Request for Additional Information

Regarding Private Fuel Storage's

Analysis of the Potential Consequences of an F-16 Aircraft

Crashing into the Proposed Private Fuel Storage Facility

And the Responses to the Staff's August 15, 2003 Request for Additional Information

Preface:

This Request for Additional Information (RAI) is based upon the U.S. Nuclear Regulatory Commission (NRC) staff's review of the September 4th and 5th, 2003, response provided by Private Fuel Storage, LLC (PFS), to the staff's August 15, 2003 RAI and the series of reports and analyses submitted by PFS to address the potential consequences of an F-16 Aircraft crashing into the proposed Private Fuel Storage Facility (PFSF). Each request below references either a PFS response to the staff's August 15th, 2003 RAI, or one of the consequence analysis reports listed below.

The NRC staff is carrying out this review in order to reach a conclusion about the consequences of an F-16 crash into the proposed PFSF, in connection with the ongoing proceeding before the NRC Atomic Safety and Licensing Board (the Board). In its Partial Initial Decision (Regarding "Credible Accidents") (LBP-03-04), dated 03/10/2003, the Board found that PFS had not demonstrated that the probability of an F-16 crashing into the proposed PFSF is below the threshold of one in a million per year (1×10^{-6}). The Board provided PFS with the opportunity to address the consequences of such a crash, in order to demonstrate that the consequences of such a crash would not be significant.

Because the staff wishes to avoid further delays in completion of the adjudication of the consequence analysis question, this RAI is at a greater level of detail and complexity than previous RAIs issued to this applicant during the licensing process. The staff believes that this level of detail and complexity should provide PFS with sufficient understanding of the information that the staff needs to complete its evaluation.

The reports and analyses submitted by PFS regarding consequence analysis are:

- Burdeshaw Associates, "Assessment of Jettisoned Ordnance Impact Effects for the Private Fuel Storage Facility" (Author-Lancaster)

- Burdeshaw Associates, "Evaluation of F-16 Aircraft Crash Impact Speed and Angle for Skull Valley-Type Events" (Authors-Jefferson, Fly, Cole)

- A. Cornell, "Probability Assessment of the Aircraft Crash Impact Hazard for the [PFS] Facility Based on Engineering Evaluations of Storage Cask and Canister Transfer Building Structural Integrity

- Holtec International Concrete Benchmarking Report

- Holtec International HI-2033044, "Evaluation of Spent Fuel Canister Integrity in the Event of A Fuel Fire Caused by an Aircraft Crash at the PFS Facility"

- Holtec International HI-2033045, "Structural Evaluation of an F-16 Aircraft Impact on HI-STORM Overpacks at the PFS Facility"

- Stone and Webster (S&W) No. 59056, "Evaluation of Aircraft Impact on the Canister Transfer Building"

- Private Fuel Storage, LLC-Response to Staff's August 15, 2003, Request for Additional Information, submitted September 4th and 5th, 2003.

1. Related to PFS Response to RAI-4

A. Explain the basis for the assumption that the dynamic response of the bolts to lateral accelerations only depends on the area under the acceleration time-history curves.

This approach appears to be unsupported. The comparison of the areas under the acceleration time-histories does not consider the combined dynamic effects of peak acceleration, duration and shape on the bolt response.

B. Analyze the tensile force demand on the studs for the cask-to-cask impact to verify that it is enveloped by the corresponding demand for the cask-to-pad tip-over case, and that a similar conclusion can be made for the combined shear and tension case.

The applicant has not evaluated the bolt tensile loads, and tensile loads in combination with shear, resulting from accelerations in a direction normal to the lid plane.

C. Provide the velocity versus time curves for each cask, starting with the aircraft impact and until the casks come to rest.

Results of the V-N analysis showing the velocity versus time curves would be helpful to understand the aircraft impact phenomenon and verify that the results are reasonable.

2. RAI Related to PFS Response to RAI-6

A. Justify the use of the ultimate shear strength of the overpack steel lid bolts as 145 ksi and evaluate the structural adequacy of the cask lid bolts using the currently licensed approach for the HI-STORM cask under accident conditions.

