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Evaluating the feasibility of new surveillance concept for Dry Storage System through CFD methodology

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HIGHLIGHTS

- Thermal hydraulic behavior of a 3-D dry cask under several off-normal conditions has been numerically investigated by ANSYS/FLUENT.
- The simulation methodology was fully validated by comparing the measured results of VSC-17.
- The results indicated that many design bases accidents can be early detected by the purposed surveillance method.
- A simply determine rule has been developed for future application for dry storage monitoring.

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ABSTRACT

Since the Dry Storage System (DSS) has passed into a widespread middle-term storage method for Spent Nuclear Fuels (SNFs), the situation monitoring technology for a DSS should be further improved to ensure the reliability of DSS during storing time. However, a passive cooling mechanism with a full-sealed storage requirement causes that the internal situation cannot be directly monitored by thermocouples inserted into the DSS. In this study, a new surveillance method, therefore, has been proposed to overcome this problem. It can predict the DSS situation through measuring the temperature profile at the Transportable Storage Canister (TSC). A validated CFD methodology has been utilized to confirm the method through simulating the thermal characteristics of the ChinShan DSS (CSDSS). The major factors, such as the thermal loading, accident situation and flaw caused by penetrated hole probably, have been considered in this present work. The result shows that the above-mentioned issues would obviously affect the temperature profile on the TSC and can be identified via detecting the temperature profile difference on of TSC. These results confirm that the indirectly surveillance method has enough capability to replace the original monitored method and provide more system information of DSS vendor for middle-term storage.

1. Introduction

Nuclear fuel would be exhausted after two or three power cycles (about 36–54 months). The exhausted fuel is called Spent Nuclear Fuel (SNF). In the SNF, the fuel pellet still generates decay heat due to the mechanisms of fission product decay and heavy element decay. For this reason, the heat removal issue becomes the major design concern for a SNF storage facility. In general, the discharged SNFs have been stored in the Spent Fuel Pool (SFP) and it would remove their decay heat by cooling water system. The water would provide good cooling capability and radiative shielding to ensure the safety and fuel integrity purpose at the same time.

The Independent Spent Fuel Storage Installation (ISFSI) is a suitable solution for SNFs middle-term storage because the designed ISFSI is based on the passive cooling mechanism and with strong mechanical strength and radiative shielding capability to protect the SNFs and the public simultaneously. Until now, about 22 countries with over 123 ISFSI facilities have been employed to store many SNFs from BWR or PWR (AEC, 2012). In order to further understand the thermal behavior for an ISFSI, such as the Dry Storage System (DSS), many researchers applied many approaches to investigate the heat transfer mechanism of DSS. For example, Yoo et al. (2010) performed a CFD analysis of a TN-24P cask through

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Nomenclature

a_{net}	absorption coefficient
A	surface area
C_p	specific heat
F	view factor
g	gravity constant
h	heat transfer coefficient
I	radiation intensity
k	thermal conductivity, turbulence k equation
n	real component of complex index of refraction
q''	heat flux
R	residual
r	Cartesian coordinate vector
S	source term
T	temperature
v	y-component velocity

Greek symbols

β	thermal expansion
ε	surface emissivity
κ	extinction coefficient
μ	dynamic viscosity
σ	Stefan–Boltzmann constant
σ_s	scattering coefficient
ξ	1 and 0 for the solid region with and without source
ρ	density
Ω	ordinate direction vector

Subscripts

b	black body
eff	Effectively
cond	conduction
conv	convection
f	fluid
rad	radiation
s	Solid
w	wall
∞	surrounding

Acronyms

AEC	Atomic Energy Council
AOS	Add-on Shielding
CSDSS	ChinShan Dry Storage System
CFD	Computational Fluid Dynamics
DBA	Design basis accident
DO	Discrete Ordinates
DSS	Dry Storage System
ISFSI	Independent Spent Fuel Storage Installation
LOC	Limit Operating Condition
RTE	radiation transfer equation
SST	shear-stress transport
SFP	Spent Fuel Pool
SNF	Spent Nuclear Fuel
TSC	Transportable Storage Canister
VCC	Ventilation Concrete Cask
NPP	Nuclear Power Plant

a full-scope simulation using FLUENT. The full-scale CFD predictions of the TN-24P cask were compared with the experimental data. There was good agreement between FLUENT prediction and the experimental data. Kim et al. (2014) used CFD to develop the scaling methodology. This methodology was used to design the half-scale model of the concrete cask in the spent fuel dry storage. Feria et al. (2015) used the FRAPCON combined with CFD to investigate the spent fuel integrity under storage condition. Herranz et al. (2015) developed an alternative methodology for thermal-fluid dynamic modeling of dry storage cask to improve the evaluating efficiency through CFD simulation.

For the cases of ChinShan and Kuosheng Nuclear Power Plants (NPPs) in Taiwan, both of them have the licenses approved DSS facilities through CFD simulation. The DSSs of ChinShan NPP (Taipower Co., 2009) and Kuosheng NPP (Taipower Co., 2013) are concrete cask systems which can load 56 SNFs with 14 kW decay heat and 87 SNFs with 17 kW decay heat, respectively. For both of DSSs, the SNFs will be loaded into the steel basket and sealed with Transportable Storage Canister (TSC). The TSC can not only provide enough strength to protect the interior of SNFs, but also keep the refilled inert gas (e.g., helium) avoiding the degradation issue occur on the cladding of SNFs or internal components, such as the basket, aluminum-base neutron absorber.

The sealed TSC means that no penetration path exists on the boundary of TSC, which can increase the reliability of structure and reduce the probability of nuclide diffusion during the storage time. Unfortunately, this design also means that the internal status cannot be directly monitored via any temperature or pressure sensors on the sealed boundary of TSC. In order to evaluate the system situation, the thermocouple has been installed in the exit of air channel for each DSS. It can measure the air temperature values to count the heat removal rate via simplified energy balance method. However, this method cannot provide enough information for ISFSI management. For example, the safety evaluation committee of atomic energy council (AEC, 2013) noted that the vender need provide more additional information to prove the feasibility of limit operating condition (LOC) based on the outlet temperature of air-channel.

However, the additional information shows that a daily ambient temperature change (Fig. 1) would induce a significantly fluctuation of temperature difference between the both ends of air-channel. The reason is that the amount of energy stored in the components of DSS (e.g., VCC and SNFs) is larger than that of the change of convection capability, so the varied trend of component's temperatures are more stable than that of the ambient temperature. In other words, a colder air in the evening would remove more thermal power from the air channel of DSS due to the larger temperature difference, which provides well convection heat transfer capability. Based on the finding, the committee suggested

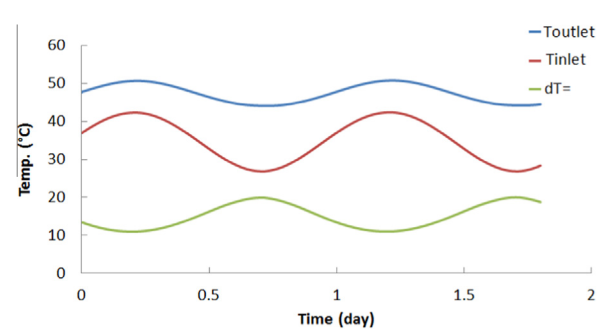

Fig. 1. The deviation of temperature difference induces by ambient temperature change.