Radioactive Waste
Management Associates

Memo

To: Bob Halstead

From: Marvin Resnikoff

Date: 12/17/2013

Re: NUREG-2125 Review

Bob:

This review began with a review of the historical documents that were omitted by NUREG-2125, but now encompasses a deeper examination of NUREG-2125 and its supporting references. In my opinion, NUREG-2125 and its supporting references cannot support the conclusion that no radioactive material would be released in a severe transportation accident involving a truck cask. This review of NUREG-2125 includes a detailed examination of the GA-4 truck cask proposed for Yucca Mountain. NUREG-2125 does not examine sabotage of a truck or train cask and we also have not discussed it here. We also have not included discussion of the recent train accident in Lac-Megantic, Quebec.

As I mentioned in a memo some time ago, something was fishy in the NRC's choice of which documents were chosen in their history leading to NUREG-2125. Documents that did not fit into their carefully constructed history were omitted. Now in examining NAC-LWT and GA-4, a clearer picture emerges. The documents omitted were by Elder *et al*[1], and Rhyne *et al*[2]. The Elder reference showed that a side impact of a reference truck cask into a rigid 1.5 m bridge column at 12.5 mph would lead to an opening of the cask cavity.

The Rhyne study had similar results. "Assuming a total steel thickness of 2.75 inches and ignoring the effect of the lead gamma shield, Table 9.3 gives the velocity required for puncture on a given projection." For a 6 inch diameter projection, the speed given in Table 9.3 is 48.7 ft/sec, or 33 mph. Smaller projections imply lower speeds.

However, using the GA-4 cask as the reference truck cask in NUREG-2125, the NRC comes to a different conclusion. NUREG-2125 employs a more sophisticated analysis for impact, puncture and thermal, but the above previous static analyses provide clues on what should be examined, namely side impacts. In this memo, we examine the basis for the revised conclusion.

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[1] Elder, H. K., W. B. Andrews, J. R. Friley, J. F. Johnson, R. A. McCann, and R. E. Rhoads. *An Assessment of the Risk of Transporting Spent Nuclear Fuel by Truck*. Rep. no. PNL-2588. Washington: Pacific Northwest Laboratory, 1978.

[2] Rhyne, W. R., R. L. Ritzman, H. E. Cothran, Jr., J. P. Allgeier, and C. J. Barton, Sr. A Scoping Study of Spent Fuel Cask Transportation Accidents. Rep. no. NUREG/CR-0811. Oak Ridge, TN: Science Applications, 1979.

The Elder study also calculated that the cavity coolant (assumed to be water) was lost when the cavity temperature reached 290 ^{o}C. This is based on the rupture disk failing at 76 atmospheres. Failure would occur about 2.5 hours after the cask was exposed to 1010 ^{o}C fire for 15 minutes. However, water coolant is not presently used, except for the proposed HEU shipments from the Chalk River reactor to the Savannah River plant.

Why is this significant for the NAC-LWT truck cask? Because the reference truck cask in the Elder study has greater stainless steel wall thickness than the NAC-LWT truck cask, as seen in the comparison table below. That is to say, an even slower speed and a shorter duration fire could compromise the NAC-LWT truck cask than the Elder reference truck cask. In examining the GA-4 truck cask, we found a major flaw in the analysis, that also pertains to Hotec's HI-Star 100 cask.

Table 1. Comparison: Reference and NAC-LWT Casks

Parameter	Elder Reference Cask (cm)	NAC-LWT (cm)	GA-4 (cm)
Length	544	508	478[d]
Outer Diameter	96.5	101.8	229
Inner cavity length	452	452	419
Inner cavity diameter	34.3	34.0	46[c]
Inner cavity wall (ss)	0.8	1.9	0.4[c]
Lead	16.8	14.6	6.6[a]
Wall (ss)	3.2	1.3	7.6[c]
Boronated Water	11.4	12.7	xx[b]
Outer wall (ss)	1.27	0.61	1.0
Total stainless steel (cm)	**5.27**	**3.81**	**16.3[e]**

Notes: [a] depleted uranium, [b] neutron shield-hydrogenous plastic, square inner and outer round [c] cask (cavity wall, depleted U and wall) is square, but outer neutron shield and wall are rounded, [d] length, w/ impact limiters, 234 in, [e] includes depleted U shell, 3.4 inch ss

NUREG-2125 Accident Impact Analysis

NUREG-2125 considers the standard impact orientations, shown in Fig. 3.1 below. Each of the orientations takes into account the energy absorption of the impact limiters. For the truck cask, in particular, a detailed analysis in NUREG-2125 for orientations in Fig. 3.1, was not carried out because, according to NUREG/CR-6672, there were no gaps between the lid and the cask body at any impact speed for the orientations in Fig. 3-1. This holds for a steel-DU truck cask, such as the GA-4 cask.

