From: "Smith, Jeffrey" <jasmith@sandia.gov>
To: "'Bernard White'" <BHW@nrc.gov>
Date: 2/18/03 9:23AM
Subject: RE: Executive Summary

Bernie:

Attached is the Executive Summary. I sent this last Friday afternoon. I got a message saying that "Attempts to connect to the remote server have failed." So, I am trying again. Please let me know if you get this.

Jeff
505-845-0299

Bernie:

Attached is the draft of the Executive Summary. There is one figure that we do not have in it yet and some of the others need work. However, I think you can work with these. I expect this will inspire some healthy discussions. You are the only one at the NRC that I am sending this too. Please forward this to the NRC staff members that you think should review it. Ken classified this as Official Use Only.

Have a great weekend.

Thanks,
Jeff
<<ExecSum.doc>>

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E/104

Executive Summary

Introduction

The events of September 11, 2001 have lead to the need to evaluate radioactive material storage and transportation casks for threats from sabotage. The following work was conducted for the Nuclear Regulatory Commission to evaluate the response of a storage and a transportation cask to a sabotage event similar to those of September 11, 2001. The threat can be summarized as a large jetliner [redacted] impacting a field of storage casks or a single transportation cask at a velocity of [redacted] The angle of attack considered was [redacted] This speed and angle of attack are consistent with the attack on the Pentagon. It was further assumed that the jetliner impacts a field of storage casks or an individual transportation cask.

Ex 2

This report should not be considered a safety analysis of the casks to this threat. Traditionally, a safety analysis would assume the worst conditions and examine the safety of the system to this worst case. This study does not attempt to examine the worst-case scenario for this threat. Nor is this a complete vulnerability assessment. A complete vulnerability assessment would examine all the vulnerabilities to this threat and then examine their likelihood of occurring for an attack. All possible scenarios are not examined in this study, and all of those examined are not analyzed in detail. However, a wide range of scenarios is examined and the results of these scenarios are examined. The study provides an overview of the many possible scenarios that might occur under these conditions and provides guidance on what would most likely happen under these conditions. Especially for the case of the field of storage casks, it is not practical to assess and quantitatively determine the results of all possible scenarios involving the jetliner impacts. Therefore, an attempt is made to provide an overview of the broad possibilities and vulnerabilities of the systems and emphasize what is considered the more likely scenario. This approach is described more fully in Section 1 and is applied and discussed in detail in Section 4.

The following is a summary of the work that was conducted in support of this study. Although some technical details are presented in this Executive Summary, the reader should consult the remainder of the report for full details of the calculations. Presented in this executive report is an examination of the vulnerability of a field of storage casks and a transportation cask to what was considered the more likely impact scenario by the jetliner. The main report discusses other possible scenarios beyond what was considered more likely. The qualitative discussion of the range of possible scenarios provides a good basis for selecting the more likely scenario and for bounding the problem.

More Likely Scenario

Field of Storage Casks

There are a large numbers of possible jetliner impact locations on an individual cask. When the crash is into a field of cask, a chaotic event results, during which many secondary cask-on-cask impacts may occur. When the field of casks is considered, the geometric possibilities become overwhelming. Cask layout, approach direction of the aircraft, and how accurately a pilot could direct the aircraft all influence the geometric possibilities. A realistic threat must be considered. It is unrealistic to expect all possible targets of sabotage to be able to withstand all conceivable threats in this post September 11th age. However, prior to September 11th few people would have conceived of such an attack.

Therefore, dismissing scenarios as unrealistic is difficult. Wherever possible, scenarios were only dismissed when it was considered physically unrealistic. When defining the more likely scenario, qualitative probabilistic considerations of physically possible conditions were considered.

The particular cask selected for this study is the HI-STORM cask. The cask (shown in Figure 1) has a nominal height of 6.4 m (21 ft) and diameter of 3.4 m. (11 ft). The cask overpack has a steel-concrete-steel sandwich construction. A multi-purpose canister (MPC) that contains the fuel rods is placed inside the overpack. These casks are typically placed on pads that can contain as many as eight casks. Numerous pads can be at any site. The spacing of the casks can vary at different sites. The typical spacing used for this study is the same as that proposed for the proposed Private Fuel Storage Site in Utah.

