Mechanical Design Features of PGSFR NSSS

Chang-Gyu PARK*, Gyeong-Hoi KOO, Jae-Hun CHO, Sung-Kyun KIM
Korea Atomic Energy Research Institute, Daedeok-daero 989-111, Yuseong-gu, Daejeon, 305-335, Korea
**Corresponding author: chgpark@kaeri.re.kr*

1. Introduction

The PGSFR is a sodium-cooled reactor with a fast neutron reactor core for Generation-IV. It is a pool-type 2-loop system with a 150MWe power capacity[1]. The NSSS(Nuclear Steam Supply System) is composed of PHTS(Primary Heat Transport System), IHTS (Intermediate Heat Transport System), and SGS(Steam Generation System). And, DHRS(Decay Heat Removal System) adopts both the active and passive systems for diversity. The structures including components and piping should be designed to ensure the structural integrity for their design life against mechanical and operational loads. In this study, the mechanical design features for the structures and components that make up PGSFR NSSS are described.

2. Mechanical Design Features

2.1 Reactor Enclosure System

Reactor enclosure system is mainly composed of reactor vessel, reactor head, rotating plug, reactor support structure and containment vessel. PGSFR adopts reactor top support concept and thus the reactor vessel has top flange prepared to attach it with the reactor support structure. Figure 1 and Table 1 shows the structural concept and design dimensions for reactor enclosure system. Every component except containment vessel is made of Type 316 stainless.

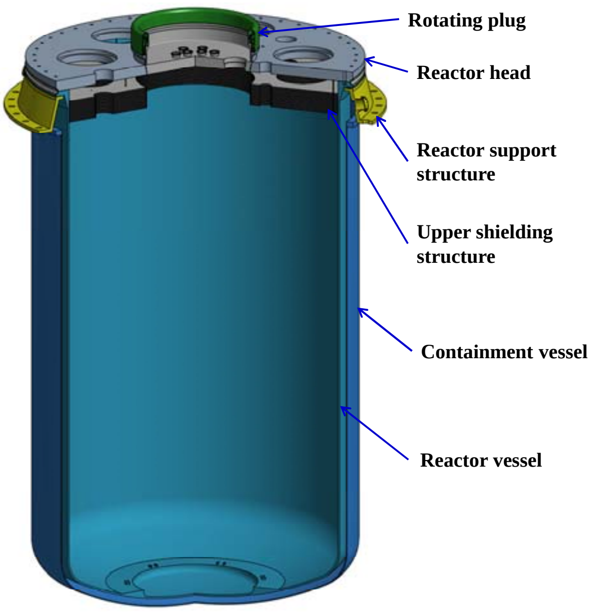

Fig. 1. Configuration of reactor enclosure system

Table I: Dimensions in reactor enclosure system

	Outer dia. (m)	Height (m)	Thk. (cm)	Mass (tons)
Reactor vessel	8.75	15.0	5.0	204
Reactor head	9.55	0.3	30.0	115
Reactor support	10.74	1.0	10.0	37
Containment vessel	9.20	12.4	2.5	96

The reactor vessel(RV) is the container and support structure for the reactor core, primary sodium and internal structures. The vessel cylinder is welded to a torispherical shell of the bottom head. It is constructed with uniform thickness of 5 cm except bottom head support flange for core support structure and top flange which rests on the reactor support structure. The RV has no penetrations and the only attachments to it are those of the core support structure. It is made up of several pieces and they will be welded together into the required configuration. The RV contains PHTS sodium but its upper region is filled with Argon cover gas. It is bolted to reactor head and rests on the reactor support structure.

The reactor head is the primary coolant boundary and provides various penetrations and supports for main components, in-service inspection, instruments, maintenance, and replacement. It is a thick circular plate with 30 cm uniformly. The weight of components attached at the penetrations is supported on the flange over the reactor head. The reactor head must not allow leakage from the RV that exceeds 0.1% of cover gas volume per day. Therefore, the many penetrations must be tightly sealed and especially, inflatable elastomeric seal is used for rotating plugs. inflatable elastomeric seal generally requires the operational temperature limit less than 150℃ and thus the reactor head is designed to operate at low temperature. The lower temperature is attained by inclusion of an upper shielding structure composed of horizontal multiple plates. It is also supported on the reactor head by support sleeve.

The rotating plug(RP) is a part of the reactor head and located in the center of it. Its structure and insulation are the same as for the rest of the reactor head. The RP is penetrated by CRD shroud tubes, IVTM port, ISI port, and small penetrations for instrumentation leads. The upper internal structure(UIS) is welded to the underside of the RP. The bearing support and sealing arrangements are prepared in the RP to provide the dynamic motion for refueling operation. Its weight and holddown force are reacted at the ledge of the reactor head opening on which the plug rests during operation.

