The Debris Particles Analysis of RSG GAS Coolant to Anticipate Sediment Induced Corrosion

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ARTICLE INFORMATION

ABSTRACT

THE DEBRIS PARTICLES ANALYSIS OF RSG-GAS COOLANT TO ANTICIPATE SEDIMENT-INDUCED CORROSION. The reliability of the structures, systems and components (SSC) of the G.A. Siwabessy Multipurpose Research Reactor (RSG-GAS) should be maintained to keep the reactor operates safely. Chemical control and management of coolant is one factor which determines the SSC's reliability. The debris sedimentation in the primary coolant system must be examined. Debris occurs in the reactor pool, originating from airborne dust from the engineering hall. Several elements contained by the sediment can induce corrosion. This research was conducted to identify the trace elements which were contained in the sediments and determine their concentrations. The objective was to anticipate the occurrence of galvanic and pitting corrosion due to the presence of elements which are more noble than aluminum. The measurement methodology is Neutron Activation Analysis (NAA). Two groups of samples were analyzed; the first group was sampled from the debris trapped in the mechanical filter after the resin column, or known as the resin trap, and second was sampled from the debris which adhered to the heat exchanger tube. The primary coolant debris analysis showed that the neutron-activated sediment contained Na-24, Na-25, Al-28, Mg-27, Cr-51, Mn-54, Mn-56, Co-58, Co-60, Ni-65, and Fe-59. The Mn, Cr, Co, Ni, and Fe are more noble than aluminum can induce galvanic corrosion while Na, Ba, Al, and Mg are not. The radionuclides contained by the result of neutron activation of sediment from the heat exchanger tube are Mn-56, Na-24, As-76, Br-82, Fe-59, Zn-65, Cr-51, La-140, and Sc-46 which are mostly carbon steel corrosion products. Those elements do not initiate galvanic corrosion. The prevention of galvanic corrosion can be done by periodic maintenance.

ABSTRAK
ANALISIS PARTIKEL DEBRIS PADA PENDINGIN RSG-GAS UNTUK MENGANTISIPASI SEDIMENT-INDUCED CORROSION. Keandalan sistem, struktur dan komponen (SSK) Reaktor Serba Guna G.A. Siwabessy (RSG-GAS) harus selalu dijaga agar reaktor dapat beroperasi dengan aman. Salah satu faktor untuk menjamin keandalan SSK adalah faktor pengelolaan kimia pendingin. Faktor adanya sedimen akibat endapan debris halus terutama dalam air pendingin primer harus diperhatikan. Debris dapat berasal dari debu udara dari engineering hall di dekat kolam reaktor. Unsur tertentu dalam sedimen akan memicu adanya korosi. Penelitian ini dilakukan untuk mengetahui dan kadar unsur-unsur yang terkandung dalam sedimen yang terjadi pada pendingin RSG GAS. Tujuan penelitian adalah untuk mengantisipasi terjadinya korosi galvanis dan pitting akibat adanya unsur yang lebih mulia dari aluminum. Metodologi yang digunakan adalah dengan Analisis Aktivasi Netron (AAN). Ada 2 kelompok sampel sedimen yang dianalisis yaitu debris yang terjebak dalam filter mekanis setelah resin pendingin primer dan debris yang terjebak dalam tabung heat exchanger. Hasil analisis debris pendingin primer yang telah diaktivasi menunjukkan adanya Na-24, Na-25, Al-28, Mg-27, Cr-51, Mn-54, Mn-56, Co-58, Co-60, Ni-65, dan Fe-59. Unsur Mn, Cr, Co, Ni, dan Fe lebih mulia dibanding aluminum sehingga memicu korosi galvanis, sedangkan Na, Ba, Al, dan Mg tidak. Radionuklida kandungan sedimen tabung heat exchanger yang telah diaktivasi adalah Mn-56, Na-24, As-76, Br-82, Fe-59, Zn-65, Cr-51, La-140 dan Sc-46 merupakan produk korosi baja karbon dari material pipa sekunder. Unsur-unsur ini tidak memicu adanya korosi galvanis. Pencegahan sel galvanis akibat debris debu halus dapat dilakukan dengan perawatan berkala.
Kata kunci: sedimen, debris, galvanis, pitting, korosi

1. INTRODUCTION

The GA Siwabessy Multipurpose Research Reactor (better known as its Indonesian language acronym "RSG–GAS", for Reaktor Serba Guna G. A. Siwabessy) is a pool–type multipurpose research reactor

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whose construction started in 1983. The reactor's first criticality was reached on July 1987[1] and the reactor's maximum power of 30 MW was first achieved on March 1992. The RSG-GAS has an average neutron flux of 10^{14} n/cm^2.s which results from fission reaction in its core. The RSG-GAS has U$_3$O$_8$Al/U$_3$Si$_2$Al fuel meat with 19.75% uranium enrichment[1].

The RSG-GAS has two coolant systems, i.e. the primary and secondary cooling systems. Both of these systems ensure that the reactor coolant temperature is controlled and safe[2,3]. These two systems are shown in Figure 1. During normal operation, heat generated in the core is taken by primary cooling system and transferred to the secondary cooling system via heat exchangers. The heat is discharged into the environment through cooling towers by forced circulation.

