REVIEW ON THE RCCS FUNCTION TO ANTICIPATE THE STATION BLACK-OUT ACCIDENT IN RGTT200K

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ABSTRACT

REVIEW ON THE RCCS FUNCTION TO ANTICIPATE THE STATION BLACKOUT ACCIDENT IN RGTT200K. RGTT200K is a conceptual design reactor based on HTGR technology, implementing active, passive and inherent safety system. The reactor safety systems are designed in "defence in depth" philosophy. RGTT200K has a reactor cavity cooling system (RCCS) which is designed to remove the heat from the reactor vessel to the structure of the containment. The RCCS is designed to fulfill this role by preserving the reactor vessel under the maximum allowable temperature during normal operation and protecting the reactor containment structure in the event of failure of all active cooling systems. The performance and reliability of the RCCS, therefore, are considered as critical factors in determining maximum design power level after heat removal. This paper discusses the review of RCCS function during the station blackout (SBO) accident. During SBO, all of active cooling systems are failed to work and the heat removal is conducted by the RCCS. The SBO is an event in which there is no electricity from diesel generator to the blower. The methodology used is based on paper review concerning the RCCS function and experiences in Germany, USA, Japan, and China. RCCS in RGTT200K has two equipments, first is active mode and second is passive mode equipment. Based on that review, the RCCS is capable to maintain the RPV temperature below 65ºC at normal operation and 125ºC during the SBO. The RCCS keep the fuel of below 1600°C and maintain its integrity to avoid radioactivity release to the environment.

Keywords: RCCS function, reactor safety, SBO, RGTT200K

ABSTRAK

KAJIAN FUNGSI RCCS UNTUK MENGANTISIPASI KECELAKAAN STATION BLACKOUT PADA RGTT200K. *RGTT200K adalah reaktor yang didesain berbasis teknologi HTGR. RGTT200K mempunyai sistem keselamatan aktif, pasif dan inherent (melekat). Sistem keselamatan RGTT200K pada dasarnya mengikuti filosofi pertahanan berlapis. Reaktor ini memiliki sistem pendinginan kavity atau dikenal dengan RCCS yang berfungsi memindahkan panas dari RPV ke lingkungan sekitar. Sistem ini didesain guna menjaga temperatur vessel pada temperatur maksimum yang diinginkan baik pada saat operasi normal ataupun kehilangan semua pendinginan aktif. Oleh sebab itu, kinerja dan keandalan dari RCCS harus dipertimbangkan sebagai faktor kritis dalam menentukan pengambilan panas pada RPV. Makalah ini membahas kajian fungsi RCCS selama kejadian Station Blackout (SBO) yang bertujuan untuk mengetahui kapabilitas RCCS selama kecelakaan tersebut. Pada saat kejadian SBO diasumsikan seluruh sistem pendinginan aktif gagal, sehingga panas dari RPV akan diambil oleh RCCS. Pada kejadian SBO diasumsikan bahwa tidak ada pasokan listrik dari luar untuk menggerakkan blower/compressor. Metodologi yang digunakan adalah metode kajian berdasarkan pengalaman negara Jerman, Cina, Amerika, dan Jepang dalam mendesain/ mengoperasikan HTGR. Berdasarkan kajian yang telah dilakukan, RCCS mampu mengambil panas pada RPV sehingga temperature pada RPV adalah 60ºC pada operasi normal dan 120°C pada kondisi SBO. RCCS juga mampu menjamin temperatur bahan bakar tidak melebihi 1600°C sehingga keutuhan bahan bakar terjamin aman dan tidak terjadi lepasan radioaktivitas ke lingkungan.*

***Kata kunci**: fungsi RCCS, keselamatan reaktor, SBO, RGTT200K.*

INTRODUCTION

RGTT200K is a nuclear reactor conceptual design based on Hight Temperature Gas -cooled Reactor (HTGR) technology. RGTT200K stands for ”Reaktor Berpendingin Gas Temperatur Tinggi 200 MW_{th} Kogenerasi”[1,2] or HTGR with 200 MW thermal output. RGTT200K implements the active, passive and inherent safety system. The reactor safety systems are generally designed by following the ”defence-in-depth” philosophy, which includes several stages of implementation i.e. prevention of failure and abnormal operation, control of abnormal operation and detection of failures, control of accidents within the design limitations, control of severe accident conditions of installation, including the prevention of the expansion of the incident and mitigation of the consequences, and the mitigation of radiological consequences of significant release of radioactive material [3]. The “defence-in-depth” philosophy on RGTT200K has been applied starting from the multiple barriers in spherical fuel. The UO_2 (uranium dioxide) kernel has 0.5 mm diameter graphite coated. The coated layers mitigate and minimize the risk of the fission products release of into the outside environment during accidents [4,5].

