RADIOLOGICAL SAFETY ASSESSMENTS FOR SIPPING TEST ON SPENT FUEL OF G.A. SIWABESSY REACTOR 30 MWT IN INDONESIA

A. WIJAYANTO, T. SUNDARI
Center for Radioactive Waste Technology - BATAN
Serpong, Indonesia
Email: adi_w@batan.go.id

Abstract

Indonesia has G.A. Siwabessy reactor (RSG-GAS) that is currently in operation. Indonesia also has Interim Storage for Spent Fuels (ISSF) that is store for Spent Fuels (SFs) of RSG-GAS 30 MWt. In the national policy on Radioactive Waste Management Strategy, SFs are categorized as High-Level Waste and are not recycled because Indonesia follows open nuclear fuel cycle. SF is a fuel element type for this Material Testing Reactor that has dimensions of 76.1 x 80.5 x 868 mm with contents 19.75 % of enriched U-235 and AlMg2 cladding 0.38 mm. After the use of the fuel element in the reactor, fission products such as noble gaseous: Kr-85m, Kr-87, Kr-88, Xe-135 and Xe-138 are generated and trapped in the matrix of the fuel element. The other fission products and Transuranic (TRU) elements may possibly leak to the environment if the isolation of the fuel cladding has a defect or crack. The fission products like Cs-137, I-133, and Sb-124 pass through the cladding by diffusion process. Currently, there are 245 SF elements remaining from the maximum storage capacity of 1448 SF elements in the ISSF. The sipping test is one of the appropriate methods to determine the integrity of SFs and to observe potential leaks of SFs cladding by detecting the existence of fission products. It has been identified that 20 SF elements releasing maximum concentration of Cs-137 = 4×10-7µCi/ml, I-133 = 5.92×10--4 µCi/ml, Sb-124 = 4.7×10--5 µCi/ml and maximum dose rate 0.22 µSv/hr were measured from the water surface test tube of the sipping test. The water pool conditions have been measured, i.e. conductivity 1.57 µS/cm, pH 5.58 - 7.14, temperature 26.76 ˚C, water level 6.31 - 6.43 m and air contamination area 0.1367 Bq/m3 and also they meet the criteria. For this reason, the results indicate that there are no leaks detected in the SFs.

1. INTRODUCTION

In RSG-GAS operation, Spent Fuel (SF) is generated after achieving the economic value. SFs contain radionuclide elements, e.g. Residual Uranium, Transuranic (TRU), fission products and activated products. SFs produce heat and radionuclide decay radiation; therefore, they are stored in temporary reactor pool for cooling for at least 100 days. SFs are then transferred into Transfer Channel-Interim Storage for Spent Fuel (TC-ISSF) which contains water as shielding function to reduce radiation exposure during SFs transfer [1].

SF is classified as High Level Waste (HLW) as mentioned in Government Regulation No. 61, 2013 Radioactive Waste Management in the national policy. However, Indonesia follows open nuclear fuel cycle implying that SF is not recycled.

Center for Radioactive Waste Technology (CRWT) as the centralized radioactive waste management has responsibility to manage the SF from G. A. Siwabessy Multi-Purpose Reactor 30 MWt. CRWT has TC-ISSF facility. The facility was built in 1993 and designed by AEA Technology, United Kingdom (UK-AEA). The main function of TC-ISSF is to receive and store the SFs and other irradiated materials. Main part of the TC-ISSF is water pool with dimension of 14 m in length, 5 m width and depth of water 6.5 m. Currently, there are 245 SF elements remaining from the maximum storage capacity of the TC-ISFSF. The ISFSF has the maximum storage capacity of 1448 [2].

One of the requirements of radiation safety and operation of a research reactor is nonexistence of radionuclides released from fission products into the environment. Sipping test is one of the non-destructive testing techniques for determining the integrity of the cladding by detection and identification the presence of fission products such as Cs-137 and others in the water [2].