The primary and secondary water quality must be managed to meet the specifications. Regular monitoring and measurements are conducted to make sure the requirements are satisfied. Mechanical and chemical treatments are conducted on the cooling system to maintain the integrity of structure, components, and system. In the primary cooling system, water is continuously passed through a purification system that consists of a mechanical filter and ion exchange resins. In the secondary cooling system, chemical additives used to suppress corrosion, scaling, and microorganisms growth[4].

The primary cooling system plays an important role in ensuring the integrity and reliability of the reactor tank. The reactor tank of RSG-GAS is made of aluminum alloy which can corrode easily if the primary coolant is not well-controlled. The occurrence of sediment due to accumulation of debris in the primary cooling water must also be examined. Debris consisting of fine dust particles occurs in the primary circuit because of airborne dust from the reactor hall. Airborne dust in the reactor hall or in the spent fuel storage facility settles on the reactor pool or spent fuel basin surfaces. The amount and nature of this dust varies depending on the extent of control of the environment in the building and the nature of the activities in the vicinity of the pools. The

dust (fine solid particles) on the pool/basin surface floats until wetted by the water. By using surface skimmers, the dust is filtered out. However, depending on the properties of the solid, mainly its density, it settles at the bottom of the pool or on any surface that it encounters as it descends through the pool or basin water[2].

Solids settle faster in stagnant regions of the pool. Fine solid particles also have a tendency to agglomerate to form larger particles that settle faster. This tendency varies with the composition and density of the particles. These solids settle on all surfaces inside pools or basins. Most of these solids eventually settle at the bottom of the pool or basin and are the main constituents of sludge. Air filters in the reactor basin room function to help limit dust. Not all dust is easily captured by mechanical filter; some dust escapes, especially small-sized particles with high density.

The gemstone (topaz) irradiation facility contributes to debris accumulation in the tank basin. Topaz irradiation plays a role in generating fouling debris in the primary coolant. There are two topaz irradiation facilities in RSG GAS, one inside the core, and another outside the core; they are known as the in-core and out-core irradiation facilities, respectively)[5]. The in-core irradiation facility contributes to debris creation even though the topaz had previously been washed during its initial treatment[4].

Debris accumulating in the bottom of the tank reactor or in areas with stagnant flow will trigger the corrosion known as sediment-induced corrosion[5]. Certain elements adhering to the tanks surface are more noble than aluminum. These elements will initiate the galvanic corrosion. Since aluminum is less noble than the element that is attached to the tank sediment, it more easily corrodes. At first, the corrosion area is very small, with a size in the micrometer range. Because of its location at the bottom of the pool or in the stagnation, this corrosion point easily settles and accumulates chloride ions. The chloride ions subsequently trigger pitting corrosion. If pitting or hole has occurred in the material surface then the tank will leak[6]. To avoid galvanic corrosion and pitting corrosion due to debris sediment, the debris should be

prevented from entering the reactor coolant and the chloride ion must be controlled as low as possible[7].

This paper discusses the measurement results concerning the chemical elements of the sediment caused by debris precipitation in the reactor coolant. The goal of this research is to anticipate the galvanic and pitting corrosion due to the elements that are more noble than aluminum that are contained in the sediment. The methods used are sediment sampling and chemical element measurement with Neutron Activation Analysis (NAA). There are two groups of samples that will be analyzed; the first one is taken from the debris that is trapped on the mechanical filter that is located after the resin column, and the second is taken from the debris that adheres to the heat exchanger tubes. The mechanical filter debris has been chosen because this system is directly connected to the basin tank, the reactor service pool, and the reactor warm-up water layer. The debris on the heat exchanger tube is taken to understand the elements contained related to possibility of galvanic corrosion in the tube. The results of this research will allow a prediction of sediment-induced corrosion.

2. THEORY

The RSG-GAS has two main loops of cooling system. Both of these systems are shown in Figure 1. The system functions to ensure a safe temperature in the core during normal operation for power levels up to the thermal design power. At high power, the heat generated by the core is transferred from the primary system to the secondary system via heat exchangers and discharged into the atmosphere through the cooling towers by forced circulation[4].

