DEFENSE NUCLEAR FACILITIES SAFETY BOARD

Washington, DC 20004-2901

November 1, 2013

The Honorable Ernest J. Moniz
Secretary of Energy
U.S. Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585-1000

Dear Secretary Moniz:

On September 25, 2013, the Department of Energy's (DOE) Senior Advisor for Environmental Management asked the Defense Nuclear Facilities Safety Board (Board) to provide its perspective on the safety implications of removing a portion of the radioactive liquid from tank 241-AY-102 at the Hanford site. The Board is unable to determine whether any safety implications exist.

The waste temperature in tank AY-102 is of particular significance to nuclear safety. The Board analyzed a report provided by DOE, RPP-RPT-53901 Rev. 2, *Management of Supernatant Level in Tank 241-AY-102*, which concludes that decanting is likely to have little effect on tank waste temperatures and the estimated leak rate. However, the Board determined that insufficient information exists to support this conclusion. Specifically, the report does not address key technical uncertainties with the condition of the tank, such as: (1) the specific cause of the leak and the leak rate remain unknown; (2) the chemical and physical conditions at the leak site are uncertain; and (3) the impact from a change in temperature, pressure, or chemistry on the leak rate are also uncertain.

If DOE proceeds with radioactive liquid decanting, the Board advises DOE to closely monitor for signs of increased leakage and blockage of the insulating refractory slots that distribute cooling air to the tank bottom. The Board also advises DOE to consider developing a more rigorous multi-dimensional, transient thermal analysis model to aid in understanding the safety significance of any observed changes in tank conditions subsequent to decanting. The enclosed report contains additional information on the Board's evaluation.

Sincerely,

Peter S. Winokur, Ph.D.
Chairman

Enclosure

c: Mrs. Mari-Jo Campagnone

DEFENSE NUCLEAR FACILITIES SAFETY BOARD

Staff Issue Report

October 24, 2013

MEMORANDUM FOR:	S. A. Stokes, Technical Director
COPIES:	Board Members
FROM:	M. Forsbacka, M. Horr, A. Poloski, R. Rosen, D. Shrestha
SUBJECT:	Safety and Integrity Implications of Decanting Liquid from Hanford Tank 241-AY-102

Introduction. Hanford waste tank 241-AY-102 (tank AY-102), the first double-shell tank (DST) at Hanford, was built during 1968–1970 and was placed into service in 1971. During a visual inspection in August 2012, Washington River Protection Solutions (WRPS) personnel discovered accumulations of material at three locations within the secondary confinement of tank AY-102. Two accumulations were located on the floor of the tank AY-102 annulus between the primary and secondary tank liners, and a third was on the primary tank dome above the waterline. None of the material was seen during the December 2006 and January 2007 visual inspections. The Department of Energy (DOE) Office of River Protection (ORP) and WRPS established a leak assessment team to review tank construction, review operating histories, and to determine the probable cause of the leak. The team met from August 28, 2012, to October 10, 2012, to gather and analyze information, formulate tank leak and non-leak hypotheses, and identify the source of the accumulated floor material. WRPS personnel completed their formal leak assessment report in October 2012.

Tank AY-102 contains 151,000 gallons (57 inches) of high decay heat sludge primarily retrieved from single-shell tank 241-C-106 and 680,000 gallons (270 inches) of radioactive supernatant liquid on top of the sludge. DOE-ORP is making plans to remove a portion of the radioactive supernatant liquid due to the identified leak. DOE-ORP approved a WRPS report, RPP-RPT-53901 Rev. 2, *Management of Supernatant Level in Tank 241-AY-102*, on September 30, 2013, which recommends decanting the radioactive supernatant liquid layer from 270 inches to 96 inches and maintaining the liquid level above 48 inches through future water additions if needed to account for evaporation. DOE's Senior Advisor for Environmental Management asked the Defense Nuclear Facilities Safety Board (Board) on September 25, 2013, to provide its perspective on the safety implications of removing a portion of the radioactive liquid from tank AY-102.