The reactor support structure is skirt-shaped and located underside of the RV top support flange to support the reactor system. It provides the access holes for in-service inspection of reactor vessel and its bottom support flange rests on the reactor concrete floor with thermally insulated.

The containment vessel provides for the retention of the primary sodium as well as a barrier to the release of radioactive material at the RV leak. Its diameter is slightly greater than that of the RV and has no penetrations for leak tight. The containment vessel should ensure that RV inspection vehicle can access through the annulus space between RV and containment vessel. It has uniform thickness over all sections and its top flange is supported on the concrete floor by the bolt joints. Its material is 2.25Cr-1Mo steel.

2.2 Reactor Internal Structures

The reactor internal structures consist of core support structure, inlet plenum, core shroud, IVS shroud, separation plate, redan structure and UIS. Figure 2 shows the configuration of reactor internal structures.

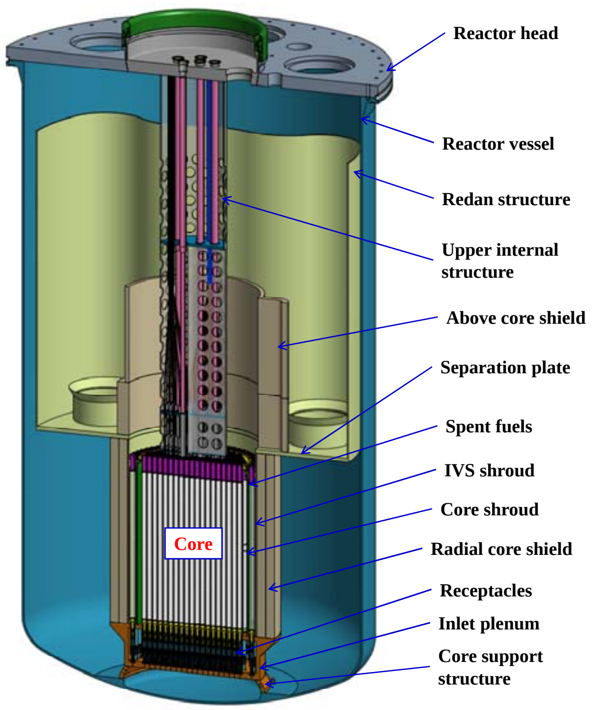

Fig. 2. Configuration of the reactor internal structure.

The core support structure provides support of the core assemblies and the inlet plenum. It is a simple skirt type structure and it has 6 keys at lower outside of skirt. The core support structure is placed on the support flange of RV bottom and 6 keys are inserted between lugs which are prepared on support flange of RV bottom and welded to the lugs. It is made of Type 316SS and fabricated by forging and machining. It is 3.728 m in diameter and 30.8 cm in height.

The inlet plenum is located in the center region of between core support and core assemblies. It receives the primary sodium from PHTS pumps and distributes it to the core via receptacle. It is composed of lower grid plate, upper grid plate, and side cylinder. All vertical loads from core assemblies are carried to the lower grid plate with 15.0 cm thickness.

The receptacle has restraint lands that mate with seats in both grid plates and a socket into which the assembly nosepiece seats.

The core shroud is a simple cylindrical structure surrounding the core assembly. It is welded to the upper grid plate and extended vertically upward. Its top flange provides the lateral support of core former ring. Provisions are made within the RV for storage of spent fuel during reactor operation. The IVS shroud placed outside the core shroud forms the annular space with core shroud and spent fuels are located in there. The IVS shroud is a simple cylindrical structure with 3.0 cm thickness. It is welded to upper grid plate and separation plate, and the radial core shield structures surrounds the IVS shroud. The IVS shroud also provides the support of redan and separation plate as well as lateral support of IHX

The separation plate is located at the top of the IVS shroud and welded to both the IVS shroud and redan structure to complete the pressure boundary across the hot and cold pools. This has circular penetrations that allow the IHXs to pass through while providing a lateral seismic support for them.

The redan is a single integrated unit that separates the hot pool from cold pool and it consists of multiple plates welded together that form a contoured shape around IHXs and UIS. The IHXs are located within the redan but the primary pumps and DHXs are located outside the redan in the cold pool. Thus, the redan is peanut-shaped structure.

The UIS is attached to the RP and extends downward into the reactor hot pool. It supports the shroud tubes of CRD and above core instrumentation drywells, and protects the drivelines from sodium flow induced vibration. The UIS cylinder of 1.65 m diameter has penetrations along the length. It has three horizontal guide plates welded to the UIS cylinder. And, UIS shroud has a U-shaped access slot to accommodate the extension of IVTM pantograph arm within the core center. Its overall length is 9.29 m and the material is Type 316SS.