The primary cooling system uses demineralized water as its heat transfer medium. The plant's demineralized water system, also known as the GCA01, produces that water. The reactor pool and all
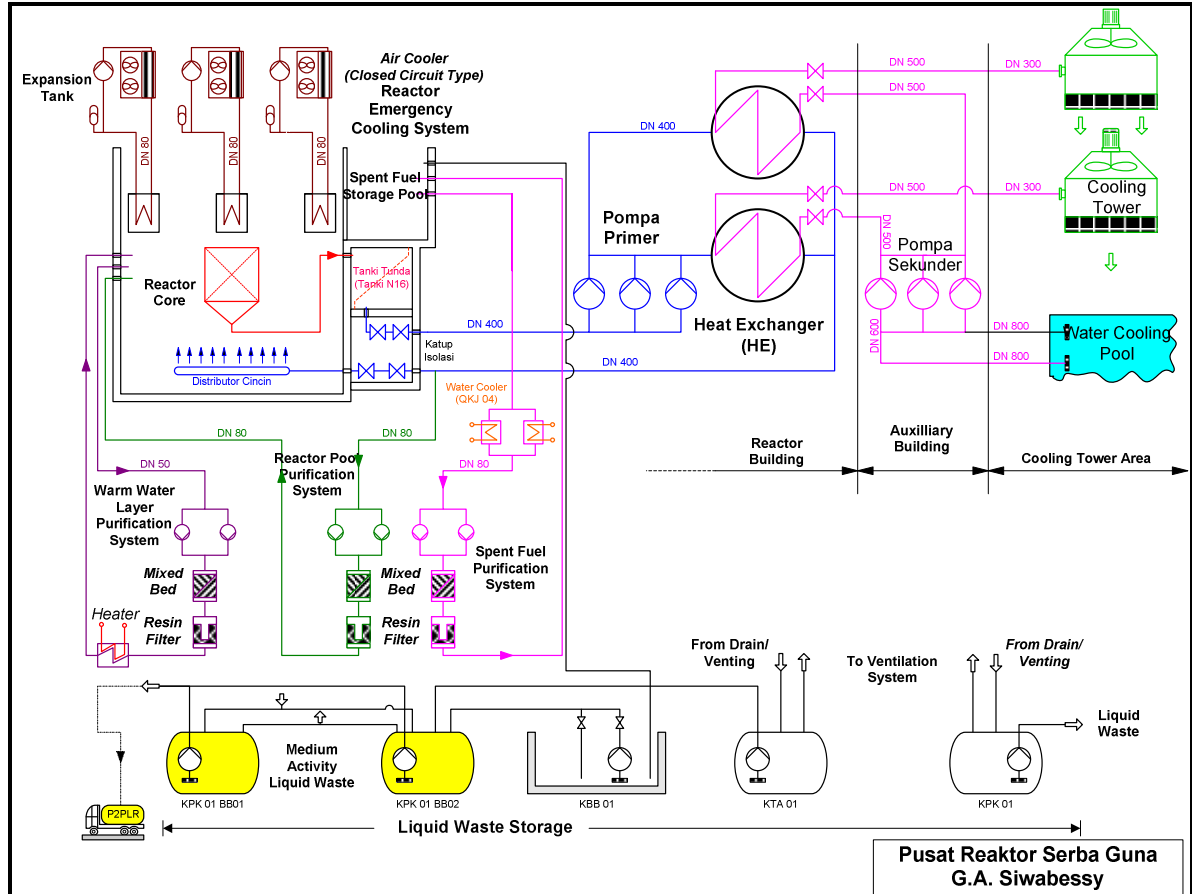

Figure 1. RSG-GAS Cooling System Including Primary and Secondary Coolant[4].
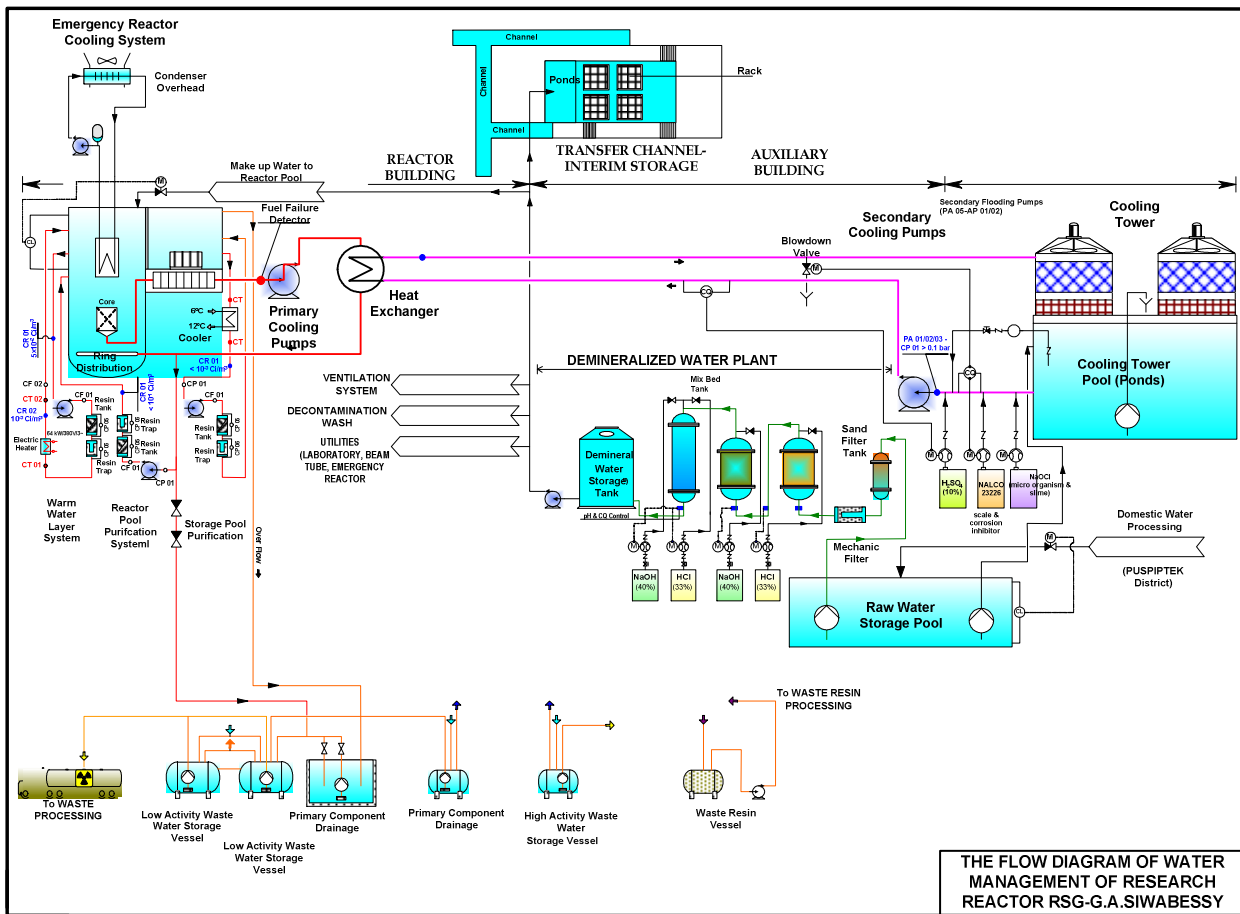
Figure 2. Flow Diagram of the Water Management of RSG GAS[3,4].

