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Concrete cask storage has been implemented in the world. At a later stage of storage period, the containment of the canister may deteriorate due to stress corrosion cracking phenomena in a salty air environment. High resistant stainless steels against SCC have been tested as compared with normal stainless steel. Taking account of the limited time-length of environment with certain level of humidity and temperature range, the high resistant stainless steels will survive from SCC damage. In addition, the adhesion of salt from salty environment on the canister surface will be further limited with respect to the canister temperature and angle of the canister surface against the salty air flow in the concrete cask. Optional countermeasure against SCC with respect to salty air environment has been studied. Devices consisting of various water trays to trap salty particles from the salty air were designed to be attached at the air inlet for natural cooling of the cask storage building. Efficiency for trapping salty particles was evaluated. Inspection of canister surface was carried out using an optical camera inserted from the air outlet through the annulus of a concrete cask that has stored real spent fuel for more than 15 years. The camera image revealed no gross degradation on the surface of the canister. Seismic response of a full-scale concrete cask with simulated spent fuel assemblies has been demonstrated. The cask did not tip over, but laterally moved by the earthquake motion. Stress generated on the surface of the spent fuel assemblies during the earthquake motion were within the elastic region.

Keywords: *Spent Nuclear Fuel, Interim Storage, Concrete Cask, Canister, Thermal Test, Drop test, Seismic Test, Stress Corrosion Cracking*

1. Introduction

The Japanese government decided to respect the "Framework for Nuclear Energy Policy" [1], issued by the Atomic Energy Commission on October, 2005, as a basic principle for the nuclear energy policy and to promote research, development and utilization of nuclear science and engineering in Japan. According to this framework, spent fuel will be reprocessed, within the available reprocessing capacity, for the time being, and the surplus amount exceeding the capacity will be stored intermediately. The construction of spent fuel interim storage facilities at NPP site or outside of NPP site is expected to be early realized. On safety technical requirements for spent fuel interim storage facility using dry cask, NISA/METI (Nuclear and Industrial Safety Agency, Ministry of Economy, Trade and Industry) issued the technical requirements on interim spent fuel storage facility (ISF) using dry metal cask and concrete cask on April 2006 [2]. In parallel with those regulatory and promoting activities on ISF, CRIEPI has been performed supportive research programs for the regulation and early realization of ISF. Key issues of these studies include safety requirements in operation and maintenance during spent fuel storage and unloading/loading for transportation, long-term integrity of metal canister and concrete materials, etc. The schedule for these programs is shown in Table 1. The concrete cask performance tests with the full-scale cask including heat removal tests and drop test have been successfully finished during the phase1 program [3,4,5] to reflect in the technical requirements issued by NISA/METI. Moreover, the phase2 program for the verification testing of cask integrity under long-term dry storage conditions including the SCC evaluation test and the seismic test has been started. This paper summarizes the main results of the phase2 program obtained up to now.

Table 1 Schedule of demonstration programs* for concrete cask

Program Item	2000	2001	2002	2003	2004	2005	2006	2007	2008
Concrete Cask Performance Test	Phase 1				***Phase 2***				
a. Basic Design	▨								
b. Fabrication of full-scale concrete cask		▨	▨						
c .Demonstration tests - Heat removal			▨	▨ *Full-Scale*					
- MPC Drop				▨	*Full-Scale*				
- Seismic	▨ *1/3scale*	▨			▨	▨ ***Full-scale***	▨		
SCC Evaluation Test					▨	▨ ***Laboratory and Filed Test***	▨	▨	▨

* These research programs have been carried out under the contract from NISA/METI.

2. SCC evaluation test

ISF in Japan is likely installed at coastal sites. As temperature decreases during storage period, salt condensation increases on the metal canister surface. Key issue for realization of the metal canister storage technology should be "Long-term integrity of canisters", considering deterioration of containment function of the metal canister in a salt water environment. Austenitic stainless steels are susceptible to stress corrosion cracking (SCC) in salty environments under a tensile stress. The type of SCC induced by sea salt particles, chlorides, for example, is called as external SCC (ESCC) or atmospheric SCC since the cracking starts from out side of the equipment in air as shown in Fig.1. The storage canister has several welding lines in the wall and lid which probably have high residual tensile stresses. Contamination by sea salt particles also is well expected during the long service life of canisters as mentioned previously. Thus, to prevent penetration through the wall thickness, susceptibility to ESCC should be evaluated carefully for candidate canister materials [6]. Therefore, since 2004, CRIEPI has started SCC evaluation tests to clarify basic deterioration mechanism as follows.