2.3 Main Components

The PGSFR has two submersible centrifugal pumps to provide primary sodium circulation within the reactor vessel. The diffuser of it is connected to internal pipe and makes the cold pool sodium enter into the inlet plenum. To guide the cold sodium beneath IHX outlet nozzle to inlet plenum, long shaft is adopted. It is inserted through penetrations in the reactor head and located in the cold pool between redan structure and RV.

There are four intermediate heat exchangers(IHX) in reactor vessel[2]. They transfer heat from primary sodium to the intermediate sodium. It consists of an upper and lower tubesheet separated by straight tubes, with a central IHX inner pipe and IHX cylinder for incoming and outgoing intermediate sodium, respectively. It has two piping nozzles which top nozzle is connected to IHTS cold leg and lower side nozzle connected to IHTS hot leg. Central coaxial pipe and expansion bellows are adopted to accommodate the relative thermal difference between hot and cold sodium of IHTS. All components of IHX are constructed of 9Cr-1Mo-V material which can eliminate the dissimilar welding between IHX and IHTS piping.

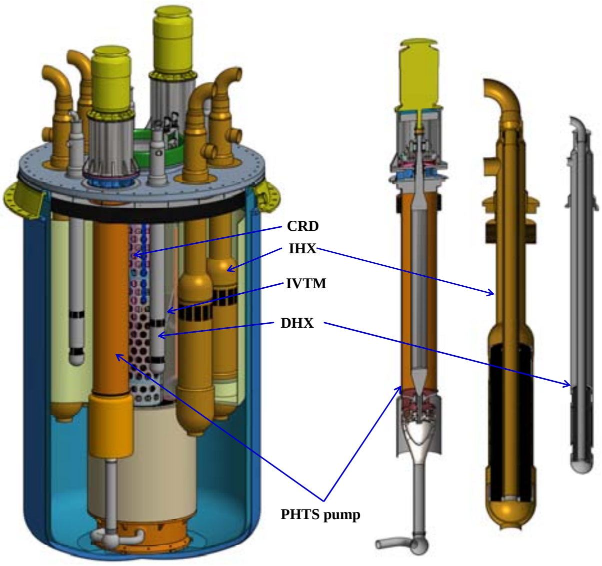

Fig. 3. Main components installed in reactor vessel

Four DHXs are located in RV and two of them are for passive DHRS and others are for active DHRS. DHX(Decay Heat eXchanger) has similar structural concept with IHX other than downward outgoing of PHTS sodium. DHX tubes are fully submerged in PHTS cold pool in all events.

The PGSFR uses nine control rods for the reactivity control and shutdown system(six for primary control system and three for secondary control system)[3]. The primary control rods can be inserted by unlatching due to gravity and/or by drive-in force using motor. A passive shutdown system is implemented in secondary control system which the gripper system automatically releases the control rods around the set temperature and drops them by gravity without any external help in an emergency event.

The pantograph in-vessel transfer machine(IVTM) is adopted to handle core assemblies[4]. It is located in a penetration in the RP and is only used during reactor shutdown. The IVTM has six motions to complete the fuel handling operation(rotation, arm travel, gripper travel, gripper rotation, gripper locking, and hold down travel). It can access over any core assembly in the core by a combination of rotating the IVTM, extending or retracting the arm, or rotating the RP. Figure 3 shows the main components installed in the reactor vessel.

2.4 IHTS and DHRS

The IHTS transfers heat from the IHXs to SGS. It consists of two independent loops and each loop is mainly composed of two IHXs, electromagnetic pump, expansion tank, steam generator as shown in Fig.4.

The steam generator(SG) transfers the heat from intermediate heat transport system to feedwater to generate superheated steam[5]. The SG is a vertically oriented, straight tube, sodium-to-water counterflow shell-and-tube heat exchanger. Expansion shell bellows on the main shell provides a flexibility to compensate for differential thermal expansion of tube bundle and shell. The tubes are supported horizontally by tube support plates of the drilled-hole type and tube support plates maintain their vertical span with tie-rods. It contains 769 heat transfer tubes and there are no tube-to-tube welds. The steam generator material is 9Cr-1Mo-V steel.