subsystems in the primary system are filled by demineralized water, but the secondary system uses freshwater supplied by the utility supplying Puspiptek (the Research Center for Science and Technology, namely the agency which manages the research area where the RSG-GAS is located). Prior to use, however, the water from Puspiptek is given mechanical treatment which includes flow through precipitation pools and sand filter pools. The water treatment in the RSG-GAS is shown in Figure 2[3,4].

2.1. The Primary Cooling System of RSG GAS

The primary system of RSG GAS functions are as a heat transfer medium, as a moderator, and as radiation shielding. The aims of this system are to maintain the structural integrity of the fuel and the reactor and to confine the radionuclides possibly released from the fuel cladding. The heat produced in the reactor core is removed from the core by water flowing through the fuel

gaps and transferred to the secondary system. The total volume of the primary system is 330 m^3, consisting of 220 m^3 in the reactor pool, 80 m^3 in delay chamber, and 30 m^3 in the piping system. GCA01 produces the demineralized water. Before the water is transferred to storage tank (labeled BB04 in Figure 2), the water quality is checked through conductivity and pH measurements. Those parameters are shown in Table 1. If the values do not meet the specification, the water is flushed to the treatment area and retreated until the required water quality is achieved.

Table 1. Demineralized Water Specification of RSG-GAS[3,4]

Parameter	Value limits
pH	6.5 – 7.5
Conductivity (max)	2 µS/cm
Chloride Concentration (max)	0.0094 ppm
Copper Concentration (max)	0.0056 ppm

The reactor pool and all primary piping system connected with it filled with demineralized water from demineralized water system GCA01. Meanwhile the secondary cooling system used Puspiptek PAM water[4].

2.2. The Secondary Cooling System of RSG-GAS

The secondary cooling system is the final loop to release the heat that has been transferred from the primary coolant. The system is designed to be able to dissipate total heat of 33,000 kW and consists of a two-part piping system with each section's capacity being 50%. Each section of the pipeline consists of pumps, heat retainer, pipes, and cooling towers. The secondary cooling system is designed to cool the primary water so that the temperature of the inlet flow to the reactor pool does not exceed 40°C[3,4].

The secondary loop consists of three centrifugal pumps, a mechanical filter, and two lines of cooling towers, valves, and piping systems. Each pump is made of carbon steel castings, volute case and equipped with connections for venting and mechanical drainage. The mechanical filter protects the pump from any material impurities such as leaves and twigs that are carried over from the secondary coolant. Each cooling tower lane consists of 3 modules with parallel operation and one additional module that is connected to the same lane. Every module is made of synthetic materials, including frames, packing, and the outer layer for corrosion resistance. Warm water from secondary piping is sprayed into the top of the tower through a nozzle distributor and flows downward to transfer the heat to the air with partial water evaporation water flow[4].

Water loss due to evaporation and splashes is replaced by adding fresh water from the processed Puspiptek's Utility water. All of secondary piping inside the reactor, including its valves, is made of stainless steel, but outside the reactor building it is made of carbon steel. The specifications of RSG-GAS secondary cooling water is shown in Table 2[4].

2.3. Galvanic Corrosion

Dissimilar metals and alloys have different reduction potentials, and when two or more come into contact in an electrolyte, one metal acts as anode and the other as cathode. The reduction potential difference between the dissimilar metals is the driving force for an accelerated attack on the anode member of the galvanic couple[8]. The anode metal dissolves into the electrolyte, and deposit collects on the cathodic metal. The electrolyte provides a means for ion migration whereby metallic ions move from the anode to the cathode. This leads to the metal at the anode corroding more quickly than it otherwise would and corrosion at the cathode being inhibited. The presence of an electrolyte and an electrically conducting path between the metals is essential for galvanic corrosion to occur[9].