Radiation safety in the management of SF is very important so that there is no release of fission product to cooling water and environmental air. Early detection of the release of fission product from SF into cooling water can be done by checking the radioactivity of cooling water. The fission product can be released from SF into cooling water due to leakage from SF cladding. Integrity tests for spent nuclear fuel cladding is one of method for checking of galvanic corrosion caused by high burn-up values of more than 50%, storage racks in the pool water more than 5 years and metal differences between spent fuel cladding and storage racks.

The purpose of the test for the integrity of SF cladding with a sipping test system was to determine whether there was a leak of radionuclides from SF cladding. This is in anticipation of the danger of radiation from the possibility of release of the fission product to cooling water and air. The sipping test is one of the non-destructive test techniques for detecting the integrity of SF cladding by detecting and identifying the presence of the fission product in the immersion water of SF. At TC-ISSF a SF sipping test system has been installed in the deep section integrated with the intermediate platform.

2. THEORY

SF is a fuel element type for Material Testing Reactor (MTR) that has dimensions of 76.1 x 80.5 x 868 mm with contents 19.75 % of enriched U-235 and AlMg2 cladding 0.38 mm. There are two types of fuel elements that have been used in RSG-GAS, namely U_3Si_2Al and U_3O_8Al with Uranium from United States (US). The cladding material for this fuel is AlMg2. Being used in the core of the reactor fuel elements produces various fission products. Fission products trapped in the matrix of fuel elements can escape out of the fuel matrix element. Noble gases such as Xe-138, Kr-87, Kr-88, Kr-85m and Xe-135 can easily escape. The other fission products and TRU elements may leak through defects or cracks to the environment since the isolation of the cladding has low integrity. Some of fission products like Cs-137 pass through the cladding by diffusion mechanism. The sipping test is appropriate method to determine the integrity of SF [2].

TC-ISSF has a pool construction containing mineral-free water whose functions are cooling, radiation protection, and radionuclide containment from SF to avoid the release of radionuclides into the environment. Pool water quality is maintained by operating a water purification system with ion exchange resins. The water cooling system of TC-ISSF is designed to remove heat, so that the pool water temperature is always < 35 °C. The Ventilation and Air Conditioning (VAC) system is operated to maintain a constant air temperature of 20 °C to 25 °C and a relative humidity of 40% to 60%, a negative pressure chamber of 100 ± 25 Pa, with air renewal 5 times per hour [3].

The fuel element used in the RSG-GAS is the Fuel Testing Material (MTR) type element with U-235 enrichment of 19.75%. There are two types of fuel elements that have been used in RSG-GAS, namely U_3Si_2Al and U_3O_8Al with Uranium from United States (US). The fuel element has the same dimension that is a rectangular cross section 76.1 x 80.5 mm with meat 600 mm and a total height of 868 mm. At the top of the fuel element there is a rod holder with a diameter of 13 mm which is used to move fuel elements from one place to another inside the reactor pool and fuel storage pool. Fuel cladding is made of AlMg2 with a thickness of 0.38 mm. The fuel element produces a number of fission radionuclides after irradiation. The fission nuclei formed besides being able to remain trapped in the fuel element matrix can also be released from the fuel element matrix. Among the most easily released fission nuclides is the noble gas group [4].

3. SCOPE

The sipping test is one of the appropriate methods to determine the integrity of SFs and to observe potential leaks in SFs cladding by detecting the existence of fission products. The SF sipping test was carried out through an analysis of radionuclides contained in the sample namely sipping water samples in various test times, TC-ISSF pool water samples, and demineralized water samples used in sipping tests. The results of this sipping nuclear fuel test are used to determine the integrity of SF cladding so that it determines the handling to be carried out on SF tested.

4. METHODS OF SIPPING TEST

SF is transferred from its rack and placed into the basket of sipping test tube that is located under water surface. Sipping Test Method System in Interim Storage for Spent Fuel is shown in Fig. 1.

