Nuclear Engineering and Design 304 (2016) 63–69

Contents lists available at ScienceDirect

Nuclear Engineering and Design

journal homepage: www.elsevier.com/locate/nucengdes

Experimental assessment on the thermal effects of the neutron shielding and heat-transfer fin of dual purpose casks on open pool fire

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HIGHLIGHTS

- An open pool fire test was performed to estimate not only the combustion effect of the neutron shielding but also the effect of the heat transfer fin of the dual purpose cask.
- The heat transfer to the inside of the dual purpose cask was reduced, when the neutron shielding burns.
- The surface temperatures are lower in the present of the heat transfer fins.
- If inflammable material is used as the components of the cask, evaluating thermal integrity using the thermal test would be desirable.

ARTICLE INFO

Article history:
Received 18 November 2015
Received in revised form 22 April 2016
Accepted 26 April 2016
Available online 14 May 2016

JEL classification:
T. Final storage

ABSTRACT

Dual purpose casks are used for storage and transport of spent nuclear fuel assemblies. They must therefore satisfy the requirements prescribed in the Korea Nuclear Safety Security Commission Act 2014-50, the IAEA Safety Standard Series No. SSR-6, and US 10 CFR Part 71. These regulatory guidelines classify the dual purpose cask as a Type B package and state that a Type B package must be able to withstand a temperature of 800 °C for a period of 30 min. NS-4-FR is used as neutron shielding of the dual purpose cask. Heat transfer fins are embedded to enhance heat transfer from the cask body to the outer-shell because the thermal conductivity of NS-4-FR is not good. However, accurately simulating not only the combustion effect of the neutron shielding but also the effect of the heat transfer fin in the thermal analysis is not easy. Therefore, an open pool fire test was conducted using a one-sixth slice of a real cask to estimate these effects at a temperature of 800 °C for a period of 30 min. The temperature at the central portion of the neutron shielding was lower when the neutron shielding in contact with the outer cask burned because the neutron shielding absorbed the surrounding latent heat as the neutron shielding burned. Therefore, the heat transfer to the inside of the dual purpose cask was reduced. The surface temperature was lower when a heat transfer fin was installed because the high heat generated by the flame was transferred to the body of the test model through the heat transfer fin. The maximum temperatures of the neutron shielding at the part where the heat transfer fin was installed were 155 °C. However, those in the part where the heat transfer fin was not installed were 183 °C. The neutron shielding was therefore adequately protected by the heat transfer fin.

1. Introduction

Management of spent nuclear fuel generated in nuclear power plants has become a major policy issue because of continued delays in obtaining safe and permanent disposal facilities. Most nuclear power plants store their spent nuclear fuel in wet storage pools. However, following decades of nuclear power generation, most storage pools have reached maximum capacity. For the nuclear power industry, finding sufficient capacity for storage of spent nuclear fuel is essential if the nuclear power plants are to continue operating.

Dual purpose casks are one possible solution for solving the interim storage problem. A dual purpose cask that contains 21 spent fuel assemblies is under development by the Korea Radioactive Waste Agency (KORAD). Because the dual purpose cask is used for both storage and transport of spent fuel assemblies, it should satisfy the requirements prescribed in the related regulations (Korea Nuclear Safety Security Commission Act 2014-50, 2014; IAEA Safety Standard Series No. SSR-6, 2012; US 10 CFR Part 71,

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http://dx.doi.org/10.1016/j.nucengdes.2016.04.040

2005). These regulatory guidelines classify the dual purpose cask as a Type B package and state that a Type B package must be able to withstand a temperature of 800 °C for a period of 30 min.

Fire tests may be performed either as a pool fire or in a furnace. The open pool fire test generates a great deal of smoke and soot and is therefore difficult to perform because of strict environmental regulations. Therefore, a fire test was conducted using a one-sixth in the length of a dual purpose cask. A smokeless fire test method was used where the smoke and soot was eliminated.

The dual purpose cask was designed as a shipping cask to accommodate 21 pressurized water reactor (PWR) spent fuel assemblies with a burn-up of 45,000 MWD/MTU and a cooling time of 10 years. The decay heat from the 21 PWR spent fuel assemblies is 16.8 kW. A description of the dual purpose cask is listed in Table 1. Its outer diameter is 2126 mm and its overall height is 5285 mm. It weighs approximately 125 t. It consists of a thick-walled cylindrical cask body, a neutron shielding, a dry shielded canister (DSC), a lid, baskets to hold the spent nuclear fuel, and impact limiters (Fig. 1). The cask body is made of carbon steel. The lid is made of stainless steel and is fixed to the cask body using stud bolts and cap nuts. The outer-shell is made of stainless steel. The baskets containing the spent fuel assemblies are made of stainless steel. The inner cavity between the outer-shell and the cask body is filled with NS-4-FR, which acts as a neutron shielding. NS-4-FR has a low thermal conductivity. Therefore, heat transfer fins are embedded to enhance heat transfer from the cask body to the outer-shell.