The ultimate shear strength of the bolts used in Holtec Report HI-2033045 is 145 ksi, which is the ultimate tensile strength of the bolts (Ref. HI-2033045, pp.22-23, 35, 47-50, Appendix B). The ultimate shear strength of the bolts, however, is not equal to the ultimate tensile strength. Test results have demonstrated that the shear strength is approximately 60 percent of the tensile strength. [Note: The terminology “ultimate shear strength” and “ultimate tensile strength” are interchangeable with “shear strength” and “tensile strength”.]

While the ultimate shear strength as a function of ultimate tensile strength is not derivable from the Maximum Distortion Energy Theory, the ultimate shear strength is nonetheless approximately 60% of the ultimate tensile strength. While PFS cites an LS-DYNA simulation to support its position that the failure theory employed in the analysis is supportable, the use of the ultimate tensile strength of the steel bolt material in place of the ultimate shear strength is unsupported, and is contrary to the value used in the HI-STORM cask Certificate of Compliance analyses. See the three references cited below.

References:

1. Charles Salmon and John Johnson, “*Steel Structures – Design and Behavior*,” Harper Collins, Fourth Edition, 1996.
2. John Fisher and John Struik, “*Design Guide Criteria for Bolted and Riveted Joints*,” John Wiley & Sons, 1974.
3. James Wallaert and John Fisher, “*Shear Strength of High-Strength Bolts*,” Journal of the Structural Division, ASCE, June 1965.

B. For the simulation model employed in response to RAI-6, determine how much of the total shear force between the lid and top plate that is resisted by friction.

C. To address the friction issue, provide a simulation analysis in which the coefficient of friction is approximately equal to zero.

In response to RAI-6, an LS-DYNA simulation model focusing on a single stud and nut together with a portion of the lid was developed. It is stated in the response that “The coefficient of friction at all sliding surfaces is set at a nominal value of 0.5.”

D. For the two simulation models (friction and no friction), provide displacement and velocity time histories of the lid beginning from time equal zero and ending at the time when the velocity of the lid returns to zero.

E. Show actual scale displacement plots and strain contour plots at the time when the velocity of the lid returns to zero and when the maximum relative displacement of the lid is reached.

F. Provide one dimensional normal stress-strain and shear stress-strain curves from LS-DYNA for static loading and for a strain rate that bounds the strain rates that occur during the simulation.

G. Provide stress-strain test data of the bolt material to confirm the stress-strain relationships used in the model.

The information in B through G, above, is needed by the staff to complete its review of the calculation which was submitted as part of the previous RAI response.

H. Provide an analysis in which the gap between the bolt and lid is uniform around the bolt at the start of the simulation.

In response to RAI-6 PFS states that “...in an actual impact, <u>all clearances would be closed at the initiation of the impact</u> and all parts of the stud would be in intimate contact with the surrounding components. The actual analysis <u>model</u> supporting this RAI <u>is conservatively implemented to incorporate</u> some, but not all, of the <u>beneficial effects of the shims.</u>” However, the HI-STORM FSAR states the following: “Shims <u>may</u> be used on the HI-STORM 100 lid bolts. If used, the shims shall be positioned to ensure a radial gap of less than 1/8 inch around each stud." (Emphasis added)

Gaps will be present at the initiation of impact and an analysis model that does not contain gaps will not produce conservative results.

3. RAI Related to PFS Response to RAI-6, 13 and 22

A. In the global analysis of cask slapdown impact onto the concrete pad, provide justification for not including the effects of local damage to the lid bolts that may have been sustained due to Side Impact Scenario 2.

B. Coordinate this response with the responses to RAIs 8 and 10.

This information is needed by the staff in order to complete its review.

4. RAI Related to PFS Response to RAI-8

Define F-16 aircraft crash events at speeds and angles of impact, that would have a probability of occurrence of 10^{-6} per year, when combined with a probability of occurrence of crash events of 4.29 x 10^{-6} per year (as calculated by the ASLB).

