FACILITY PERFOMANCE AND AGING REVIEW OF THE INTERIM STORAGE FOR SPENT NUCLEAR FUEL IN INDONESIA

TITIK SUNDARI*
Center for Radioactive Waste Technology, National Nuclear Energy Agency of Indonesia (BATAN)
BATAN, Indonesia.
*Email: titiks@batan.go.id

BUDIYONO
Center for Radioactive Waste Technology, National Nuclear Energy Agency of Indonesia (BATAN)
BATAN, Indonesia.

PARJONO
Center for Radioactive Waste Technology, National Nuclear Energy Agency of Indonesia (BATAN)
BATAN, Indonesia.

DYAH SULISTYANI RAHAYU
Center for Radioactive Waste Technology, National Nuclear Energy Agency of Indonesia (BATAN)
BATAN, Indonesia.

Abstract

The main function of the Interim Storage for Spent Nuclear Fuel (ISSF) in Serpong site is to store-underwater the Spent Nuclear Fuel (SNF) arising from the operation of the GA Siwabessy Multipurpose Reactor (GAS-MPR). Structure, system, and components (SSCs) of ISSF was built in 1997 and was designed by AEA Engineering, United Kingdom (UK - AEA). ISSF began to obtain operating licenses in 2008 which is valid for 10 years until 2018. In order to extend the operating licence for next decade, the operatory body have to ensure that the ISSF will be safely operated by determining the result of the facility performance and aging review. Review of the facility performance require some analysis of SSCs from nuclear installations to assess and concludes whether the SSCs would be working properly to support the function of ISSF or not. While the aging review should present determination of the latest performances and conditions of the SSCs, including evaluations of each age related to the failure or indication of significant material degradation and justification of performance, future aging process, and remaining operating life of components. The scope of this research includes review of facility performance and aging of the ISSF's SSCs. The review was conducted major in SSCs which important to safety such as liner inspection by ultrasonic detector, sipping test of the SNF to detect leakage of the cladding, corrosion study of cladding and liner material, support system perfomance, etc. The results show that the thickness of the liner is still 3 mm, no leakage detected of the cladding which have tested, corrosion rate is 0.002 mpy which is predicted to hold for more than 40 years operation, the water parameters are well maintained, and all the support systems are working properly as designed. From the results of the facility performance and aging review, it can be concluded that ISSF still can be used to store the spent nuclear fuel safely.

1. INTRODUCTION

Indonesian Transfer Channel – Interim Storage for Spent Nuclear Fuel (TC-ISSF) was built in 1993. The installation was designed by AEA Engineering, United Kingdom (UK - AEA). The main function of the ISSF is to receive and store-underwater, Spent Nuclear Fuel (SNF) arising from the operation of the GA Siwabessy Multipurpose Reactor (GAS-MPR). The capacity of the ISSF is to be sufficient to store the fuel arising over 25 years of reactor operation, specified as 1448 elements (1400 + 1 core unload). Spent nuclear fuel from GAS-MPR will be stored initially in the storage racks in the reactor pool and will only be transfered to the ISSF after a minimum of 100 days decay. The ISSF will also be used for storing experimental fuel or irradiated materials from the adjacent laboratories, and 125 standard cans for irradiated scrap. Movement of all radioactive material to the ISSF is carry out underwater by means of Transfer Channel (TC). This TC connects the ISSF to the Reactor Installation (GAS-MPR), Radioisotop Production Installation (RPI), and Radiometallurgy Installation (RMI) buildings. Dimensions of the ISSF facility is length x width x depth: 14 m x 5 m x (-6.5 m) [1][2].

The boundary conditions for the normal operation of TC-ISSF are shown in Table 1.