The reactor safety systems of RGTT200K also implement the defence-in-depth philosophy consisting of active safety systems, passive safety systems and inherent safety system [5]. Passive safety system means that without human intervention and active means such as electricity, the system will operate automatically. It works using the influence of gravity, mass density differences of cooling, air pressure differences, and others. During the operation of passive safety system, it is assumed that there is no electricity supply from diesel generator as backup power [6].

RGTT200K is equipped with a reactor cavity cooling system (RCCS). The RCCS is designed to remove the heat transferred from the reactor vessel to the structure of the containment [7,8]. This RCCS is installed in the cavity between the reactor vessel and the containment. It is designed to fulfil this role by preserving the reactor vessel under the maximum allowable temperature during normal operation and protecting the reactor containment structure in the event of failure of all active cooling systems [9]. This paper contains a review and discussion regarding the capability of the RCCS in case of failure or unavailability of all other shutdown cooling system. Related to the initating event, the station black out as occurred in the boiling water reactor type in Fukushima will be considered to review the RCCS capability to maintain the RGTT200K in a safe condition.

THEORY

Basically the reactor does not need any active safety intervention in the event of a depressurization loss of forced coolant (DLOFC) and a pressurized loss of forced coolant (PLOFC). The reactor system automatically reverts back to a normal state after the shutdown transient [10]. The goals of safety design in RGTT200K are as follows:

- There shall be no design based event, either from internal reactor or from external sources, which would cause anyone living near the site boundary to take shelter or be evacuated [11]. This goal is achieved with the advanced fuel design for RGTT200K as shown in Figure 1. The danger to the public for any nuclear reactor lies in the fission products contained within the fuel and its TRISO layer [6,12].

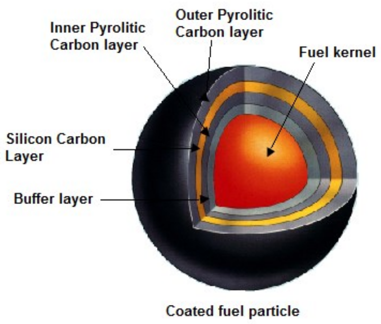

Fig. 1. Coated fuel particle in RGTT200K or TRISO [6]

To prevent the radioactive product release, the vast majority of the fission products must remain within the fuel for all possible events as well as events with a very low expectancy of occurrence. For the RGTT200K fuel, this can be virtually guaranteed as long as the maximum fuel temperature remains below 1600 °C [11,13]. To achieve that, the reactor is equipped with inherent safety mechanism. Inherent safety means that the safety system relies on the negative coefficient of reactivity, in which as the reactor temperature increases, the reactor core temperature does not exceed 1600 °C. The fuel kernel has 4 layers with porous carbon buffer (95µm of diameter) layer, inner pyrolytic carbon (40µm of diameter), silicon carbide barrier coating (35µm of diameter) and outer pyrolytic carbon (40µm of diameter) [6]. The characteristics of the porous carbon coating on the particle TRISO buffer can accommodate fission product of UO_2 kernel [14]. The function of the other layers is to maintain the possibility of the release of fission products out of TRISO particles. Thus the fuel balls construction can be said to be perfect to avoid the fission products release to the reactor coolant. The fuel kernel graphite has a melting point of about 2500 °C, so that in case of fuel failure, the temperature raises until 1500 °C. This will not affect or damage the integrity of the fuel balls or TRISO particles inside. TRISO particles will begin to damage (melting) at temperatures above 2000 °C as shown in Figure 2 [6].