F-16 aircraft speeds and angles used for structural analysis are based on the probabilistic approach explained in the Cornell report. The approach is based on selecting speeds and angles for structural analysis, and demonstrating that all events with speeds greater than the selected speed and impact angle have a probability of occurrence of less than 10^{-6} per year. This approach does not define the minimum speed and associated impact angles of the aircraft crash having a probability of occurrence greater than 10^{-6} per year and, although conservative, may not proivde realistic results.

5. RAI Related to PFS Response to RAI-9 and RAI 12

The response to RAI-9 addresses the penetration effects only. The response must address the structural capability of the CTB walls and pilasters to withstand the impact forces due to the full aircraft. The structural response is addressed in response to RAI-12. Therefore, the following RAIs relate to both RAI-9 and RAI-12 responses.

A. Provide the rationale for selecting cases I and II (page 9 of S&W calculation no. SC-5) for dynamic structural analysis for the F-16 impact force time-histories.

Both cases I and II are for loads at the Pedestal along column lines 9 and 5. The F-16 aircraft impact between the column lines may be more severe because the wall capacity is lower than the pedestal capacity.

B. Explain the rationale for applying the static load at the pedestal along column line 5 (page 13 of S&W calculation no. SC-5, Case I) and using the results of the stiffness based on this analysis for determining the barrier equivalent mass (page 21 of SC-5).

The stiffness calculations are for the load applied at the pedestal, while the fundamental East-West frequency includes the maximum displacement at a wall location between the pedestals (page 12 of SC-5).

C. Verify if the use of a Peak value of the F-16 Fuselage crushing force instead of the average crushing force used in the calculation SC-5 (page 20) would yield similar results and conclusions.

The average crushing force for fuselage strength (page 20) is significantly less than the Peak crushing strength shown in Ref. Table C2.2 of DOE, UCRL-ID-123577, included as Attachment 2 in Holtec Report no. HI-2033045.

D. Provide bases for selecting the Yield Line Diameter and its effects on the ductility requirements. Also, compare the barrier force with the F-16 Riera loads to discuss how the CTB walls would prevent the aircraft from entering the CTB (page 25 of SC-5).

E. Provide the rationale for not considering the strength reduction factor, φ, in calculation of M_U (pages 17 and 18 of SC-5).

F. Evaluate effects of the vertical loads on the CTB wall in the calculation of bending moment capacities, especially for bending about the horizontal X axis.

G. Provide the bases for the "Barrier Equivalent Weight" and "Duration of Load 3" in the SBMMI calculations (Ref. pages 26 and 27 of SC-5).

H. Provide SC-5 references 9, 10, CTB drawings references 12 through 19.

This information is needed by the staff to complete its review of the calculation which was submitted with the previous RAI response.

6. RAI Related to PFS Response to RAI-10

Provide references 2 through 6 of the Material Handling Equipment, Inc. Report MHE PO2363-R1.

This information is needed for the staff to complete its review of the calculation submitted with the previous RAI response.

7. **RAI Related to PFS Response to RAI-13**

A. **In the global analysis of the cask slapdown impact onto the concrete pad, justify the inclusion (or exclusion) of any of the horizontal inertia forces of the multi-purpose canister (MPC) and its contents in the calculation of tensile stresses in the lid bolts.**

B. **Describe all the forces acting on the lid, just prior to and during impact, that contribute to shear and tension forces in the lid bolts.**

C. **Justify, (include calculations) that horizontal translation of the cask does not occur and that the only motion that occurs is rotation about a point at the bottom edge of the cask.**

Prior to and during slapdown impact, the MPC and its contents, which weigh approximately 90,000 lbs, will be subjected to horizontal inertia forces. The inertia forces in the MPC can be calculated from the rigid body acceleration equations presented on page A-12 of Appendix A of HI-2033045. The portion of the MPC closest to the cask lid is subjected to a horizontal acceleration approximately equal to the acceleration (Ay) of the lid, as shown in Figure RAI-13-5, and decreases with greater distance from the lid. The horizontal inertia force of the MPC is resisted at any given time, in total or in part, by friction between the MPC and cask inner shell and by the cask lid and cask lid bolts. Should horizontal movement of the MPC occur, it is the cask lid fastened by the lid bolts to the storage overpack that prevents the MPC from sliding out of the storage overpack during the slapdown event.