TABLE 1. TABLE LIMITS OF OPERATING CONDITIONS FOR TC-ISSF[1]

No	Parameters	Limitations
1.	Exposure of gamma throughout installation	< 10 µSv/hours
2.	Air contamination in the working area	<70 Bq/m^3
3.	Release of I-131 into the air	<2,57 x 10^{6}Bq/hours (70 Bq/m^3)
4.	Water temperature of ponds and canals	< 35°C
5.	pH pond water and canals	5,5 – 7,5
6.	Conductivity of pond water and canals	< 8 µS/cm
7.	Water pond height from top of the spent fuel	> 2,5 m
8.	Negative air pressure	100 Pa $\pm$ 25 Pa
9.	Air Temperature	$\leq$ 25°C

Structure, system, and components (SSCs) of TC-ISSF was built since 1997 with AEA Engineering design. TC-ISSF began to obtain operating licenses in 2008 [3]. Operating activities history from 2008 to 2018 are as follows:

(a) Re-export or repatriation of spent fuel (SNF). The related activities of repatriation that was done in

Indonesian ISSF are:

(i) Transfer of 42 spent fuel bundles from GAS-MPR to TC-ISSF pond during 18th May – 27th May 2009;
(ii) Transfer of spent fuel as much as 42 bundles from pond to TN-MTR transfer cask during 29th June 2009 – 3rd July 2009.

(b) SNF storage activities
At the present, 287 spent fuel is stored in ponds, consist of 2 bundles of RMI's experimental spent fuel and 285 bundles of GAS-MPR's spent fuel.

(c) Transfer of irradiated target material
The transfer of irradiated material from GAS-MPR to RPI (INUKI) passes through the transfer channel (TC) 2-3 times in a month and has been done since 2009 till now [2] [4].

The scope of this research includes review of facility performance and aging of the ISSF's SSCs. The review was conducted major in SSCs which important to safety such as liner inspection by ultrasonic detector, sipping test of the SNF to detect integrity of the cladding, corrosion study of cladding and liner material, support systems perfomances, etc. This study is important due to safety factor of the SFSP. The results will be used to assess and conclude whether the SSCs would be working properly to support the function of ISSF or not.

2. METHODOLOGY

Review of facility performance and aging was done by testing the current condition of the facility were compared to the basic of design. SSCs which are important for safety was tested and analyzed whether they can still working well to perform their functions.

3. RESULTS AND DISCUSSION

3.1. Facility perfomance

Some designing activities in TC-ISSF shall be carried out with established procedures. Design modifications of SSCs in TC-ISSF must be carried out by qualified personnel. The design modifications undertaken shall refer to the quality and safety standards. In that event, design modifications related to safety aspects must be assessed by the TC-ISSF Safety Committee before obtaining approval from National Nuclear Regulatory Agency of Indonesia (BAPETEN).

TC-ISSF facility was designed as a wet type of interim storage for Spent Nuclear Fuel (SNF) and irradiated material. For the achievement of nuclear safety objectives, TC-ISSF facility was designed to have SSCs that support safety systems, which have function as:

— Confinement of stored nuclear material;
— Radiation barrier (shielding);
— Heat removal of snf;
— Means to keep the snf in subcritical condition;
— Confinement of radionuclide release into the environment.

SSCs that are important for safety and their reviews shown as below:

(a) Concrete and stainless-steel liner

Reinforced concrete has 0.295 m thick with a density of 3.0 - 3.5 g/cm^3. The inside was given a stainless-steel (SS) liner with a thickness of 3 mm. The outer part of the concrete is covered with mild steel as a secondary containment. Mild steel is surrounded by concrete and structurally below ground level. Stainless-steel 304 has 3 mm thickness. The concrete has K300 level with cube strength characteristic of 30 N/mm^2.

Review:

(i) SS liner thickness testing was performed by ultrasonic method. Measurements of the liner thickness was conducted at 20 points of areas. The results show that SS liner thickness is still 3 mm (same as the basic design).
(ii) The concrete cracks testing has been done in 2017 at pond, canal, and building of the TC-ISSF. Cracks do not occur in the concrete structure of the pond but occur only at some point of the building concrete structure that easily repairable.

(b) Building structure

This building structure is a class II. The roof thickness of the building is 0.6 m. The wall thickness of the building above the ground surface is 0.4 m, while the underground 0.6 m. Walls made of reinforced concrete with heat insulation and waterproof. The Concrete has density of 3 - 3.5 g / cm^2.

