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Thermo-mechanical Study of Bare 48Y UF_6 Containers Exposed to the Regulatory Fire Environment

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ABSTRACT
Regulatory agencies may require that cylinders used for the transportation of natural UF_6 and depleted UF_6 survive a fully-engulfing fire environment for 30 minutes as described in TS-R-1. The primary objective of this project is to examine the thermo-mechanical performance of 48Y transportation cylinders when exposed to the regulatory hypothetical fire environment using advanced analysis techniques to optimize the thermal protection that is currently used for shipments in those countries where such protection is required.

Several studies have been performed in which UF_6 cylinders have been analyzed to determine if the thermal protection currently used on 48Y cylinders is necessary for transport. However, these studies reached different conclusions on the survival time of a bare 48Y cylinder when exposed to the regulatory fire environment. As a result, a consortium of companies that transportUF_6 is interested in optimizing the current thermal protectors for 48-inch cylinders. Sandia National Laboratories has outlined a comprehensive analysis project to determine if the current thermal protectors for 48-inch cylinders can practically and economically be optimized while withstanding the regulatory thermal environment. Sandia-developed coupled physics codes will be used for the analyses that are planned. The analyses will consider the state of UF_6 under thermal and pressure loads as well as the weakening of the steel container due to the thermal load.

INTRODUCTION
Uranium hexafluoride (UF_6) is a chemical compound of uranium and fluorine which is used for the enrichment of uranium. For this purpose, it has to be shipped from conversion facilities to enrichment plants. Millions of tons of UF_6 have been transported throughout the world for many decades with no significant incidents that resulted in serious consequences from either the radiological or the chemical nature of UF_6. This excellent safety record is at least partially due to the robustness of the UF_6 packagings. The most common packaging is the type 48Y, which is a mild steel cylinder described in ANSI and ISO standards [1, 2]. A bare 48Y container is shown in Figure 1.