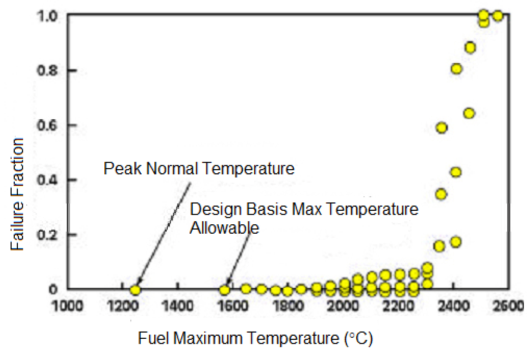

Fig. 2. Correlation between TRISO failure fractions and fuel temperature [6,15]

- There shall be no need for moving mechanical components to ensure that safety targets are achieved. This second goal is achieved by using a passive cooling system such as RCCS. Passive cooling systems have many advantages over normal cooling systems [15]. By using a passive system, the design, installation, operation and maintenance of the cooling system is much simpler compared to a normal cooling water pumping system. A total of 80 % reduction in pipe usage is possible if the passive coo-ling system is used [16]. This makes it both very economically as well as functionally competitive.

- Exposure of plant personnel shall be significantly lower than the best international values presently being achieved. It will be achieved partly by the fuel design and partly by the radiation shield as part of the RCCS. The radiation shield will be constructed from steel that will act as a γ-ray absorber and will be placed between the RPV and the concrete citadel. The concrete citadel surrounding the reactor will also act as insulation. The RCCS design types of all HTGR in the world are shown in Table 1.

Table 1. RCCS design types of HTGRs [17]

Reactor	RCCS Coolant type	Secondary coolant type
HTTR-Japan	Water forced convection	Water forced convection
HTR10-China	Water natural convection	Air natural convection
PBMR-South Africa	Water natural convection	Air natural convection
GT-MHR-USA	Air natural convection	No secondary cooling
MHTGR-USA	Air natural convection	No secondary cooling
RGTT200K-Indonesia	Water forced convection	Air natural convection

METHODOLOGY

This paper is a literature study about RCCS function during the SBO accident. RGTT200K has two parallel water cooling systems are in surrounding the pressure vessel, located in front of the concrete wall of the containment. This stand pipes connected to the boil off tanks to discharge the heat. During the SBO, all active cooling systems are assumed to fail and the diesel generator is not available to supply electricity in to primary blower and the RCCS water pump. Refer to the Fukushima accident, the combination of an earthquake followed by a tsunami is initiating event for the SBO. The earthquake causes the normal supply of electrical power from the electrical grid for the RGTT200K nuclear plant to be lost. The following tsunami will disable the emergency diesel generators at the site to provide electricity power to essential emergency equipments. The study focuses on the thermal-fluid analysis of the Reactor Cavity Cooling System (RCCS) with water flows up the pipes to cool the containment.

During loss offsite power, the RCCS pumps did not work, and the heat from the RPV is removed water by natural circulation. The water is circulated in RCCS because of temperature difference between hot water in the stand pipe near to the RPV and cold water in the storage tanks.

Core decay heat is transferred to the reactor vessel by conduction and radiation and the RCCS absorbs the thermal energy from the reactor vessel directly by radiation and indirectly from the guard containment atmosphere by convection.

RESULTS AND DISCUSSIONS

There are two events concerning to the lost of helium coolant, first is PLOFC or Pressurized Loss of Force Coolant and second is DLOFC or Depressurized Loss of Force Coolant. PLOFC is an event, in which the helium flowing in the primary system stops and the primary system remains pressurized. The primary helium flow is automatically stopped upon reactor shutdown followed by SCS (shutdown cooling system) operation to remove the after heat. The two safety-related aspects of PLOFC are the core heat-up transient with the potential for delayed radioactivity release from the fuel, and the heat up of metallic structures and equipment, particularly in the upper plenum (e.g., control rod drives) and other primary system pressure boundaries and critical components. Since the primary system is still under pressure, natural circulation of helium within the core helps equalizing the core temperatures with the maximum core temperatures migrating nearer to the top of the core. The helium recirculation would consist of up flow in the (hotter) center regions in the fuelled areas and down flow perhaps in the cooler core-side areas but more pronounced in the cooler reflector areas through other coolant channels and spaces between blocks. The maximum fuel temperatures in the PLOFC events are typically well below prescribed accident limits. DLOFC is an assumed long-term loss of primary system circulation and helium inventory. In some cases, "leak-before-break" assumptions are allowed by regulatory authorities for limiting the magnitudes of large-pipe or vessel rupture scenarios that need to be considered. The major consequence of a DLOFC is the long-term core heat up and potential radioactivity release into the confinement, and eventually, to the environment (filtered and/or unfiltered). Unlike the PLOFC, heat transfer due to helium natural circulation within the core is negligible. Maximum fuel temperatures would typically reach peak values in a few days, near the middle or beltline of the core, and then begin a 7 days long, slow decrease. In general, the reactor is designed so that the maximum fuel temperature in a DLOFC should not exceed the point where any significant fuel failure is expected. Typically, the reactor's design (rated) power level is selected based on this calculation of "best-estimate" maximum fuel temperature in the DLOFC accident. The heat up of metallic structures and potential material damage within and outside the primary system also need to be evaluated. During a depressurization, some of the primary circulating activity, including radioactive graphite dust, may be released along with the helium. Depending on the confinement design and break size, a large prompt helium release may go unfiltered. During the core heat up process, some fuel failures may occur although (by design) any heat up should result in only minor releases. These delayed, slow releases would typically be filtered (in a confinement design) before exiting to the environment. The following piping breaks and depressurization would cause pressure distribution transients within the reactor, which could be very dynamic for large breaks. The pressure redistributions and vibrations would need to be evaluated to ensure the structural stability of the reactor internals as it would cause possible external damage in the reactor confinement building and to the RCCS in particular. The potential for RCCS failure may be greater in the DLOFC event. RGTT200K has 2 heat removal systems, which are power conversion system and shutdown cooling system as seen in Figure 3a. Both systems are used to remove core heat and decay heat under normal operating conditions and those are active cooling system. In the event that two active systems are not available, the RCCS around the RPV serves as cooling system, as shown in Figure 3b and 3c as stated.

