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Experience of Storage by Dry Storage Cask in Fukushima Daiichi Nuclear Power Plant

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Abstract

Spent fuel storage using Dry Storage Cask (DSC) in Japan has been experienced approximately for 20 years since 1995. In addition to the advantage of easy maintenance, storage area flexibility and convenience of transportation, the safety of DSC is increasingly focused in particular after the Great East Japan Earthquake, because DSC is cooled by natural air circulation without utilities such as electric power during storage.

Kobe Steel, Ltd. manufactured 20 DSCs which have forged shell for Tokyo Electric Power Company and 9 of them have been operated since 1995 at Fukushima Daiichi Nuclear Power Station. In 2000 after 5 years' storage and 2005 after 10 years' storage, the primary and secondary lids were opened for one of these DSCs as a representative, and the soundness of stored fuels and the securement of containment function were confirmed.

At the Great East Japan Earthquake in March 11th, 2011, these 9 DSCs were being operated at the cask storage facility in the power station. A large amount of seawater, sand, rubble, etc. were flowed due to tsunami (seismic sea wave) in the cask storage facility, then the DSCs were completely submerged in the seawater temporarily. However, it was confirmed by the detailed investigations performed later that there were no problems with the containment function, the keeping sub-criticality function, the heat removal function, the radiation shielding function and the soundness of stored fuels for all 9 DSCs affected by the tsunami. These DSCs now continue to be operated with loaded spent fuels at the new cask temporary storage facility after cleaning of sealing surface for secondary lid and replacement of metal gasket. Furthermore, the other 11 DSCs in which spent fuels from the common pool were loaded are operated at the cask temporary storage facility.

This paper introduces the outline of manufacturing process for the DSC and the experience of storage in Fukushima Daiichi Nuclear Power Station.

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Introduction

Concerning the storage of spent fuels, various methods have been developed and put to practical use in the world. In Japan, storage by spent fuel pool or metal cask is put to practical use at the storage facility in the nuclear power station. The features of storages by spent fuel pool and metal cask are as follows.

(1) Storage by Spent Fuel Pool

The spent fuels are operated in the rack (frames made of metal) established in the spent fuel pool. The decay heat of the spent fuels is removed in the water and the radiation from spent fuels is shielded. Spent fuel pool is suitable for the storage of a large amount of spent fuels at nuclear power station and the storage of spent fuels with high decay heat just after removed from the reactor vessel because of superiority in heat removal performance.

(2) Storage by Metal Cask

The spent fuels are operated in the dry storage cask made of metal which can endure any shock and fire disaster. DSC has four fundamental safety functions which are the heat removal function, the containment function, the radiation shielding function and the keeping sub-criticality function. There are some merit such as suppressing of initial investment and ease of investment planning, because the storage capacity can be expanded at necessary timing with comparative ease. In addition to the advantage of easy maintenance, storage area flexibility and convenience of transportation, the safety of DSC is increasingly focused in particular after the Great East Japan Earthquake, because DSC is cooled by natural air circulation without utilities such as electric power during storage.

In Japan, the spent fuel storage by DSC has been experienced since 1995 at Fukushima Daiichi Nuclear Power Station in Tokyo Electric Power Company and since 2001 at Tokai N.2 Power Station in Japan Atomic Power Company, and then the soundness of stored fuels and the securement of containment function were confirmed by the investigation in 2000 and 2005 at Fukushima Daiichi Nuclear Power Station.

Outline of manufacturing process for the DSC

Design of DSC

DSC has the safety functions of “heat removal”, “radiation shielding”, “containment” and “keeping sub-criticality” as follows, and DSC is designed to have the structural strength which is necessary to maintain these functions.

1) Heat removal function : Remove the decay heat of the spent fuels appropriately
2) Radiation shielding function : Shield the radiation of the spent fuels appropriately
3) Containment function : Confine the radioactive materials contained in the spent fuels appropriately
4) Keeping sub-criticality function : Prevent DSC with spent fuels to go criticality

5) Structural strength : Have the structural strength which is necessary to maintain the heat removal function, the radiation shielding function, the containment function and the keeping sub-criticality function

Structure of DSC

Two types of DSCs “medium size type” and “large size type” were manufactured by Kobe Steel, Ltd. for Fukushima Daiichi Nuclear Power Station and these DSCs can contain 37 and 52 spent fuels respectively. Aspect of DSC is shown in Fig.1 and its structure is shown in Fig.2.