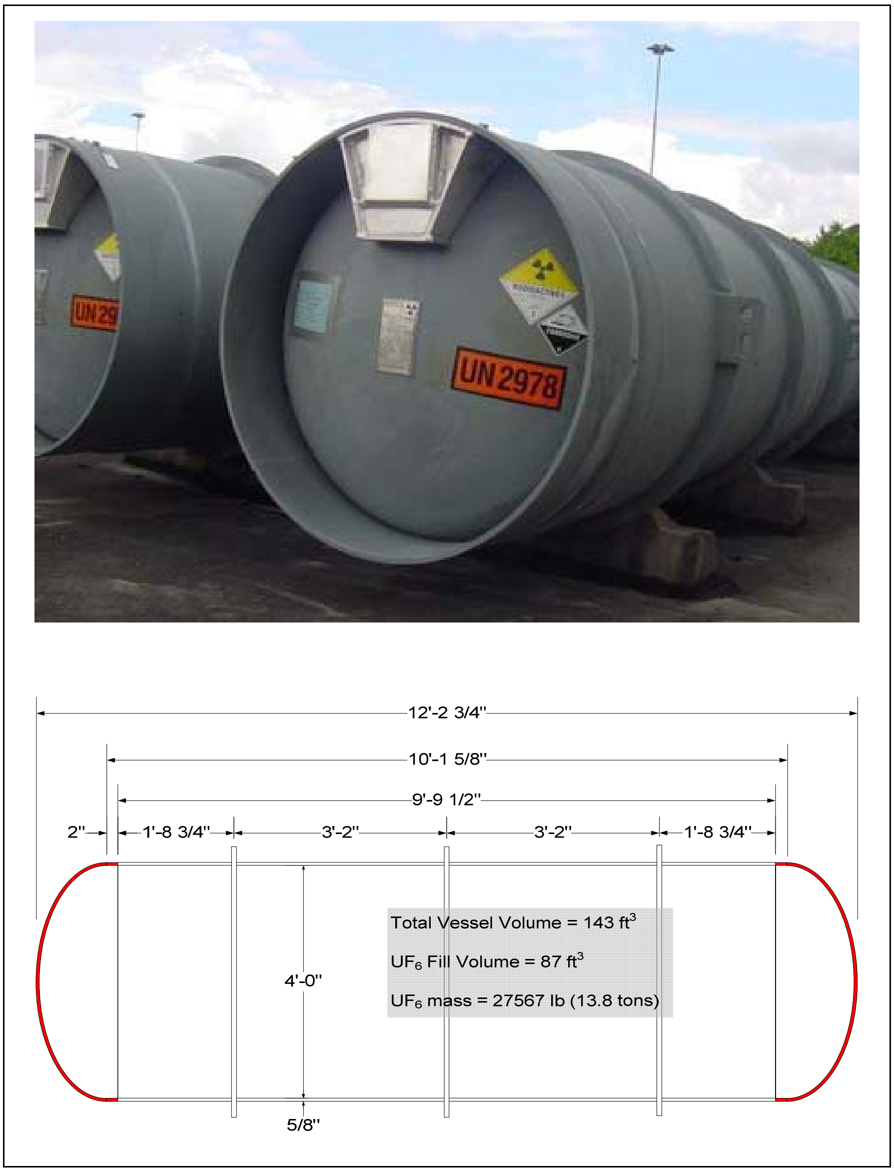

Figure 1. The 48Y UF_6 container

Transport regulations require the package to survive an 800°C fully-engulfing fire environment for 30 minutes [3]. Two types of thermal protectors are used on 48-inch cylinders containing non-fissile and fissile excepted UF_6 for transport in Europe and for international transports since January 2005. These are the Blanket Thermal Protectors (BTPs) and the Composite Thermal Protectors (CTPs). A 48Y container with these two types of thermal protectors is shown in Figure 2. Several handling, logistics, and safety issues and concerns are associated with the use of these thermal protectors [4]. Therefore, the study discussed in this paper will attempt to optimize the thermal protection currently used on 48Y cylinders. To do this, data collected from previous studies and tests will be considered and newer and more powerful multi-physics computational tools will be used in a coupled manner. Packages for fissile UF_6 are not part of the scope of this study.

Figure 2. 48Y UF_6 container with the BTP (top) and the CTP (bottom)

SIMPLIFIED MODELING AND LIMITATIONS

Simplified modeling techniques can be used to analyze the performance of the 48Y container with UF_6 inside when exposed to a fire. The event progression diagram shown in Figure 3 and the liquid level progression diagram shown in Figure 4 were developed using a simplified spreadsheet approach to the problem. Figure 5 shows the overall thermodynamic response of the system. As part of the simplified analysis, temperature-dependent properties were considered (i.e., weakening of the container walls due to the increase in temperature), and the factor of safety as a function of temperature was calculated. The results of this analysis are presented in Figure 6.

