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INTRODUCTION

One of the important requirements for Gen. IV High Temperature Gas Cooled Reactors (HTGR) is passive safety. Currently all the HTGR designs use Reactor Vessel Auxiliary Cooling System (RVACS) for passive decay heat removal. [1] The decay heat first is transferred to core barrel by conduction and radiation, and then to reactor vessel by thermal radiation and convection; finally the decay heat is transferred to natural circulated air or water systems. RVACS can be characterized as a surface based decay heat removal system. Similar concepts have been widely used in sodium cooled fast reactor (SFR) designs, advanced light water reactors like AP1000. The RVACS is especially suitable for smaller power reactors since small systems have relatively larger surface area.

RVACS tends to be less expensive. However, it limits the largest achievable power level for modular HTGRs due to the mismatch between the reactor power (proportional to volume) and decay heat removal capability (proportional to surface). When the relative decay heat removal capability is reduced, the peak fuel temperature increases, even close to the design limit. Annual designs with internal reflector can mitigate this effect therefore further increase the power. Another way to increase power is to increase power density. However, it is also limited by the decay heat removal capability. Besides safety, HTGRs also need to be economical in order to compete with other reactor designs. The limit of decay heat removal capability set by using RVACS has affected the economy of HTGRs. Forsberg [2] pointed out other disadvantages of using RVACS such as conflicting functional requirements for the reactor vessel and scaling distortion for integral effect test of the system performance.

A potential alternative solution is to use a volume based passive decay removal system, call Direct Reactor Auxiliary Cooling Systems (DRACS), to remove or mitigate the limitation on decay heat removal capability. DRACS has been widely used in SFR designs and in liquid salt cooled high temperature reactors. The containment cooling system in BWR is another example of volume based decay removal systems. DRACS composes of natural circulation loops with two sets of heat exchangers, one in reactor side and another is in environment side. DRACS has the benefits of increasing the power as needed (scalability) and modularity. This paper introduces the concept of using DRACS to enhance HTGRs passive safety and economy.

DESIGN DESCRIPTION

The DRACS for HTGRs will be similar as used in SFRs with high temperature fluid flowing in the loops. In the reactor side, thermal radiation will transfer heat to one or several rows of cooling pipes. Those small diameter pipes can be compared to water panels in a typical coal fired power plant boiler. During normal operation, a small amount of heat will leak into DRACS to keep the fluid from freezing. During accidents, elevated reactor temperature will rapidly increase radiation heat transfer since it is proportional to the fourth power of temperatures.

Different high temperature fluids can be considered depending on operation temperature range, chemical inertness, natural circulation capability, and material compatibility. Fluoride salts are excellent high temperature coolants with potential operation temperature range from 400°C to 1600°C. [3] Liquid fluoride salts are stable and only slowly react with air or water. Therefore use of liquid salts will not affect the safety of HTGRs. Lead can be considered too.

Depending on the locations of cooling pipes, three different designs are proposed as shown in Fig.1. Although the concept is demonstrated for a prismatic type of HTGRs, it also works for a pebble bed type of HTGRs.

Design A: Cooling Pipes near Reactor Vessel

One or two rows of cooling pipes are set close to the inner surface of the reactor vessel. In this design, the total heat removal capability is still limited by the available surface area. But by being closer to the heating source and bypassing the reactor vessel, we have slightly higher heating temperature therefore better heat transfer and the flexibility to eliminate the reactor vessel from the heat transfer path. This design may increase the decay heat removal capability slightly. In the region between the core barrel and the reactor vessel, neutron radiation level is low and temperature can be controlled below 700°C. Less expensive high temperature alloys can be chosen as structure material.

Design B: Cooling Pipes in the Permanent Reflector

In this design, the cooling pipes will be inside the holes in the permanent reflector blocks. The cooling pipes will have a gap to the graphite surface. Graphite has excellent heat conduction property. By taking advantage of this feature, we can have a volume based method to remove decay heat. If we need to remove more decay heat, we can simply have more rows of cooling pipes. The outer rows can still absorb slightly less heat from the graphite blocks than the rows closer to the inside of the core since the heat can easily conduct through the graphite gaps between the holes. By removing the limit on decay heat removal due to the limited available surface area, we can increase the reactor power or power density without losing passive heat removal feature. At this location, the temperature is still not too high so that high temperature alloys such as Alloy 617 can be considered as pipe material. The fast neuron influence is also low due to the thick graphite's protection from the active region.

Design C: Cooling Pipes in the Inner Reflector

In this design, the cooling pipes are arranged inside the holes in the inner reflector blocks near the center of the reactor. Due to very high temperature at this location, thermal radiation is so efficient that only very small amount of heat transfer area is needed to remove enough decay heat.

For a cogeneration plant, high temperature process heat can also be extracted from here by forced circulated loops with similar liquid fluid. This process heat transfer loop design will greatly simplify the system arrangements and improve economy. No intermediate heat exchanger (IHX) is needed to transfer process heat from helium to process fluids. The largest challenge on the IHX design – high temperature and high pressure difference – will be removed. Increased temperature will also increase efficiency of use of process heat.

The feasibility of this design will depend on the availability of suitable structural material. At this location, very high temperature and high fast neutron influence exist at the same time. Some advanced composite material such as SiC or carbon fiber composite material could be potential candidates. Since the inner reflector must be replaced several times during the reactor life time, the cooling pipes need to be replaceable too.

PRELIMINARY ANALYSIS RESULTS AND DISCUSSION

Lumped parameters models and RELAP5-3D models are used to verify the feasibility. A deep burn HTGR design [4] is used as an example. The results show much improved heat removal capability by DRACS than RVACS.

Use of DRACS in HTGRS for passive decay heat removal is a new idea. This idea opens new opportunities to greatly improve HTGRs economy. However, to realize those potentials, further detailed investigations are necessary to find optimized designs and how much power the HTGRs with DRACS can reach while still maintaining passive cooling capability. Material research and innovative mechanical designs are additional keys to realize the benefits.

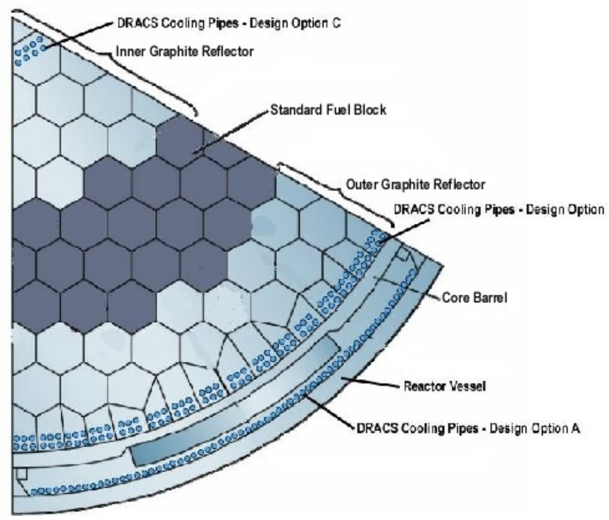

Fig. 1. DRACS cooling pipes arrangement cases.

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