1) Corrosion Test
2) Chloride Deposition Velocity Test
3) Crack Growth Test
4) Salt Particle Collection Test
5) MPC Surface Inspection Test

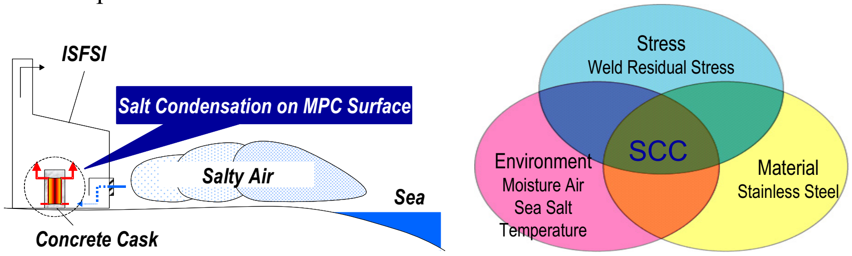


Fig.1 Deterioration of Metal Canister in a Salt Water Environment

2.1 Corrosion test

To evaluate ESCC susceptibility, two candidate materials (S31260, S31254) and one reference material (S30403) were chosen. Tensile specimens with a gage section of 1.5mm (S31260) and 2mm (S30403, S31254) thick, 5mm wide, and 30mm long were machined from the matrix and attached to a loading apparatus that uses a spring to apply a constant stress as shown in Fig.2. Applied stress ranged from $1.1\sigma_y$ to $1.5\sigma_y$ of the SS (where σ_y: 0.2% proof stress). The range of the resultant surface chlorine concentration was between 0.1 and $10g/m^2$ as Cl on the gage section. The loading apparatus with a specimen each was placed in constant temperature and humidity chambers kept at temperatures of 323K with RH=35%, 333K with RH=25%, 343K and 353K with RH=15%, which conditions were set considering the canister surface condition in the actual storage. Fig.3 shows the threshold chloride density for emerging rust with comparison between S31260 and S30403. Since the threshold value of the candidate material for canister is greater than that of the reference material, both the candidate materials has a superior ESCC resistance.

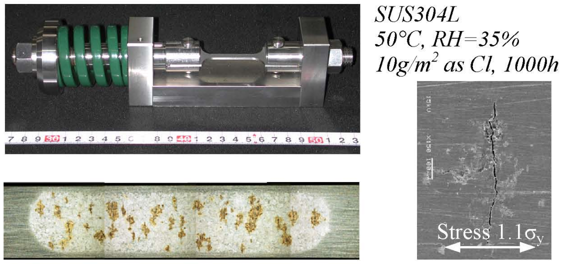
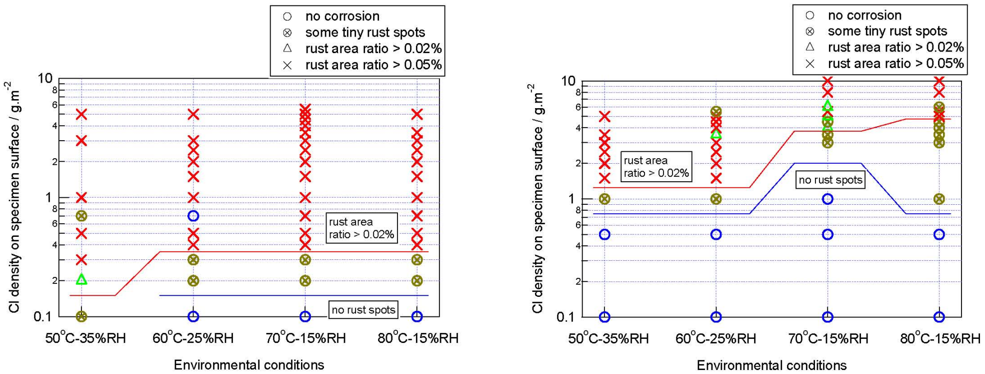


Fig.2. Corrosion Test with S30403



(S30403) (S31260)

Fig.3. Threshold Chloride Density for Emerging Rust

2.2 Chloride deposition velocity test

To evaluate the occurrence of ESCC or emerging rust, it is important to verify the estimation of the chloride accumulation transported by salty cooling air on the metal canister surface. The cooling air goes up along the canister surface in the concrete cask. The salt particles in the air may collide with the surface by the diffusion and turbulence effect. To measure the deposition velocity, two kinds of test were performed. One is a laboratory test, another is a field test. In the laboratory test, a wind tunnel in a vertical position was used. The cross section of the wind tunnel is 40x40cm and the height is about 6m. In the wind tunnel, the salt particles were sprayed. The density of the salt particle in the wind tunnel is 10^3~10^4 times as much as that near the sea. Test specimens of 75x75mm were attached on the surface of the wind tunnel, and taken off after the test and the amount of salt deposited on the surface was measured.