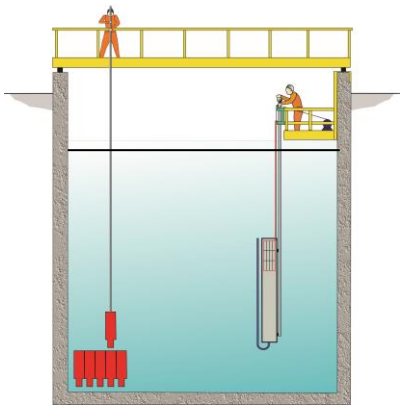

FIG. 1. Sipping Test Method System in Interim Storage for Spent Fuel.

4.1. Background Sampling

Background sampling consists of dose rate monitoring, air contamination monitoring and water pool sampling.

4.1.1. Dose Rate Monitoring

The dose rate background monitoring around the intermediate level closed to the sipping tube for measuring effective dose received by workers.

4.1.2. Air Contamination Monitoring

Air contamination monitoring is conducted in around of pool for ensuring air contamination level during sipping test.

4.1.3. Water Pool Sampling

Water pool sampling consists of background general gamma ray sample (Water Pool) 500 ml and background natural gamma ray sample (Water Sipping Tube) 500 ml.

4.2. Sipping Test

The sipping test procedure starts from transferring SF from spent fuel to Gamma Spectroscopy Identifying and Analyzing

4.2.4. Transferring SF from Rack to Test Basket

SF is transferred from its rack and placed into the basket of test tube that is located 2 m under water surface as shown in Fig. 2

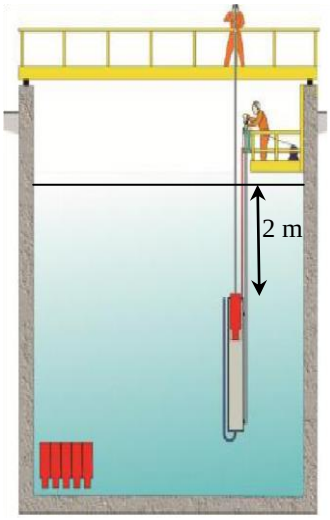

FIG. 2. Sipping Test Tube that Located 2 m under Water Surface

4.2.5. Raising Sipping Test Tube

The sipping tube is raised by rolling up the wire rope sling with an electric motor until the top of the test tube appears slightly above the water surface.

4.2.6. Filling Sipping Test Tube with Demineralized Water

Demineralized water is pumped into the test tube through water inlet port at the bottom of the tube. It is estimated that 5 times test tube volume of demineralized water is needed to ensure that water inside the tube has been fully replaced by the demineralized water. Capacity of the test tube is 0.053 m^3, so five times of it is 0.265 m^3. It takes about 15.9 minutes to pump demineralized water using a pump with capacity of 1 m^3/hr.

4.2.7. Initial Water Sampling

Water sample is taken from the test tube for radioactivity background analysis.

4.2.8. Stirring Water inside Sipping Test Tube

The test tube with spent fuel is left inside for 4 hours. Air is blown into the test tube to stir the water to be agitated as shown in Fig. 3.

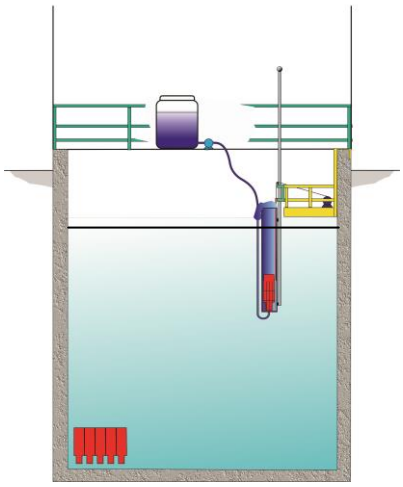

FIG. 3. Air is Blown into the Sipping Test Tube to Stir the Water

4.2.9. Water Sampling

A water sample is taken from the test tube for radioactivity analysis.

