Highly Radioactive Liquid Waste in NAC-LWT Cask

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Background

Concern has been expressed about the US Department of Energy's unprecedented plan to ship 6000 gallons of highly radioactive liquid from Canadian Nuclear Laboratories (CNL) at Chalk River, Ontario, to the Savannah River Site (SRS) in South Carolina – a distance of over 1000 miles. The transport of this material would require 100-150 truckloads over a period of several years, each truckload carrying about 68 gallons of the radioactive liquid in a modified NAC-LWT shipping cask.

The NAC-LWT cask was designed over 30 years ago by NAC International. It is a Legal Weight Truck (LWT) cask, originally designed to carry a maximum of one or two solid irradiated fuel assemblies extracted from a Light Water Reactor (LWR), or an equivalent amount of irradiated fuel in the form of solid rods, pins, or elements, extracted from other types of reactors. See http://www.nacintl.com/lwt .

The company has modified its NAC-LWT cask to carry four inner elongated steel "bottles", each containing about 17 gallons of the radioactive liquid from Chalk River, in the innermost cavity of the cask, instead of the "baskets" containing solid irradiated fuel for which the casks were originally designed. The cask also incorporates lead shielding to attenuate the gamma radiation emitted by fission products contained in the liquid solution, as well as neutron absorbers to attenuate the neutron flux, because the liquid solution contains weapons-grade highly-enriched uranium that emits neutrons.

Accident Response of NAC-LWT Cask

This paper presents a short discussion of the accident response of the NAC-LWT cask. We will consider the cask's ability to withstand a fire, both a hypothetical fire as defined by the regulations, and a real fire, which may be considerably more intense than the one hypothesized. We will also consider the cask's ability to withstand a crash.

All discussion of thermal response of the NAC-LWT has been redacted from publicly available documents, so it is impossible for the public or for independent experts to verify the safety of the cask in a real fire. We've had to make some assumptions in this report.

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We will first describe the design features of the NAC- LWT and then discuss the cask response under the NRC's hypothetical accident conditions, and potential real accident conditions.

The NAC-LWT design is over 30 years old, and much of the design detail is proprietary. But casks almost identical to the NAC-LWT have been examined by researchers at Lawrence Livermore Lab, in a study called the Modal study.[3][1] So there is some public information on which to rely, and it is used in this report.

NAC-LWT Cask

As shipping casks for highly radioactive materials go, the NAC-LWT container is not a robust shipping cask; it has thin walls and is relatively light, so it is vulnerable to fires and sidewise crashes. In our opinion, the NAC-LWT is borderline safe under regulatory conditions, but may not withstand real severe accident conditions. This short paper focuses on the thermal and crash conditions.

A type B shipping cask, like the NAC-LWT, must be designed to withstand certain hypothetical accident conditions as detailed by the NRC (10 CFR71.73): (1) a free drop a distance of 30 feet onto a flat essentially unyielding horizontal surface, (2) a puncture, (3) a fire, and (4) submersion. These hypothetical accident conditions are illustrated in Figure 1.

The NAC-LWT is illustrated in Figure 2. No casks presently in use, including the NAC-LWT, have actually been physically tested. The tests have been by computer simulation only.

As seen in Figure 3, the outer layer of stainless steel is 0.25 inches thick. The next layer consists of borated water, or perhaps plastic, intended to absorb neutrons. In a severe impact, this layer would be destroyed[4]. After another shell of stainless steel 1.25 inches thick there is a layer of 5.25 inches of lead, intended to attenuate the gamma radiation.

The inner wall is a 0.50 inch thickness of stainless steel surrounding the cavity that holds the four "bottles" of highly radioactive liquid material. The exact shape of the "bottles" holding the liquid in the cavity is proprietary, but from NRC questions and NAC responses, we see that the liquid is contained in four long steel containers that slide horizontally into a lattice. The containers are not completely filled with liquid, to allow for expansion in case of freezing or fire.

The NAC-LWT cask was originally designed to hold a wide variety of solid radioactive materials, so there are slight variations from the specific cask design depicted in Fig. 3.

Hypothetical Impact

As seen in Figure 1, according to NRC regulations a cask in a hypothetical accident must withstand a drop of 30 feet (9m) onto a flat unyielding surface. With such a fall, the cask would be traveling at 45 mph on impact. As shown in Figure 3, the cask is designed to have impact limiters at each end to absorb the shock from the 30 foot hypothetical drop.

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[3] Fischer, *et al, Shipping Container Response To Severe Highway And Rail Way Accident Conditions,* NUREG/CR – 4829, Lawrence Livermore National Lab, Feb 1987.