When wood and resin such as NS-4-FR are heated, they produce pyrolysis products such as a char, tars, and gases. The remaining pyrolysis products of the wood and resin are gases consisting of a mixture of hydrocarbons (Quintiere, 2006). These gases, generated due to pyrolysis of the resin and wood, are burned. However, accurately simulating the combustion effect of the resin and wood in the thermal analysis is very difficult.

Table 1
Description of the dual purpose cask.

Item	Description
Storage capacity components	21 PWR assemblies Cask body DSC (dry shielded canister) Impact limiters
Dimension	Cask body: 2126 mm(∅) × 5285 mm(l) × 215 mm(t) Neutron shielding: 2369 mm(∅) × 4305 mm (l) × 104 mm(t) Outer-shell: 2384 mm(∅) × 4355 mm(l) × 10 mm(t) DSC: 1686 mm(∅) × 4880 mm(l) × 25 mm(t)
Weight	Impact limiters: 3600 mm(∅) × 1090 mm (l) × 665 mm(t) Cask body: 103 tons (loaded canister) Neutron shielding: 5.1 tons DSC: 24.1 tons (loaded fuels)
Material	Impact limiters: 16.5 tons (upper + bottom) Cask body: carbon steel & stainless steel (Cladding) Neutron shielding: stainless steel housing & NS-4-FR DSC: stainless steel & boral (B_4C + Al)
Design basis fuel	Impact limiters: stainless steel housing & balsa wood Burn-up: 45,000 MWD/MTU Cooling time: 10 years Enrichment: 4.5 wt% ^{235}U Decay heat: 16.8 kW

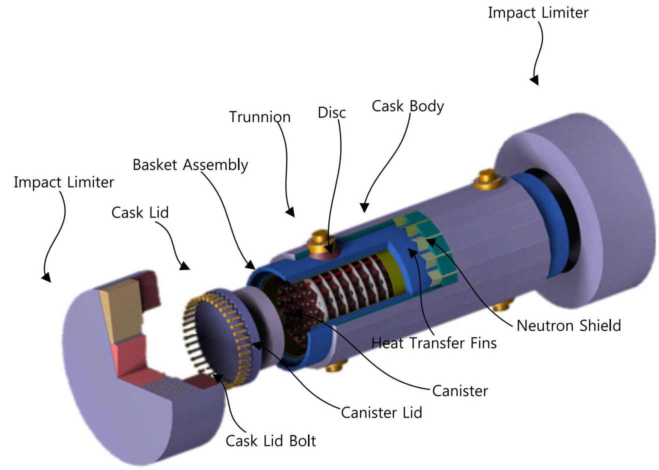

Fig. 1. Configuration of the dual purpose cask.

The heat transfer fin, which is embedded to enhance the heat transfer due to the low thermal conductivity of the NS-4-FR, is very thin. Therefore, accurately simulating the heat transfer fin in the thermal analysis is also difficult.

This paper presents an experimental approach used to estimate not only the combustion effect of the neutron shielding but also the effect of the heat transfer fin on the dual purpose cask at a temperature of 800 °C for a period of 30 min.

2. Fire test

2.1. Description of the test model

The test model is a one-sixth in the length of a real dual purpose cask where the thermal conditions could potentially be the most severe. Fig. 2 shows the configuration of the thermal test model. The test model had an outer diameter of 2384 mm and an axial length of 850 mm. To minimize heat loss in the axial direction, both ends of the test model were covered with an insulator.

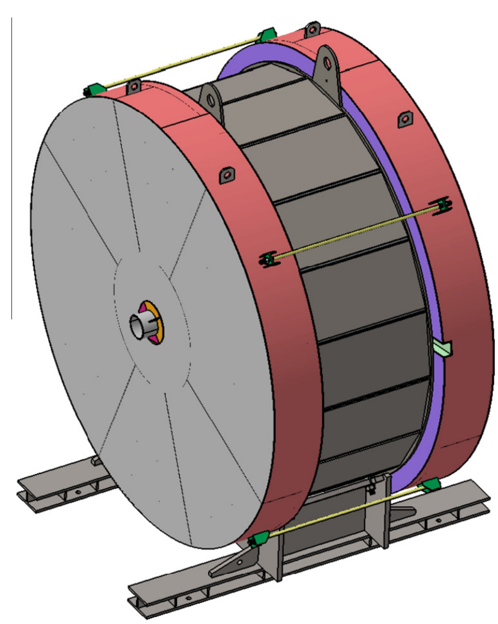

Fig. 2. Configuration of the fire test model.