Department of Energy
Washington, DC 20585

APR 14 2003

E. William Brach
U.S. Nuclear Regulatory Commission
NMSS/SFPO
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Washington, D.C. 20555-0001

Dear Mr. Brach:

Last year, a team from the Department of Energy (DOE) Office of Environmental Management (EM) transportation program and Sandia National Laboratories staff at Albuquerque, New Mexico reviewed and analyzed some transportation accidents suggested by Robert Halstead as potentially severe enough to compromise the integrity of spent fuel casks (see reference 1 "*Comments of Robert Halstead on Behalf of the State of Nevada Agency for Nuclear Projects Regarding the U.S. Nuclear Regulatory Commission Study Assessing Risk of Spent Nuclear Fuel Transportation Accidents presented at the Public Meeting in Henderson, Nevada*"). The following accidents were reviewed using the data available in the accident reports filed with Federal, State and local authorities:

1. Collapse of a Suspended Span of Interstate Route 95 Highway Bridge over the Mianus River, Greenwich, Connecticut on June 28, 1983.
2. Collapse of New York Thruway (I-90) Bridge over the Schoharie Creek near Amsterdam, New York on April 5, 1987.
3. Collapse of the Cypress Street Viaduct of the Nimitz Freeway in Oakland, California as a Result of the Loma Prieta Earthquake on October 17, 1989.
4. Collision between a Tractor-Semi-Trailer Transporting Bombs and an Automobile Resulting in Fire and Explosions at Checotah, Oklahoma on August 4, 1985.
5. Tanker Trailer Truck Accident and Resulting Explosion, Memphis, Tennessee, December 23, 1988.
6. Hazardous Materials Release Following the Derailment of Baltimore and Ohio Railroad Company Train No. SLFR, Miamisburg, Ohio, July 8, 1986.
7. Collision and Derailment of Montana Rail Link Freight Train with Locomotive Units and Hazardous Materials Release, Helena Montana, February 2, 1989.
8. Derailment of a CSX Transportation Freight Train and Fire Involving Butane, Akron Ohio, February 26, 1989.
9. Train Derailment, May 12, 1989, at San Bernardino California and Fire, May 25, 1989 at the same location.

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10. Derailment of CSX Transportation Inc. Freight Train and Hazardous Materials Release near Freeland, Michigan on July 22, 1989.
11. Train Rear-End Collision near Cajon, California on December 14, 1994.
12. Derailment of Freight Train H-BALT1-31 Atchison, Topeka and Santa Fe Railway Company near Cajon Junction, California on February 1, 1996.

Careful examination of the available reports on the accidents suggested by Mr. Halstead revealed no accidents that were outside the event trees and accident severity already considered in NUREG/CR-6672. In most cases, the accidents were found to be within the regulatory test sequence limits described in 10CFR71.

The attached study is presented to you as an information document for your appropriate consideration. If you have any further questions, please call me at (202) 586-5151 or Kent Hancock, Director, Office of Transportation at (301) 903-2102.

Sincerely,

Patrice M. Bubar

Patrice M. Bubar
Associate Deputy Assistant Secretary
for Integration and Disposition
Office of Environmental Management

Attachment

U.S. Department of Energy
National Transportation Program
Albuquerque, NM

Comparison of Selected Highway and Railway Accidents to the 10CFR71 Hypothetical Accident Sequence and NRC Risk

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April 8, 2003

Comparison of Selected Highway and Railway Accidents to the 10CFR71 Hypothetical Accident Sequence and NRC Risk Assessments

Accident reports for some of the severe accidents suggested by Robert Halstead [1] that may compromise a spent fuel transportation cask were reviewed The environments associated with these accidents are compared to the 10CFR71 Hypothetical Accident Conditions [2] and the accident environments (both regulatory and extra-regulatory) investigated in "Shipping Container Response to Severe Highway and Railway Accident Conditions" [3], which is commonly known as the Modal Study, and in "Reexamination of Spent Fuel Shipment Risk Estimates," NUREG/CR-6672 [4]

BACKGROUND

Radioactive material packages are required to withstand the hypothetical accident conditions of 10CFR71.73 without releasing their contents For large packages, the hypothetical accident conditions consist of a 30-foot free drop onto an essentially unyielding surface, a free drop of 40 inches onto a 6-inch diameter puncture spike, exposure to a 30-minute fully engulfing hydrocarbon fuel/air fire, and immersion in 50 feet of water. For the accidents considered in this report, the relevant environments are provided by the impact and thermal accidents.

