DRAFT 11/5/02

Section 3.0 of the Paper
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This section describes structural impact effects of a jetliner crash on to a dry cask storage facility, generally referred to as an Independent Spent Fuel Storage Installation (ISFSI), and on to a transportation cask. Effects of the crash on the jetliner fuel tanks, and potential for fire affecting the cask vulnerability, are described in section 4,Thermal Evaluation, of this paper. Four types of dry storage cask systems out of the seven approved dry cask storage systems, and two casks systems out of sixteen approved transportation cask systems, are selected for evaluation of the structural vulnerability. The commercial jetliner selected for the evaluation was( )because the mathematical model for the jetliner was available, and the jetliner is widely used around the world. Section 2.0 of this report describes various types of commercial jetliners, and the reasons for selecting the( )for detailed evaluation in this section. Ex2

The four storage casks were selected based on the structural vulnerability to a jetliner crash, the type of construction (steel or concrete), the extent of their use, and the type and quantity (heat-load) of the spent fuel content. The two transportation casks were selected based on the structural vulnerability to a jetliner crash, the mode of transportation (one a large dual-purpose cask for rail transport, the other a small cask for truck transport), and the type and quantity (heat-load) of the spent fuel content. The storage casks evaluated were free-standing, and were HI-STORM 100, NUHOMS 32P, TN-68 and VSC-24, while the transportation casks evaluated were NAC-UMS and NLI 1/2, tied down to a rail or a truck bed, respectively.

SCENARIOS OF A JETLINER CRASH

Scenarios of a jetliner crash for evaluation of the dry cask storage and transportation systems include the crash angle and the maximum speed of the jetliner at the time of the crash. The crash angle and the maximum speed of the jetliner crash were selected based on the probabilities that the pilot of a jetliner may be able to hit the targets of sizes similar to a dry cask storage facility and the transportation vehicle. Evaluation was performed for a range of crash angles varying from xxxxx degrees to xxxxx degrees with the horizontal, and with the maximum speed of the jetliner of xxxxx, to determine the cask damage. The maximum speed of the jetliner was selected based on the available information for the( ) Ex2

3.1 STRUCTURAL EVALUATION

3.1.1 STORAGE CASK

The dry cask storage system described herein is the HI-STORM 100 system at an Independent Spent Fuel Storage Installation. Other dry cask storage systems, mentioned earlier in this section, are not evaluated at this time. The HI-STORM 100 system has a number of casks on a pad, spaced approximately 15 to 18 feet in a square or a rectangular patten (Figure 3-1). A jetliner crash would, therefore, affect a number of casks at the same time, some being impacted by the fuselage and the other being impacted by the wings and engines. Since the shear strength of wings connections to the fuselage is not significant, the wings would be separated from the fuselage immediately after the crash, and the fuselage impact on a single cask would be the governing case for the cask vulnerability. Therefore, the structural

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evaluation of a dry cask storage system is performed using a jetliner crash on a single cask, and then considering the interaction of the impacted cask on adjacent casks.

The HI-STORM 100 cask includes a concrete overpack (approx. 27 inches thick with a 0.75 inches thick exterior steel shell and a 1.25 inches thick interior shell, and a 4 inches thick bolted steel lid). The MPC containing the spent fuel in a fuel basket is stored inside the overpack. The cask has an outside diameter of 132.5 inches and a height of approx. 231 inches. The total weight of the fully loaded storage cask is approximately 360,000 lbs. Evaluation of the HI-STORM cask for a jetliner crash was performed analytically using a computer code, CTH, for the global responses, and the computer code, PRONTO, for the cask-to-cask interaction. Effects of the rigid components of the jetliner, such as the landing gears and the engines on the cask, were also determined using the PRONTO code.

Two bounding analyses were performed using the CTH code, one for a low coefficient of friction between the cask and the concrete pad, yielding the maximum cask sliding velocity, and the other for a high coefficient of friction between the cask and the pad, yielding the maximum angular velocity of the impacted cask, rotating about the corner. For determining the maximum sliding velocity, the jetliner was assumed to impact a single free-standing vertical cask horizontally with the [redacted] Figure 3-2). For determining the maximum cask angular velocity, the jetliner was assumed to impact the cask Ex 2 horizontally with the [redacted] (Figure 3-3). The jetliner mass and stiffness distribution were modeled using the information available in the public arena.

The CTH code simulates numerically the highly dynamic event of a short duration (impact), as a jetliner crashing on to a dry cask storage system. A system of differential equations, established through the application of the principles of conservation mass, momentum and energy, are solved in an Eulerian (spatial) description of the cask and the jetliner. Since the impact phenomenon involves material strains significantly beyond the yield strength of the material and into the plastic behavior, the normally used Lagrangian finite-element method with the mesh deforming with the loads, is not suitable. The Eulerian description defines the mesh spatially and remains fixed with the material flowing from one cell of the mesh to another. The PRONTO code is a finite-element code, which solves differential equations in a time-domain using a Lagrangian description of the mesh.

Results of the CTH analyses are shown in Figures 3-4 and 3-5 for the maximum cask sliding and angular velocities, respectively. Using these values as initial conditions, the PRONTO code was used to analyze the cask impact on adjacent casks, and determine the vulnerability, defined as a breach of the multi-purpose canister (MPC) containing the spent fuel (Figures 3-6 and 3-7).

Local penetration effects of the rigid components, such as the landing gear, and the engine components, on a cask are determined using the PRONTO computer code. The landing gear is represented as a hollow cylinder, approximately 12 inches in outside diameter, approximately 24 inches long, and weighing approximately 1500 pounds. Analyses are performed for the Ex 2 landing gear impacting the cask shell horizontally at the [redacted] (Figure 3-8). The Lid is evaluated for the [redacted] (Figure 3-9). Effects of the engine impact on a cask were evaluated using the Riera method for a flexible component impacting a rigid target, for a [redacted] (Figures 3-10 and 3-11).

