Analysis on the Role of RSG-GAS Pool Cooling System during Partial Loss of Heat Sink Accident

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Abstract. RSG-GAS is a 30 MW reactor that is mostly used for radioisotope production and experimental activities. Recently, it is regularly operated at half of its capacity for efficiency reason. During an accident, especially loss of heat sink, the role of its pool cooling system is very important to dump decay heat. An analysis using single failure approach and partial modeling of RELAP5 performed by S. Dibyo, 2010 shows that there is no significant increase in the coolant temperature if this system is properly functioned. However lessons learned from the Fukushima accident revealed that an accident can happen due to multiple failures. Considering ageing of the reactor, in this research the role of pool cooling system is to be investigated for a partial loss of heat sink accident which is at the same time the protection system fails to scram the reactor when being operated at 15 MW. The purpose is to clarify the transient characteristics and the final state of the coolant temperature. The method used is by simulating the system in RELAP5 code. Calculation results shows the pool cooling systems reduce coolant temperature for about 1 K as compared without activating them. The result also reveals that when the reactor is being operated at half of its rated power, it is still in safe condition for a partial loss of heat sink accident without scram.

Keywords: RSG-GAS, RELAP5, pool cooling system, loss of heat sink, transient

1. Introduction
The G.A. Siwabessy Multi Purpose Nuclear Reactor (RSG-GAS) is a pool-typed material testing reactor which is at the moment mostly operated for radioisotope production taking advantage of its relatively high neutron fluxes[1-3]. In addition, some other activities were also performed such as experiments for code validations [4-6], reactor fuel studies [7-10], neutronic-thermalhydraulic related investigations[11, 12] and safety analysis [13]. By design, the reactor has rated thermal power of 30 MW, but at present predominantly average operation is at around 15 MW for a cost efficiency reason. During normal operation, reactor core which is made up of plate-type fuel assemblies, provides heat to primary side water coolant that be circulated into two heat exchangers [14] for transferring the heat into secondary side. The inlet and outlet temperatures of the core is about 313 K (40.2 °C) and 322 K (48.9 °C). The coolant circulation is driven by two constant speed pumps; each has supply capacity of 430 kg/s. At the secondary side the heat removedfrom the heat exchangers is then dump into the environment through cooling towers using two secondary pumps. During shutdown, where the main
pumps are stopped, the core’s decay heat is removed by the pool cooling system consisting of three modules called JNA 10/20/30 (see Figure 1). These modules are demineralized water circulating closed circuit that independent of one another. Each module composed of finned pipe submerged in reactor pool for a certain depth, circulation pump and two air cooled heat exchangers located outdoor. Every module is designed to be able to deliver heat of 63 kW.

During an accident, particularly loss of normal heat sink (either due to failure of secondary side pump or cooling tower system), the cooling for reactor coolant is very important as the core still produce energy from decay heat. Investigation conducted by S. Dibyo[16], that performed numerical analysis with RELAP5 using simplified/partial model shows that there is no significant coolant temperature increase if the reactor successfully trips and JNA system works as designed. However, lessons learned from the Fukushima accident revealed that analysis for worse condition needs to be performed as accident can happen not only due to single failure but also from multi failures [17] which could bring condition beyond its design limit. Recall that the reactor and it supporting systems are ageing, then there is an upturn probability that multiple failures accident could happen in RSG-GAS. In this paper, the role of pool cooling system when a partially loss of heat sink accident occurs (i.e. one of secondary-side pumps broken) at steady state operation of 15 MW followed by failure to trip is investigated. As the reactor remains on power, the accident causes a rapidly increase pool temperature because only half of the secondary-side system works. One way to resist the increase is by activating the pool cooling system (JNAs). For that reason, this research studies the dynamic of the coolant temperature. The purpose is to clarify the characteristic of reactor transient and final state of coolant temperature. The method used is through numerical simulation, i.e. by modeling reactor system including its pool cooling system into RELAP5[18]. The simulation performed starts at steady state which then undergo a secondary pump failure but fail to have shutdown. The result of this study is for complementing the document of safety review required by Nuclear Energy Regulatory Agency (BAPETEN) for extension of the operation license.
2. Reactor System Modeling
To be able to analyze the role played by the JNAs during loss of heat sink, the RSG-GAS hydrodynamic and the JNA systems must be modeled in RELAP5. Figure 2 shows diagram of RSG-GAS which includes primary and secondary sides of the reactor cooling system. The JNAs themselves are located in the reactor pool as shown in Figure 1. Main characteristic of the reactor for input deck development is presented in Table 1. The system shown in Figure 1 and 2 is then represented using generic models available in RELAP5 such as PIPE, VOLUME, BRANCH, JUNCTION, TIME DEPENDENT VOLUME, TIME DEPENDENT JUNCTION and HEAT STRUCTURE. The complete representation is displayed in Figure 3. In addition, connection of JNAs with reactor system is shown in Figure 4.