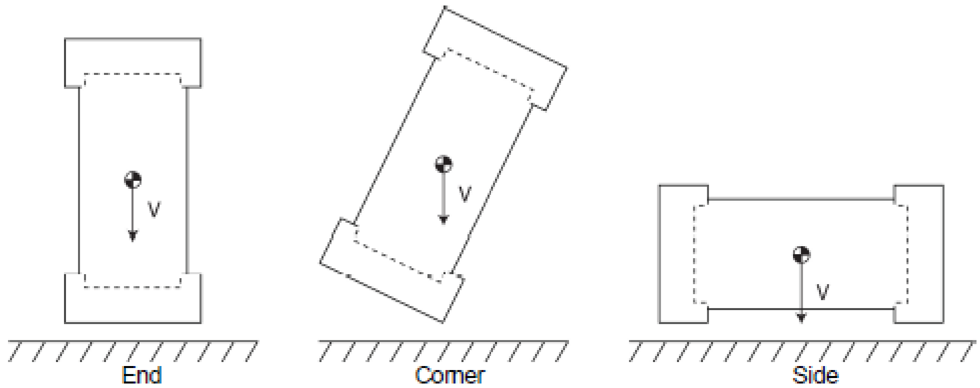

Figure 3-1 Impact orientations analyzed

Though the cask orientations are interesting and satisfy NRC cask regulations, in the real world, not all impact surfaces are flat. A cask may impact a bridge column sideways, or a structure, such as the Cypress Creek structure in Oakland, CA may collapse onto a cask. These side or back- breaker impacts were also not considered in NUREG-2125, but the authors claim they were considered elsewhere. We consider the claimed references below.

Package Performance Study[3]

The back-breaker scenario was considered in the Package Performance Study[1] (PPT) (see Fig. 34 below). The NRC claimed "the level of strain was not high enough to cause tearing of the containment boundary and there was no permanent deformation in the closure region and no loss of containment." No "permanent deformation" does not mean "temporary displacement" when bolts stretch. As discussed below regarding the interaction of an engine train sill and cask, the bolts can stretch and the opening of the cask lid can indeed remain open. Other details, such as the internal pressure also need to be considered.

As seen in Fig. 34, the interior of the cask was modeled as a solid composite, rather than as individual fuel assemblies, shown in the cross-section of the GA-4, Fig. 1. In addition, the ends of the cask were not modeled to include impact limiters which add one-ton weights to each end of the cask, similar to a barbell.

Most importantly, the bolts and cask cover were not modeled in detail in the PPT, so it is not possible to state that there was "no loss of containment." A stretching of the bolts would allow gases and fine particles to be released. Without detailed modeling of the bolt region, it is not possible to state "permanent deformation" could not occur.

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3 U.S. Nuclear Regulatory Commission, "United States Nuclear Regulatory Commission Package Performance Study Test Protocols," NUREG-1768, Washington, DC, 2003(b).

