Ensuring Safe Containment of Special Nuclear Material Through Advanced Computational Modeling

Tim Ashworth[1], Pawel Woelke[2], Rob English[3]

[1]Consulting Engineer, Thornton Tomasetti, Warrington WA4 6HL, UK (tashworth@thorntontomasetti.com)

[2]Consulting Engineer, Thornton Tomasetti, NY 10271, USA (pwoelke@thorntontomasetti.com)

[3]Consulting Engineer, Thornton Tomasetti, Warrington WA4 6HL, UK (renglish@thorntontomasetti.com)

Abstract

Storing Special Nuclear Material (SNM) in gas-tight packages can lead to high concentrations of certain gases. If these gases are released (through a leak or diffusion) into other layers of the package filled with air, deflagration could occur. Under such circumstances, the principal consideration becomes whether the energy of the deflagration is sufficient to damage the packaging and result in a loss of SNM containment.

A system of nested cans (typically three or four) is one packaging method used to store SNM. The stored material can generate high concentrations of certain gases inside the inner packages, which could then be released into other layers of the package and mix with air. This could lead to a deflagration and consequently a loss of SNM containment.

Many of the packages in question have been in situ for a significant period, and ensuring they adhere to modern safety protocols, including internal and external hazards such as seismic activity, is challenging yet essential for continued operation. The seismic hazard can cause sliding, rocking, "walking," and even overturning, each of which has the potential to damage integrity.

A number of experimental trials have been undertaken to investigate this issue. However, for some historic package configurations, there were no residual packages for experimental trials. Therefore, there was a requirement to develop a computational model of the relevant packaging configuration, validate this model against experimental results, and use it to predict the effect of the deflagration on the SNM packaging.

The scenario under investigation involved complex non-linear behavior of multiple metal pressure vessels (i.e., cans) immersed in fluid (i.e., gas mixture). The deflagration leads to a pressure wave, which drives the deformation and possibly failure of the cans. Solving this problem required understanding and accurate numerical representation of multiple thermo-chemo-mechanical behaviors within the entire multi-domain system. Given the challenges associated with this problem, existing simulation technology could not be readily used to qualify the packaging system.

Thornton Tomasetti developed a detailed predictive tool within the environment of existing finite volume (fluid) and finite element (solid) software packages to simulate the deformation of a set of nested packages resulting from internal hydrogen deflagration. The model used Computational Fluid Dynamics (CFD) and Finite Element Analysis (FEA) approaches and was used for qualification of the SNM packaging system. These developments were validated against existing test data for a sub-system (i.e., controlled deflagration inside the test chamber) and used for evaluation of the entire system.

The most critical elements of the computational model (e.g., combustion model, fluid-structure coupling, ductile fracture of metallic cans), once validated against carefully designed tests, were effectively used to

analyze more complicated or alternative configurations, including the entire packaging system. The ultimate goal was to use the resulting methodology for qualification of packaging options that were not available for testing.

This tool also has the ability to change assessment parameters and remove some of the conservatism from previous assessments. This allows nuclear operators to improve their understanding of the scenarios that would and would not cause failure of the packages and the level of conservatism associated with existing calculations and assessments.