Approach. In response to DOE's request, members of the Board's staff evaluated DOE's plans to decant tank AY-102 supernatant liquid. This report documents the staff members' evaluation. RPP-RPT-53901 concluded that decanting is likely to have little effect on tank waste temperatures and the estimated leak rate. The staff members performed a technical evaluation of RPP-RPT-53901 to assess if these key conclusions are well-supported. This effort included reviewing supporting DOE technical reports, tank schematics, in-tank temperature data, and independent calculations to understand how changes in liquid level might affect waste temperature, the estimated leak rate, and other potential impacts on tank safety. For example, hydrogen generation and corrosion rates are dependent on temperature, following an Arrhenius-type behavior where the reaction kinetics increase exponentially with temperature. Therefore, the waste temperature in tank AY-102 is of particular significance to nuclear safety.

Background. Figure 1 shows a schematic of a Hanford DST as shown in HNF-EP-0182, *Waste Tank Summary Report for Month Ending December 31, 2012*. The DST's primary steel liner rests on an insulating refractory layer on top of the floor of the secondary steel liner. The entire system rests on a concrete foundation. The bottom plate of the primary tank liner is 3/8-inch thick and the bottom plate of the secondary tank liner is 1/4-inch thick. The tank annulus refers to the space formed between the primary tank and secondary tank liners, and extends from the base of the tank to the dome of the tank. The secondary tank liner is 80 feet in diameter, and the primary tank liner is 75 feet in diameter. The resulting annulus is 2-1/2 feet wide. The capacity of tank AY-102 is one million gallons of high-level radioactive waste. Current temperature monitoring capabilities for tank AY-102 include approximately 40 operating thermocouples in the tank at various heights and radial locations and thermocouples embedded in the concrete foundation, the refractory, and the tank dome. Additionally, ENRAFs, a type of level sensor, are used to measure liquid height.