The severity of the impact environment is caused by the requirement that the impacting surface be essentially unyielding Such a surface forces all of the kinetic energy of the impacting cask to be absorbed by the cask and none by the target. In real accidents, the kinetic energy is also absorbed by the conveyance and the impacting surface. To construct an essentially unyielding target for a spent fuel cask requires a block of concrete that weighs 10 times the weight of the cask (that is, about 500,000 pounds for a truck cask and 2,000,000 pounds for a rail cask) that is topped with a 4-inch thick plate of steel. Most surfaces that are available for impact are much less rigid than this type of target, and will therefore absorb a substantial amount of the kinetic energy of the impact. This makes the regulatory 30-foot free drop onto an unyielding target equivalent in severity to much higher drops onto softer surfaces. For example, the Modal Study states that for a rail cask impacting a concrete roadway in a side-on orientation, a drop of more than 100 feet is required to produce the same amount of damage as the regulatory impact

The severity of the thermal environment is caused by the requirement that the fire be fully engulfing. The joint probability of the necessary things that must happen 'just so' to fully engulf a transportation cask by a long-duration fire after an accident is very low (based upon accident statistics presented in the Modal Study and by Clauss et al. [5], only about 0.06% of all fires resulting from truck accidents and 0.5% of all fires resulting from rail accidents meet these criteria). That is, enough fuel must be supplied to a pool configuration just below the transportation cask and have a source of ignition for it to occur. The other possibility is for fuel to flow under the cask at the right rate and form a thin film of fuel, along with an ignition source, to be able to burn and engulf the cask. However, a permeable ground (dirt or gravel) will absorb the liquid fuel, which will limit the size, intensity, and duration of the fire. If a spent fuel truck cask were subjected to a regulatory fire, a pool size of 39 feet by 27 feet would be used For the 30-minute fire duration in this pool, about 3280 gallons of jet fuel would be consumed. To fully engulf a rail cask, the pool size would be 39 feet by 30 feet and the amount of fuel consumed would be 3650 gallons. The regulatory fire temperature is 800°C, which results in an initial heat flux to the cask of about 75kW/m^2. The heat flux to the cask decreases as the outer surface temperature of the cask increases during the fire.

In a scenario where the cask is not inside the flame envelope of the fire, the amount of heat that it can receive depends greatly on the offset distance of the object from the fire. If the cask is very close to the fire, it could receive heat by convection and radiation. If, on the other hand, the cask is away from the fire, it will receive heat from the fire by radiation only at the same time it is being cooled, due to the convection and radiation heat loss to the environment.

When the cask is engulfed by optically dense flames, it cannot lose heat to the environment (it can't "see" it) Therefore, the cask is only receiving and radiating heat from the local fire temperature environment and not losing any energy directly to the environment, posing a worst-case fire scenario under no-wind atmospheric conditions. If high wind conditions exist, a worst-case (maximum heating) scenario would occur if the cask were placed on the

leeward side of the fuel pool where turbulent mixing enhances combustion. This is due to the enhanced mixing of air and fuel produced by the vortexes (large eddies) in the wake of the fire.

For the case of a train accident where train cars pile up during a derailment (five train derailment accidents are analyzed in this report), the closest distance a car carrying a spent fuel transportation container can be from a car potentially leaking hydrocarbon fuel can be approximated by assuming that the buffer car ended up in between the leaking car and the car carrying a spent fuel transportation container, all three side-by-side. The center-to-center distance from the leaking car to the car carrying a spent fuel transportation container would then be about 20 feet. Previous analyses performed by Lopez and Koski [6] indicate that a truck cask, which will heat up faster than a train cask because it is smaller, can survive (no seal failure or spent fuel rod rupture) when exposed to a fire flare that is 28 feet away. Furthermore, in the case of a pile-up scenario, the buffer car will shield the heat from the fire, protecting the spent fuel cask from being heated Only if the hydrocarbon liquid is drained to the bottom of the train car carrying the spent fuel package can it be fully engulfed by a fire. For this scenario, the bed of the train car would shield the cask from a portion of the fire, making this scenario less severe for the cask. If the train car happens to tip over, the cask would not be placed at a height where burning flames exist. More likely, it would be inside the vapor dome of the fire and therefore would not receive as much heat as if it were in the flame region of a fully-engulfing fire. If the train cars do not pile-up, the spent fuel cask would be farther away from any liquid fuel hauled in the train than in the pile-up case, and the increased distance would protect the cask.