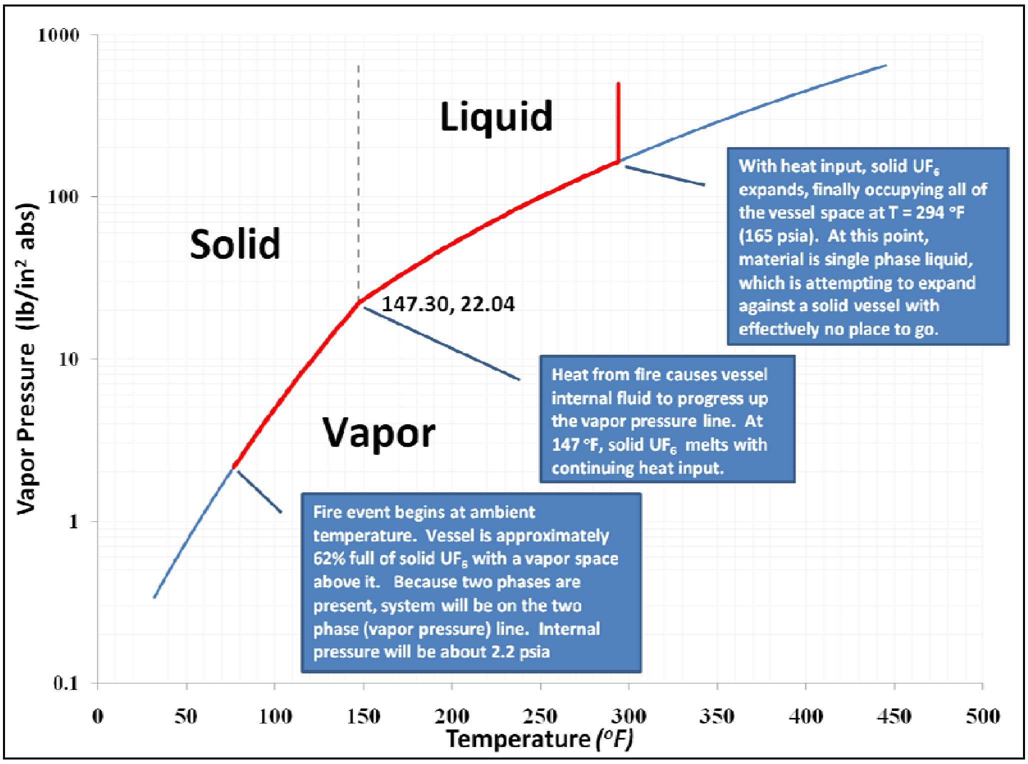

Figure 3. Simplified model event progression

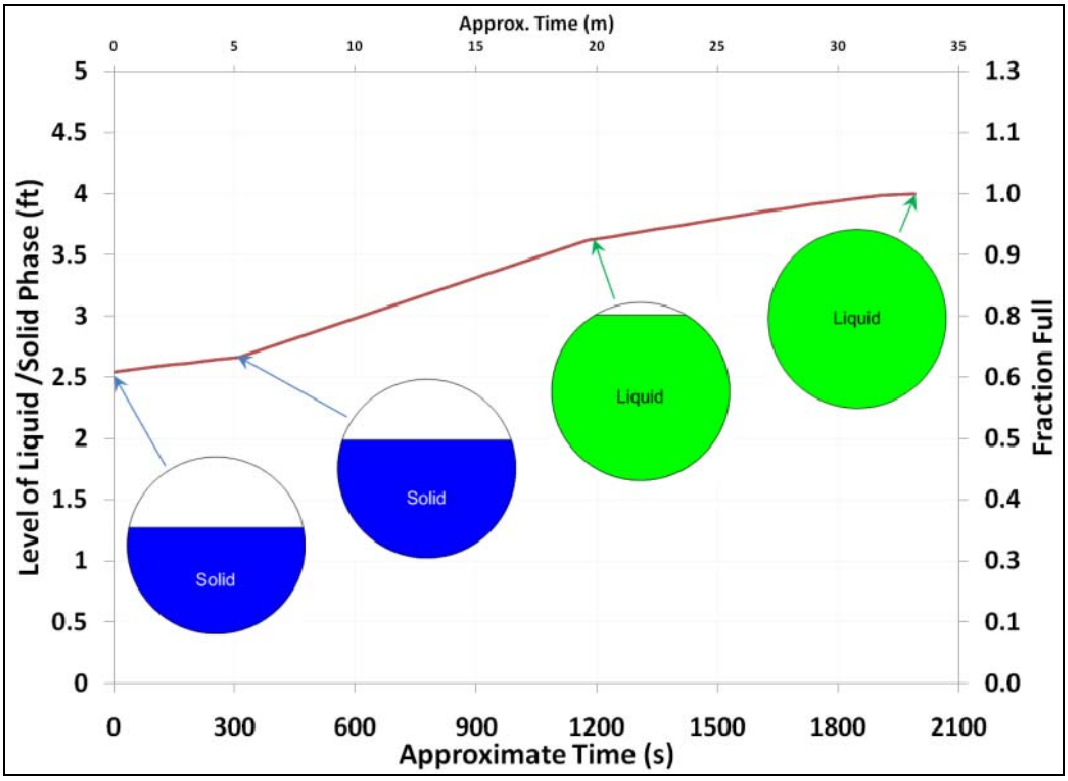

Figure 4. Simplified