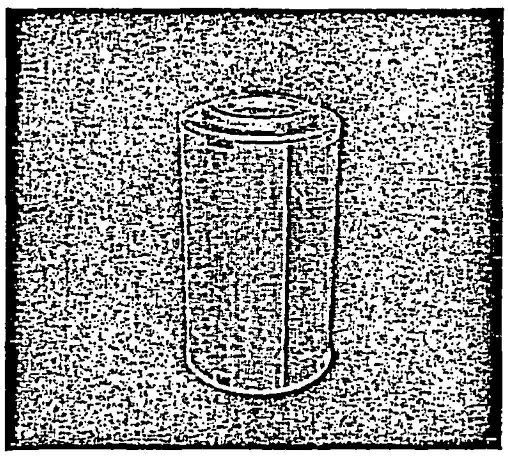


Figure 1. HI-STORM cask.

Figure 2 provides some perspective of the relative size of the HI-STORM cask to a [redacted] The cask is approximately 1/3rd the height of the Pentagon and 1/67th the height of the World Trade Center towers. A field of casks provides a much more likely target than a single cask on a pad. It would require great skill or luck to make a direct hit on a specific cask. Therefore, this study assumes that the jetliner impacts the field of casks and focuses on a single pad of eight casks. To provide a realistic study of the cask-on-cask impacts that would be caused by the jetliner crash, a range of geometric possibilities were considered. Figure 3 provides perspective on some of the geometric considerations for a typical field of casks. Ex2

Figure 2. Scale Drawing of and HI-STORM Cask.

Ex 2

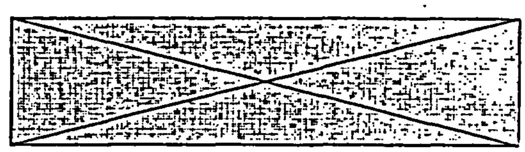
b). Although maintaining level flight paths that low to the ground at high velocities is difficult, nevertheless, (see Figure 3a & To ensure that the jetliner impacted the casks [redacted]

is considered for the more likely scenario. The more likely scenario is chosen with these parameters:

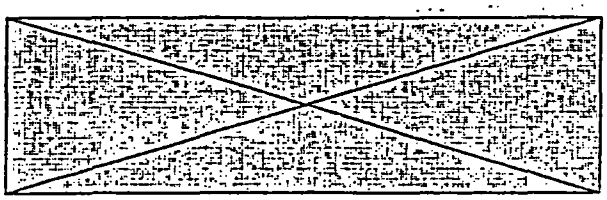
Ex 2

The thermal and structural studies described in detail in this report provide insight into the vulnerability of the casks under this and other less likely scenarios.

3a) Dry Storage Cask Layout with Scale Jetliner.



3b) Scale Side-view of Casks and Jetliner.



3c) Scale View of Jetliner Approaching Field of Casks at

Ex 2

Figure 3. Scale Views of the Jetliner and the Field of Storage Casks.

Structural Analysis of the More Likely Scenario

Field of Storage Casks

The analysis of a jetliner impacting a field of storage casks and the associated cask vulnerabilities is a much more complicated problem than the evaluation of a single cask. Not only is there an issue of the jetliner and its associated hard components impacting a single cask, but also there is the issue of the cask-to-cask impacts that will ensue after the initial impact of the jetliner. It is important to note that while these initial cask-on-cask impacts are taking place, the jetliner is still imparting momentum to the casks. Because cask-to-cask impacts will occur, the cask spacing on the pad is important. Figure 5 shows the cask-to-cask separation distances on a single pad. The jetliner is shown to scale on the figure. For a jetliner impact from the side of the pad where it could potentially interact with all eight casks there are three distances that are significant: 1) the 1.2 m (4 ft) separation distance of the casks placed directly across the pad from each other; 2) the 3.4 m (11 ft) separation distance between the casks on a diagonal from each other; and 3) distances greater than 3.4 m (11 ft), where impacts may occur if a cask is knocked off of the pad. If a cask or casks leaves the pad the cask may tip over, come to a rest beyond the pad, or possibly impact casks on other pads. These are the specific impact scenarios that have been evaluated for this study within the context of the more likely scenario, the crash of the jetliner into a pad with eight casks.