D. **Provide a consistent and transparent analysis of cask slapdown impact onto the concrete pad. Describe the relative makeup of the components of displacement (i.e., concrete crushing, pad and soil deformation) that contribute to the total displacement shown in Figure RAI-13-4. Justify the magnitude of the deformations.**

In response to the RAI-13 in paragraph 1 (page 30), the applicant states that for the tip-over case, concrete crushing results in 24 inches of penetration by the cask. Then in paragraph 3, the penetration is stated to be approximately 5 inches, which is then revised, or tuned, to result in 17 inches displacement. The plot on page A-14 of the HI-203345 shows a maximum displacement of 24 inches at node 84392, which is the node number on the cask lid center line as shown in Fig. 3.A.18 of the HI-STORM SAR. Clarification is required.

E. **Correct the safety factors calculated on page 32 and shown in the last column of the Table on page 33 by taking their square root.**

This information is needed to ensure that the staff has all necessary information to complete its review.

F. **Analyze the global response of the cask due to F-16 impact at the top of the cask, in which the cask rotates at the base and impacts an adjacent cask approximately**

4 feet away. Demonstrate whether or not this scenario is more damaging than either the slap down impact or the horizontal translation impact.

For the two impact scenarios analyzed by PFS, the horizontal translation impact into an adjacent cask (response to RAI-4) provides the harder impact surface, while the slapdown impact on the pad (response to RAI-13) provides the higher impact velocity. Based on the angular velocity curve provided by PFS in RAI-15, the cask would have achieved at least 90% of the maximum velocity at slapdown by the time it has rotated and impacted the hard surface of the adjacent cask approximately 4 feet away.

8. RAI Related to PFS Response to RAI-14

A. Analyze the impact of an <u>F-16 fuselage with engine</u> into the cask at mid-height between radial plates and into the cask just below the lid bolts at or near the radial plate (whichever location is more damaging). Determine whether or not such an impact adversely affects the structural integrity of the MPC and lid bolts.

In response to the previous RAI-14, PFS conservatively calculates the damage caused to the cask by the F-16 fuselage impact ahead of the engine strike to be approximately equal to 50% of the damage caused by an engine impact alone. However, PFS has not evaluated the effect of a 50% increase in impact damage due to aircraft impact on the structural integrity of the MPC and lid bolts.

B. Provide the methodology by which the impact forces in Figure 12A (F-16 Aircraft Force Time-History Input, xxx mph, 34000 lbs) were derived.

Figure 9 (page 68) of HI-2033045 is the impact force time-history of a 31,000 lb F-16 traveling at xxx mph that impacts the cask at an angle of xx degrees. To obtain the horizontal component of the impact force the values in Figure 9 are multiplied by the cosine of xx degrees. The aircraft weight differences scale the values in Figure 9 linearly by the ratio of 34/31. Multiplying the values in Figure 9 by the cosine of xx degrees and the ratio 34/31, the staff obtains results that are 10% higher than those found in Figure 12A and the Excel spreadsheet on page A-26 of HI-2033045.

C. Analyze the cask, with both vertical and horizontal components of impact force included in the analysis of local damage to the cask, particularly for impact in the vicinity of the lid bolts and near the top of the cask where the shell is welded to the top.

D. Justify why the missile model used in the analysis was not applied at an angle of xx degrees with a Riera force-time history corresponding to an impact velocity of xxx mph. If for any reason the attributes of the current model would have prevented it from being applied at xx degrees, justify why another model was not used that could have applied the total impact force at an angle of xx degrees.

HI-2033045 states that: “The baseline scenario for impact analyses was assumed to be an aircraft velocity of xxx mph (xx knots) traveling at an angle of xx degrees from the horizontal at the time of impact. .... To evaluate the response to local damage, the F-16 engine was assumed to be traveling at the horizontal component of this velocity (i.e., xxx mph) directly perpendicular to the side of the cask along its centerline." (HI-2033045, page 3)

The vertical component of the impact force, which has been neglected, is 41% of the total impact force at xxx mph. The exclusion of this vertical component should be justified or its effect evaluated.