In general, it is difficult to justify any fire that could be more severe than a fully-engulfing fire. In the case of a sudden spillage of liquid hydrocarbon fuel onto the ground (e.g., a big hole was punctured in the tank carrying the fuel), a fire would not be able to burn for long since either the fuel would be absorbed by the ground and not be available for combustion, or, if the surface is not permeable, the fuel would disperse, limiting pooling effect and therefore the fire duration. With a slow fuel leak from a tank carrying the liquid fuel, the fire is most likely to burn locally by the small puncture hole, creating no significant fire environment to make a cask fail, even if it were near the fire. For all of these events, the tank carrying the liquid fuel would have to be punctured at a location that allowed the fuel to drain

Spent fuel transportation risk assessments take into consideration the accident environment and calculate the response of casks to these environments. Two recent examples of generic spent fuel risk assessments are the Modal Study and NUREG/CR-6672.

The Modal Study analyzed how steel-lead-steel truck and rail spent fuel casks responded to unusually severe collisions and to long-duration, fully engulfing fires. It then used the results of these calculations and experimental data to estimate the radioactive releases that might occur if these casks were involved in unusually severe collisions or fires Data about the response of the casks to impacts and fires was developed by performing finite element calculations that predicted how the cask body would respond to large mechanical (collision) or thermal (fire) loadings The response of the cask closure (the cask lid and the bolts that attach the lid to the cask body) and of the fuel rods inside the cask was then inferred from the response of the cask body. Experimental data on the release of fission products from sections of spent fuel rods that failed by heating to burst rupture was used to define release fractions for unusually severe collision and fire accidents. In addition, the Modal Study used truck and train accident data to define sets of accident scenarios by constructing accident event trees and accident fire-duration and speed distributions, which allowed the chance that the cask would be involved in a high-speed accident or a long-duration fire to be estimated

NUREG/CR-6672 extended the methods of analysis developed by the Modal Study in four important ways:

1. NUREG/CR-6672 examined four types of spent-fuel casks: a steel-lead-steel truck cask, a steel-lead-steel rail cask, a steel-depleted uranium-steel truck cask, and a monolithic steel rail cask.

2. A parallel processing computer was used to perform three-dimensional finite element impact calculations that directly examined the response of the cask closure to unusually severe high-speed (up to 120 mph) impacts. The results of these calculations were used to extrapolate rod strains calculated for a low-speed impact to higher impact speeds. Comparison of these strains to a strain failure criterion for rod failure then allowed the number of rods failed by unusually severe collision accidents to be directly estimated

3. Fire durations that would heat a cask and the rods inside to temperatures where the rods would fail by bursting were calculated.

4 The experimental data on the release of fission products and particles of spent fuel from sections of rods that failed by heating was critically evaluated to determine how to estimate releases, from spent fuel rods that might fail during unusually severe collision or fire accidents

Collapse of a Suspended Span of Interstate Route 95 Highway Bridge over the Mianus River, Greenwich, Connecticut on June 28, 1983 [7]

The 100-foot span of the bridge that failed took the eastbound lanes of I-95 across the Mianus River. The collapse occurred when the hanger that held up the southeast corner of the span slipped off the pin due to a build-up of corrosion products between the hanger and the bridge. This led to an overload condition on the northeast hanger, causing the east end of the bridge to fall first, then pulling the west end off of its bearings, which also fell. Two passenger cars and two tractor-trailers dove off the failed bridge and plunged approximately 70 feet into the water. The driver and passenger in one of the cars and the driver (the only occupant) of one of the trucks were killed in the fall. The driver (the only occupant) of the other car and the driver and passenger of the other truck were seriously injured. At the point of collapse, the Mianus River is tidal, and was about eight feet deep at the time. The collapsed span was not the main span across the river and the water is shallower on the east side of the span than on the west side. Figure 1 shows the collapsed bridge.

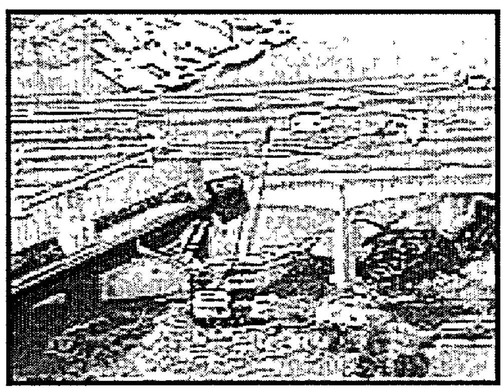

Figure 1. Cleanup of the collapsed Mianus River Bridge span

If one of the trucks had been carrying a spent fuel cask, the impact from a fall of 70 feet would result in an impact velocity of 46 mph (the horizontal component due to the truck's speed when it left the bridge is parallel to the impact surface, and thus does not increase the severity of the impact) The impact orientation would most likely be a corner impact. A corner impact of 46 mph into water is much less severe than the regulatory impact of 30 mph into an essentially unyielding target. In fact, the Modal Study says a corner impact of 150 mph into water is necessary to produce damage equivalent to the regulatory impact. Therefore, there would have been no significant damage to the cask and it would have remained leak-tight. The shallow water at this location could not damage the cask from external pressure, and since the cask would remain leak-tight, there would be no possibility for water ingress. Recovery of a spent fuel cask from this accident would take only a short period of time

