6–6 Development of a Novel RPV Cooling System for HTGRs

— Comparison of the Structural Differences Between RPV Cooling Systems and Effects of External Parameters on RPV Cooling —

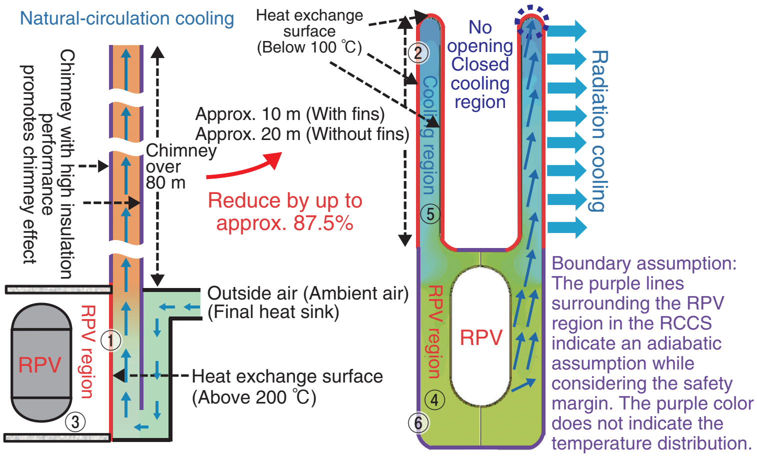

Fig.6-12 Structural differences between a natural circulation cooling system (left) and a radiation cooling system (right)
Natural-circulation cooling system (left): The outside air (ambient air), which is the final heat sink, is absorbed directly into the duct. The air inside the duct is heated by the heat radiated from the RPV. The heated air rises inside the chimney with high thermal insulation performance to promote the chimney effect, and subsequently, it is released to the outside air again from the chimney outlet. The height of the chimney should be 80 m or more to promote the chimney effect. Radiation cooling system (right): Heat is directly radiated from the RPV to the cooling region (⑤). Simultaneously, the heated air in the RPV region (④) rises to the cooling region (⑤) by natural convection. The air accumulated in the cooling region (⑤) can be cooled by radiation from the outer surface of the cooling region (②), and the air descends. The height of the cooling region of the radiation cooling system (right) is less than the chimney height of the natural circulation cooling system (left) by up to approximately 87.5%.

(a) Normal operation

Natural-circulation cooling system (Fig.6-12 left)	Radiation cooling system (Fig.6-12 right)
The temperature of the heat exchange surface (①), which is in contact with the outside air, reaches 200 °C or higher. It is necessary to consider the possibility of low-temperature ignition of combustible materials taken (that intrude) into the duct along with the outside air. If low-temperature ignition occurs, the promotion of fire (combustion) by the chimney effect should be considered. Moreover, when ducts and chimneys are clogged, the temperature rises sharply.	The temperature of the heat exchange surface (②) exposed to the outside air is 100 °C or less. There is no possibility of low-temperature ignition of combustibles taken in with the outside air because the RPV region (④) containing the RPV is wrapped by a highly insulating wall (⑥) and does not come into contact with the outside air.
The outside air temperature, wind speed, humidity, duct and chimney lengths, surface roughness, number of bends, etc., affect the amount of heat removed.	Only the ambient temperature affects the amount of heat removed. The parameters of wind speed and humidity are not included in the radiation formula.
Since the internal gas inside the duct and chimney is the outside air, an unstable phenomenon in natural circulation (natural convection) occurs. There is an uncontrolled increase or decrease of the amount of heat removed because of fluid vibration. It is necessary to consider the impact of this effect on structures.	Since the internal gas in the RPV region (④) and the cooling region (⑤) is not outside air, there is no unstable phenomenon or fluid vibration, and consequently, no impact on the structures.