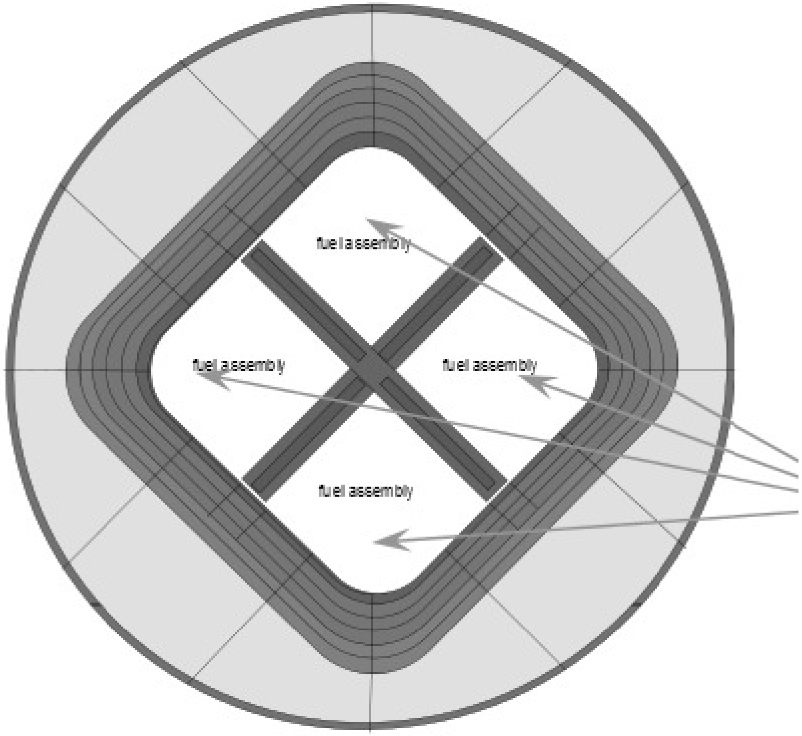

Fig. 1. Cross-section of the GA-4 cask, including the propylene neutron absorber.

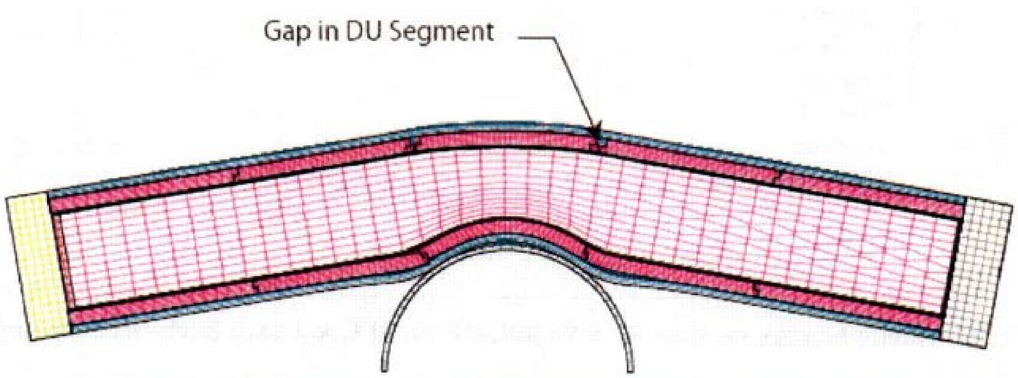

Figure 34. GA-4 cask after 96 kph [60 mph] back-breaker impact.

Why do the conclusions in NUREG/CR-0811 and the Package Performance Study differ? Aside from the method of analysis, different casks were considered (the GA-4 is far stiffer). NUREG/CR-0811 considered punches with different diameters; a punch with a 6 inch radius, could tear the cask wall at 33 mph, while the PPT required speeds greater than 60 mph for a rounded bridge column. Of course, many sharper objects exist in the real world.

Locomotive impact on cask

NUREG-2125 cites a study by Ammerman[4], also the author of NUREG-2125, to show that no radioactive material would be released in an impact of the GA-4 cask with a train sill. The Ammerman study investigated the impact of a locomotive into the side of the GA-4 truck cask, shown in the graphic below.