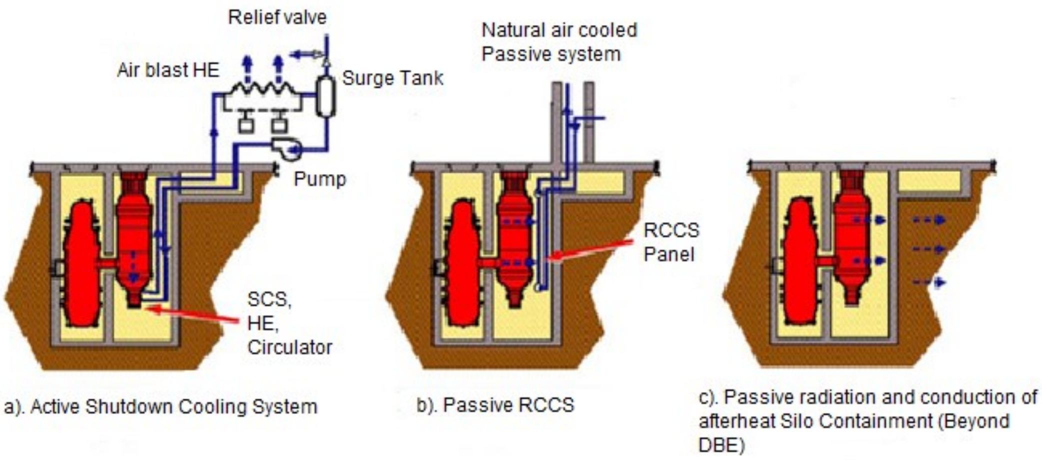

Fig. 3. The active SCS and passive RCCS in RGTT200K [18]

The Reactor Cavity Cooling System (RCCS) is designed in RGTT200K to create an ultimate heat sink. The RCCS ensures that the thermal integrity of the nuclear fuel, the core, the reactor pressure vessel (RPV) and all equipments in the reactor cavity are achieved. At normal operation condition, the RCCS ensure that the concrete structure surrounding the RPV is kept below 65 °C and below 125 ºC in case of total loss of the primary helium coolant accident. The RCCS for RGTT200K is typically a safety grade system, either with passive or with highly-reliable, redundant forced-convection cooling systems, designed to remove heat in the core in the unlikely case of failure or unavailability of the main and all other shut-down cooling systems. The objective of most RCCS designs is to serve as an ultimate heat sink, ensuring the thermal integrity of the fuel, core, vessel, and critical equipment within the reactor cavity for the entire spectrum of postulated accident sequences. During normal operation the temperature achieved in the fuel surface is around 1000 °C. In the accident of DLOFC, the fuel temperature rise up to approximately 1500 °C [18], and will decline again caused by the reactor cavity cooling system.

The RCCS of RGTT200K is used water forced circulation during normal operation. There are two operation modes of RCCS, which are the active and passive mode. The active mode means that the cold water is circulated by pumping from the water tanks to the stand pipes to take the heat from RPV and goes back to water tanks. The heat from the hot water then is discharged to the environment, through the cooling tower. The passive mode does not need any force circulation, and the water flows by natural circulation because of the difference between the hot and cold water temperature. The detail conceptual design of RCCS is shown in Figure 4.