(b) Natural disasters

Natural-circulation cooling system (Fig.6-12 left)	Radiation cooling system (Fig.6-12 right)
Changes in back pressure due to disturbances resulting from natural disasters, such as typhoons, hurricanes, tornadoes, and heavy rains, affect the natural circulation in ducts and chimneys. In addition, stagnation and backflow occur in ducts and chimneys.	There are no ducts or chimneys. The natural convection heat transfer coefficient of the large heat exchange surface (②) and the large depression (凹) of the cooling region (⑤) are designed under no-wind conditions; therefore, when a natural-disaster-induced disturbance occurs, the natural convection heat-transfer coefficient will increase. Consequently, the heat removal performance can be improved.

Table 6-2 Comparative study results of two types of passive RPV cooling systems
Both during normal operation (Table 6-2(a)) and during natural disasters (Table 6-2(b)), safety of radiation cooling system (Fig.6-12 right) even in any accident conditions, can be enhanced because the number of external parameters and items to affect radiation cooling system (Fig.6-12 right) is smaller than those to affect natural circulation cooling system (Fig.6-12 left).

Recently, there has been increasing demand for High Temperature Gas-cooled Reactors (HTGRs) that do not cause core meltdown. Conventional cooling systems adopt active Reactor Pressure Vessel (RPV) cooling systems using the forced circulation of water, such as that achieved by pumps, to remove the heat released from the RPV. However, the pumps cannot be operated if the power supply shuts down, and there is a possibility that the heat removal activity (i.e., cooling activity) will decrease drastically. Even in this accident condition, core meltdown will not occur in the HTGR, but there is a possibility that the temperature of the RPV will exceed the operating limit temperature and its operation will be shut down.

Therefore, unlike the case of the facility where the TEPCO's Fukushima Daiichi NPS accident occurred, safer RPV cooling systems in which the heat sink is never lost and active systems or emergency power sources, etc. are never needed and wherein the decay heat can be passively removed from the reactor core even under any accident conditions are being explored.

At present, a passive RPV cooling system employing the natural circulation of outside air (ambient air) is proposed as a candidate for commercial HTGRs (Fig.6-12 left). The coolant of the outside air is never lost. However, a large number of external parameters and items are to be considered (Table 6-2), and they affect the natural-circulation cooling system (Fig.6-12 left). Therefore, we have developed a novel passive RPV cooling system based on radiative cooling (Fig.6-12 right). The amount of heat removed from the RPV for a practical HTGR should be equivalent to 3 kW/m^2* when converted to heat flux. Through experiments using the heat-transfer test equipment that can simulate an actual cooling system, we confirmed that approximately 7 kW/m^2 of heat can be removed.

Next, to make possible the practical use of the natural-circulation cooling system and radiation cooling system, it is necessary to evaluate their safety features to check whether both systems can remove passively the decay heat during normal operation (Table 6-2(a)) and under any accident conditions, including natural disasters (Table 6-2(b)).

Therefore, we investigated the structural differences between the two systems and the effects of external parameters on them. During normal operation, in the natural-circulation cooling system, the combustible materials that are introduced (absorbed) into the duct along with the outside air are heated on the heat exchange surface (①), and low-temperature ignition may occur without any heat sources; consequently, temperatures in the clogged duct and chimney will increase remarkably.

In addition, there are some risks that the heat removal ability will decrease because of the large number of external parameters and factors that affect the natural-convection heat transfer coefficient. Some such factors are the occurrence of unstable phenomena in natural circulation and fluid vibration. Furthermore, when natural disasters, such as a typhoon or heavy rainfall event, occur, the disturbance of the outside air affects the natural-circulation cooling system, and there is a possibility that the heat removal ability will decrease. In contrast, in the case of the radiation cooling system, we confirmed that the system can remove heat safely and reliably both during normal operation and natural disasters and clarified the possibility of achieving better safety in the event of an accident compared to the natural-circulation cooling system. Although the RPV regions (③ and ④) of both cooling systems are closed regions, the pressure rise due to the increase in temperature of the internal gas does not pose a problem (i.e., there is no effect of the pressure rise).

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Reference

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