Review:

(i) Buildings was designed to operate for 40 years;
(ii) The structure of the building has not changed from its original design;
(iii) During the period of 2008 – 2018, TC-ISSF experienced an earthquake. The phenomenon that occurs does not cause damage to the structure of the building and TC-ISSF equipment that was indicated by the post-earthquake inspection report. As known that the function of the TC-ISSF building is as a radiation containment, so if there is contamination, the air does not leave the building without going through the filtration process. Data on building wall cracks from the test results indicate that the cracks are slight and easily repaired so that it can be ensured that the function of the building as a containment is still guaranteed.
(iv) The results of the visual tests found no significant cracks or deformations.

(c) Ventilation system

It consists of chillers, cooling coils, pressure gauges, pipes, valves, ductings, dampers, motor fans, cables, relays, contactors, power supply, timer, termination, HEPA/ Charcoal filters, and manometers.

Review:

(i) Performance assessment conducted during the period of 2008-2017 shows good results. Temperature, humidity and negative pressure of HEPA filter meet the requirement. They can be maintained in air temperature 25°C, humidity 40% to 75% and nominal negative pressure below 100 ± 25 Pa.

(ii) Ventilation system components are provided redundant and spare parts are easily available. System maintenance has been implemented in accordance with TC-ISSF maintenance program.

(iii) Revitalization of the TC-ISSF ventilation system with Human-Machine Interfaces (HMI) was done to provide an easily monitored system parameters.

(d) Water Purification System

It consists of caesium resin tank, mixed resin tank, pipes, valves, flow meters, conductivity meters, pumps, cables, relays, contactors, power supply, timer and termination.

Review:

(i) Performance assessment conducted during the period of 2008-2017 shows a good performance seen from the important parameters of water conductivity after the purification system of modes 1, 2, 4 and 5 are 1.9; 1,2; 2.1; and 1.5µS/cm. Spare parts of purification system components are easily to be replaced and obtained on the market;

(ii) System maintenance has been performed in accordance with TC-ISSF maintenance program;

(iii) TC-ISSF water purification system has been visualized with Human-Machine Interfaces so that system parameters are easily monitored and controlled.

(e) Cooling system

It consists of Self-contained Chiller, Primary Heat Exchanger, Secondary Heat Exchanger, Pipes, Valves, Flow Meters, Pressure gauges, Thermometers, pumps, Cables, Relays, Contactors, Power supply, Timer and Termination. The vessel and heat exchanger materials are SS 304. The operating fluid in primary heat exchanger is demineralized water that has conductivity <15 µS/cm.

Review:

(i) The assessment of cooling system performance performed during the period of 2008-2017 was still considered as good from the important system parameters i.e the primary Heat Exchanger (HE) output temperature <30°C, and the decrease of pool water temperature (ΔT) between in and out around 4.8 - 5.9°C.

(ii) Spare parts of cooling system components are easily to be replaced and obtained on the market;

(iii) System maintenance has been performed in accordance with TC-ISSF care program;

(iv) TC-ISSF cooling system has been visualized with Human-Machine Interface so that system parameters are easily monitored and controlled.

(f) Demineralized System

It consists of carbon filter, cation filter, anion filter, mixed-bed filter, pump, compressor, water reservoir, pipes, and valves.

Review:

(i) Assessment of system performance was done during 2014-2017. The results show that the demineralized system performance is still good and capable of producing demineralized water with excellent quality (average conductivity was 0.18 µS/cm).

(ii) Spare parts of demineralization systems are easily to be replaced and obtained on the market;
(iii) System maintenance has been performed in accordance with TC-ISSF maintenance program.

(g) Spent Fuel Racks

The spent fuel racks were made from stainless-steel material. The size of SNF storage rack is 0.94 m x 0.94 m with a distance between SNF is 140 mm. Configuration yields caused the value of <0.95 K_{eff}. The storage rack was designed so that no criticality occurs. In the bottom of the storage racks were given a retainer so that there is no significant shift if an earthquake happens. This arrangement provides assurance that the cooling water flow will be able to remove the resulting decay heat.