In other cases, such as mixed metals in piping (for example, copper, cast iron and other cast metals), galvanic corrosion will contribute to accelerated corrosion of parts of the system. Corrosion inhibitors such as

Table 2. Specification of Water for Secondary System of RSG GAS and Puspiptek[4]

Secondary water specifications		Puspiptek water specifications	
pH	6.5-8	pH	7-7.5
Conductivity at normal operation	950 µS/cm	Conductivity at normal operation	–
Conductivity (max)	1500 µS/cm	Conductivity (max)	150 µS/cm
Calcium (as $CaCO_3$) max	280 ppm	Calcium (as $CaCO_3$) max	34 ppm
SO^-_4 max.	320 ppm	SO^-_4 max.	67.8 ppm
Hardness (total)	480 ppm	Hardness (total)	40 ppm
Fe total	1 ppm	Fe total	1 ppm
Chloride (max)	1775.5 ppm	chloride (max)	7.1 ppm
Corrosion rate (max)	3 mpy		
Bacteria (total)	10^6 bacteria/ml		

sodium nitrite or sodium molybdate can be injected into these systems to reduce the galvanic potential[10]. However, the application of these corrosion inhibitors must be monitored closely. If the application of corrosion inhibitors increases the conductivity of the water within the system, the galvanic corrosion potential can be greatly increased. Acidity or alkalinity (pH) is also a major consideration with regard to closed-loop bimetallic circulating systems. Should the pH and corrosion inhibition doses be incorrect, galvanic corrosion will be accelerated[11].

The metal that has the lower corrosion resistance will act as an anode and its couple as a cathode. Galvanic corrosion of an anodic metal can occur as uniform corrosion or localized corrosion, depending on the configuration of their couple. Galvanic corrosion is determined by the position of the metal in the Volta, or electrochemical, series[12]. A more noble metal is more difficult to corrode, while a less noble metal is more easily corroded. As with the couple of Al and Fe, the Al metal will be more easily corroded than Fe because Fe is more noble than Al. Galvanic corrosion of Al and other metals in adjacent pairs can be reduced by avoiding its galvanic pair to less noble metals and by reducing water conductivity to as low as possible, or practically to the range of 1-3 µS/cm. It is also required to use deionized water, to prevent corrosion and increase resistance against the current flow.

2.4. Pitting Corrosion

Pitting corrosion is a form of localized corrosion that attacks in the form of spots or pits. Pitting corrosion, also known as holes corrosion, may occur in stainless steels or aluminum in neutral or acid solutions containing halides, primarily chlorides (Cl^-), such as seawater. Pitting corrosion attacks most often take place at points where the passive layer is weakened, for example by slag inclusions, a damaged surface, or imperfections in the passive layer. Scratches or surface defects become ideal places to trigger pitting corrosion. Once the attack has started, the material can be completely penetrated within a short time. If the defect has occurred and the environments contains chloride ions (Cl^-) the pit will initiate. The severity of the pitting corrosion attacks depend primarily on the chloride content, the pH value (acidity), and the temperature. If pitting has taken place and the environment is not too corrosive for the steel grade, a spontaneous repair of the passive layer will occur in the presence of oxygen[11,12]. At the stagnant flow area, chloride ions will easily precipitate and accelerate the hole deepening. Pitting corrosion depth is defined by equation (1).

$$D_{p(max)} = A(t)^{1/3} \tag{1}$$

where D_p (max) is the maximum depth of pitting and A is a parameter that depends on the alloy composition, water quality, and temperature.

The value of the parameter A is very difficult to determine, and Pathak *et al.*[9], has found an empirical equation to predict the nature of pure water's corrosiveness for aluminum in a wide range of ambient room temperatures. The relationship is shown in equation (2)[12].

$$\begin{aligned}
\log PRI &= 2.5 - 0.28\log(SO_4^{-2}) + 0.18\log(Cl^-) \\
&\quad - 0.20\log[(ph-7)^2 \times 100] \\
&= 0.42\log(30000/R) \\
&\quad - 0.064\log[(Cu^{+2}) \times 10^3]
\end{aligned} \tag{2}$$

where PRI is the pitting rate index, R is the resistivity (Ohm.cm), and SO_4^{-2}, Cl, Cu^{+2} are the concentrations of the corresponding species (ppm).

PRI values under 25 indicate aggressive water. The very small hole by pitting is difficult to detect by visual observation; as a result, over time the material will leak. Pitting may occur in the fuel cladding that are made from aluminum alloy[13].