Table 1. Main Characteristics of GA Siwabessy Reactor.[14]

| Parameter                        | Value                       |
|----------------------------------|-----------------------------|
| Nominal power                    | 30 MW                       |
| Fuel (enrichment)                | $\text{U}_3\text{Si}_2\text{-Al, LEU (19.75\%)}$ |
| Total number of plates           | 960                         |
| Plates per standard assembly     | 21                          |
| Plates per control assembly      | 15                          |
| Standard assemblies in core      | 40                          |
| Control assemblies in core       | 8                           |
| Average power per plate          | 31.25 kW                    |
| Average heat flux                | $0.415 \text{MW/m}^2$       |
| Core flow rate                   | 3270 m$^3$/h                |
| Static pressure (top of the core)| 0.1997 MPa                  |
| Flow direction                    | Downward                    |

Figure 2. RSG-GAS system schematic diagram
Figure 3. RSG-GAS system representation in RELAP5

Figure 4. RELAP5 model for Pool Cooling System

Figure 4 shows that the upper part of the reactor pool model is connected with three JNAs. Each JNA consists of 2 boundary volumes (TMDPVOL), 1 coolant driving device (TMDPJUN), 1 connecting pipe (SNGLJUN), one pipe (PIPE) and a model for heat transfer calculation (HEAT STRUCTURE) which has two faces. One face is connected to a volume in the upper side of the pool and the other face is with PIPE of pool cooling system. From that model, the input deck was developed where the parameters used are shown in Table 2. Recalling that the focus of this study is fuel and coolant temperatures, and the overall response of reactor then the modeling of JNA is simplified by looking at its capability to remove heat from the pool. Noting that there are three modules, then in the modeling there are also three JNA models connected with reactor system.
Table 2. Main Characteristics of Pool Cooling System

| Parameter                                      | Value                                      |
|------------------------------------------------|--------------------------------------------|
| Type                                           | Finned tube immersion coolers with 6 straight fins along the tube |
| Material                                       | Material Al Mg3                            |
| Design Operation Temperature                   | 338 K (65 °C)                              |
| Mass flow rate                                 | 7.6 kg/second                              |
| Thermal Power                                  | 63 kW                                      |
| Air dry bulb Temperature                       | 309 K (36 °C)                              |
| Cooling tower inlet-outlet temperatures difference (during commissioning) | 3.5 K – 4.5 K                              |
| Number of finned pipe per module               | 16 pipes                                   |
| Pipe length                                    | 10 m                                       |
| Pipe Diameter (ID/OD)                          | 30/35 mm                                   |
| Effective surface area per module              | 20 m²                                      |
| Operating pressure                             | 5 Bar                                      |

2.1. Operating Limit[19]

Safety Analysis Report (SAR) of RGS-GAS describes safety limit and operation limit of the reactor. The safety limit is used for safety analysis in the safest condition, while operation limit is implemented for reactor protection system. The limit described below is limit from the thermal hydraulic point of view. In RELAP5, operation limit is used for the LOGIC modeling for reactor scram.

a. The Safety limit, among others are:
   1. Maximum core inlet temperature is 317.5 K (44.5°C)
   2. Minimum coolant flow to the core is 85% of primary cooling flow rate
   3. Minimum safety limit of flow instability (S) in overpower operation (114% form nominal power) is 2.67

b. Operation limit, among others are:
   1. Maximum core inlet temperature is 315 K (42°C).
   2. Maximum reactor power is 114% of nominal power
   3. Minimum flow rate id 85% of total primary system flow rate
   4. Minimum safety limit of flow instability (S) in nominal power operation is 3.38

In this research, it is assumed that trip fails to occur, so then some of the above operation limit is not considered.