model liquid level progression

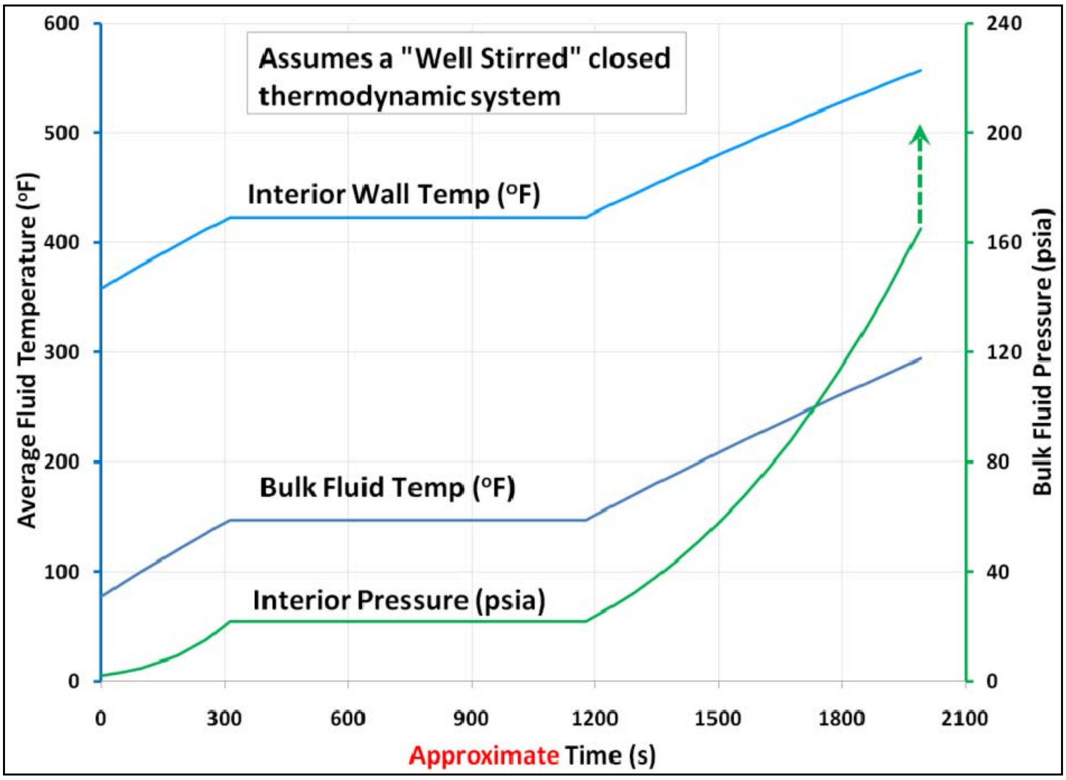

Figure 5. Overall thermodynamic response of the package (container and contents)