Collapse of New York Thruway (I-90) Bridge over the Schoharie Creek near Amsterdam, New York on April 5, 1987 [8]

This accident was caused when flooding of Schoharie Creek undermined the spread footings under pier 3 of the bridge, causing it to collapse. The spans on either side of this pier then collapsed into the rain-swollen creek Four passenger cars and one tractor-trailer plunged off the bridge. Three of the passenger cars and the truck were

traveling eastbound and one car was traveling westbound. All occupants of these vehicles were killed. The spans were approximately 80 feet above the creek, whose waters were about 30-feet deep. The western span was 120 feet and the eastern span was 110 feet. About 90 minutes after the initial collapse, pier 2 also failed, causing another span to fall into the creek. The bed of the creek at this location is about 10 feet of alluvial material, consisting of sand and cobbles. Under this layer is about 40 feet of compacted glacial till. Figure 2 shows the span of the bridge that would collapse about 90 minutes after the initial collapse.

Figure 2. Span 2 of Schoharie Creek Bridge. Pier 2 can be seen on the left side of this figure. Later, this pier and span would also collapse

If the truck that went off the bridge had been carrying a spent fuel cask, the impact from a fall of 80 feet would result in an impact velocity of 49 mph (the horizontal component due to the truck's speed when it left the bridge is parallel to the impact surface, and thus does not increase the severity of the impact). The impact orientation would most likely be a corner impact. A corner impact of 49 mph into water is much less severe than the regulatory impact of 30 mph into an essentially unyielding target. In fact, the Modal Study says a corner impact of 150 mph into water is necessary to produce damage equivalent to the regulatory impact. Therefore, there would have been no significant damage to the cask and it would have remained leak-tight. Subsequent impacts due to being in the channel of the flooding creek (from debris carried in the flood waters) would all be much less severe and would have not caused any further damage. Recovery of the cask from the deep, muddy, rapidly-moving water would have been difficult, but there would be no consequence resulting from delaying the recovery operations until they could be conducted safely.

Collapse of the Cypress Street Viaduct of the Nimitz Freeway in Oakland, California as a Result of the Loma Prieta Earthquake on October 17, 1989 [9]

The Cypress Street Viaduct, a portion of Interstate 880 in Oakland, California, was a two-level structure. The upper level carried southbound traffic and the lower level carried northbound traffic The road surface on the lower level was about 25 feet above the ground and the road surface of the upper level was about 38 feet above the ground During the Loma Prieta earthquake, the upper level collapsed onto the lower level. The free-fall distance was 15 feet. At no location along the viaduct did the lower level collapse to the ground. The total width of the upper level was about 54 feet and the spans ranged from 68 feet to 90 feet. The roadway consisted of concrete box girders weighing about 11,000 pounds per lineal foot. The lower portion of the box was 5.5 inches of concrete and had eight vertical members, each 8 inches thick. Each box girder was supported by bents made up of two columns and a transverse beam. The reinforced concrete transverse beam was 8 feet deep and 4 feet wide. Each of these beams weighed about 260,000 pounds Figure 3 shows the configuration of one of the bents.