4.2.10. Gamma Spectroscopy Identifying and Analyzing

Radioactivity analysis is conducted to determine the activity concentration of Cs-137. Graph of Cs-137 activity concentration versus time is created using the analysis data obtained. Based on the graph, it can be predicted whether the spent fuel has leaked or not. The activity of noble gases is identified and measured using gamma spectrometry device.

5. RESULTS

It has been identified that 20 SF elements bundles stored in TC-ISSF with a sipping test system but this paper, the results of the SF integrity test only three (3) SF bundles stored in TC-ISSF with a sipping test system are presented. SF bundles with numbers RI-68, RI-190 and RI-187 were chosen because they have different ages, namely 21, 18 and 16 years from loading date in the reactor.

6. ANALYSIS AND DISCUSSION

At present, there are 245 SF elements remaining from the maximum storage capacity of 1448 SF elements in the TC-ISSF. The sipping test is one of the appropriate methods to determine the integrity of SFs and to observe potential leaks of SFs cladding by detecting the existence of fission products. The results of the measured parameters in TC-ISSF are shown in the Table 1.

TABLE 1. RESULTS OF THE MEASURED PARAMETERS IN TC-ISSF

Interim Storage for Spent Fuel	Parameter	
	Safety Limit	Measurement
Capacity Maximum	1458 Fuels	245 Fuels
Height for Surface Water	3.9 -7.5 m	6.31 - 6.43 m
Temperature	<35˚C	26.76˚C
pH	5.5-7.5	5.58 - 7.14
Conductivity	<15 µS/cm	1.57 µS/cm
Air Contamination	$<5.3 \times 10^2$ Bq/m^3	0.1367 Bq/m^3
Dose rate	30 µSv/hr	0.22 µSv/hr

The sipping test was carried out for 8 days following the Standard Operating Procedures (SOP). The sipping test with consideration for 8 days was sufficient to detect if there was a SF leak. The test water sampling was carried out on days 1, 2, 3, 4, and 8 to produce some test water data with variations in the testing time (resting time) carried out according to work days/work schedules. The sipping test tube is lowered using a crane with the basketball position above. SF that will be tested for sipping is removed from the shelf using the SF handling tool on the sliding bridge. The fuel is lifted up and taken to the sipping area using a sliding bridge. SF loading and unloading in the sipping test tube were carried out in pool water with pool water depth from the pool water surface to a minimum SF peak of 1.5 m to minimize the radiation dose received by radiation workers who performed sipping tests, especially in the intermediate platform space. The 300 liter demineralized water supply which exceeds the flushing standard 5 times the volume of the sipping test tube (275 liters) aims to optimize the SF rinsing process in the sipping test tube. The supply of compressed air using a compressor is done to homogenize the test water in a sipping test tube so that the water samples taken can represent sipping test water. The SF sipping test activity at TC-ISSF is conducted in the deep section area with sipping test kits installed at the intermediate platform. In the TC-ISSF facility pool water monitoring system, radionuclide levels are analyzed in pool water every 2 weeks. The results of radionuclide analysis in pool water are shown in Table 2.

TABLE 2. RESULTS OF RADIOACTIVE ANALYSIS IN WATER POOLS

Sample code	Radionuclide	Activity (μCi/ml)	Half Life	Product
02091501	Sb-124	7.26×10^{-5}	60 days	Fission Product
23021602	Cs-137	2×10^{-7}	30 years	Fission Product
16061603	I-133	5.52×10^{-5}	20 years	Fission Product

Table 2 shows the presence of radionuclide contamination in pool water caused by the release of split radionuclides, namely: Cs-137, Sb-124, and J-133. In canal and pool water there are no detectable radionuclides such as I-131, Kr-85, and Xe-133, these radionuclides are the main fission products in the gas phase, so they are easily released into the ambient air. Whereas radionuclide contamination produced from corrosion products activated by elements such as Fe-59, Co-60, Mn-54 were also not detected.