2.5. Sediment-Induced Corrosion

The particle's sedimentation in fluids follows Stokes' law in the equation (3):

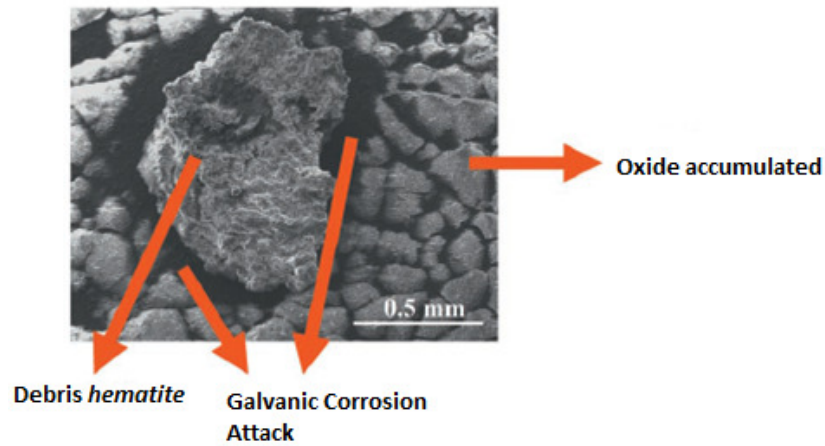$$U = \frac{2gr^2}{9\eta\eta(-\rho_0)} \tag{3}$$

Figure 3. Corrosion Attack Caused by Debris (Hematite) Sedimentation[14].

where: U is the sedimentation rate of the particles, g is the gravitational acceleration, r is the radius of the particle, ρ is the density of the particles, ρ_o is the density of water, and η is the viscosity of the fluid.

It can be seen that the sedimentation rate is directly proportional to particle diameter. The smaller particles have a stronger tendency to remain in the fluids compared to the larger ones.

The solids attack the passive layer and initiate the galvanic corrosion. This impact will be greater in high conductivity water[14]. Aluminum coupled with stainless steel is one of probable galvanic cases. A galvanic corrosion attack sample caused by hematite deposition is shown in Figure 3.

3. METHODOLOGY

The methodology used in this study starts with sediment sampling in a predetermined location. The first group of samples consist of sediment samples were from a resin trap which is located after a resin column. Resin traps filter damaged resin and sediment mechanically from the primary coolant system. The second group of samples was taken from crust in the heat exchanger tubes. The crust samples were taken from the heat exchanger tube is shown in Figure 4. The water sample containing crust was then filtered by paper, dried, and analyzed using NAA (Neutron Activation Analysis).

The basic principles of the technical analysis of NAA can be seen in Figure 5. The NAA is based on thermal neutron capture by the target (sample) through the (n, ɣ) reaction[13]. The sediment shot with neutrons generates several radionuclides. These radionuclides emit certain radiation that can be analyzed to identify the radionuclide and determine the element from which the radioisotope was generated.

Using NAA analysis, the amount of radionuclides produced depends on the number of nuclei in the target, the neutron fluence received by the target, the irradiation

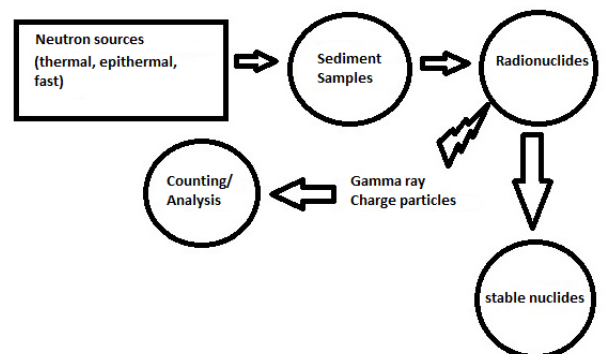Figure 4. The Sediment Samples from Heat Exchanger Tube.

Figure 5. Simplified Diagram of Neutron Activation Analysis (NAA) Procedure.

time, the type of target material, and material cross section[15]. Thermal neutrons are absorbed by the target and generate new nuclei and new neutrons which are not stable. The nuclei then likely to reach a stable state by releasing the excess energy through isomeric transitions, β– decay, or β+ decay, and those are generally followed by ɣ-rays. The ɣ-rays correspond to specific radionuclides, and are used to identify an activation radionuclide[16,17]. Activated radionuclides will decay according to its characteristic decay scheme. The radiation distribution will be affected by the decay time of each radionuclide formed.

4. RESULT AND DISCUSSION

The sediment samples have been taken from two locations, the sediment caught in the resin trap and sediment adhering to the heat exchanger tube. The resin trap is a mechanical filter installed after the resin columns in the primary water purification. This filter contained impurities from the primary coolant. There are three resin columns in the reactor; they are located in the water layer purification system, the reactor tank water purification system, and the temporary spent fuel water purification system (usually called service pool). Each system is equipped with a resin column containing a mixture of anion and cation resins. The output line is connected to a resin trap each. The resin trap serves to collect the broken resin pieces which are detached from the column and prevent them from entering the core. The primary cooling impurities are categorized into ionic and non-ionic impurities. Ionic impurities will be cleaned by using the column resin while non-ionic impurities (dust, debris, and organic compounds) are filtered using a mechanical filter.