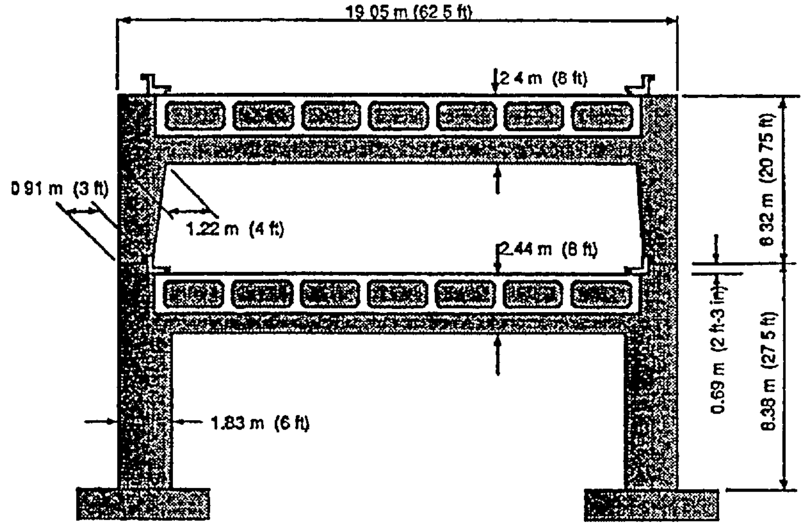

Figure 3 - Typical bent of Cypress Street Viaduct

If a truck carrying a spent fuel cask had been on this structure at the time it collapsed, it would be exposed to several accident environments. If the truck were on the upper level, it could fall to the lower level. The drop height is only 15 feet, so this accident is clearly less severe than the regulatory accident. It could also possibly fall to the ground (although none of the vehicles on the viaduct did) In this case, the drop distance would be 38 feet onto either soil or roadway. The energy absorbed by the impacted surface makes this accident less severe than the regulatory impact. If the truck were on the lower level, it could be crushed by the falling upper level. The box girder structure is not strong enough to exert a significant crush force onto the cask (the 5 5-inch concrete bottom is much weaker than a cask). If the cask were under one of the bents when it collapsed, it would be struck by the transverse beam. The worst case would be if the entire weight of the beam impacted the cask. The impact energy of the beam (weight times drop distance) is about the same as the impact energy for a 78-foot drop (48 mph) The results of NUREG/CR-6672 show that a truck cask closure seal will not fail at impact velocities greater than 90 mph. Therefore, if a spent fuel cask had been on the Cypress Street Viaduct when it collapsed, there would have been no release of radioactive material.

Collision between a Tractor-Semi-Trailer Transporting Bombs and an Automobile Resulting in Fire and Explosions at Checotah, Oklahoma on August 4, 1985 [10]

In this accident, a flatbed tractor-trailer carrying 10 2000-pound Mk-84 bombs struck the left rear portion of a Ford LTD as it was pulling from the shoulder onto I-40 at the outskirts of Checotah, Oklahoma. The collision ruptured the nearly full fuel tank of the LTD, resulting in a gasoline fire. The fire quickly engulfed the rear of the car and the front of the truck. The truck driver attempted to fight the fire with a portable fire extinguisher, but was unable to stop it by the time his extinguisher was exhausted, and retreated to a safe distance. Shortly after the accident, fire fighters from the Checotah Fire Department arrived on scene. When they saw that the truck was carrying Class A explosives, they withdrew from the fire. About 15 minutes following the collision, there was an explosion (probably from a single bomb) A second explosion (again, probably from a single bomb) occurred 15 minutes after the first one. A third, much larger explosion occurred about 20 minutes later. (This explosion may have involved 5 bombs.) This final explosion destroyed the truck and the car, and created a crater 27 feet deep and 35 feet wide in the roadway. During the clean-up, one intact, undamaged bomb adjacent to the accident site, one intact bomb partially filled with explosives about 160 feet from the accident site, and one section of a bomb filled with explosives were recovered about 160 feet from the accident site.

The Mk-84 bombs contained 945 pounds of tritonal explosive, a mixture of 80% TNT and 20% aluminum powder. The bombs being transported did not have their tail assemblies, boosters, or fuzes. They were about 99 inches long

(without tail assemblies), 18 inches in diameter, and weighed 1,970 pounds. An estimated maximum thickness for the bomb casing is 0.5 inches (assuming all the nonexplosive weight of the bomb is in a steel casing)

If a truck carrying a spent fuel cask had been at the accident site, the duration and size of the fire would not have damaged the cask thermally. The explosive force of the first two explosions was not sufficient to even throw the remaining bombs from the flatbed trailer. The third explosion did not damage two of the bombs, whose maximum 0.5-inch casing was less robust than the wall of a spent fuel cask, and both were loaded adjacent to the bombs that exploded. From this, it can be inferred that the explosion would not have caused a spent fuel cask loaded on an adjacent truck to fail.

Tanker Trailer Truck Accident and Resulting Explosion, Memphis, Tennessee, December 23, 1988 [11]

A tanker trailer truck loaded with liquid propane skidded on its side and released its cargo as it struck a concrete bridge support At the time, the truck was negotiating a highway ramp at about 30 mph. The cargo of 9500 gallons of liquid propane was released in what one witness described as a "white cloud of gas," which subsequently ignited, blowing the trailer truck a large distance and killing a total of eight persons: the driver, five in other vehicles, and two in a residence struck by a portion of the trailer.