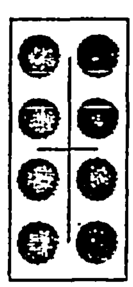


Figure 5. Typical ~~Pad Layout,~~ Separation Distance, and Scale

Global impact analyses were conducted using CTH, a Eulerian shock physics code, to determine the cask velocity during and after the impact of a jetliner. These analyses examine the interaction of the mass of the jetliner with the cask. The imparted momentum translates the cask. From these analyses the resulting velocity of the cask as a function of time and distance was determined. Two different conditions were evaluated. The first case considers a

is not considered the more likely case because it would be difficult for a jetliner to directly impact the cask at this location. As stated previously, an impact at the The resulting velocity plots for the are shown in Figures 6 and 7.

Ex 2

Ex 2

Figure 6. Velocity vs. Time Figure 7. Velocity vs. Distance

The time for the complete impact of the jetliner and cask is approximately 300 msecs. Within 130 msec the translating cask has moved 1.2 m (4ft) and in 200 msec the cask has translated 3.4 m (11 ft). From this data shown in these plots, velocities as a function of translational distance were determined. These velocities were used for cask-on-cask impact evaluations and for evaluations of casks coming to a sudden deceleration (stop) by impacting another cask, soil, gravel, or concrete. The resulting velocities are shown in Table 1.

Table 1

Separation Distance		
1.2 m (4 ft)		
3.4 m (11 ft)		
Beyond 3.4 m (11 ft) (max velocity distance)		

Ex 2

Using the velocities listed in Table 1, finite element evaluations for cask-on-cask impacts at the 1.2 m (4 ft) and 3.4 m (11 ft) separation distances were performed to support evaluation of these more likely scenarios. For the 1.2 m (4 ft) cask separation, an evaluation of a of two casks at was performed. Since the internal MPC has a gap between it and the overpack, it can potentially impact the overpack during the cask-to-cask impact. Therefore, the evaluation of the cask system included a separate analysis of the cask overpack and the internal MPC. The results show that for a

Ex 2

An evaluation of a cask-on-cask impact of

Portions Ex 2

of casks on a pad. This case is considered less likely than the 1.2 m (4ft) impact. It is also important to note that if the casks are placed accurately, this type impact Ex 2

Once the initial jetliner impact and the cask-on-cask impacts have occurred, there are two potential threats to the cask integrity that have been evaluated. One consideration is that the cask (or casks) The first impacted cask cannot The second cask could potentially The second possibility that was evaluated was a This could happen by In this case, the threat is Ex 2

A separate evaluation of the MPC impacts into the overpack was conducted to evaluate the Ex 2

has been demonstrated to be xx m/s (xx mph). (NOTE: exact value is still being determined)

For the more likely scenario, the In a realistic event the [redacted] Ex 2

In addition to these scenarios discussed above, the casks were evaluated for the impact from the hard components from the jetliner. The casks were evaluated for impact from the jetliner engine and nose landing gear traveling at Finite element analysis of the jetliner engine impact results in a Ex 2

Numerous finite element analyses of the nose landing gear strut impacting the cask at a variety of locations and orientations have been performed. These analyses show that for the However, further analyses would have to be conducted to examine an impact of the Ex 2

Therefore, this scenario was not pursued any further.

Transportation cask

The direct impact of an aircraft into the rail cask was examined by de-coupling the impact. First, structural analyses of hard components of the aircraft impacting the cask were performed. An examination of an impact by the nose landing gear and the jetliner engine were performed using finite element analyses. Direct impacts from each of these components at

Second, in the event that the cask

Ex 2

This finite element analysis also showed that there This study did not take into account the railcar or support of the cask on the car that would be absorb some of the energy of impact.