[4] *Ibid.*

But what if the drop is sideways onto an unyielding and uneven surface like a concrete bridge pier or abutment? For example, one of the potential transportation routes would take the cask over the Peace Bridge near Buffalo, New York, which in places is 100 feet high. If the container dropped off the bridge and the cask hit the concrete pier it would be traveling 80 mph on impact; the cask would be so damaged, particularly if it struck the pier sideways, that it would very likely release its contents. Calculations by Pacific Northwest Laboratory[5] show that the NAC-LWT cask striking a bridge abutment sideways at a mere 12.5 mph could open the cask cavity. See Figure 4, which is copied from Page 6-4 of PNL-2588.

The NAC-LWT is vulnerable to a sideways impact because such an accident would avoid the impact limiters and because the cask is so thinly constructed, with a total thickness of only 2 inches of stainless steel.

Fire Accident

A type B cask must withstand a fully engulfing fire with flame temperature of 800° C (1475 °F) for a period of 30 minutes without the release of its contents, according to NRC regulations. As discussed in the Modal Study, cited earlier, the liquid contents of the NAC-LWT would likely boil in such a fire accident. The Modal Study calculates the temperature at the middle of the lead shield thickness. The fire thresholds are discussed in PNL-2588, p. 6-4:

The first response level, labelled T-I in Figure 5, is attained in one hour for a regulatory fire. T-1 is defined as the temperature 500 ° F at the middle of the lead shield thickness. This temperature is selected because the test seals, incorporating such materials as silica and fluorocarbon, at that temperature become degraded.

The second response level T-2 is defined as temperature 600 ° F at the middle of the lead shield thickness. At this temperature, the lead at the outermost stainless steel wall of the cask is still below 621°F, the melting point of lead; however, the cask closure seals can degrade and potentially release limited amounts of radioactive material. Level T-2 occurs in approximately 1.4 hours for a regulatory fire.

The third response level T-3 is defined as the temperature of 650 ° F at the middle of the lead shield thickness. At this temperature lead melts and its density decreases, resulting in swelling of the lead layer. Actually 10% of this density change results in an increase in the lead volume sufficient to cause significant plastic straining. This exerts considerable pressure on the inner cask wall and causes some deformation. Level T-3 occurs at approximately 2.2 hours into a regulatory fire.

Finally the modal study calculates a level T-4 for which the temperature of 1050 ° F is reached in 3.2 hours at the middle of the lead shield thickness. For temperatures in the range between 650 ° F and 1050 ° F, the lead shield thickness expands further and leads to cracking of the inner cask wall.

These times and temperatures are illustrated in Figure 5 for a hypothetical regulatory fire.

[5] Pacific Northwest Laboratory, *An Assessment of the Risk of Transporting Spent Nuclear by Truck*, PNL-2588, Richland, WA., November 1978.

Of course, real fires can burn much hotter than those considered in the NRC regulations. For example, in the Caldecott Tunnel fire[6], the Howard tunnel fire in Baltimore[7], and the MacArthur Maze[8] fire, the temperatures all reached 2000 ° F or more, and lasted for several hours. In Figure 6, at an external fire temperature of 1000 ° C (or 1832 ° F), which is the temperature of a typical diesel fire, we see that the lead shield mid-thickness temperature at the T-1 level occurs in only 0.6 hours, while level T-2 occurs in 0.8 hours, level T-3 in 1.4 hours, and level T-4 in 1.9 hours. So we see (Figure 6) that for an external fire burning at 1832 ° F, all these critical temperature levels at the middle thickness of the lead shield will occur much more rapidly than for a regulatory fire.

Since water boils at 212 ° F, it is expected that steam will be created in the four cylinders holding the liquid even at the T-1 temperature level. For this reason, NRC requires that the radioactive liquid bottles have a free space of one gallon per container. This is entirely inadequate if the liquid boils, likely creating sufficient pressure to burst the four bottles. We say "likely" because the thermal section of every edition of the NAC Safety Analysis Report[9] has been redacted so it is not possible to access or verify the NAC calculations.

The PNL-2588 report illustrates the damage to be expected from a realistic diesel fire, if an NAC cask were fully loaded with a "green" irradiated fuel assembly immersed in water (see table). This type of loading was sometimes employed in the early years of NAC-LWT usage – it was the only previous instance of a liquid being transported in such a cask. We expect similar destructive effects following the failure of tubes holding radioactive liquid from Chalk River (due to excessive steam pressure caused by a realistic diesel fire), but details of such an analysis are hidden from the public.