A spent fuel cask hypothetically placed at the scene would not have suffered significant damage. The explosion and fire duration was short, and large, blunt objects striking the cask would have caused external damage (for example, damage to a neutron shield), but would not have damaged the containment boundary or seals of the cask. In 1999, BAM in Germany conducted a test with a spent fuel cask adjacent to a propane tank, engulfing both in fire [12]. The propane tank exploded due to a boiling liquid, expanding vapor explosion (BLEVE) and was hurled against the cask. The damage to the cask was less than what results from the regulatory accident sequence. For these reasons, the accident lies within the accident event-tree scenarios considered in NUREG/CR-6672 and within the envelope defined by the regulatory test sequence defined in 10CFR71.

Hazardous Materials Release Following the Derailment of Baltimore and Ohio Railroad Company Train No. SLFR, Miamisburg, Ohio, July 8, 1986 [13]

This derailment occurred while the 44-car train was traveling at 45 mph across a plate bridge. Hazardous cargo consisted of yellow phosphorus and molten sulfur at 245°F. Major difficulties in handling the accident arose because the car containing phosphorus was damaged during derailment in a location that was difficult to access. Yellow phosphorus, unless covered with water or oil, ignites at 86°F when exposed to air. Damage to the tank car containing yellow phosphorus allowed phosphorus to leak onto the ground and surroundings, creating phosphorus combustion and hazardous combustion products in the area.

Because the combustion of yellow phosphorus was limited to the immediate area of the tank car, there is no evidence that a spent fuel cask in the area of the damaged car would have been exposed to a fully engulfing 1800°F (1000°C) fire environment, as described in NUREG/CR-6672. Because of hazardous cargo separation rules, any cask would have been one or more car lengths from other hazardous cargo. While the phosphorus fire continued for several days, one objective of the accident control effort was to allow combustion of the phosphorus in a controlled manner. To that end, the car was opened and repositioned to allow the phosphorus to complete combustion Molten sulfur, while hazardous to humans at 245°F, is well below temperature design limits for spent fuel casks and within the envelope defined by the 10CFR71 regulatory test sequence.

Collision and Derailment of Montana Rail Link Freight Train with Locomotive Units and Hazardous Materials Release, Helena, Montana, February 2, 1989 [14]

This early-morning accident was initiated when the train crew attempted to reorder the locomotives on a mountainous grade in extremely cold weather because of an inoperative heater in the lead engineer's cab. While the locomotives were decoupled, the unattended 49 rail car train, which did not have the brakes properly set, rolled

downhill until colliding at 15 to 25 mph with a standing locomotive in the rail yards. No fatalities or severe injuries were reported, but two large explosions caused significant damage to the train and surrounding structures. Of the 49 cars, 21 were involved in the accident and 15 derailed, although many remained upright. The tank cars contained hydrogen peroxide, an oxidant, and isopropyl alcohol. The explosions were attributed to interactions between the hydrogen peroxide and polypropylene pellets transported in a hopper car.

Although cargo fires existed, they were left to burn by the fire department, possibly because of the extremely cold weather. Persons evacuated from the area were allowed to return to their homes and businesses the afternoon following the early-morning explosions. From the report, there is no indication that large, fully-engulfing fires of the type described in 10CFR71 would have endangered a spent fuel cask at the accident scene. Because there was not a large pile of rail cars in this accident, requirements for separating hazardous cargoes in freight trains would have also eliminated the possibility of an engulfing pool fire environment that could threaten the cask The fire environment described in NUREG/CR-6672, which includes both regulatory and extra-regulatory fires, easily envelops the possible cargo fire scenarios in this accident. The principal damage to a hypothetical spent fuel cask in this particular accident scenario would be from the explosions As demonstrated in Droste and Schulz-Forberg [12], significant structural damage to a spent fuel cask in such a situation is not likely because of the robust nature of cask design.

Derailment of a CSX Transportation Freight Train and Fire Involving Butane, Akron, Ohio, February 26, 1989 [15]

On February 26, 1989, 21 cars of a 51-car freight train derailed at about 42 mph in the vicinity of a B F. Goodrich Chemical Company Plant in Akron, Ohio. The cause of the accident was determined to be poor maintenance of one tank car and poor maintenance of the railroad tracks at the site of the wreck. Of the 21 derailed cars, nine were tank cars containing butane, and three of the butane cars leaked or lost contents. One butane car ruptured and expelled its contents as a large fireball that endangered the chemical plant The other two cars continued to leak for several days with spot fires associated with the leaks. The chemical plant was safely shut down following the accident. A second incident occurred several days later as the damaged tank cars were being moved to a rail yard for off-loading of contents and further processing One loaded butane tank car rolled on its side during this movement, but no fire occurred.