Thermal Analysis of the More Likely Scenario

Historical airplane crash data show that fire duration after a crash is inversely proportional to the impact velocity. The data also suggest that in order to have a fire duration of 1 hour or more the impact velocity would have to be below 112 m/s (250 mph). A study of crash fire data performed in 1990 for the NRC by Lawrence Livermore National Laboratory (LLNL) suggests the maximum fire duration after a high-speed commercial aircraft accident is about 30 minutes. As discussed in Section 3 of this report, for high-speed impacts most of the fuel will burn in the fireball and dispersal of the fuel not consumed in the fireball will be so great that it cannot form a pool that will burn for a long period of time. Therefore, based on the speed of the jetliner that is being considered for this study, the historical data, and the LLNL study, it is believed that any jet fuel pool fire that occurs will not burn much longer than 30-minutes.

The temperature of the pool fire was determined by examining data that was collected from fire experiments that suggest flame temperatures range from 1000 K to 1500 K with a rough average flame temperature of 1300 K. Therefore, a 1300 K, 30-minute fire, is the more likely thermal environment that both the transportation cask and a storage cask on a dry storage pad will be exposed to after an intentional jetliner crash at if the crash produces a pool fire. Nevertheless to be conservative, preliminary analyses were carried out for 1-hour fires. These analyses show that the cask canister is not failed even if the cask containing the canister is exposed to a 1-hour fire. However, preliminary analyses were carried out for one hour to capture the phenomena and are discussed below. It is shown that there is no canister failure in a 1-hour fire. Ex 2

Field of Storage Casks

The fire and heat transfer analyses for the HI-STORM dry storage cask were conducted for the cask in both the upright position and with the cask tipped over on its side. Different jet fuel pool configurations were considered. The heat transfer analyses estimated the temperature response of the canister to these various fire scenarios. It was found that for a 1-hour fire the hot gases entering the overpack through the cooling vents heated the multi-purpose canister (MPC) walls to 900 K. Although heat transfer from the overpack to the canister continues after the fire goes out, the maximum temperature at the center of the canister only reached 740 K fifteen hours after the fire goes

 Portions Ex2

out. From thermo-mechanical analysis of the MPC it was determined that in order to fail the canister within an hour, the temperature of the MPC walls and the gas contained in it would need to exceed 1000 K. On the other hand, the canister will not fail if the temperature of the walls and gas contained inside are less than 900 K. For this analysis it was conservatively assumed that all the fuel rods inside the canister were failed by the high-speed jetliner impact. Therefore, it can be concluded that given the thermal load of the fire environment described above for the HI-STORM cask, Ex 2

Transportation Cask

The NAC-UMS transportation cask was also analyzed for exposure to a fully engulfing 1-hour fire. The maximum calculated internal temperature of the canister was 730 K. Based on the thermo-mechanical analysis described above for the HI-STORM canister, it is estimated that the NAC-UMS canister (which is very similar to the HI-STORM canister) Ex 2

Conclusions and the Effects of Analysis Complexities on Estimates of Cask Vulnerability?

An evaluation of what has been considered the more likely scenario for an intentional jetliner crash into on a field of dry storage casks or a rail transportation cask has found that it is Ex 2 The rail transportation cask appears However, the study did evaluate . Analysis of this type of accident is very difficult, because the event is highly unpredictable and the interaction of a relatively soft jetliner with a relatively hard cask initiates an extremely nonlinear event. The analyses required the combination of many technical resources to provide an integrated solution.

Section 4 of this report discusses all of the scenarios examined, uncertainties and mitigation possibilities. The response of the aircraft structure to this type of accident is not understood well and modeling this behavior is difficult. For the most part, this study has de-coupled the behavior of the jetliner, the momentum transfer of the jetliner to the cask system, the impact of hard components of the jetliner into casks, and the resulting impact of one cask into another or onto other surfaces. Material behavior in these types of accidents is difficult to predict. Where possible, parametric analyses were performed to examine the influence of material variability. For the global analyses of the jetliner impacting the field of casks the cask material and the jetliner material were varied to examine this issue.

Cask spacing for the field of storage casks appears to be one of the most critical issues in determining cask vulnerability. Larger cask spacing enables the jetliner to impart more of its momentum to an individual cask, which would cause the cask to attain a higher velocity. After the jetliner impact has ended, the cask Ex 2 will begin to slow down due to impacts with other casks, the pad, site roads, and the ground. Therefore, the possible