The test parameters were air velocity and temperature of the specimen. The chloride deposition velocity was obtained as a function of time as shown in Fig.4. The chloride deposition density is higher when the air velocity is high and the temperature of the specimen is low. In the field test, five wind tunnels in a test house were set near the sea. The cross section of the wind tunnel is 20x20cm and the height is about 3m. The air including natural sea salt particles flows in the tunnel. The test is going on now.

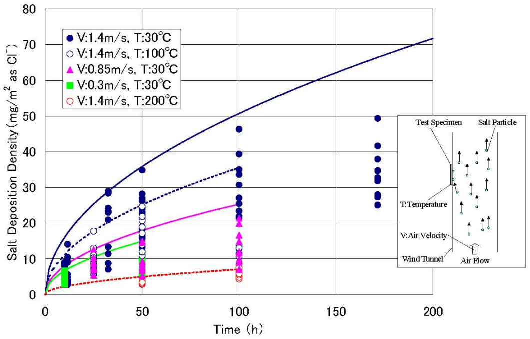


Fig.4 Chloride Deposition Velocity in the Laboratory Tests

2.3 Crack growth test

In-service inspection interval during the storage should be determined so that any SCC cracks do not penetrate the canister wall before next inspection. It is important to obtain the SCC crack growth rate through the canister wall. CT specimens were machined from the matrix material. Droplets of synthetic sea water were put into the groove of the specimen by a micro-pipette. After synthetic sea water deposition, the loading apparatus with a specimen each as shown in Fig.5 was placed in constant temperature and humidity chambers kept at temperatures of 323K with RH=35%, 333K with RH=25%, 343K and 353K with RH=15%, which conditions were set considering the canister surface condition in the actual storage. The range of K value was between 10 and 30MPa·m$^{0.5}$. The crack growth rate was measured by RDCPD (Reverse Direct Current Potential Drop) method. Fig.6 shows the temperature dependency of the crack growth rate of various stainless steel. It seems that the candidate materials have the crack growth rate smaller than the reference material by three orders of magnitude.

Fig.5. Crack Growth Test

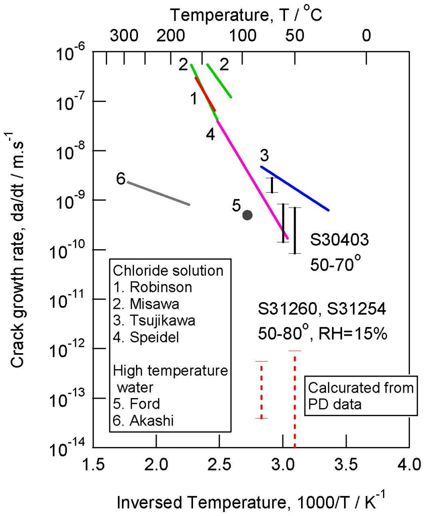


Fig.6. Temperature dependency of the crack growth rate

3. Salt particle collection test

As an optional countermeasure against SCC with respect to salty air environment, the reduction of the salt particles induced by the natural cooling air into the storage facility is one of the practical options. To develop the salt particle collection device with a low flow resistance which doesn't affect the heat removal performance of the storage facility, the salt particle collection performance test has been started to evaluate the effectiveness of such device from 2007. The outline of the salt particle collection device designed by CRIEPI is shown in Fig.7. The device might be attached at the inlet for natural cooling of the cask storage building and consists of multiple layered trays with a certain amount of water. When the air including sea salt particles goes through the trays, a part of sea salt particles in the cooling air might be trapped by collision with the water of trays. The top surface of each tray has projections to make the air collide with the water surface effectively. The salted water is discharged out of the facilities by overflowing these trays.

This device has the following characteristics.