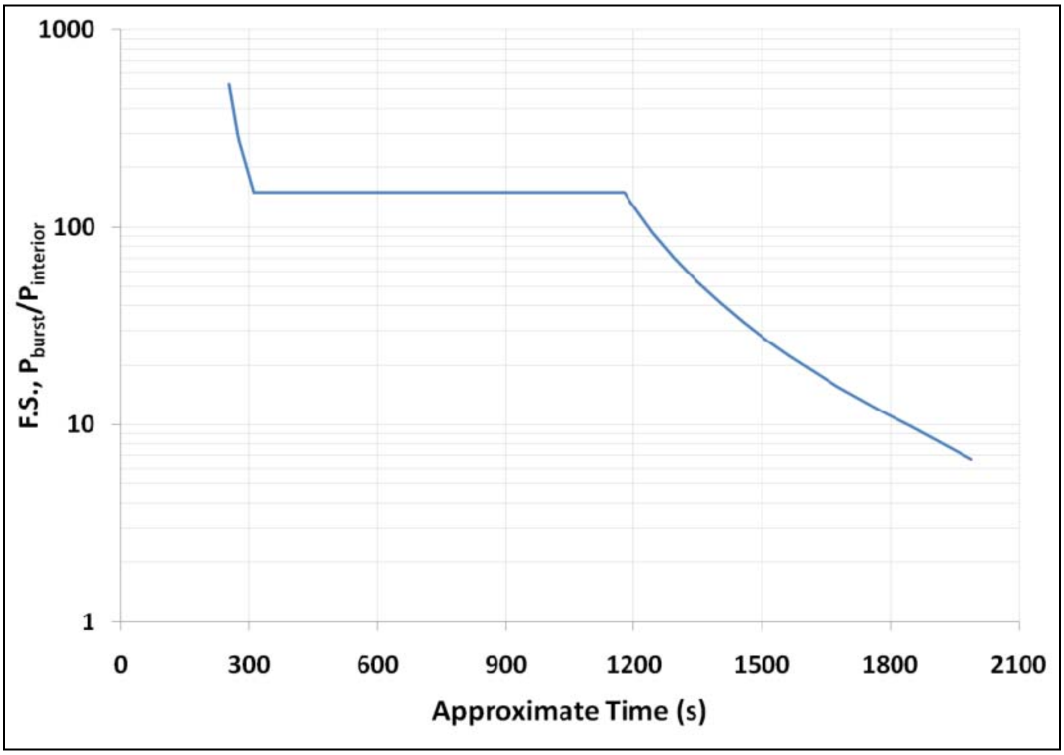

Figure 6. Factor of safety obtained from a simplified model

Note that the factor of safety decreases as the temperature increases. While the factor of safety is about 10 at the end of the 30-minute fire, it is in a downward trend. From this simplified model, one can say that the container will probably survive the 30-minute fire. However, the assumptions and uncertainties need detailed examinations as there is only a small margin for error. Therefore, a more comprehensive modeling effort would help advance the current knowledge and better define the margin of safety. In addition, a more comprehensive modeling effort can result in the optimization of the thermal protection that is currently being used.

SCOPE OF THE NEW DETAILED STUDY

As discussed above, simplified models provide guidance, but when a problem is on the edge of pass or fail as in this case, uncertainties associated with simplified models prevent a definitive answer. Therefore, a more detailed coupled analysis of the package under fire is deemed necessary to close some of the knowledge gaps that exist today. Thus, a new detailed thermo-mechanical study is expected to advance the state of knowledge and findings that were reported in a study by Shin Park in 2004 [5] and any additional applicable studies that may be identified in the course of conducting the study. In general, the scope of work for this study is to utilize advanced computer simulations to evaluate the complex thermo-mechanical behavior of a full type 48Y cylinder under the regulatory thermal performance test conditions and optimize the thermal protection required for a 48Y cylinder. The following bullets expand on the scope of work:

- Three-dimensional Modeling of a UF_6 Cylinder Exposed to the Regulatory Fire Conditions. Coupled computer models in Sandia-developed codes will be created to solve for the heating of the cylinder and UF_6, the phase change of the UF_6, and the thermo-mechanical response of the cylinder. These simulations will assume uniform heating from an 800°C source. Estimates of time to failure at welded joints and at very high temperatures will be made based on relevant published technical data. This would be the first time this problem is computationally solved in such a comprehensive manner and will advance current knowledge in this area.

- Three-dimensional Modeling of a UF_6 Cylinder Exposed to Realistic Fire Conditions. Uneven fire-like heating of the canister, as would be the case if it were to be exposed to a real fire, will reflect a more realistic thermo-mechanical response of a cylinder in an accident scenario. While uneven heating could make some regions of the cylinder more likely to fail, uneven heating may also slow down the phase change of UF_6 and result in less pressurization of the cylinder. Sandia will use state-of-the-art coupled CFD fire, heat transfer, and mechanical codes. The CFD fire code can model the fire environment in a realistic fashion; the coupled fire and heat transfer codes can accurately track the heating of the components and the mechanical code can track deformations and rupture of the cylinder. The concept is to use a computational environment that allows codes that are written to solve different physics to communicate between each other. It is also possible to model the UF_6 inside the cylinder, all in a coupled manner, and obtain results from this very advanced modeling technology.

- The properties of the UF_6 will be modeled based on current published data and information available.

- Several models will be analyzed on large supercomputers. These include:
  - 48Y with complete thermal protection - both CTP and BTP
  - 48Y with the middle section thermally protected - both CTP and BTP
  - 48Y with outer (ends) sections thermally protected - both CTP and BTP

– 48Y with no thermal protection. This analysis will be used as reference and for comparison with previous studies.
– Additional modeling will include an enhanced cylinder without thermal protection. An enhanced cylinder is one that is built to ISO/ANSI standards, but with increased quality parameters such as reduced corrosion allowance, high end of wall thickness tolerances, and 100% of weld verification.

SUMMARY

The comprehensive re-evaluation described in this paper is expected to advance the current state of knowledge on the performance of 48Y containers exposed to hypothetical fire environments. Advanced modeling techniques and computational tools running on supercomputers will be used to help quantify the margin of safety of different configurations of the 48Y container and thermal protectors. Finally, the main objective of this study is to use the results obtained from advance computational analyzes to optimize the use of thermal protectors and facilitate the shipment of UF_6.

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