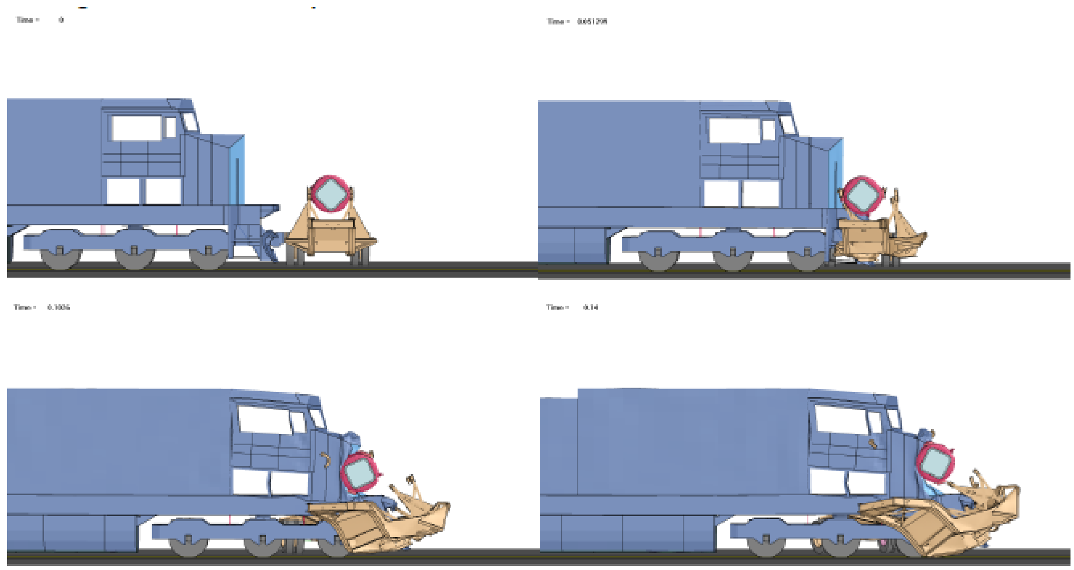

Figure 3-19 Sequential views of a 129 kph (80 mph) impact of a locomotive into a GA-4 truck cask
Figure source: (Ammerman et al., 2005)

As seen, with the assumed height of the cask on the truck bed, the cask rolls into the sheet metal of the engine and is not directly impacted by the solid engine undercarriage or sill plate. The Sandia crash films show a similar scenario. But, other scenarios are possible. If the track bed at the railroad crossing were raised (hump crossing), and the truck straddled the track bed, as shown in Fig. 2 below, the solid part of the engine (sill plate) could strike the cask directly. This more serious impact was considered by Ammerman. At 70 mph, the cask bolts would stretch 0.059", above yield, and a gap of 0.043" would remain. The cask would experience forces of 140g. Some radioactive material would be released from the cask, but Ammerman could not quantify the amount because individual fuel assemblies and internal pressure in the cask and fuel assemblies were not modeled; the entire contents of the cask were one homogeneous block. Sanders *et al* [5]claim that the forces would need to exceed 200 g for the fuel assembly cladding to fail, but the analysis assumed the cask would remain rigid, which is not so for the back-breaker case.

Further, in the Ammerman model, the one-ton impact limiters were not included; inclusion of one-ton impact limiters would have increased the bending of the cask when struck by the locomotive.

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[4] Ammerman, D.J., Stevens, D., and Barsotti, M., "Numerical Analyses of Locomotive Impacts on a Spent Fuel Truck Cask and Trailer," Proceedings of the American Society of Mechanical Engineers Pressure Vessels and Piping Conference, Denver, CO, July 2005.

[5] Sanders, T.L., et al, "A Method for Determining the Spent Fuel Contribution to Transport Cask Containment Requirements," SAND90-2406, Sandia National Laboratories, November 1992.

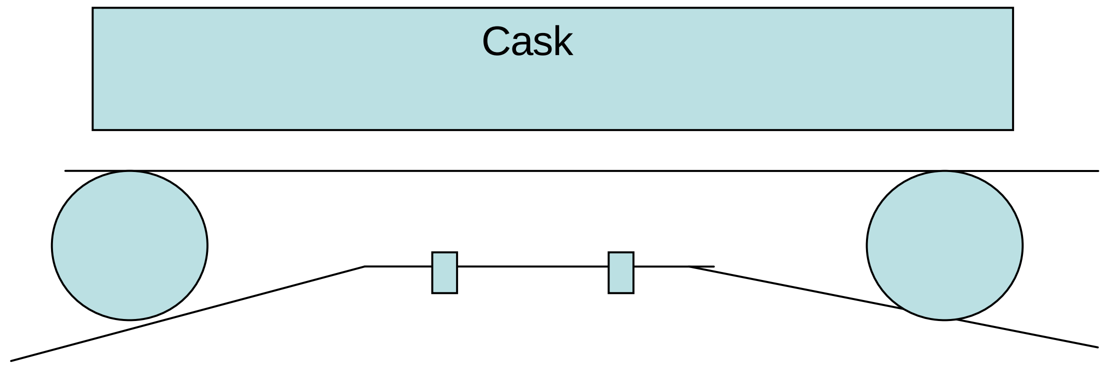

Fig. 2. In a hump crossing, truck cask is lower than if flat bed is on level ground and train sill plate can directly meet cask.

My conclusion from the Ammerman study is that the forces on the cask bolts would exceed yield and the cask lid would open and remain open. Further, the fuel rods would break ("shatter" is a more appropriate description) and release gases and semi-volatile radionuclides, such as Cs. Far from supporting the conclusion of NUREG-2125 that no material would be released in a truck/locomotive accident, this reference contradicts it.