9. RAI Related to PFS Response to RAI-16

A. Provide plots of the concrete compression stress-strain curve to failure as derived directly from the LS-DYNA concrete element material model used in the cask analysis. Show the influence of confining pressure and strain rate on the stress-strain curve. The plots should extend to a strain of 0.010 in/in or to where the compressive strength diminishes to less than 10% of the ultimate strength.

B. Provide plots of the concrete tensile stress-strain curve to failure as derived directly from the LS-DYNA concrete element material model used in the cask analysis.

The plots of the concrete compression stress-strain curve provided by PFS do not extend to failure as requested. In Figure RAI-16-3 the stress is still increasing when the plot is terminated at a strain of 0.003 in/in. In Figure RAI-16-4 the plot is terminated when the ultimate strength is reached, which coincides with a strain of 0.0012 in/in. The minimum failure strain for unconfined concrete is well above 0.003 in/in.

10. RAI Related to PFS Response to RAI-22

A. Demonstrate that the impact of an F-16 at the top of the cask (Side Impact Scenario 2) at the location of the radial steel plate, and several degrees to either side of the radial plate, does not jeopardize the structural integrity of the lid bolt(s).

B. Describe how the bolts are modeled, and provide the load-displacement curve of the lid (to bolt failure) relative to the top plate due to the horizontal force applied to the lid.

C. Provide the maximum relative displacement of the cask lid with respect to the cask top plate and threaded lug at each of the bolts, and the time at which it occurs.

D. Provide "snap shots" in time of the bolt/lid/cask region for the most highly stressed bolt showing the deformation process that takes place up to the end of the event (i.e., when the velocity of all components returns to zero).

E. Provide the value of the coefficient of friction (if any) that was assumed between the lid and top plate and the amount of total shear force absorbed by friction.

F. Coordinate this response with the response to RAI 8, above.

In its response to the staff's August 15, 2003, RAI-22, PFS only addressed Side Impact Scenario 1. Side Impact Scenario 2 was not addressed (HI-2033045, Figure 30 page 90, Section 7.1). Side Impact Scenario 2 should be analyzed.

11. RAI related to PFS response to RAI-30

A. Verify and/or correct the three column tabulation of F-16 crash impact speeds and angles in Tab L(2) of "Evaluation of F-16 Crash Impact Speed and Angle for Skull Valley-Type Events" (the Burdeshaw report).

In reference to Tab L(2) of the Burdeshaw report, the three column tabulation of impact speeds and angles in the lower half of the page appears to be in error. Specifically, the listed impact speeds do not correspond to the accidents identified by date in the first column. It appears that a sorting on impact angles did not produce a concurrent sorting on accident dates, such that the listing of impact speeds no longer corresponded to the correct accident dates.

B. Verify and correct the transition value for the angle θ, wherein the distance "W_G reduces to zero", is stated to be arctan(19.5/39), on page 3 of Appendix B of "Probablitlity Assessment of the Aircraft Crash Impact Hazard for the PFS Facility Based on Engineering Evaluations of Storage Cask and Canister Transfer Building Integrity" (the Cornell Report).

It appears that a second term is missing.

C. Provide a basis for using only the pitch angle in estimating the impact angle (assumed to be the descent path of the aircraft prior to impact), without taking into account the angle of attack, as well as bank (roll) angle in cases where that is significant (e.g., more than 45 degrees).

A review of the impact angles in Tab A of the July 15, 2003 report on F-16 crash impact speeds and angles indicates that in a number of cases the impact angle was equated to the documented aircraft pitch angle at impact. For example, this appears to be the case for accidents described in PFS Exhibits 119, 128, 134, 143, 156, 173, 189, 191,198, as well as Joint Exhibits 4 and 7.

If the pitch angle and the angle of attack are independent variables, then for a given pitch angle it is possible for an aircraft to be flying at various angles of attack that differ from the pitch angle.

D. Clarify the source of the six speeds listed on page 5 of Appendix A of the Cornell report.

On p.5 of Appendix A to the Cornell report it is indicated that six out of seven accidents on the Skull Valley Type Events data set had an impact speed of 141 mph. Statistically, it is not expected that six accidents would all have the same numerical value for the impact speed.