TABLE 6.3. Thermal Failure Thresholds

Type of Failure	Minimum Duration of Fire[a] to Cause Failure
Loss of Coolant from Rupture Disk	15 min.
Closure Seal	30 min.
Drain Valve Seal	30 min.
Vent Valve Seal	30 min.

(a) All fires assumed to be 1010°C (1850°F).

In our opinion, the NAC-LWT may be borderline safe under regulatory conditions, but it could not withstand more severe realistic accident conditions. For this reason, the highly radioactive liquid from Chalk River should not be transported in the NAC-LWT cask. The liquid should be solidified before transport, or not transported at all.

6 NUREG/CR-6894, Rev. 1, Spent Fuel Transportation Package Response to the Caldecott Tunnel Fire Scenario, Pacific Northwest National Laboratory, January 2007

7 NUREG/CR-6793, Numerical Simulation of the Howard Street Tunnel Fire, Baltimore, Maryland, July 2001, National Institute of Standards and Technology, January 2003

8 NUREG/CR-7206, "Spent Fuel Transportation Package Response to the MacArthur Maze Fire Scenario.

9 NAC-LWT, Safety Analysis Report, Section 3vin NRC.gov Adams ML13009A024

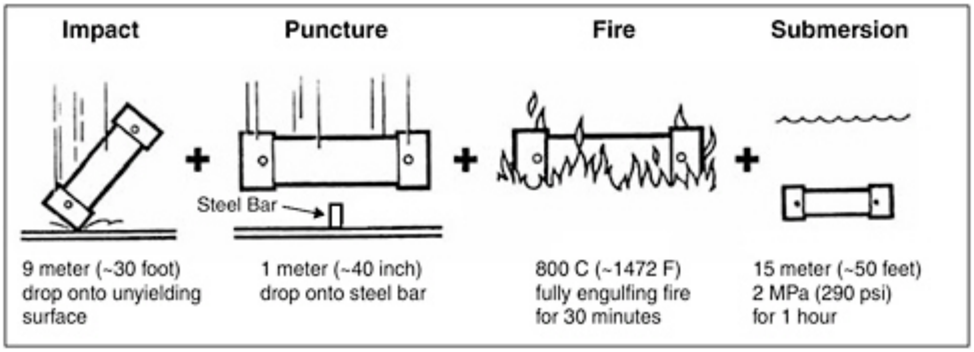
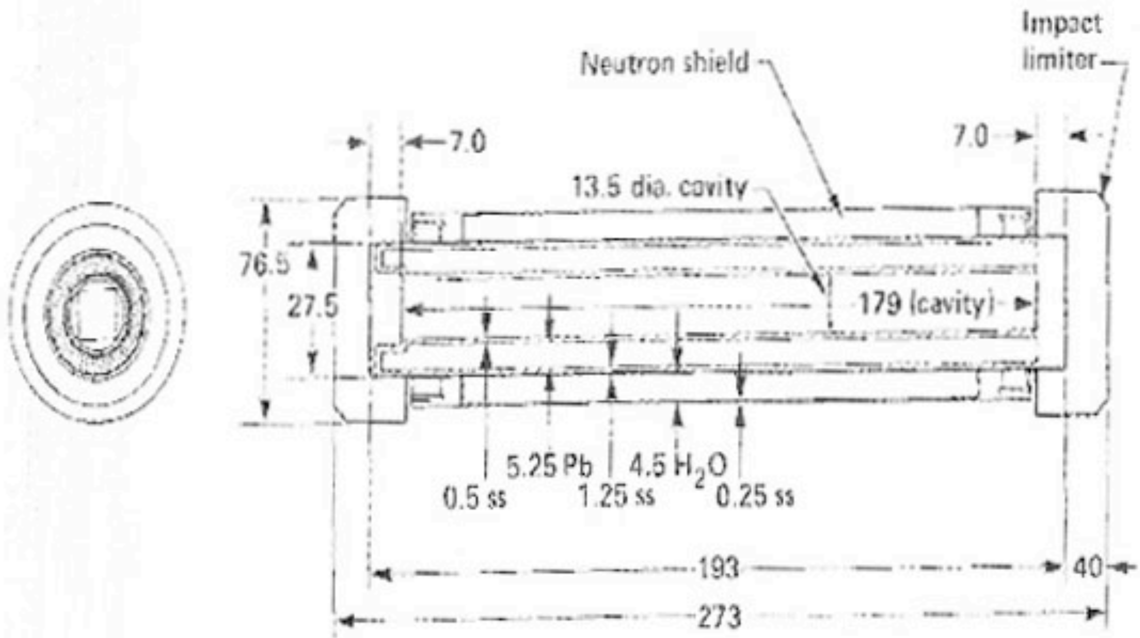


Fig. 1 Nuclear Regulatory Commission Hypothetical Accident Conditions

Fig. 2. NAC-LWT cask in a truck shipping container



All dimensions in inches

Item	Weight, lbs
Body	32,000
Limiter	4,500
Contents	2,500
	39,000

Figure 3. NAC-LWT is constructed of 2 inches of stainless steel and lead.