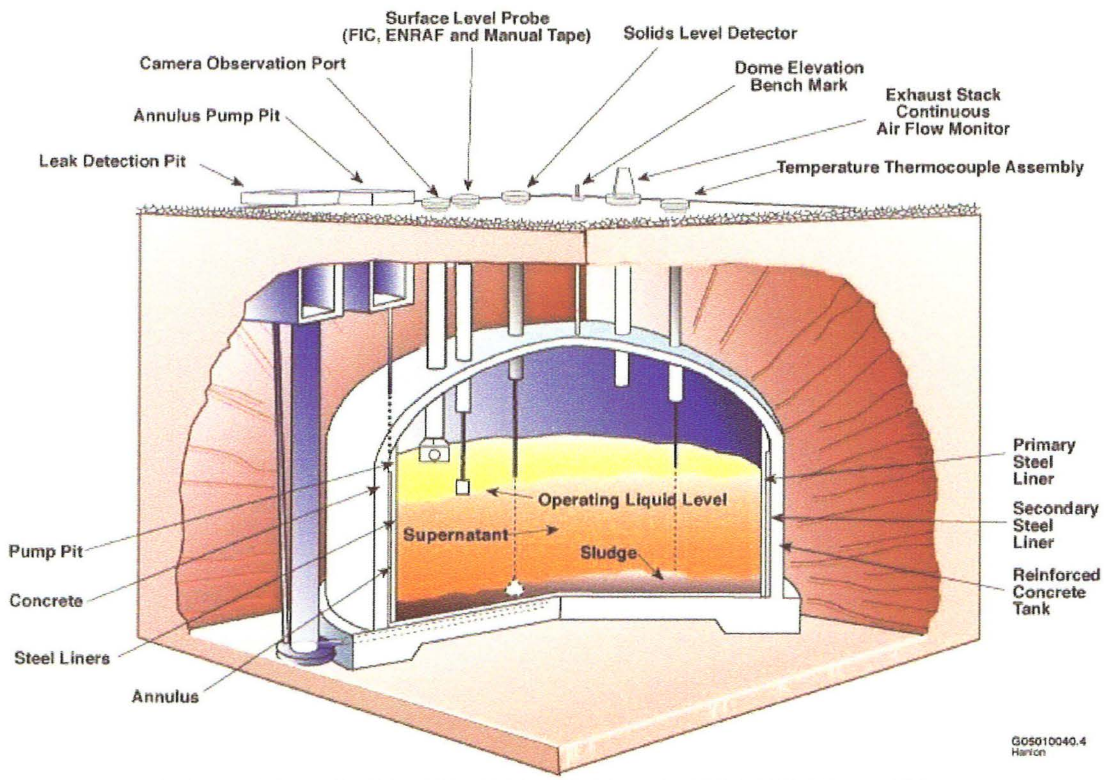

Figure 1. Hanford double-shell tank (from HNF-EP-0182 Rev. 297).

During September and October 2012, WRPS personnel collected and analyzed samples from two waste accumulation locations on the annulus floor. The material was radioactive, and its composition was consistent with tank AY-102 waste. Detailed records for tank 241-AY-101, the second DST built at Hanford, were also studied for comparison. The leak assessment team concluded that the likely cause of the material on the tank AY-102 annulus floor was the result of a breach on the bottom of the tank's primary liner from high-temperature corrosion. Tank AY-102, being a first-of-a-kind DST at Hanford, encountered numerous difficulties during its construction period. The WRPS team concluded that these construction difficulties resulted in the primary tank's bottom being more susceptible to eventual failure than other DSTs constructed afterwards. Figure 2 shows details of the annulus, including the insulating refractory between the primary and secondary liners. Figure 2 also shows a diagram of the slots in the refractory on the tank bottom which distribute annulus ventilation air to the tank bottom for cooling. The total leakage volume from the primary tank, estimated on February 7, 2013, was 190–520 gallons. A significant portion of the liquid has since evaporated, leaving 20–50 gallons of dry waste in the tank annulus. Figure 3 shows an image of the dried waste, labeled as "Crystal Nodules."