TABLE 3. RESULTS OF SPENT FUELS SIPPING TEST

Sample	Spent Fuel ID					
	RI-68		RI-187		RI-190	
	Radionuclide	Concentration (μCi/ml)	Radionuclide	Concentration (μCi/ml)	Radionuclide	Concentration (μCi/ml)
Day -1	none	-	I-133	5.23×10^{-4}	Sb-124	4.26×10^{-5}
Day -2	I-133 Sb-124	2.78×10^{-5} 4.66×10^{-5}	I-133 Sb-124	5.47×10^{-4} 4.06×10^{-5}	I-133 Sb-124	5.44×10^{-4} 3.96×10^{-5}
Day -3	Sb-124	3.9×10^{-5}	I-133 Sb-124	5.92×10^{-4} 4.08×10^{-5}	none	-
Day -4	I-133 Sb-124	6.07×10^{-5} 4.6×10^{-5}	I-133	3.34×10^{-5}	I-133 Sb-124	5.29×10^{-4} 3.58×10^{-5}
Day -8	I-133	4.74×10^{-4}	Sb-124	4.7×10^{-5}	I-133 Sb-124	5.83×10^{-4} 4.76×10^{-5}
Demineralized Water	none	-	none	-	none	-
Pool Water	none	-	I-133 Sb-124	5.57×10^{-4} 3.54×10^{-5}	none	-

Table 2 shows that in pool water sampled at the time of sipping test, I-133 and Sb-124 radionuclides were detected in 1 of 3 samples. For SF ID RI-68, I-133 and Sb-124 radionuclides were detected on days 2 to 8. For SF ID RI-190, the I-133 and Sb-124 radionuclides were detected on day 1, and day 2, undetectable on day 3, then detected again on day 4 and 7. For SF ID RI-187, I-133 and Sb-124 radionuclides were detected from day 1 to day 8. Of the three SF tested, only I-133 and Sb-124 radionuclides were detected oftenly in pool water. Radionuclides I-133 and Sb-124 are short-lived split radionuclides, each of which has a half-life of 20 hours and 60 days. The frequent detection of these two radionuclides in pool water indicates that these two radionuclides are contaminant radionuclides carried on SF after being removed from the reactor. The absence of radionuclides other than I-133 and Sb-124 from the third sipping water SF showed that there were no leaks in the tested SF with IDs RI-68, RI-190, and RI-187 [6].

7. CONCLUSION

The sipping test is one of the appropriate methods to determine the integrity of SFs and to observe potential leaks of SFs cladding by detecting the existence of fission products. Three (3) SF elements releasing fission products of Cs-137 with maximum concentration 4×10^{-7} μCi/ml, I-133 with maximum concentration

5.92×10^{-4} µCi/ml, Sb-124 with maximum concentration 4.7×10^{-5} µCi/ml and maximum dose rate 0.22 µSv/hr were measured from the water surface test tube of sipping test. The water pool conditions have been measured, i.e. conductivity 1.57 µS/cm, pH 5.58 - 7.14, temperature 26.76 °C, water level 6.31 - 6.43 m and air contamination area 0.1367 Bq/m^3 and also they meet the criteria. For this reason, the results indicate that there are no leaks detected in the spent fuels. The dose estimation for the radiation workers under normal operating conditions are insignificant when compared to the permitted dose limit or even the radiation dose of the natural background.

From the results of analysis of sipping test water from SF with IDs RI-68, RI-190, and RI-187; only radionuclides I-133 and Sb-124 were detected from all of them which are the radionuclides which are often detected in pool water. There were no other split radionuclides or radionuclides contained in in the three SFs. From this, it can be concluded that the fuel cladding of the three SFs does not leak or can be said to have good integrity.

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