3. Calculation Results and Discussion

3.1. Steady state.

To be able to perform a transient analysis on the role of JNA 10/20/20 during accident using RELAP5, a steady state execution is performed first. Noting that at present and in the future reactor is going to be operated at half of nominal power, the execution values are shown in Table 3.
Table 3. Reactor data for steady state calculation at 15 MW.

| Parameter                        | Value                   |
|----------------------------------|-------------------------|
| Reactor power                    | 15 MW                   |
| Primary system flow rate         | 960 kg/s                |
| Pool coolant level               | 12 m                    |
| Core outlet temperature          | 314 K (41 °C)           |
| Core inlet temperature           | 309.5 K (36.5 °C)       |
| Average secondary coolant inlet temp. | 305 K (32 °C)     |
| Average secondary coolant outlet temp. | 308 K (35 °C) |

Data from steady state calculation is for initial condition of the accident scenario.

3.2. Transient

Transient calculation performed is simulation of failure at one of secondary pumps without reactor trip. The calculation was performed two times, i.e. condition with the all JNAs is disabled and activated. The results are then compared in order to look at the role of the JNAs in contributing the heat removal. The first result is shown is Figure 5.

Figure 5. Typical heat transfer and coolant temperature in RSG-GAS without JNA activation
In Figure 5, the reactor is initially at steady state of 15 MW which is then at t= ~1000 seconds having failure in heat sink system. It can be seen that since the loss of heat sink partially, the coolant temperature gradually increased, both in core’s inlet and outlet. This increase happens in consort with the losing of heat removal capability due to in loss of heat transfer in one of heat exchanger. The increase is finally reaches equilibrium when the heat transferred by the remaining active HE equals to the core power. The equilibrium temperature at the inlet and outlet of the core is about 318 K and 323 K.

In the second simulation, all JNAsis activated. It was assumed that the operator takes such action manually within 15 minutes after the pump failure. Result of the calculation is shown in Figure 6.

![Figure 6. Typical heat transfer and coolant temperature in RSG-GAS with JNA activation](image)

Figure 6 shows the dynamic of heat transfer and coolant temperature in the system with activated pool cooling system. It can be observed that some of the heat is removed through JNAs. At the beginning of the transient, heat tranfer in the active HE oscillates as a result of temperature fluctuation from JNA activation. However, the trend of temperature coolant increase follow the shape of condition without JNA activation. From this figure, the role of JNA for heat removal is not significant, that is about 420 kW. Furthermore, equilibrium temperature of core inlet and outlet is 1 K lower than if the JNA is activated, or around 318 K and 322 K. In both scenario discussed above, the fuel temperature is still below operational limit and there is no possibility of core damage. From those conditions, it can be concludedthat even there is no reactor trip during partially loss of heat sink at power of 15 MW, the safety of reactor remains intact.
4. Concluding Remark

Investigation on the role of pool cooling system of RSGGAS for a partial loss of heat sink accident followed by trip failure has been conducted. The investigation was performed through simulation using numerical model in RELAP5 which includes reactor system and pool cooling system (JNA). Calculation runs for two transient scenarios at power level of 15 MW, i.e. with and without JNAs activation. The result shows that under prescribed condition the reactor still under safe condition where the final core inlet and outlet temperatures are 318 K and 323 K. Furthermore, the calculation also shows that the use of JNA would contribute to reduce temperature for about 1 K.

Acknowledgement
This work was supported by the national project fund (DIPA) 2016 and the author would like to acknowledge the National Atomic Energy Agency of Indonesia (BATAN) for providing facilities to perform the calculation.

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