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LLNL-TR-660976

Consequence Analysis for Used Fuel Extended Storage

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September 23, 2014

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

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Introduction and Objectives

Early identification and evaluation of security issues related to the extended storage of used nuclear fuel is critical. A breach in a dry fuel storage container has the possibility of external gas from the atmosphere interacting with the used fuel rods at high temperatures, resulting in rapid oxidation and possibly the ignition of a zirconium fire. In support of this idea, the current work aims to develop a computational model of heat transfer and fluid flow in and through a breached dry fuel storage cask to determine if the resulting flow conditions are likely to result in a fire.

R&D Overview

Modeling the heat transfer and fluid flow within a dry fuel storage cask is a challenging problem. It requires accurate models for the heat loss as well as detailed models of the fluid flow. Due to the complex geometry inside the cask, the internal gas flow is very complicated with a wide variety of length and time scales which must be resolved. Therefore, simplifications are typically used to model some of the complex flow features, while still predicting the overall structure of the flow. The hydrocode ALE3D is being used for the current calculations. The calculations are employing the incompressible flow model coupled to the thermal solver to accurately simulate the natural convection within the cask. The flow model can simulate multiple materials through interfaces or species diffusion. An LES turbulence model is available, and a porosity model can be used to model flow loss through the fuel assemblies. Additional enhancements may be added to the model as needed for future calculations.

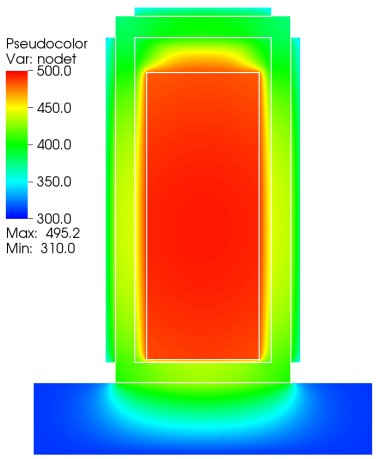
Accomplishments

The goal for FY 2014 was to evaluate various computational models in ALE3D for the simulation of used fuel storage containers. Initial studies focused on the verification of the thermal models using simplified geometries, a homogenized source, and heat loss through thermal conduction, radiation, and forced convection. The calculations were compared to analytical solutions, verifying that the computational models are accurate.

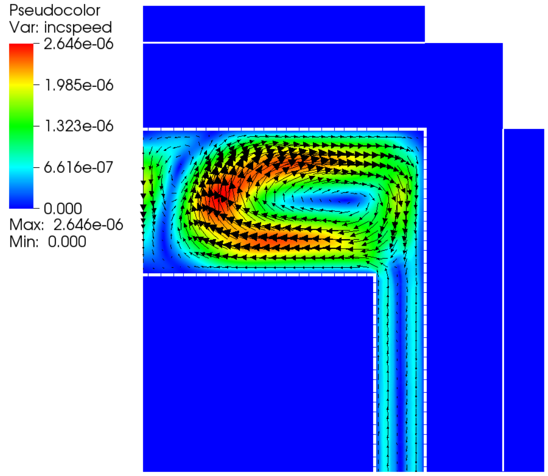
With the thermal models behaving as expected, the next calculations evaluated the incompressible fluid model for simulating the natural convection within a sealed TN-32 dry storage cask. A simplified 2D axisymmetric geometry was used to represent the cask with a homogenized source for the fuel assemblies. Although cooling gas is expected to flow along the fuel rods in a typical storage cask, the current model does not allow flow through the assemblies. This restriction is not strictly valid, but the model is a reasonable test for evaluating the model for future simulations. The calculations shown in the figures below revealed that although there is substantial flow around the homogenized assembly block, the temperature change due to internal natural convection is very small. It was also found that the flow pattern within the cask is highly unsteady. Additional artificially dissipation was required to obtain stable solutions. The effect of the extra dissipation on the solution accuracy is unclear and will need to be investigated further in future calculations.

Work planned for FY 2015 will focus on enhancing the calculations to allow flow through the assemblies using a porous media approximation to model the flow resistance from the fuel rods and support structure. A breach in the seal of the container will also be simulated to investigate the infusion of external gasses into the cask and evaluate the potential for a fire.

Temperature (Kelvin) distribution inside a simplified TN-32 storage cask.



Velocity vectors show the circulation pattern in the upper cavity of the cask.



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