Because the tank car that failed did so rapidly from a large gash in its side, the conditions of a fully-engulfing pool fire for 30 minutes were not approached. Thus, a cask at the scene would not have been exposed to a fully-engulfing pool fire of the type specified in 10CFR71. The fireball was brief, but apparently did start a fire on the roof of the adjacent chemical plant The tank cars that leaked butane did not create the conditions of a fully-engulfing pool fire, and continued to burn locally. A spent fuel cask hypothetically placed near the leaking cars would not have received the heat input associated with a fully-engulfing pool fire. Therefore, the fire environment described in NUREG/CR-6672 would not have been exceeded, and the fire would have been within the regulatory test sequence described in 10CFR71. Some concerns regarding the possibility of a BLEVE were expressed by the emergency responders, but such an explosion did not occur. If a BLEVE had occurred, the danger to a spent fuel cask would be structural, rather than thermal, in nature. As demonstrated in Droste and Schulz-Forberg [12], significant structural damage to a spent fuel cask in such a situation is not likely because of the robust nature of cask design.

Train Derailment, May 12, 1989, at San Bernardino, California and Fire, May 25, 1989 at the Same Location [16]

These two accidents are linked by damage to a liquid-petroleum pipeline caused during the cleanup effort that followed the train derailment. In the initial incident, a 69-car mixed-freight train derailed at high speed. The weight of the hopper cars containing trona ore was underestimated, leading to the assignment of inadequate dynamic braking, which caused the derailment. The cars derailed on a curve at high speed in close proximity to a residential neighborhood. No fires were associated with the derailment. The pipeline was undamaged during the initial derailment, but during cleanup efforts, the pipe was damaged by heavy equipment. Nearly two weeks after the derailment, the pipeline failed catastrophically, and the associated fire killed two people and damaged 10 houses

The speed of the train at the time of derailment was estimated to be 100 mph. The surface at the site of the derailment consisted of tillable soil. If the derailed train had carried a spent fuel cask, it would have been exposed to a maximum impact of 100 mph into soft soil. In NUREG/CR-6672, soil impacts at speeds of 100 mph are shown not to produce seal failures or releases of radioactive material In the derailment, there were many car-to-car impacts as the train piled up Nearly all of the cars wound up side-by-side, so there would have been no potential for puncture. The only possible puncture-probes in this accident were the railcar couplers It has been demonstrated that a coupler cannot exert a large enough force to puncture a spent fuel cask.

Although a train had passed shortly before the pipeline failure, no train was involved in the fatal fire For this reason, no engulfing fire environment that could affect a spent fuel cask is associated with this accident scenario. The probability that a pipeline break could affect radioactive materials shipments by rail was recently examined by Koski, Mills, and Lopez [17] They concluded that, while the probabilities vary with the shipping campaign, the probability of pipeline-spent fuel cask fire interaction is similar to the probability of a meteor strike to a cask. Such low-probability, high-consequence events do not contribute significantly to overall risk in risk-based studies such as NUREG/CR-6672.

Derailment of CSX Transportation Inc. Freight Train and Hazardous Materials Release near Freeland, Michigan on July 22, 1989 [18]

This derailment was initiated when one wheel of a special-purpose flat car carrying an oversized cargo lifted under dynamic loads and left the tracks. In the train of 33 cars with two locomotives, 14 freight cars, including six tank cars, derailed. Three cars that contained flammable materials ignited and continued to burn for several days.

The flammable cargoes that were released and burned were acrylic acid, trimethylchlorosilane, and naptha. The duration of the initial intense fire was not reported, but the car containing naptha had a large 10-inch by 14-inch hole and apparently the contents burned rapidly. This rupture, depending on local drainage and soil conditions, could have caused a fully-engulfing pool fire at the accident scene, although the accident report doesn't describe the fire as such. The car containing acrylic acid continued to burn via a 3-inch by 6-inch hole until the next day. The car with trimethylchlorosilane continued to burn for 5 to 6 days. Because of the potential for hazardous vapors, the trimethylchlorosilane fire was encouraged to consume the fuel, and an area around the car was cleared to increase the burn rate. Finally, after several days, the car was pressurized with nitrogen to enhance the drainage and burn rate until the fire extinguished from lack of fuel.