TABLE 6.1 Summary of Spent Fuel Cask Mechanical Failure Threshold Estimates[(a)]

	Target	Cask Velocity km/hr (mph)	Failure Type
End Impact	Rigid Plane	78.1 (48.5)	Seal to Cask Cavity
	Rigid Plane	153 (95.5)	Larger Opening to Cask Cavity
	Rigid Plane	61.0 (37.9)	Rupture Disk Venting
Side Impact	Rigid Plane	64.7 (40.2)	Seal to Cask Cavity
	Rigid 1.5 m Column	20.1 (12.5)	Opening to Cask Cavity

(a) Taken from Appendix F

Fig. 4. A sideways impact at 12.5 mph could open the cask cavity

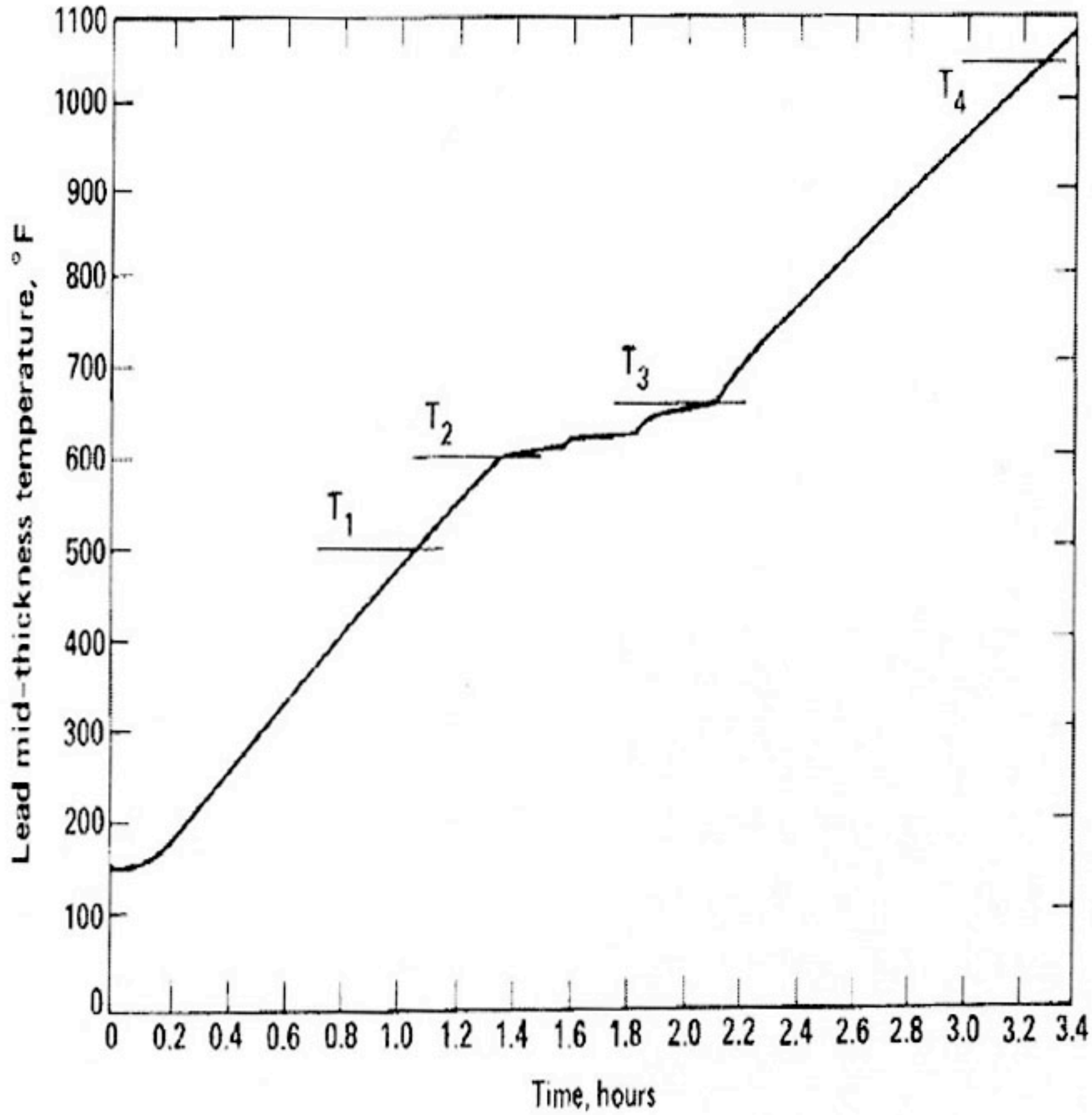


Fig. 5. The temperature at mid lead thickness under a regulatory fire of 1475°F.