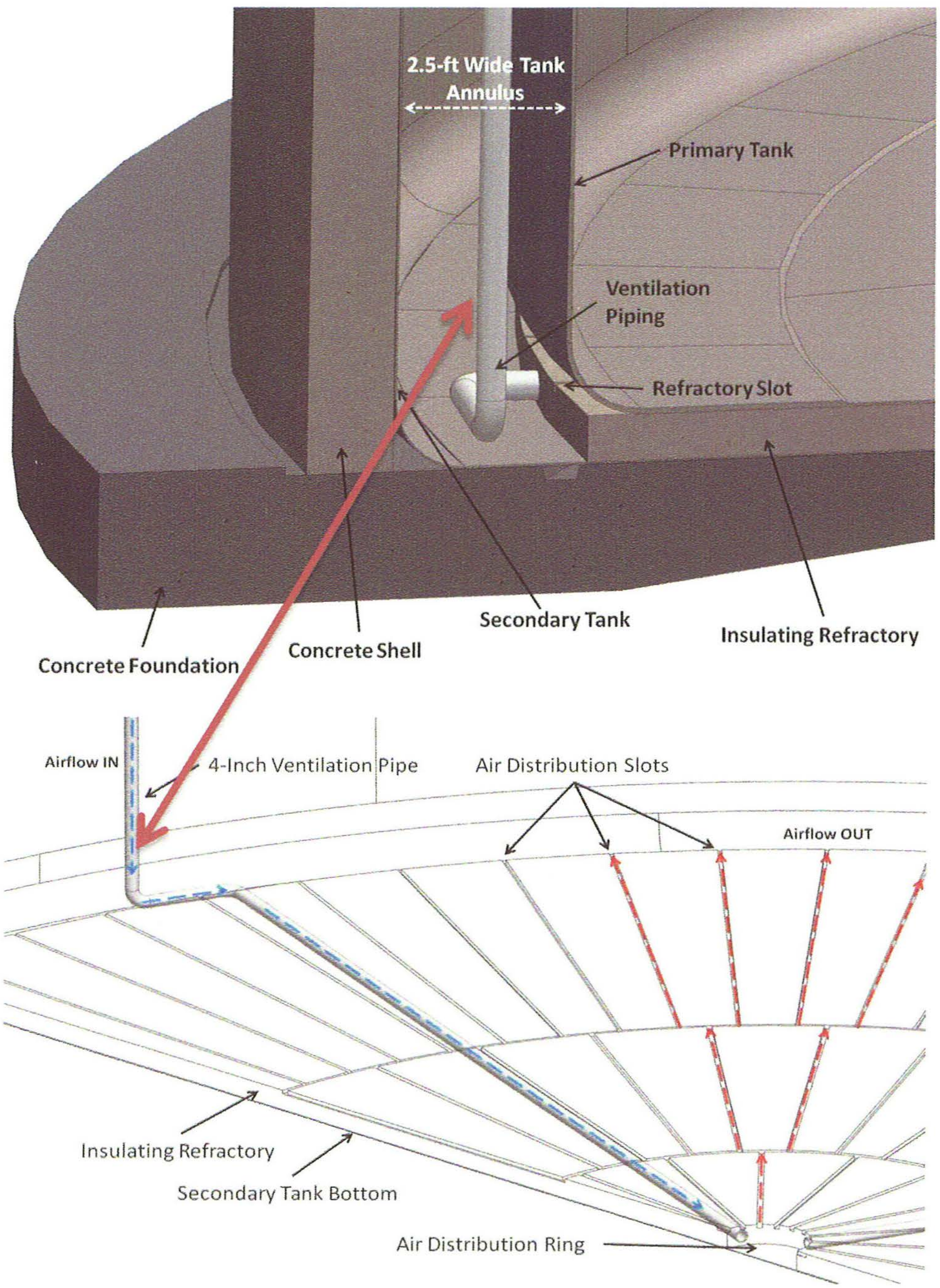

Figure 2. Top—Hanford double-shell tank annulus (from RPP-ASMT-53793); Bottom—Secondary ventilation system air distribution for 241-AY-102 (from RPP-ASMT-53793).