For a hypothetical cask located at this scene, the initial exposure to a naptha fire could have produced the most significant pool fire threat of the type considered in 10CFR71. Petroleum naptha would burn like the hydrocarbon fuels normally considered in risk studies The duration of the initial fire was not recorded The type of tank car that was carrying naptha has a capacity of about 27,000 gallons. For a minimal engulfing fire, the fire size would have to be 22 × 36 feet Assuming the tank car was full and all of the fuel pooled results in a fuel depth of 4.5 feet. The longest duration engulfing fire would be about 5 hours. Drainage, seepage, residual fuel in the tank, or larger pool size would decrease this fire duration. Because NUREG/CR-6672 evaluates long-burning, fully-engulfing fires that are both shorter than the regulatory limits and longer than the regulatory 30 minutes, the described fire environment is within the fire envelope considered in the report. NUREG/CR-6672 states that an 800°C fire must burn for more than 6 hours to produce a significant radioactive material release from a rail cask. The fires from the acrylic acid and trimethylchlorosilane, while long in duration, would not have threatened a cask located at the site of the accident. Separation requirements for hazardous cargoes in freight trains would have eliminated fire exposures. Slowly draining fires tend to remain in the immediate vicinity of the damaged car, and do not threaten adjacent cargo

Train Rear-End Collision near Cajon, California on December 14, 1994 [19]

The collision occurred when the brakes of a four-locomotive, 55-car, mixed-freight train descending Cajon Pass partially failed due to a blockage in the break line. Only the four locomotives and the first three cars had functioning brakes. The resulting brake force was insufficient to slow or maintain the speed of the 4,882-ton train (the weight of the trailing cars; total weight would also include the weight of the four locomotives) through this long descent. The runaway train struck a stopped coal train at about 45 mph The coal train consisted of three lead locomotives on the

downhill end, 82 loaded coal cars, and two trailing locomotives. In the collision, the two locomotives at the end of the coal train, the four locomotives of the freight train, and the first three cars of the freight train were destroyed. The fourth car of the freight train derailed and was damaged. The remaining cars stayed on the rail and were undamaged. The first two locomotives of the freight train rode over the rear locomotive on the coal train. The first three cars of the freight train jackknifed into the wreckage.

If a spent fuel cask were involved in this accident, the worst location for it would be at the rear of the coal train (instead of the trailing locomotives). In this position, it would be subjected to the impact from the runaway locomotives. In the Modal Study, impacts by train sills were examined. For end impacts (as occurred in this scenario), an impact velocity of 150 mph is required to produce the same amount of damage as the regulatory impact Therefore, the cask would not be significantly damaged and there would be no release of radioactive material.

Derailment of Freight Train H-BALT1-31 Atchison, Topeka and Santa Fe Railway Company near Cajon Junction, California on February 1, 1996 [20]

The high-speed derailment of a mixed-freight train was caused by a failure of the train braking system on a steep downgrade. All four engines and 45 of the 49 freight cars, including 12 of 14 tank cars, derailed in a relatively small area adjacent to a curve. The pileup of cars continued to burn for several days, with local spot fires fueled by tank car leakage and cargo fires After a brief initial attack, no efforts were made to suppress the fires The fires were attacked instead by dragging individual cars from the wreckage with heavy equipment. One derailed tank car containing butyl acrylate remained intact, and after being dragged from the pile, was identified as a potential explosion hazard because the contents had apparently exceeded the 257°F limit of the chemical stabilizer. After determining that internal tank pressure was increasing, a hole was blown in this tank car with plastic explosives to provide pressure relief and drainage.

An examination of the accident report indicates that if a spent fuel cask were in the cargo manifest, the accident conditions would be enveloped within the long-term fire conditions assumed in NUREG/CR-6672. In NUREG/CR-6672, the response of four spent fuel cask designs to 1800°F (1000°C) long-duration (beyond regulatory test limits), fully-engulfing fires is calculated. For this case, the conditions would not have fully engulfed a cask, since personnel access permitted removal of damaged cars while the fires continued to burn The fact that the butyl acrylate tank car remained intact indicates that a much more substantial spent fuel cask would also have survived intact. The chemical stabilizer temperature of 257°F is well below seal and rod burst temperatures of a spent fuel cask, so cask fire exposure under similar conditions would not have led to a cask failure. With additional data on the equivalence of long-term exposure in small fires to short-term exposure in fully-engulfing fires, the confidence in this conclusion could be further improved Inclusion of such detail often removes conservatism from the study, and thus reduces the overall level of risk reported in NUREG/CR-6672.

CONCLUSIONS

Careful examination of reports on the accident scenario suggested by Halstead revealed no accidents that were outside the event trees and accident severity already considered in NUREG/CR-6672. In most cases, the accidents were found to be within the regulatory test sequence limits described in 10CFR71. In one instance (see the Freeland, Michigan accident description above and [18]), because fire duration was not reported, the possibility that the 30-minute 10CFR71 regulatory duration was exceeded could not be determined However, even if the fire had lasted longer than 30 minutes, it would be within the range of extra-regulatory conditions considered in NUREG/CR-6672. As mentioned in the background section of this report, rules for separating hazardous cargoes in freight trains would have lowered the probability that a cask would be close to the fire zone.

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