Figure 1 Aspect of DSC

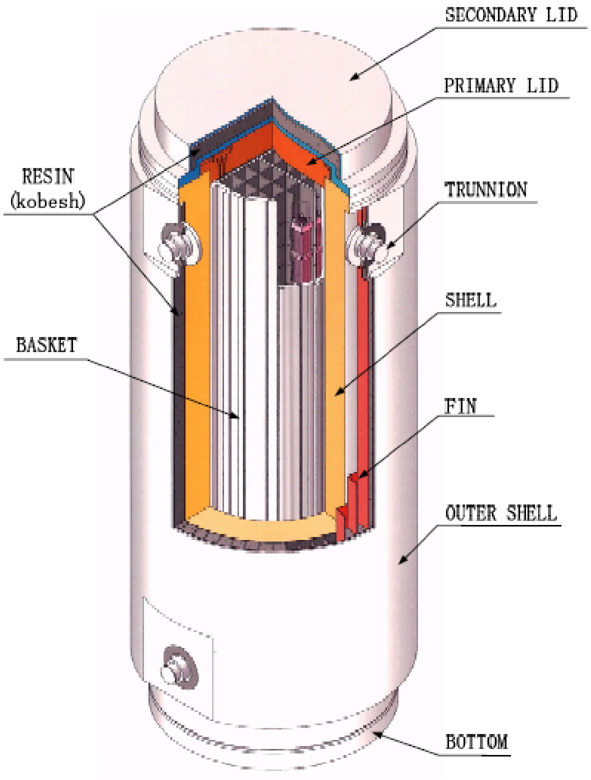

Figure 2 Structure of DSC

This DSC consists of three main components which are the Body, Lid and Basket. These structures are shown below.

(1) Body

Thick cylindrical Shell and discoid Bottom, which are made of low alloy steel, are welded. The Shell and Body are designed as pressure vessel in order to endure the internal and external pressure, and also main parts of gamma-ray shield. Outer Shell made of carbon steel is welded on the outer surface of Shell. Fin made of copper for thermal conductor and Neutron shielding made of mainly silicone rubber for neutron shielding are assembled between the Shell and Outer Shell.

For the handling of DSC and lashing during storage, two pairs of Trunnions at the upper side (opening side) and one pair of Trunnions at lower side (bottom side) made of stainless steel are assembled to Shell using Trunnion Bolts.

Al/Zn thermal spray at the inside surface of cavity and paint at the outside surface are applied for corrosion prevention.

(2) Lid

Lids consist of Primary Lid and Secondary Lid.

The Primary Lid is made of low alloy steel and assembled using bolts on the upper side (opening side) of body. The Primary Lid is designed in order to endure the internal and external pressure, and also main parts of gamma-ray shield. Double rings metal gasket is installed in the gasket groove of Primary Lid and the gasket ensures the containment performance between body and lid. There is a detector hole between two rings of the metal gasket and the leak test for the gasket can be performed using the detector hole. The Primary Lid also has the orifice which is used for drain and vent during operation. Al/Zn thermal spray at the inside surface of cavity and paint at the outside surface are applied for corrosion prevention.

The Secondary Lid is made of stainless steel with Neutron shielding on the upper surface and assembled using bolts on the upper side (opening side) of the body. Double rings metal gasket is installed in the gasket groove of Secondary Lid as same as the Primary Lid and the gasket ensures the containment performance between body and lid. There are a pressure sensor and a valve for filling the helium gas. The seal monitoring can be performed by detecting the pressure fluctuation of helium gas installed at the space between Primary Lid and Secondary Lid.

(3) Basket

The Basket is to align the fuel assemblies at the prescribed location in the DSC and ensure the relative distance between each spent fuels. The panel plates are multi-stacked and constitute the rectangular compartments where the fuel assemblies are installed for entire length in the DSC. The Basket is formed by mechanical jointing without welding. Aluminum alloy with enriched boron is used for the panel plates with the functions of boron (B-10) as neutron absorbing material in order to prevent the DSC loaded spent fuels from criticality.

Manufacturing of DSC

1. Main Item

Main items used for DSC are as follows.