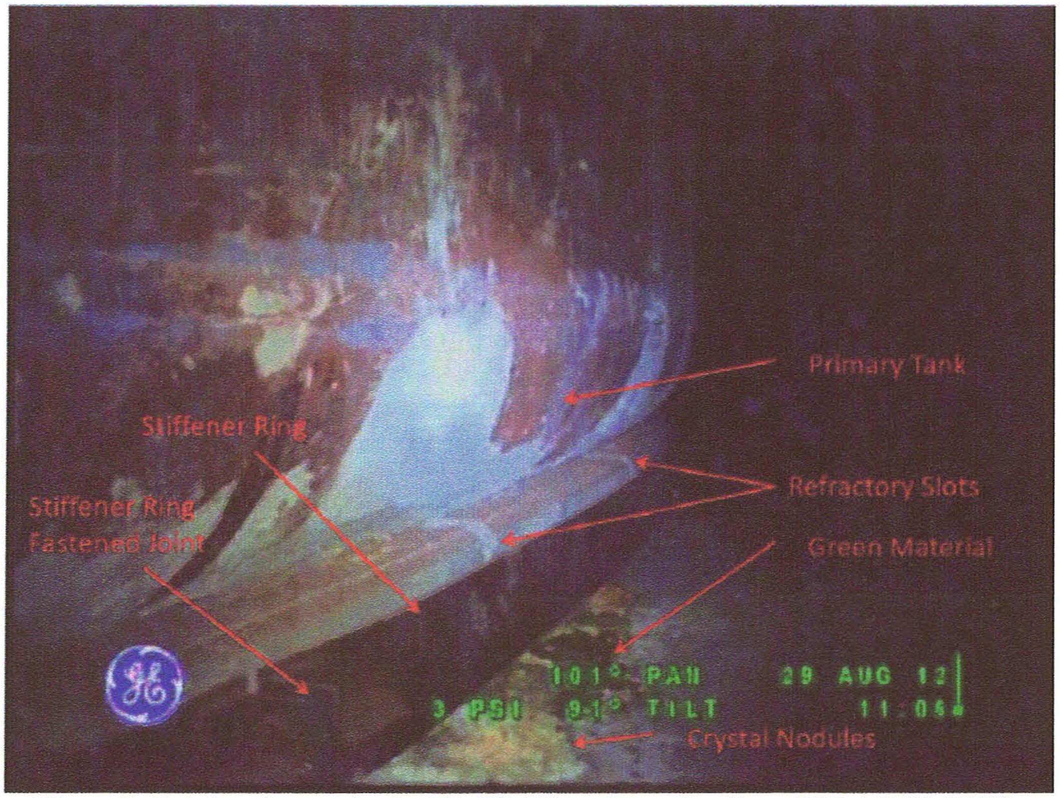

Figure 3. Dried tank waste in the 241-AY-102 tank annulus (from RPP-ASMT-53793).

Technical Evaluation of RPP-RPT-53901. The staff members found that the analyses contained in RPP-RPT-53901 are insufficient to determine the effect of supernatant level changes on waste temperatures and leak rates. RPP-RPT-53901 did not account for several key physical aspects of the relationship between supernatant height and heat transfer mechanisms that could result in a more adverse thermal condition than analyzed. For instance:

- The analyses do not account for the reduction in the heat transfer surface area between the supernatant layer and primary liner wall resulting from the reduction in the height of the supernatant layer.
- The analyses do not properly account for heat transfer rates varying with waste temperatures in accordance with Newton's law of cooling.
- The analyses use bulk average temperatures and do not consider higher localized temperatures that could exceed AY-102 corrosion control limits.

On October 3, 2013, the staff members held a teleconference with DOE-ORP and WRPS personnel to discuss RPP-RPT-53901. WRPS personnel stated that the primary purpose of the report was to produce a general thermal analysis to support maintaining an adequate supernatant liquid height for this high decay heat tank. Information and analyses that could improve predictions of waste temperatures and leak rates due to changing supernatant liquid height include the following:

- Radial and axial heat transfer mechanics inside the primary liner. This includes heat transfer behavior between the heat generating layer of sludge, the supernatant liquid, the tank walls, and the ventilated air in the tank headspace.

- Radial and axial heat transfer mechanics between the primary and secondary liners. This includes heat transfer behavior between the primary liner and the ventilated refractory layer beneath the vessel, the ventilated air space in the tank annulus, and the surrounding soil.

- Both of these areas are dependent upon how the heat transfer mechanisms change with ventilation status.

An analytical tool that can adequately account for these phenomena is a validated, multi-dimensional, transient heat transfer model. Results from such a model would be helpful in understanding the effects of changing the waste height due to the decanting operation and ventilation status on waste temperatures. The modeling approaches used by previous Hanford tank farm contractors in the late 1990s, are an example of the level of technical detail that could assess this type of complex thermal system. These efforts did produce predictions of radial and axial temperature distributions in tank AY-102 including transient effects from primary and secondary ventilation outages, but did not contain modeling results for the specific supernatant liquid decant scenario under evaluation.

DOE's current plan to partially decant tank AY-102 will cause a corresponding reduction in hydrostatic pressure at the bottom of the primary tank liner. Although Darcy's Law predicts that a reduction in hydrostatic pressure would correspond to a reduction in leak rate, RPP-RPT-53901 concludes the leak rate through a leakage site in the floor of the primary liner is likely insensitive to hydrostatic pressure because, once the liquid waste enters the presumed small leak opening and starts its tortuous path through the underlying refractory, pressure is quickly dissipated over a distance of a few inches.