Review:
(i) No dimension changes of the racks;
(ii) SNF rack replacement analysis has been performed from SS to aluminium to reduce the effect of galvanized corrosion. Calculation of SNF rack with aluminium material criteria using Monte Carlo N-Particle version 6 (MCNP6) program obtained K_{eff} value of 0.7709.

In order to improve the performance of the SSCs, some modification that have been made to facilitate the operation and maintenance of the TC-ISSF Facility are mentioned below:

(a) Visualization of TC – ISSF Support System with Human-Machine Interface (HMI)

Background:
Require modification of technology automation to facilitate in controlling Purification System, Demineralization System, VAC, Cooling System, and Room Monitoring without eliminating manual control system.

Result and review:
The Human – Machine Interface can be realized to monitor and control the system parameters.

(b) Revitalizing TC - ISSF Demineralization System

Background:
The demineralization system was not functioning and was supplied from the GAS – MPR. So, revitalizing the demineralization system is needed to ensure the supply of demineralized water to the transfer channel and ISSF pool is easily done.

Result and review:
Demineralization water supply system to TC-ISSF pool was guaranteed. Production of the demineralized water has a nominal flow 1 m3/hour. The reservoir tank for the demineralized water has a capacity of 16 m^3.

(c) Establishment of pipeline system to the Integrated Liquid Effluent Monitoring

Background:
Ensure liquid effluent from TC – ISSF was channelled through integrated liquid effluent channels before being released into the environment.

Result and review:
A pipeline system of effluent that are equipped with a support system (container tank, pump, piping, valve, level indicator, flow meter) was built to send the effluent to the Integrated Liquid Effluent Monitoring.

(d) Neutralization system for liquid waste from regeneration of demineralization system

Background:

(i) The neutralization system tank was still operated manually;
(ii) The tank was unable to accommodate the regenerated liquid;
Neutralization required concentrated liquid penetrating and potentially dangerous chemical exposure.

Result and review:
Neutralization can be done easily (using a pump), sufficient tank capacity, and the potential danger of chemical exposure can be minimized.

(e) Skimmer on Transfer Channel

Background:
Cleaning of transfer channel surface water was done manually using a sieve.

Result and review:
Cleaning of surface water in transfer channel can be done automatically.

3.2. Aging review

TC-ISSF critical SSCs screening was carried out in three stages. The first phase of screening was done by an event tree analysis method to evaluate and determine the system which if it fails can cause (directly or indirectly) a reduction or loss of safety functions. In screening, the second stage, a list of consequences for operating safety resulting from the first stage of screening, then analyzed to determine the SSCs which are important to safety. The second stage of the screening results was evaluated based on the provisions of BAPETEN Chairman Regulation No. 7 of 2012 article 15 that those which included critical SSCs are not redundant, not easily replaced and not easily repaired. The third stage of screening produced a critical SSCs TC-ISSF. The results of the SSCs groupings that are important to safety are shown in Table 2.

TABLE 2. SSCs GROUPING

Class	Structure, System and Component Group
SSC I (critical); important for safety, not redundant, not easily repaired or not easily replaced stainless steel liners and include pool and canal concrete structures.	Stainless-steel liner at concrete structure
SSC II; important for safety, but redundant or easy to do SSCs inspection or replaced	1. Building 2. Ventilation 3. Cooling system 4. Purification 5. Main electrical power supply 6. Demineralized water 7. Spent fuel rack 8. Rack for defect SF 9. Rack for irradiated scrap
SSC III; not SSCs that is important for safety but it is not easy to do SSCs inspection or repair	1. Crane 2. Mast Transfer Unit (MTU) 3. Movement bridge 4. Sluice gate
SSC IV; other components	1. System control 2. Alarm 3. Compressed air 4. Sanitation 5. Communication 6. Fire protection 7. Radiation protection

The potential cause of aging, mechanism of aging and effects of aging on the stainless-steel liners of spent nuclear fuel storage pools which were classified as critical SSCs are shown in Table 3.

