs are got rid of from the core to the fuel building through IVS, IVTM, EVS, cask (or a shoot), fuel cleaning station, and this is similar



FA loaded in the Basket for transporation

FA that is ready for being gripped by FACM

Fig. 5 FTB composition for transporation (left) and loading (right) positions to PGSFR. Particularly, EVS is one of the most costly components in construction [5]. Considering the medium size of PGSFR, the moderate quantity of drive FAs, and also the dry storage scheme of spent FAs, EVS has not been chosen for PGSFR, but spent FAs are directly transported from IVS to the storage facility. For the FFTF case, it had employed three singular rotatable plugs and three IVTMs, and both IVS and EVS were used. The FTFF plant had not generated electricity, and the RV diameter of FFTF was the half of PGSFR's, implying an insufficient in-vessel storage space.

3. Conclusion

In this paper, the PGSFR refueling components were reviewed, and we discussed briefly about functions, benefits and disadvantages of the system. In the future, detailed element design tasks of the refueling system can be added to the completion of fulfilling the Gen-IV design goals.

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