The samples were analyzed by NAA. The neutron irradiation process was carried out in Rabbit System irradiation facility. The neutron flux was 3.5×10^{13} n.cm^{-2}.s^{-1}. The irradiation duration needed depends on the elements to be detected. An irradiation duration of one hour is needed for activation nuclides with long half-lives, 10 minutes for the medium half-life ones, and 1 minute for short half-life ones.

For comparative NAA method, the measurement of ɣ energy was performed using an HPGe detector. By this method, the ɣ energy spectrum and the intensity of the elements contained in the sample being activated are obtained. Qualitative analysis is done by identifying the elements contained in the sample. The results of the analysis are shown in Table 3.

Neutron irradiation may cause the sediment core containing various elements to experience neutron capture reactions (which include neutron activation) and fission reactions. Almost all nuclides except Helium-4 can be involved in neutron capture reactions (n,ɣ). Other neutron capture reactions are the reactions (n,α) and (n,p) which occur in several nuclides with low mass numbers. In general, nuclides with low mass numbers have relatively short half-lives.

NAA identifies the elements contained in the sediment. The quantitative analysis was carried out by the comparative method by comparing the peak area of gamma ray of a particular energy in the spectrum of the sample with the corresponding standard peak area for the radionuclide with the same gamma energy.

In the primary cooling system, all pipes which is connected to the reactor pool is made of the AlMg$_3$ alloy, as are the reactor tank and the fuel cladding, while the pipes outside the pool are made of stainless steel (SS304). The

Table 3. Radionuclides Contained in the Activation Result of the Resin Trap Sediment as Determined by NAA

Radionuclides	Half-life	Concentration (%)
Na-24	15 hours	0.053
Na-25	1 minute	0.032
Al-28	2.3 minutes	0.32
Mg-27	9.5 minutes	0.86
Cr-51	27.8 days	0.82
Mn-54	312.5 days	0.44
Mn-56	2.58 hours	0.55
Co-58	70.8 days	0.076
Co-60	5.27 years	0.092
Ni-65	2.56 hours	0.83
Fe-59	44.6 days	1-2%
Organic	–	Residual elements

order of elements in the electrochemical series is Li − Ka − Ba − Ca − Na − Mg − Al − Mn − Zn − Cr − Fe − Ni − Co − Sn − Pb− (H) − Sb − Bi − Cu − Hg − Ag − Pt − Au. Galvanic cells will be formed when two pieces are connected and adjacent material. Elements in the left side of the electrochemical series are less noble than the elements on the right side. To determine the effect of sediment to aluminum, the elements contained in the sediment are determined, and their place in the electrochemical series is checked. The elements whose isotopes are shown in Table 3, Mn, Cr, Co, Ni, and Fe are located on the right side of Al, so these elements are more noble than aluminum. The more noble elements adhering to the aluminum tank surface will form a galvanic cell. When the galvanic cell has formed, the less noble material will corrode more easily. In this case, aluminum will corrode earlier than Mn, Cr, Co, Ni, and Fe. At the beginning this corrosion did not have significant impact because its size is very small (micrometers size), but if the fluid contains chloride ions (Cl^-) then the defects caused by galvanic corrosion will lead to pitting corrosion. If corrosion and pitting has occurred over time, the holes or pits formed will be deepened. This leads to leaking pipes and must be prevented.

The elements Mn, Cr, Co, Ni, and Fe can be released to the coolant because the primary coolant's pipes are made of stainless steel (SS) 304. In addition to Fe, the elements contained in SS304 are C, Mn, Si, P, S, Cr, Ni and N. Those elements are released to the coolant by corrosion that has occurred, or is occurring, in some spots in the pipeline. The corrosion products are then transported into the coolant flow. The aforementioned steps constitute uniform corrosion or erosion corrosion of the pipe surface. Concerning to the the amount of elements which come from SS304 in the sediment the possibility of corrosion is still very small because the amount of each of these elements in sediments is less than 1%. The nuclide Co-60 was present because of corrosion product activation from Fe-59 to Co-60.

Na-24 and Mg-25 are less noble than aluminum, making them secure against potential galvanic corrosion. Based on Table 3, it is known that the organic compounds are the largest constituent of the sediment. Because the sediment which was analyzed came from the resin trap, much of the organic compounds originated from broken resin matrix which was released to the primary coolant flow. Solid particles or debris in the primary coolant of RSG-GAS can be derived from the fine dust from the engineering hall near the pool. Although the area is regularly cleaned, solid particles could still enter the pond because much maintenance work of the reactor is carried out in the area.

Visitors or guests who enter engineering hall indirectly contribute the dust accumulation into the reactor pool. The frequent opening and closing of the access door caused by visitors can increase the probability of fine dust entering the engineering hall. Although the door access is controlled and visitors are managed, fine dust can enter pool because of the high frequency of visitors. Visitor control by the reactor management include, among others, the use of lab coats and shoe covers. The solid particles in the primary coolant is transported through the air from the engineering hall close to the pool.