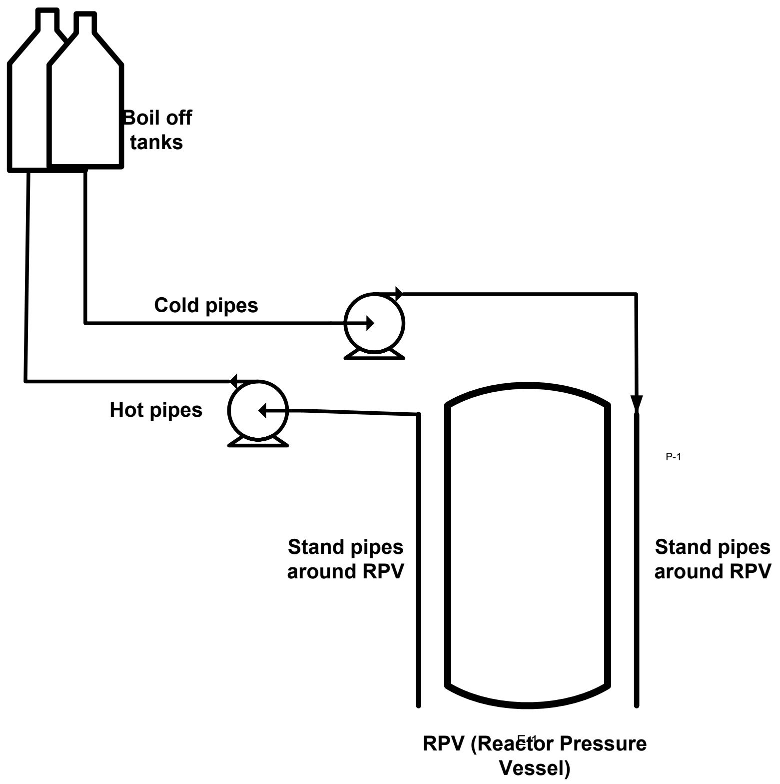

Fig. 4. Detail of RCCS conceptual design of RGTT200K [18]

The RCCS is designed with stand pipes, which are installed surrounding the RPV. Referring to the Fukushima accident, all of electrical supply from outside plant are not available causing that the primary coolant blower fails, and the RCCS active mode also fails. On that event, the RPV cooling is conducted via the reactor cavity between the RPV and the ground/earth. The air takes the heat from RPV by natural convection and is still capable to maintain temperature below its design limit. The cavity is connected to the atmosphere directly and the heat can be released. The fuel temperature will decrease until 800 °C within 20 days.

With natural circulation, the RCCS eliminates the remaining decay heat. The heat is transferred by conduction to the pressure vessel and then by radiation from the pressure vessel to the RCCS and by natural circulation of the air inside the reactor cavity. Because the RCCS water pumps also are assumed to fail, the heat is transferred by radiation and convection from the reactor cavity to the earth and surrounding areas and by conduction inside the earth, this assumption is shown in Figure 3c. This mechanism is perfectly adequate to keep the core temperatures below the maximum design limit. In the normal operation, the fuel maximum temperature is 1000 °C. If there is no helium coolant circulated in the primary system, the fuel temperature will increase to 1500 ºC. While the fuel temperature increases from 1000 to 1500 ºC, in the same time the RCCS removes the RPV heat to continuously decrease the fuel temperature until equilibrium temperature. The allowable fuel maximum temperature is 1600 ° C. The SBO does not endanger the RGTT200K design, because of the RCCS can maintain the integrity of the fuel temperature beyond its design limits. The RCCS absorbs the thermal energy from the reactor vessel directly by radiation and indirectly from the guard containment to atmosphere by natural convection.

CONCLUSIONS

RGTT200K has a reactor cavity cooling system (RCCS), which is equipped to remove the heat transferred from the reactor vessel to the structure of the containment. The RCCS is designed to satisfy this role by preserving the reactor vessel under the maximum allowable temperature during normal operation and protecting the reactor containment structure in the event of failure of all active cooling systems. During SBO, all of active cooling system were failed to work and the heat removal is conducted by RCCS. By design, the RCCS in RGTT200K is capable to maintain the RPV temperature below 65ºC at normal operation and 125ºC during the SBO, and to keep the fuel temperature 1600 °C.

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