In addition to uncertainty about the impacts of reducing hydrostatic pressure by decanting, there are several other complicating factors that make determination of the net effect of decanting on the leak rate uncertain. Most of these factors are unknown or have significant uncertainty. They include:

- The mechanism that led to the original tank liner failure (e.g., pitting, stress corrosion cracking, or preexisting flaw) and how the growth rate for this type of leak site increases as a result of increased waste temperatures.

- How the size, shape, and tortuosity of the leak site and the leak flow path change due to hydrostatic pressure, thermal expansion, and the drying of the leaked waste.

The complexity of the competing factors in this system is illustrated by liquid waste in the leak path to the tank annulus drying and forming solid deposits. For example, solid deposits can limit or plug the leak from the tank bottom. Conversely, because the leak path to the annulus is through the refractory slots, solid deposits can plug the air distribution system along the tank bottom (see Figure 4). Blockage of the refractory slots reduces air flow and limits the annulus ventilation air from cooling the tank bottom. Because the total volume of refractory slots is on the order of several hundred gallons, a relatively small tank leak volume could significantly alter air flow in localized regions of the tank bottom. Any reduction of cooling would increase localized temperatures and thermal gradients on the tank bottom, potentially significantly increasing the corrosion rate.

Figure 4. Close-up of dried tank waste in the refractory slot (from RPP-ASMT-53793).

RPP-RPT-53901 acknowledges that over time, leaked waste might eventually inhibit air flow through the channels in the refractory. Consequently, annulus ventilation flow might be lost beneath the primary liner. The report states that accurately estimating temperature rise requires a complex three-dimensional heat transfer model, but asserts that the historic temperature behavior of single-shell tank 241-C-106 (the source of the tank AY-102 high heat sludge) can be used to bound tank AY-102 waste temperatures if the annulus ventilation is lost. RPP-RPT-53901 further states that during the 1990s, the maximum solids temperature in C-106 was 160 to 170°F and that similar temperatures should be expected in tank AY-102 settled solids if the annulus ventilation system were not operated, assuming that the primary ventilation system continued to operate and supernatant depth was maintained at over 12 inches. This conclusion is only valid if, after accounting for decreases in decay heat from the 1990s, the heat transfer resistance from the waste in a single-shell tank to the surrounding soil is greater than or equal to an analogous DST. Heat transfer through the air-filled annulus in a DST to the soil is expected to add an additional heat transfer resistance term resulting in a higher corresponding waste temperature. The WRPS report did not analyze thermal transport differences between a single-shell tank and a DST.

The primary and annulus ventilation systems provide significant heat removal for the sludge heat source. While these ventilation systems are in operation, decreasing the supernatant liquid height between 96 to 48 inches is not likely to significantly raise the temperature of the waste. However, as discussed above, leaked waste can inhibit operation of the annulus ventilation system. The staff members' analysis finds that temperatures on the tank bottom increase significantly when the annulus ventilation system is off. Figure 5 shows that the temperature of the refractory layer at the tank bottom increased steadily during a test when the primary ventilation system was on and the annulus ventilation system was cycled off. When the ventilation system was cycled on, the tank bottom was rapidly cooled.