* Because of the low flow residence, the device doesn't block the inflow of the air which is needed for cask heat removal and the maintenance is not complicated because of the simple structure.
* Rainwater may be re-usable for this device.

The performance test is ongoing to verify the pressure loss of the device, the efficiency of salt particle collection, and its optimum shape.

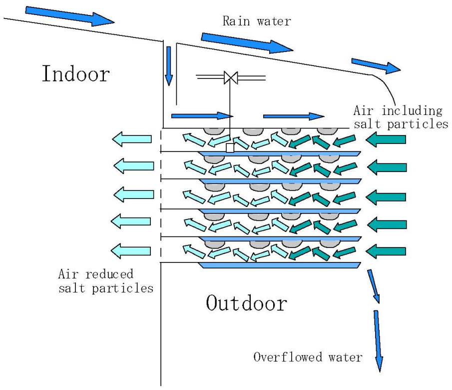
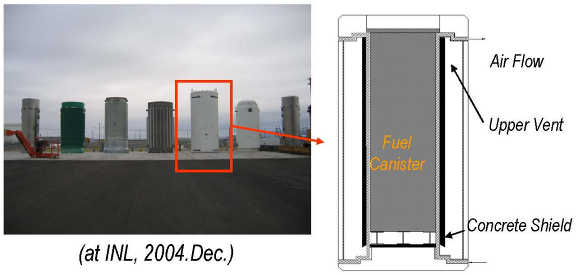


Fig.7. Salt particle collection device

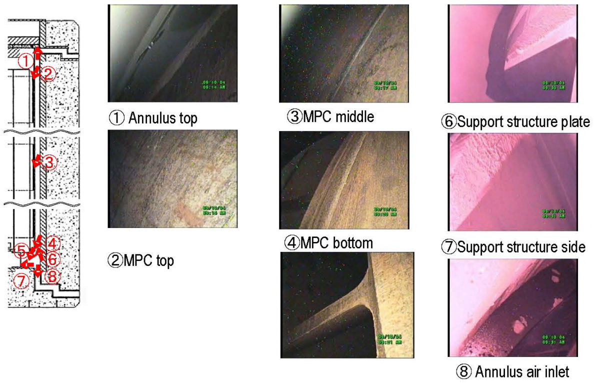
4. Canister surface inspection test [7]

Inspection of canister surface was carried out using an optical camera inserted from the air outlet through the annulus of a concrete cask (VSC-17). The VSC-17 has been storing spent nuclear fuel for over 15 years as part of a dry cask storage demonstration project at Idaho National Laboratory (INL) as shown in Fig.8. The VSC-17 was designed to contain 17 PWR fuel assemblies, which was scaled down from the commercially produced VSC-24 units to be compatible with the INL cask mover that was used to move casks from the cask storage pad to the hot shop. VSC-17 has a concrete wall thickness of 51 cm and the inner liner of the annulus is A-36 steel that is 89 mm thick, which provides structural support and additional shielding. The annular gap between the steel liner and the canister is 76 mm. Fig.9 shows photographs of the surface of the canister. They were snapped by an optical camera inserted from the air outlet through the annulus of a concrete cask. According to the visual inspections, since there is some surface rust present but no large scale flaking, it seems that no gross corrosion, pitting, or general attack, and all coatings appear to be intact. Moreover, there is no considerable indication that the canister support beams have undergone any structural degradation. However, for future application to detect any pitting corrosion on the canister surface made of stainless steel, additional development of a camera system (such as, internal lightning, zoom capability, and pan/rotation function) would be necessary.



(at INL, 2004.Dec.)

Fig.8. VSC-17 at INL



① Annulus top
②MPC top
③MPC middle
④MPC bottom
⑥Support structure plate
⑦Support structure side
⑧ Annulus air inlet