The debris source can include a shifting crane movement in the reactor hall, research sample immersion, or inadequately cleansed irradiated materials. The topaz irradiation facility contributes the addition of debris particles get into the cooling. Although washing process has been done but the fine dust may still be brought into the cooler. Based on experiments to prevent the irradiation process from adding fine dust to the coolant, topaz sample cleaning should be done by ultrasonic cleaning. The cleaning process will greatly reduce the amount of fine dust carried in the topaz to be irradiated.

The spent fuel system is connected to the primary cooling system. Thus, airborne dust from the spent fuel storage room has a potential entrance into the primary cooling system. The amount and characteristics of the dust vary depending on the extent of the control over the environment inside the reactor building and the nature of the activities around the reactor pool. Dust in the pool will initially float on the surface of the pond and, immediately after wetted by water, they will agglomerate and settle at the bottom. The speed of the process depends on the

characteristics of dust materials, especially their density. High-density particles tend to be settle more rapidly in the basin and or in the stagnant flow. Fine debris particles agglomerate to form larger particles and gradually form sediment. Air filter in the engineering hall access door help to suppress the growth of sediment at the bottom of the pool.

Efforts to reduce fine dust that enters the reactor pool or to the RSG-GAS's primary coolant has been made. To prevent dust from entering the cooling system through engineering hall near the reactor pool, surface dust removal devices called skimmers have been provided. These tool slowly move over the pool's surface and absorb the dust that floats on the water. In a skimmer, there is a filter which has to be periodically replaced; it is usually replaced during the annual maintenance.

The air ventilations also increase the amount of debris that enters the engineering hall. HEPA filters are installed in the ventilation ducts to separate the dust. This filter will be replaced when it is saturated as indicated by pressure indicators on input and output sides. The porosities of the filters used in RSG-GAS are 5 μm and 3 μm, chosen based on the size of airborne dust particles to be filtered.

The chloride ion is the species that most commonly initiate pitting. Thus, its concentration in the coolant is monitored by daily measurements and controlled. As given in the Safety Analysis Report (SAR), the maximum chloride concentration allowed in the primary coolant is 10 ppb. One method used to control the Cl^- concentration is by removing the sediment in the tank basin by pumping. This cleaning process is performed once per year during annual maintenance. The waste from the sediment is collected in the waste tank and sent to the waste processing center.

The second group of samples used in this research was taken from sediment adhering inside the heat exchanger tube. The RSG-GAS use shell-and-tube heat exchangers. The secondary coolant flows in the tube side, while the primary coolant flows in the shell side. During the annual maintenance, the heat exchanger cover is

Table 4. Radionuclides Detected by NAA from the Heat Exchanger Tube Sediment Activation results

Radionuclides	Half life	Concentration (%)
Mn-56	2.58 hours	0.0561
Na-24	15.0 hours	0.0234
As-76	26.0 hours	0.0019
Br-82	1.471 years	0.0013
Fe-59	44.6 days	67
Zn-65	243.8 days	2.1
Cr-51	27.7 days	0.0138
La-140	1.678 days	<< (very low)
Sc-46	83.83 days	<< (very low)

opened, and the tube is cleaned mechanically. The samples of the second group were analyzed using NAA and the results are shown in Table 4. There is some scaling inside the tube, and it was sampled to be analyzed. In the shell, there is no sediment because the water is maintained very well.

Table 4 shows all of the radionuclides contained by the neutron irradiation results of the tube sediment. Those elements are related to the corrosion product of carbon steel are used in almost all secondary cooling piping system of RSG-GAS. The main elements of carbon steel are Fe, S, P, Sn, Sb, As, Cr, Zn, and Mn. All of elements probably originated in cooling tower material or fine dust from the environment surrounding the plant. The secondary piping system is connected to the heat exchanger to remove the heat from the primary coolant. From the physical connection between SS304 and carbon steel, it can be seen that there is a galvanic cell between them. These two materials have different resistance to corrosion and carbon steel will corrode earlier than SS304. To surpress the corrosion, chemical additives are used in the secondary coolant. There are three kinds of additive used, namely the anticrust (antiscaling), anticorrosion, and antifungal additives.

5. CONCLUSION

The nuclides contained in the sediment in the primary coolant of RGS-GAS are Na-24, Na-25, Al-28, Mg-27, Cr-51, Mn-54, Mn-56, Co-58, Co-60, Ni-65, and Fe-59.

From the electrochemical series, (Li-Ka-Ba-Ca-Na-Mg-Al-Zn-Mn-Cr-Fe-Ni-Co-Sn-Pb-(H)-Sb-Bi-Cu-Hg-Ag-PT-Au) it is seen that Mn, Cr, Co, Ni, and Fe are more noble than Al, while Na, Ba, Al and Mg are not. The more noble elements in the sediment will form a galvanic cell if they adhere to the aluminum surface, and this must be prevented. Prevention can be done by cleaning during annual maintenance or daily filtering with skimmers. The elements in the secondary loop debris from heat exchanger tubes are mainly from corrosion products of carbon steel. The galvanic relationship carbon steel with 304 stainless steel in the heat exchanger is not harmful because it corrodes the carbon steel first. To suppress corrosion in the secondary cooling system of the RSG-GAS, anticorrosion additives are used, in addition to maintaining the pH and conductivity of the coolant.

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