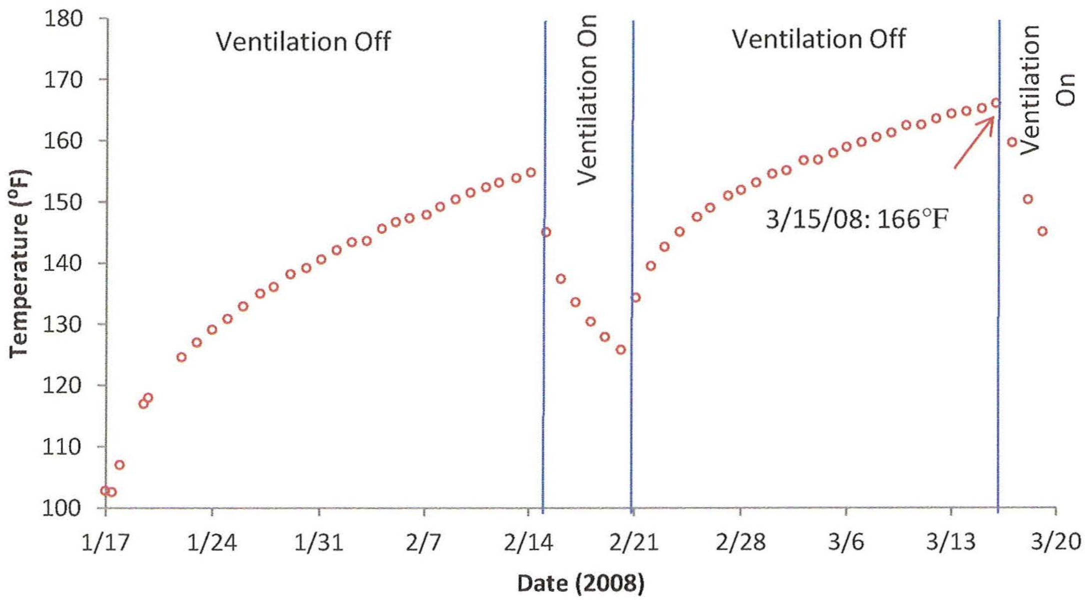

Figure 5. Tank AY-102 refractory temperatures from a thermocouple 21 ft from the tank centerline when the primary ventilation system is on and the annulus ventilation is cycled on and off (source: Tank Waste Information Network System).

After a decade of additional radioactive decay after retrieval from tank C-106 in the 1990s, on March 15, 2008, the temperature of the tank AY-102 refractory reached about 166°F and appeared to be steadily increasing until the annulus ventilation system was turned back on at the end of the test (see Figure 5). Based on these data, it is apparent that the historical C-106 maximum solids temperature range of 160 to 170°F does not represent an upper bound for tank AY-102. Because the half-life of the radioisotopes primarily responsible for the decay heat in the tank waste is about 30 years, 5 years for additional radioactive decay from 2008 to 2013 is not expected to significantly change this conclusion. These data show that a prolonged annulus ventilation outage will raise the temperature of the tank bottom, which may lead to increased hydrogen generation and corrosion rates. Higher localized tank temperatures can exist between tank thermocouple locations. The final tank temperatures cannot be accurately predicted or bounded with the existing WRPS analysis. A multi-dimensional, transient thermal transport model would be useful in assessing tank bottom temperature increases relative to corrosion control limits resulting from restricted air flow on the tank bottom.

Conclusions. DOE's analysis supporting an interim change in radioactive liquid level from 270 to 96 inches is insufficient to determine if there is an immediate positive or negative effect on the safety condition of tank AY-102. The annulus ventilation system is a significant contributor in keeping the tank bottom temperatures cool. The ongoing leak in the primary liner of tank AY-102 appears to have obstructed a portion of the air distribution slots immediately below the primary tank bottom, which is a key section of the annulus ventilation system. If a significant portion of this cooling air distribution system is lost, waste temperatures will increase.

Reaction kinetics increase exponentially with temperature. Hence, the potential exists for increased corrosion and hydrogen generation rates.

Continued visual inspections of the tank annulus and close monitoring for variations in waste temperature (particularly near the tank bottom) and annulus ventilation, which can be indicative of increased leakage and blockage of the refractory slots that distribute cooling air to the tank bottom, are prudent steps if DOE proceeds with radioactive liquid decanting. Further analysis, including development of a more rigorous multi-dimensional, transient thermal transport model could provide better understanding of the significance of any observed changes.