Fig.9. Photographs of the surface of the canister

5. Seismic Test [8]

For a vertically free-standing concrete cask on the floor pad in the cask storage facility, its tip-over and sliding behavior and the integrity of the spent fuel during strong seismic motions are still the technical key issues to guarantee its safe performance. A full-scale concrete cask and a storage house floor were set on a three-dimensional shaking table in 3-D full-scale earthquake testing facility “E-Defense “ designed and constructed by National Research Institute for Earth science and Disaster prevention as shown in Fig.10. The test canister can store 21 PWR spent fuel assemblies. As for spent fuel structures, one full-scale PWR fuel assembly (17x17) and 20 dummy PWR fuel assemblies were fabricated. The hold force between the fuel rods and the grid cells of the test fuel was mitigated by resizing the grid cell configuration considering the loss of the hold force after the discharge from the reactor. Fig.11 shows the summary of the seismic response of the full-scale concrete cask. The rapid increase of the response angle beyond the up-lifting limit level (about 650gal) was observed. For JMA Kobe wave (Hyogo-ken Nanbu earthquake 1995, Max. acceleration level 818gal), the maximum rotational response angle was about 0.028rad, and the maximum sliding displacement was estimated to be over 80cm. It was found that the tip-over of the full-scale cask did not occur at the acceleration level which exceeds the input level 1.5 times as strong as the uplifting limit level, but the special attention should be paid for the sliding or jumping behavior of the cask under the strong earthquake motion. Moreover, although the impact velocity of the fuel, which was loaded in the center of the canister, exceeded 300mm/s, the corresponding max deformation reached to 250μm/m, and the spent fuel structures still seemed to be in the elastic region under the strong seismic motion.

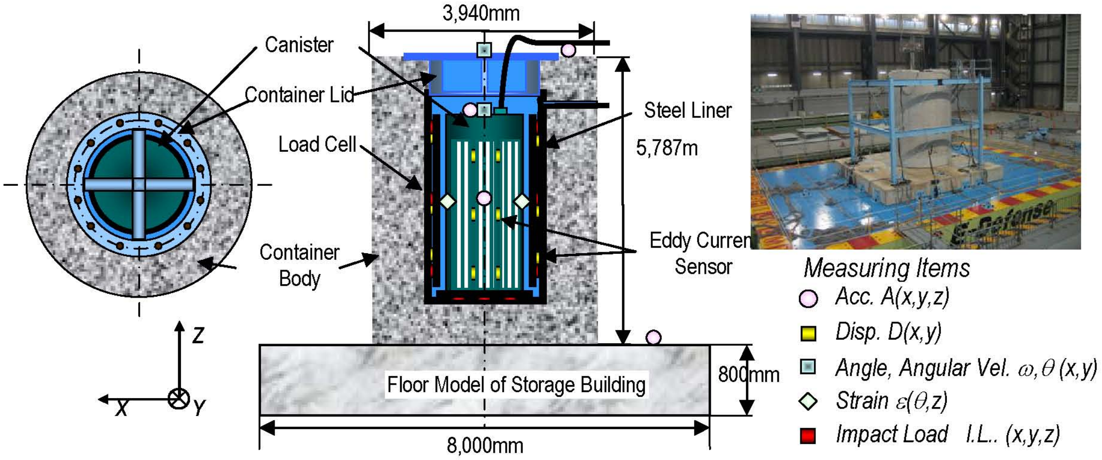


Fig.10. 3D Earthquake Testing with Full-Scale Concrete Cask and Concrete Floor

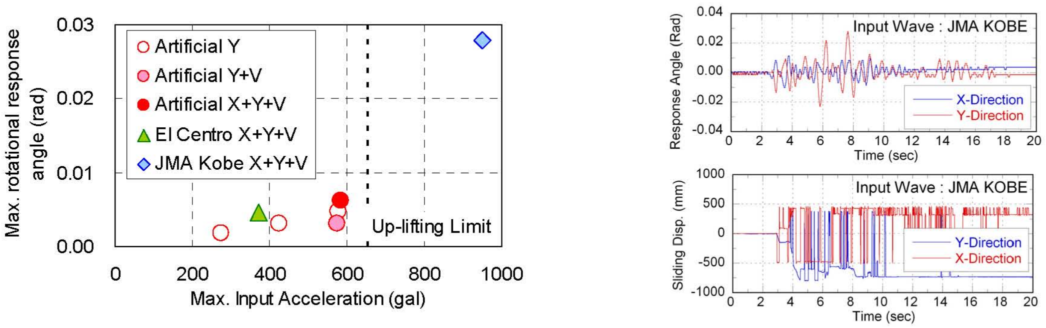


Fig.11. Summary of the Seismic Response of the Concrete Cask

6. Conclusions

In Japan, utilities are planning to commence the operation of the first ISF in 2010. Regulatory authority correspondingly modified the reactor regulation law and has been settling the relevant safety rules to operate the interim storage facility. To prepare the safety requirements and promote the rational reviewing procedure for the application of ISF establishment license, CRIEPI is steadily performing the key research studies, such as degradation of cask component and seismic safety issues.

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