1) Shell, Bottom, Trunnion, Primary Lid and Secondary Lid

   Shell, Bottom, and Primary Lid are forged products made of low alloy steel. Trunnion and Secondary Lid are forged products made of stainless steel. Ingot made from molten steel is forged to rough shape by forging press, and then the forging is machined to the required shape.

2) Outer Shell

   Carbon steel plates are cut to the required size, and then two half-round Outer Shells are formed by bending the plates

3) Fin

   Copper plates are cut to the required size, and then L-shaped fins are formed by bending the plates.

4) Neutron shielding

Neutron shielding materials (kobesh SRTTM) developed by Kobe Steel, Ltd. are used.

5) Basket Plate

Aluminum alloy steel plates with enriched boron developed by Kobe Steel, Ltd. are cut to the required size.

2. Manufacturing Process

Manufacturing process of DSC is shown in Fig.3 and its outline is shown below.

(1) Body

Shell and Bottom are joined by welding, various items are welded on the inner and outer surfaces, heat treatment after welding is performed, and then it is machined to the required dimensions. Radiographic testing and magnetic particle testing are performed in order to ensure the soundness of welding and “pressure test” by applying a hydrostatic pressure to DSC inside is performed in order to ensure that the DSC can endure the required inner pressure.

Two half-round Outer Shells with Fins and neutron shielding installed between Shell, Outer Shells and Fins are wound and welded around the outer surface of Shell.

Trunnions are assembled using Trunnion Bolts, and then “load test” is performed in order to ensure that there is no significant deformation after applying the required load at Trunnions.

Thermal spray at the inside surface of cavity and paint at the outside surface are applied for corrosion prevention.

(2) Primary Lid

Gasket sealing surface and the orifice area on the forged material for Primary Lid are overlay welded, the parts for a detector hole are welded, heat treatment after welding is performed, and then it is machined to the required dimensions. Liquid Penetrant Testing is performed in order to ensure the soundness of welding and “pressure test” is performed with the body.

Thermal spray at the inside surface of cavity and paint at the outside surface are applied for corrosion prevention.

(3) Secondary Lid

Various items are welded on the forged material for Secondary Lid, Neutron shielding is installed, the cover is welded after Neutron shielding installation, and then it is machined to the required dimensions. Liquid Penetrant Testing is performed in order to ensure the soundness of welding.

(4) Basket

Lattice frames are prepared by assembling of panel plates which surfaces are treated by anodizing oxidation. These lattice frames are multi-stacked, fixed at the corner of each frame using the coupling items, and then the Basket is completed.