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AREAS OF UNCERTAINTY

Following are the major areas of uncertainty in the analysis for the jetliner crash on to an ISFSI.

A. Jetliner Model: The jetliner model used in the CTH analyses is based on the information available in the public arena, and may not be realistic. This may affect the results to some extent but not significantly. The information used for the engines for the PRONTO analysis is based on test data, and is judged to be realistic. The information for the landing gear used for the PRONTO analysis is based on the available public information, and thus may not be realistic. The modeling information for the jetliner is planned to be confirmed by the jetliner manufacturer Boeing. If the changes to the jetliner model are required as a result of the Boeing review, reevaluation of the analyses and results will need be performed.

B. Material Properties: Since the materials impacted by the jetliner crash undergoes very large strains and changes into a liquid state, the equation of state relating the density and pressure are required to be used in the CTH code. The information presently used in the CTH analyses for concrete material properties are based on test data for concrete strength greater than the concrete strength of the cask. Uncertainty associated with the material properties is not expected to affect the results significantly.

C. Analytical uncertainty: Uncertainty in analytical results exist due to a need to define the physical phenomenon in mathematical equations using conservation of mass, momentum and energy, and in the process of solving the equations in finite space and time. The amount of uncertainty associated with this process is not significant because the CTH and PRONTO codes have been verified for similar application. However, use of the codes for an event with a large flexible object at high speed crashing into a heavy free-standing object is for the first time.

RESULTS OF THE EVALUATION

The maximum cask sliding velocity of the HI-STORM 100 storage cask was determined to be approximately xxxx m/sec or xxxxx mph, while the maximum angular velocity at the time of impact on an adjacent cask was xxxx rad/sec. Local cask damage due to the jetliner impact is [redacted] (Figures 3-6, 3-7). Analyses performed using the PRONTO computer code for cask-to-cask impacts at these velocities indicate that the casks, [redacted] Ex2

Results of the local penetration analyses due to rigid components impacting the cask shell and the Lid show that the casks [redacted] (Figures 3-8 through 3-11). Ex2

CONCLUSIONS

Based on the analyses performed to date for a jetliner crash on to a typical dry cask Independent Spent Fuel Storage Installation, it is concluded that the jetliner crash would [redacted] Ex2

3.1.2 TRANSPORTATION CASK

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The Transportation cask NAC/UMS is a transport rail cask. The cask is cylindrical and has a metal overpack with a dual-purpose metal canister used for transporting spent fuel. The overpack consists of a 2 inches thick interior steel shell, 2.75 inches thick chemical copper Lead, a 2.75 inches thick exterior steel shell, and approx. 5 inches thick neutron shield. The cask has an outside diameter of approx. 93 inches, and a height of approximately 209 inches without impact limiters. The fully loaded cask weighs approximately 255,000 lbs.

A jetliner crash in a lateral (either normal or at an angle to the longitudinal axis) direction on the NAC/UMS cask during the transportation, would cause the cask to separate from the rail platform because the tie-down system is designed to resist 5 times the weight of the cask, while the impact forces are estimated to be greater than [redacted] times the weight of the cask. Therefore, the behavior of the cask due to a jetliner crash would be [redacted] which has been analyzed for the jetliner crash. Assuming that the energy transferred to the cask during the crash is linearly proportional to the area of the cask impact, the maximum sliding lateral velocity of the NAC/UMS cask can be computed from the computed velocity of the HI-STORM cask. The maximum sliding velocity is computed as xxxx m/sec or xxxx mph. Assuming that the cask also has a longitudinal velocity same as the traveling rail speed of xx mph, the vectorial addition of the speeds would yield the maximum cask sliding velocity of xxxx mph. Ex2

The cask traveling at the maximum sliding velocity is assumed to impact realistic targets, similar to soils or concrete targets used in NUREG/CR-6672, section 5.2. Based on this evaluation, it is concluded that the NAC/UMS cask MPC could withstand an impact on a real target of a velocity of xxxx mph without being breached, which is greater than the predicted maximum sliding velocity of the cask due to a jetliner crash. Therefore, it is concluded that the NAC/UMS cask would maintain the structural integrity during a jetliner crash.

3.2 REWORK REQUIRED

Structural evaluation discussed in Section 3.1 require re-evaluation as described below:

A. Review the [redacted] jetliner mathematical model, used in the CTH analyses, with the Boeing Company, to verify the accuracy of the model. Ex2

B. Re-perform the CTH analyses for the full duration of the impact, and re-evaluate the casks for the increased maximum cask sliding and angular velocity.

C. Re-perform the CTH analyses for a jetliner speed consistent with the PRONTO analyses.

D. Re-perform the PRONTO analyses using a revised model incorporating the mass and stiffness of the MPC and the fuel basket.

E. Address the uncertainty in material properties, including the effects of the environmental temperatures on the jetliner metal, and storage/transportation casks materials (steel, concrete, etc.).

3.3 ADDITIONAL WORK TO BE COMPLETED

To address the vulnerability of the spent fuel casks in storage and transportation to a jetliner crash, the following additional work is required to be completed.

A. Evaluate a jetliner crash on other types of storage cask systems (NUHOMS 32P, TN-68, VSC-24)..

B. Evaluate a jetliner crash on a truck transportation cask (NLI 1/2).

C. Evaluate the storage and transportation casks, evaluated for other commercial jetliners, such as( ) Ex2

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