Cypress Street Viaduct Collapse

The Cypress Street Viaduct was a 1.6 mile long, raised two-tier, multi-lane (four lanes per deck) freeway constructed of reinforced concrete that was originally part of I-880 in Oakland, California. It officially opened to traffic on June 11, 1957 and was in use until the 1989 Loma Prieta earthquake, when much of the upper tier collapsed onto the lower tier due to poorly designed bridge columns. Fig. 3 below shows the before and after of the Loma Prieta earthquake.

Fig. 3. Cypress Street Viaduct Before and After Collapse

D.J. Ammerman, the author of NUREG-2125, analyzed the effect of the crush forces on a postulated truck cask accident[6]. These are not impact forces, but crush forces on a truck cask. His conclusion was a truck cask would survive the crush forces. I requested a copy of his study and have not reviewed it as of this writing.

MacArthur Maze Fire and Roadway Collapse

The 3rd truck accident referred to in NUREG-2125 was the MacArthur Maze Fire and Roadway Collapse, evaluated by Bajwa *et al*[7]. In the MacArthur Maze fire, on April 29, 2007, a tanker carrying 8,600 gallons of gasoline overturned on an I-880 exit ramp in Oakland, California. The fire burned intensely for 40 minutes. At 17 minutes, a ramp above the overturned truck collapsed onto the I-880 ramp roadway. A second portion of the overhead ramp collapsed at 40 minutes after fire initiation, reducing the fire which continued to burn for an additional 60 minutes. Based on samples collected and analysis, the NRC estimated the temperature of the fire below the overpass ranged between 1562 °F and 1832 °F, that is, considerably greater than the regulatory 1475 °F. Near the truck, the temperatures were between 1328 °F and 1706 °F. Based on these fire temperatures and duration, the NRC estimated the peak fuel cladding temperature would approach, within 55 °F, the Zircaloy burst temperature limit of 1382 °F.

In my opinion, the NRC has not properly modeled the cask in a fire scenario and I have serious reservations regarding these calculations. These reservations extend to modeling of Holtec's HI-Star 100 rail cask as well. A review of the Safety Analysis Report by General Atomics[8] shows neutron shield support tubes connecting the square stainless steel cask body to the outer cylindrical stainless steel shell. Boronated propylene fills the space between the steel cask body and the outer shell. These

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[6] Ammerman, D.J. and Gwinn, K.W., "Collapse of the Cypress Street Viaduct—Effect on a Postulated Spent Fuel Truck Cask," *Proceedings of the 45th Institute of Nuclear* Materials Management Annual Meeting, Orlando, FL, August 2004.

[7] Bajwa, C.S., Easton, E.P., Adkins, H., Cuta, J. Klymyshyn, N., and Suffield, S., "Effects of the MacArthur Maze Fire and Roadway Collapse on a Spent Nuclear Fuel Transportation Package," Proceedings of the 2011 Waste Management Conference, Phoenix, AZ, February 27–March 3, 2011.

[8] General Atomics, Legal Weight Truck From Reactor Spent Fuel Shipping Cask, Safety Analysis Report for Packaging, NRC Docket 71-9226, August 1994.

neutron shield supports serves as a heat conductors from the interior of the cask to the outer shell. Without this conduction path, the neutron shield would act as a blanket, allowing the cask interior to heat up from the fuel assembly heat production. General Atomics models the combination of heat conduction through neutron shield supports and neutron shield material with an effective specific heat and shows steady state temperature will be maintained. However, the neutron shield material is a plastic, which will quickly decompose in a fire. In fact the plastic adds to the heat of an external fire. The problem is how to model the heat transfer when the propylene decomposes. General Atomics assumes that the space between the cask body and the external skin, formerly occupied by the neutron absorbing material, is not present and is replaced by air, which is an effective insulator from the external fire. But this is not correct; General Atomics has ignored the heat conduction channels via the neutron shield supports. In other words, the neutron shield supports are a 2-way street – they conduct heat out under non-accident conditions, and conduct heat in under accident conditions involving a fire. In our opinion, properly including the neutron shield supports implies the peak cladding temperature would be higher.

This same oversight applies to Holtec's HI-STAR 100 rail cask[9], where the neutron absorbing material plus metal supports to the outer metal skin have an effective specific heat, but is replaced with an air space in Holtec's analysis of a fire accident.

[9] Holtec International Report No. HI-951251, Safety Analysis Report for the Holtec International Storage, Transport, And Repository Cask System (HI-STAR 100 Cask System), Revision 12, dated October 6, 2006, as supplemented..