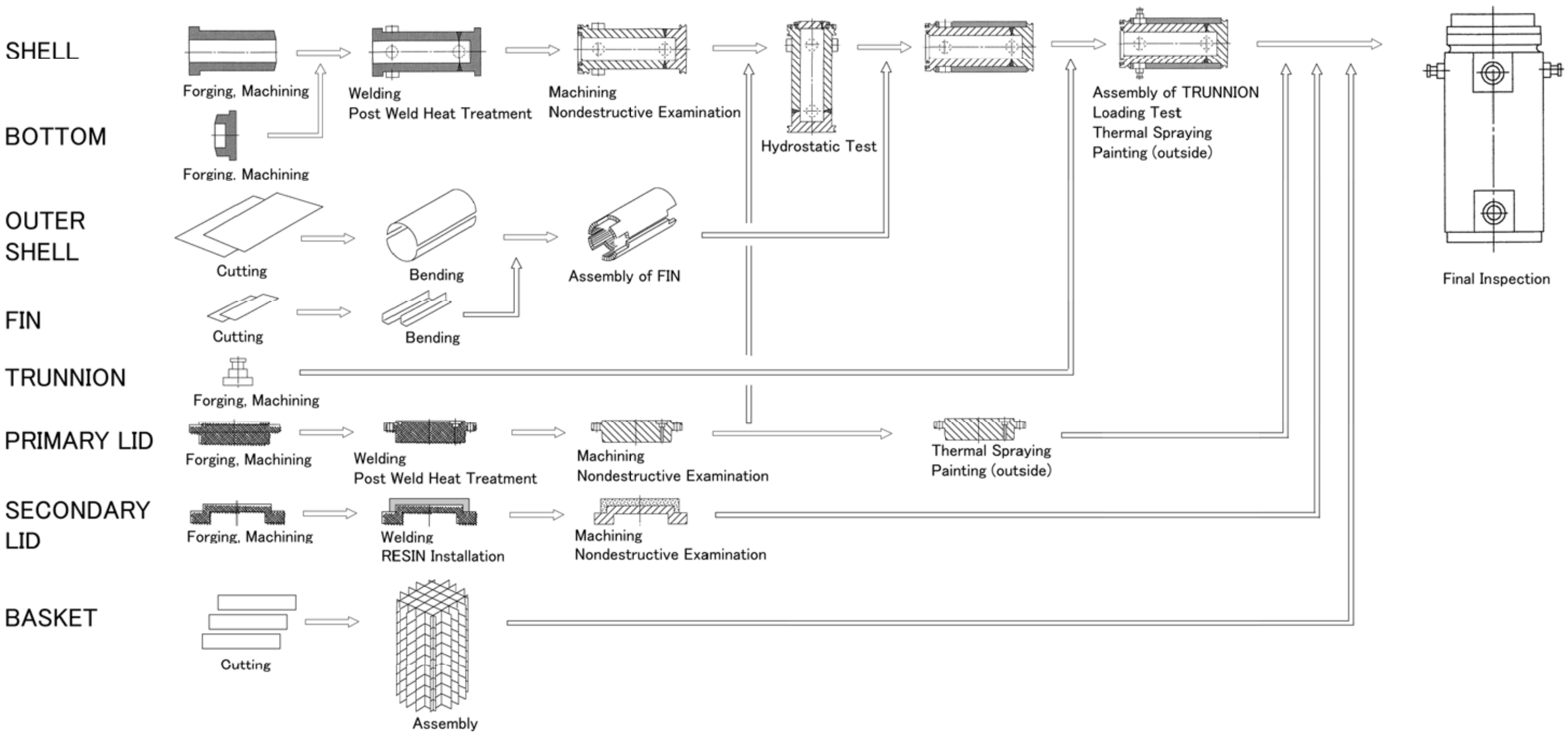

Figure 3 Manufacturing Process of DSC

(5) Assembly and Test

It is confirmed that there is no abnormality for each completed item by visual and dimensional inspection. After assembly of these items, some kind of test such as “thermal test” to confirm the heat removal function by installing the heaters simulating spent fuels in the DSC and “leak tightness test” to confirm the containment function of Primary Lid and Secondary Lid are performed in order to ensure that the DSC has been manufactured with satisfaction of all design requirements. Other tests such as “Operational test” to confirm that the DSC can be handled without trouble are also performed.

Experience of storage for DSC

Soundness for long term storage

9 DSCs (4 for medium size type and 5 for large size type) which were manufactured and delivered by Kobe Steel, Ltd. have been operated since 1995 at Fukushima Daiichi Nuclear Power Station. In 2000 after 5 years’ storage and 2005 after 10 years’ storage, the primary and secondary lids were opened for one of these DSCs as a representative, and the soundness of stored fuels and the securement of containment function were confirmed as follows.

(1) Soundness of stored fuel

As a result of inner gas sampling, Krypton gas was not detected and it was confirmed that there was no damage on the fuel cladding. As a result of visual check, it was also confirmed that there was no abnormality for the fuel assemblies.

(2) Securement of containment function

As a result of leak test for Primary Lid, it was confirmed that the containment function was secured. It was also confirmed that there was no abnormality on the gasket and gasket sealing surface.

Affect of the Great East Japan Earthquake

1. State of cask storage facility

The state of cask storage facility in Fukushima Daiichi Nuclear Power Station after the Great East Japan Earthquake was reported by Tokyo Electric Power Company (TEPCO) [1]. At the Great East Japan Earthquake in March 11th, 2011, 9 DSCs (for 408 spent fuels) delivered by Kobe Steel, Ltd. were being operated at the cask storage facility. A large amount of seawater, sand, rubble, etc. were flowed due to tsunami (seismic sea wave) in the cask storage facility, then the DSCs were

Figure 4 Cask storage facility after the Great East Japan Earthquake

completely submerged in the seawater temporarily. Though the rubble, etc. were on the outer surface of DSCs, they didn't move from the original position fixed by bolts and any problem concerned the soundness was not found from the appearance. The state of cask storage facility after the Great East Japan Earthquake is shown in Fig.4.

