FAI Recognized for Contributions to Hanford Spent Nuclear Fuel Technical Basis

by Dr. Martin G. Plys

Fauske & Associates was recently recognized by Fluor Daniel Hanford, Inc. for valuable contributions to the technical basis for processing and storage of Hanford spent nuclear fuel (SNF). At the U.S. Department of Energy Hanford (DOE) site in Eastern Washington on the banks of the Columbia River, metallic uranium fuel was used in production reactors to create plutonium until the early 1980's, and most but not all of this fuel was processed at the time. About 2000 metric tons of SNF were placed into two underwater storage pools called the K-basins. Many fuel elements suffered damage to their zirconium or aluminum exterior cladding upon reactor discharge, and long-term corrosion has resulted in extensive damage because of progressive cladding failure and formation of oxides, hydrated oxides, and hydrides of uranium. The fragility of the K-basins, their proximity to the river, and the cumulative problems caused by continuing corrosion have motivated the DOE to relocate this fuel to dry storage on an arid plateau safely away from the Columbia.

FAI played a key role in demonstrating process safety by evaluating the potential for pyrophoric reactions of metallic uranium and its hydride, and by working with SNFP engineers on design improvements to improve heat rejection during processing.

Technical difficulties associated with this project include a wide range of fuel and corrosion product physical and chemical characteristics, limited knowledge of the state of about half the fuel which is stored in closed canisters in the K West basin (canisters of fuel elements in the K East basin are open on top), the potential for pyrophoric behavior of uranium metal fragments and uranium hydride, and radiolytic decomposition of hydrates during long-term storage. The original process called for underwater (for shielding) placement of 6 tons of fuel and scrap at a time into multi-canister overpack (MCO) containers of stainless steel measuring 2 feet in diameter and about 13 feet in length including a top shield plug, pumping out the water, removing most residual water by vacuum drying at 50°C, staging the MCOs while a hot conditioning facility was build, processing the fuel at 300°C to remove remaining moisture, decompose water-bearing compounds, decompose uranium hydrides, and partially oxidize exposed metal surfaces, and finally placing the MCOs into storage tubes in an above-ground dry storage facility cooled by natural convection through a vault surrounding the storage tubes.

FAI played a key role in simplification of the process by proving that after cold vacuum drying, the MCO water inventory would be low enough to allow direct sealed dry storage of the MCOs with no pressure relief or hot conditioning process required. The current process therefore involves welding a seal cap atop the MCO after it is shipped to the storage facility from the vacuum drying station, and placing it into dry storage for the forty year design lifetime. FAI also played a key role in demonstrating process safety by evaluating the potential for pyrophoric reactions of metallic uranium and its hydride, and by working with SNFP engineers on design improvements to improve heat rejection during processing. A key feature of process safety is the reactive surface area and kinetic rate of reaction of the damaged fuel. The uranium-water vapor reaction follows linear Arrhenius kinetics below about 300°C because the oxide density is about half the metal density and oxide layers are regularly shed at a few microns thickness - so reaction rates per unit area do not decrease during processing.

Hydride inclusions are typically submicron to several micron size, and in principle cause large surface area enhancement; these inclusions are encountered at surfaces but also populate cracks which are frequently observed in damaged fuel. The combination of high-surface area uranium metal and hydride with water vapor oxidant, power from radioactive decay, and heat transfer resistance in the MCO clearly leads to a concern about the potential for runaway oxidation reactions during processing.

FAI was able to quantify the surface area associated with fuel fragments, known as scrap, using characterization data obtained by SNFP engineers and employing probabilistic methods (a Monte-Carlo analysis given the possible geometries of scrap pieces). FAI also applied ignition theory techniques used in commercial chemical process safety to provide safe combinations of heat rejection capability, process temperature, and reactive surface area, and

worked with SNFP engineers on scrap basket design concepts that would be thermally stable with adequate margin. FAI supplied a computer program, HANSF, to the SNFP for evaluation of coupled thermal, chemical, and aerosol problems in a multi-compartment facility, for normal process analysis and off-normal consequence evaluation. This program can be applied to commercial chemical facility analyses and will be described in a later newsletter.

FAI also worked with SNFP engineers to establish the inventory of water-bearing compounds prior to and after vacuum drying, and FAI provided a model for prediction of hydrogen and oxygen generation due to radiolysis in the MCO during dry storage, and the resulting pressurization. Expected pressures were shown to be almost an order of magnitude below the design pressure of 450 psig, and gas concentrations were shown to be normally nonflammable except when combinations of bounding parameters were employed. These facts ultimately led to confidence in the integrity of the vacuum drying process, and the ability to safely store fuel directly after vacuum drying.

In its letter to Dr. Fauske, Fluor Daniel wrote about the contributions of Dr. Martin Plys saying "Marty has brought to the SNF Project a solid background in chemical process engineering, a keen insight and powerful work ethic. He has completed difficult tasks on time, and has proven himself to be a strong partner in the explanation of our technical positions to our customer and our regulators, including the Defense Nuclear Facility Safety Board technical staff." In fact, Dr. Plys was supported by Dr. Michael Epstein, Dr. Sung Jin Lee, and Mr. Boro Malinovic for these technical contributions.

Articles Available From FAI

The Reactive System Screening Tool (RSST): An Easy, Inexpensive Approach to the DIERS Procedure

Sizing Rupture Disks (RDs) for Two-Phase Flow

An Easy, Inexpensive Approach to the DIERS Procedure

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Simplified Vent Sizing Equations for Emergency Relief Requirements in Reactors and Storage Vessels

Flashing Flows or: Some Practical Guidelines for Emergency Releases

A Quick Approach to Reactor Vent Sizing

Generalized Vent Sizing Nomogram for Runaway Chemical Reactions

The Next Step to Accommodate Major Chemical Accidents

Pressure Relief and Venting: Some Practical Considerations Related to Hazard Control

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Estimation of Peak Pressure for Sonic-Vented Hydrocarbon Explosions in Spherical Vessels

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Practical Containment Concepts in Connection with Chemical Accidents and Vapor Cloud Modeling

Runaway System Characterization and Vent Sizing Based on DIERS Methodology

Preventing Explosions During Chemicals and Materials Storage

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Multi-Phase Flow Considerations in Sizing Emergency Relief Systems for Runaway Chemical Reactions

Scale-Up For Safety Relief of Runaway Reactions

The Onset of Two-Phase Venting Via Entrainment in Liquid-Filled Storage Vessels Exposed to Fire

Emergency Relief Systems-Sizing and Scale-Up

Emergency Relief Vent Sizing for Fire Emergencies Involving Liquid-Filled Atmospheric Storage Vessels

Large-Scale Experiments of Emergency Relief Systems

New Experimental Technique for Characterizing Runaway Chemical Reactions