TABLE 3. POTENTIAL, MECHANISMS AND AGING EFFECTS ON CRITICAL SSCs

SSCs	Material	Potential Causes of Aging	Aging Mechanism	Effects of Aging
Pool liners & canals	SS 304	Water chemistry	corrosion	— cracks — leaking

To eliminate the potential causes of critical SSCs aging (inappropriate water chemistry), the SSCs of the purification system, the water supply system, the main power supply system and the skimmer must function properly.

Aging surveillance activities were carried out continuously during the life of the installation operation. The aging surveillance activities consider the results of SSCs screening, technical specifications, aging identification results, in-service inspection requirements, parameter monitoring requirements, performance test requirements, and operating experience. Critical SSCs surveillance is shown in Table 4.

TABLE 4. CRITICAL SSCs SURVEILLANCE

SSCs	Check Item	Period
Pool liners & canals	Chemical examination of storage pond water (pH and conductivity)	1 time / week
	Coupon corrosion checks made from SS 304 liners	1 time / 2 years
	Visual inspection to see leaks	1 time / 3 months

3.3. Data and information on the results of aging surveilance

Information results of the implementation of aging surveillance were the chemical quality of storage pool water which has been maintained at a pH value of 5.5 to 7.5 and conductivity less than 15µS/cm. Inspection results of the corrosion rate for coupons of SS 304 material in the TC-ISSF pond water environment was 0.002 milli inch per year (mpy).

During the TC-ISSF operation, routine monitoring of aging pool liners was carried out. The component that most likely affects the aging of the steinless-steel liner in the SNF storage pool is the condition of the pool water quality. Therefore, monitoring pH value and water conductivity of SNF storage ponds has been carried out routinely and continuously. Regular monitoring has been carried out at least once a week using calibrated equipment. The results of monitoring during operations are as follows:

TABLE 5. WATER MONITORING RESULTS

Object monitored	Measured value	Limit of normal conditions
pH	5,3 – 7,1	5,5 – 7,5
Conductivity	1,36 - 1,54	< 15 µS/cm

Coupon checks for SS 304 have been carried out which have been dipped in collagen for SNF storage. Data from the measurement of the corrosion rate of SS 304 material was 0.002 milli inch per year. The corrosion rate test was also conducted using potentiostat/galvanostat method. The test results show that SS 304 corrosion rate was 0.002 mpy on TC-ISSF water pool medium and can withstand corrosion attack for more than 40 years. With these results, the SNF storage pool liner that uses material with SS304 still has a thickness of 2.999 mm. To ensure the condition of the liner in accordance with the results of the method of measuring the coupon corrosion rate above, a method of directly measuring the thickness of the liner was also carried out with an ultrasonic device. The measurement results show that the pool liner and canal are still 3 mm thick. So, the two methods produce almost the same measurement value.

The aging of the SNF cladding was also detected through the cladding integrity test using the SNF sipping test system. Sipping test is one non-destructive testing technique for detecting the integrity of the bulk materials of the nuclear fuel by detecting and identifying the presence of fission radionuclides in the immersion water of SNF. The SNF sipping test program has been carried out for about 30 from 287 SNF. All the results show that no leak was found on the SNF which had been carried out by the sipping test

4. CONCLUSIONS

Facility performance and aging review of TC-ISSF facility were done by review of SSCs and supporting facilities of TC-ISSF. Several modifications were also made to facilitate the operation and monitoring of support system. The review was conducted in SSCs which important to safety, there are liner inspection by ultrasonic detector, sipping test of the SNF to detect leakage of cladding, corrosion study of cladding and liner material, support system perfomance, etc. The results show that the thickness of the liner is still 3 mm, no leakage detected of the cladding which was tested, corrosion rate is 0.002 mpy which was predicted to hold for more than 40 years operation, the water parameters are well maintained, and all the support system are working

properly as designed. From the review results, TC-ISSF can still be operated properly for at least the next 20 years.

ACKNOWLEDGEMENTS

The authors would like to thank the Center for Radioactive Waste Technology for funding this research.

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