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Original Article

FRAPCON analysis of cladding performance during dry storage operations

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A R T I C L E I N F O

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A B S T R A C T

There is an increasing need in the United States and around the world to move used nuclear fuel from wet storage in fuel pools to dry storage in casks stored at independent spent fuel storage installations or interim storage sites. Under normal conditions, the Nuclear Regulatory Commission limits cladding temperature to 400°C for high-burnup (>45 GWd/mtU) fuel, with higher temperatures allowed for low-burnup fuel. An analysis was conducted with FRAPCON-4.0 on three modern fuel designs with three representative used nuclear fuel storage temperature profiles that peaked at 400°C. Results were representative of the majority of US light water reactor fuel. They conservatively showed that hoop stress remains below 90 MPa at the licensing temperature limit. Results also show that the limiting case for hoop stress may not be at the highest rod internal pressure in all cases but will be related to the axial temperature and oxidation profiles of the rods at the end of life and in storage.

1. Introduction

Currently, there is a focus on moving fuel out of spent fuel pools into dry storage systems in the United States and around the world. Increasingly, this fuel will be high-burnup fuel, greater than 45 GWd/MTU. The current rod average fuel burnup limit in the United States is 62 GWd/MTU which corresponds to an assembly average burnup of about 55 GWd/MTU. Previous work has been carried out to analyze conditions of dry storage Ref. [1] in low-burnup fuel with older designs. With this in mind, it is useful to investigate whether the current regulatory limits on fuel in dry storage still have a valid basis for modern, high-burnup fuel. Three different fuel designs were analyzed with three different axial temperature profiles to simulate steady state, bounding, dry storage conditions. These conditions also encompass bounding temperatures for drying and loading operations. The varied analysis characterizes the effects of fuel design and storage system design on the cladding conditions. Temperatures were imposed so that the peak cladding temperature is at the current licensing limit to bound hoop stress and rod internal pressure (RIP) results.

1.1. Current regulations

The Nuclear Regulatory Commission has limited the maximum peak cladding temperature during normal conditions of dry storage to 400°C (752°F) for fuel with a burnup greater than 45 GWd/MTU. This limit is set to protect the fuel rod cladding and the storage system components from damage mechanisms related to high temperature Ref. [2]. The principle mechanism for cladding damage at these temperatures is embrittlement due to radial hydride reorientation. This occurs at high temperatures and stresses where hydrogen in the cladding will orient itself into a radial direction due to the hoop stress in the cladding. This makes the cladding more susceptible to crack growth and fracture during long-term storage. With this knowledge, the 400°C thermal limit is meant to keep cladding hoop stress below 90 MPa Ref. [2]. Previous research Ref. [2] has determined these temperature and hoop stress limits to be a reasonable bound for avoiding reorientation.

There is a higher 570°C limit during short-term operations. The 570°C limit may only be applied provided that applicants for a certificate of compliance under 10 CFR 72.3 can show hoop stress remains below 90 MPa Ref. [2]. Applicants do not need to analyze hoop stress if clad temperature remains below 400°C. Most cask licenses are based on maintaining the 400°C limit and do not attempt to characterize hoop stress. However, because of the methodology laid out in ISG-11 Ref. [2], it is important to analyze hoop stress at 400°C and determine if it remains below the 90 MPa limit for hydride reorientation in high-burnup fuel.

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1.2. Dry storage system background

Dry storage systems fall into two broad classes, canistered and noncanistered. An example of a noncanistered system is the TN-32, shown in Fig. 1. Noncanistered systems consist of grid structures to support the fuel, with a thick metal wall and support structures for shielding, heat removal, and structural integrity. The cask interior is filled with helium which is chosen for its lack of reactivity and its heat transfer properties.

Canistered systems are more common in the United States than the noncanistered systems due to their versatility and generally lower cost. Similar to the noncanistered system, there is a metal grid to hold the fuel assemblies; however, this grid sits in a relatively thin canister (Fig. 2) instead of the thick walled cask. This canister may have different industry names, such as multipurpose canister, dry shielded canister, or transportable storage canister. This design allows the canister to be placed in a vertical ventilated storage system such as the HI-STORM 100 (Fig. 2) or a variety of other systems. For example, a single canister could be placed in vertical storage modules, horizontal modules, underground storage modules, onsite transfer casks, and offsite transportation casks.