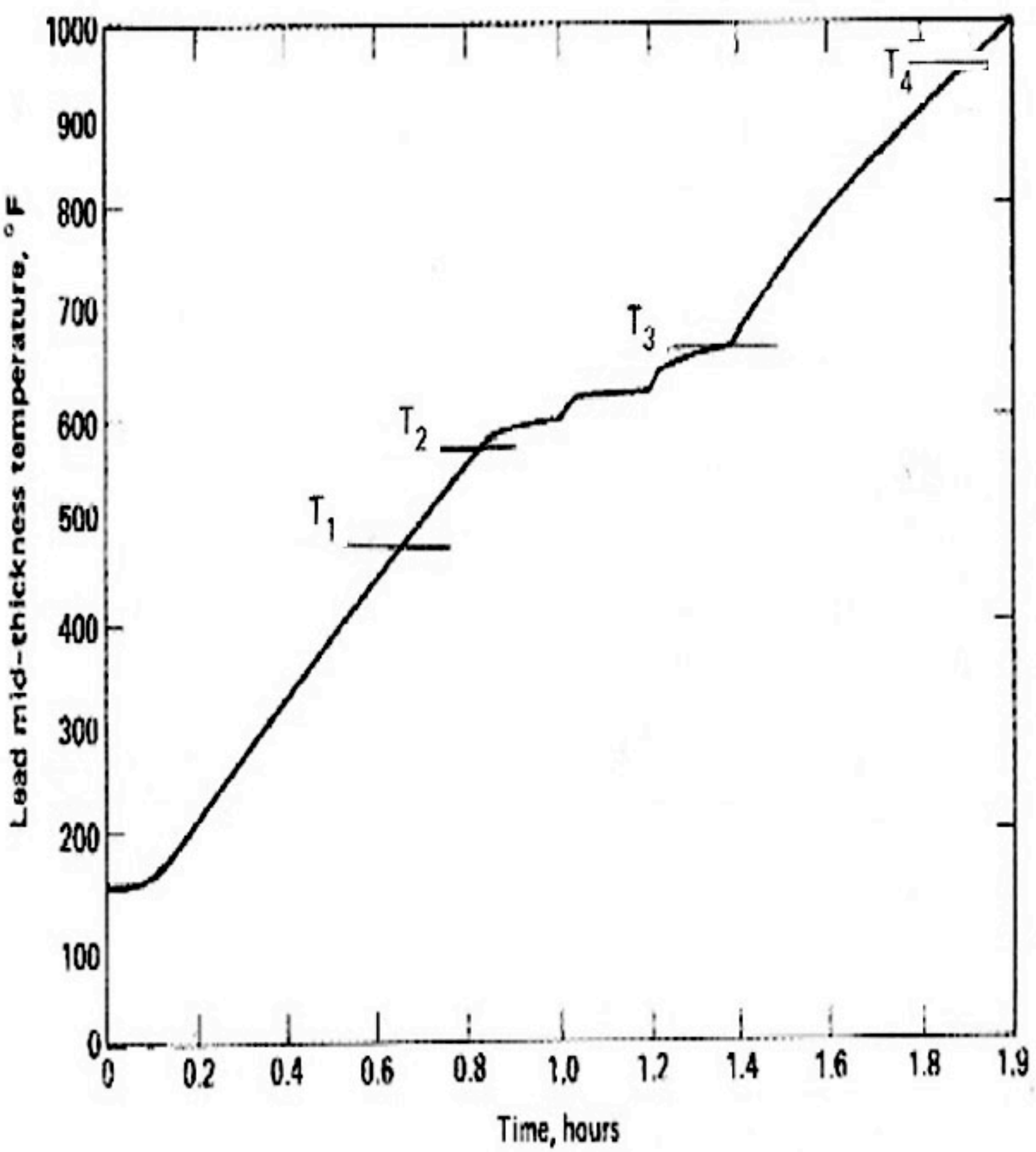


Fig. 6. The temperature at mid lead thickness under a diesel fuel fire of 1832^{O}F