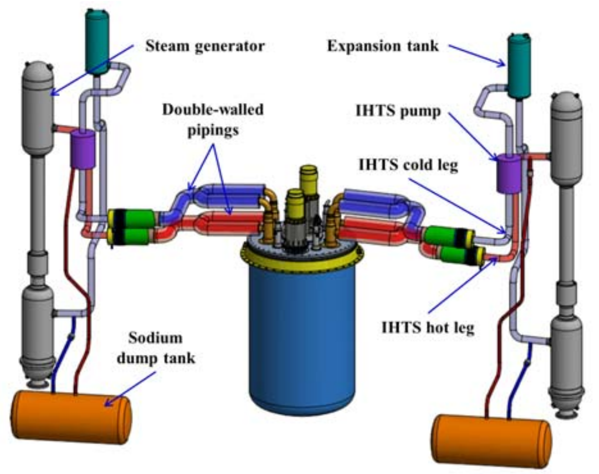

Fig. 4. Arrangement of the intermediate heat transport system

The IHTS piping is made of Mod.9Cr -1Mo steel which has a less thermal expansion. The IHTS piping layout is simplified by using the T-branch piping in both the hot and cold legs. The IHTS piping is 559 mm in outer diameter and 15.88 mm in thickness. Double-walled piping is adopted inside reactor containment building whereas single wall piping is outside containment boundary. The expansion tank is placed at the top of cold leg piping to accommodate the expansion of the IHTS sodium. A annular linear induction pump(ALIP) is installed in a cold leg piping for the IHTS sodium circulation.

The decay heat removal system(DHRS) removes all reactor decay heat in two ways; active type(ADHRS) and passive type(PDHRS). ADHRS consists of DHX, blower, FHX, circulation pump, and expansion tank. But PDHRS consists of DHX, AHX, and expansion tank. FHX is a finned-tube-type sodium-to-air heat exchanger whereas AHX is a helical-type sodium-to-air heat exchanger. FHX, AHX, expansion tank and piping are made of 9Cr-1Mo-V. Figure 5 shows the component arrangement of ADHRS and PDHRS.

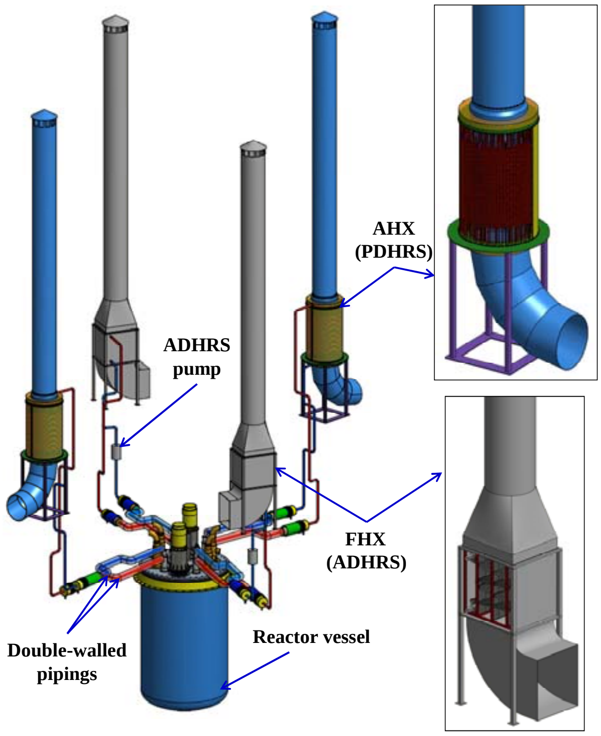

Fig. 5. Component arrangements of ADHRS and PDHRS

3. Conclusions

The mechanical design features of structures and components for a PGSFR NSSS are described. The structures are being designed to maintain the structural integrity for their design lifetime by considering the high temperature operating condition. Further works will be followed to satisfy the design requirements.

Acknowledgement

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REFERENCES

[1] System description of SFR prototype reactor, SFR-000-SP-403-001, 2015.

[2] S.K.Kim, et al., Structural Integrity Evaluation of Intermediate Heat Exchanger in a Steady State Condition, Transactions of the Korean Nuclear Society Spring Meeting, Korea, 2015.

[3] J.H.Lee, G.H.Koo, Conceptual Design on Primary Control Rod Drive Mechanism of a Prototype Gen-IV SFR, Transactions of the Korean Nuclear Society Autumn Meeting, Korea, 2012.

[4] S.H.Kim, G.H.Koo, Conceptual Design of the Pantograph Type In-Vessel Transfer Machine in PGSFR, Transactions of the Korean Nuclear Society Autumn Meeting, Korea, 2013.

[5] C.G.Park, et al., Structural Evaluation of a PGSFR Steam Generator for a Steady State Condition, Transactions of the Korean Nuclear Society Spring Meeting, Korea, 2015.