2. Investigation of DSC

The results of investigation after the Great East Japan Earthquake for 9 DSCs operated at the cask storage facility were reported by Tokyo Electric Power Company (TEPCO) [2)]. It was confirmed that there was no problem with the containment function, the keeping sub-criticality function, the heat removal function, the radiation shielding function and the soundness of stored fuels as follows.

(1) Containment function

a. Result of leak test for Primary Lid and Secondary Lid

As a result of leak test for Primary Lid and Secondary Lid before opening of each lid, the leak rate was less than the required value.

b. Result of pressure measurement between Primary Lid and Secondary Lid

As a result of pressure measurement between Primary Lid and Secondary Lid before opening of Secondary Lid, the remaining pressure was less than the required value.

c. Result of visual inspection for metal gasket used at Primary Lid and Secondary Lid

As a result of visual inspection for the metal gasket used at Primary Lid, there was no abnormality such as flaw or crack (confirmed only for one DSC). On the other, some corrosion (white discoloration) due to penetration of seawater were found on the outer surface of Secondary Lid, but it was confirmed that there was no through-hole on the gasket and the inside of DSC have been isolated from the external environment.

(2) Keeping sub-criticality function, Soundness of fuels

a. Result of visual check for Basket

As a result of visual inspection from the top of Basket, there was no abnormality such as deformation or damage (confirmed only for one DSC).

b. Result of visual check for fuel assemblies

As a result of visual check (4 sides) for 3 fuel assemblies removed representatively, there was no abnormality such as deformation or damage (confirmed only for one DSC).

c. Result of inner gas sampling from DSC

As a result of check for inner gas by Krypton monitor, there was no significant change on the monitor and the soundness of fuel cladding was confirmed.

d. Result of measurement for neutron dose equivalent rate

There was no abnormality for the neutron dose equivalent rate and it was confirmed that there was no abnormality for the keeping sub-criticality function.

(3) Heat removal function, Radiation shielding function

There was no abnormality for the surface temperature and the dose equivalent rate, and it was confirmed that there was no abnormality for the heat removal function and the radiation shielding function.

(4) Liquid Penetrant Testing (PT) result for Secondary Lid and Body

Stress Corrosion Cracking (SCC) was concerned because the white discoloration was found on the seal area of Secondary Lid. As a result of PT on the sealing surfaces of the Secondary Lid and Body, it was confirmed that SCC was not generated.

Storage at cask temporary storage facility

Due to tsunami generated by the Great East Japan Earthquake, the cask storage facility at Fukushima Daiichi Nuclear Power Station could not be used continuously. 9 DSCs in operation now continue to be operated at the new cask temporary storage facility after cleaning of sealing surface for secondary lid and replacement of metal gasket.

Furthermore, the spent fuels operated in the common spent fuel storage pool were loaded in the other 11 DSCs which were newly delivered by Kobe Steel, Ltd. in order to make spaces at the common spent fuel storage pool, and these DSCs have also been operated at the cask temporary storage facility.

At the cask temporary storage facility, the DSCs mounted on the support frame for storage were fixed by fixing bolts as same as at the cask storage facility before earthquake, and then each DSC was covered by concrete module individually. 50 DSCs including 20 DSCs (9 DSCs + newly delivered 11 DSCs) manufactured by Kobe Steel, Ltd. can be operated at the cask temporary storage facility.

Conclusions

Kobe Steel, Ltd. delivered 20 DSCs for Fukushima Daiichi Nuclear Power Station so far. 9 of them have been experienced approximately for 20 years, and the soundness of DSCs were verified even after these DSCs have fallen victim to the tsunami due to the Great East Japan Earthquake. In Japan, the demand of DSC is expected to continue to increase. Kobe Steel, Ltd. will continue to manufacture DSCs in order to play a role for the restoring nuclear accident and Japanese national policy of nuclear energy.

References

1) Tokyo Electric Power Company, “Fukushima Nuclear Accident Analysis Report”, 2012.6.20

2) Tokyo Electric Power Company, “Fukushima Daiichi Nuclear Power Station, Investigation Report of Dry Storage Cask”, 2013.5.31