2. Model description

2.1. Application of FRAPCON

For this analysis, the primary goal was to obtain bounding estimates for cladding hoop stress and RIP at loading and during

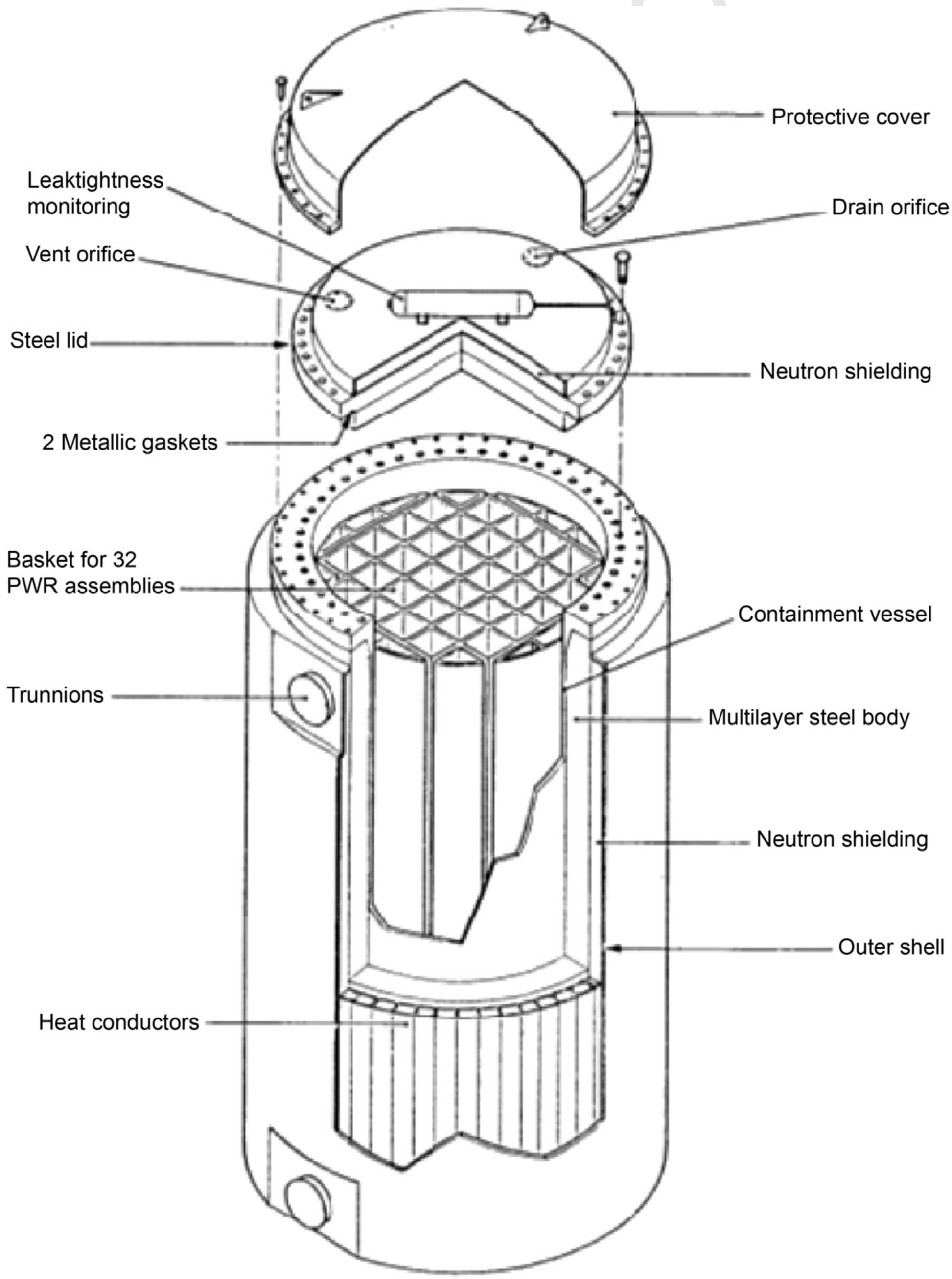

Fig. 1. TN-32 used fuel storage cask Ref. [3].
PWR, pressurized water reactor.