Development of On-Site Accident Criteria for Waste Transfer Casks

Evert D. Uldrich

Westinghouse Idaho Nuclear Company, Inc., Idaho Falls, ID USA

INTRODUCTION

Department of Energy (DOE) contractors who move radioactive waste on DOE sites have a challenge to prepare Safety Analysis Reports for Packaging (SARPs) that must be approved by the DOE operations offices and withstand the scrutiny of the public and various regulatory offices. Currently, there is no standard accident criteria or methodology for intra-site shipments at the Idaho National Engineering Laboratory (INEL). Since the radioactive waste transfer casks only carry material within the INEL site boundaries and are not used for normal over-the-road transport, the requirements of 10 CFR 71 "Packaging and Transportation of Radioactive Material", do not provide suitable requirements for cask design or safety analyses. The objective is to develop realistically conservative accident scenarios consistent with the limited uses at the INEL for which the cask is approved.

At the INEL, waste from the Remote Analytical Laboratory (RAL) must be transported in a transfer cask from the Idaho Chemical Processing Plant to the Radioactive Waste Management Complex (RWMC), 8.6 miles away. This movement is complicated by the fact that in transport this cask must negotiate several curves, cross a public highway, and cross a dry flood control canal. Using this travel route, a list of hypothetical accidents was developed. Even though the requirements of 10 CFR 71 do not apply for on-site shipments at the INEL, they were used as a guide to relate the INEL hypothetical accidents to usable analytical or testing criteria. This procedure can be used by other DOE sites to develop appropriate accident requirements for their respective sites.

CURRENT CRITERIA

Radioactive material shipping requirements currently in effect at the INEL state that the packaging "...shall be evaluated by the designer against the consequences of the maximum credible accident..." (DOE Order ID 5480.1). The regulations also state that "Packaging and administrative controls utilized for on-site radioactive shipments shall provide a degree of safety appropriate for the inherent hazards of the shipment". Also required is "...supporting technical information demonstrating a degree of safety for on-site radioactive and fissile shipments equivalent to that required by DOE and DOT regulations for off-site shipments". These regulations are not specific in required accident analysis, accident criteria, or acceptance criteria for accident conditions. In 1980, the accident criteria was that a fully loaded cask separates from and falls off the transport truck traveling at 20 miles per hour at -40°F. The cask comes to a stop in a roadside

ditch. The acceptance criteria specified that the cask body shall retain its contents and remain intact without fracture and/or separation from its base plate. In 1985 and 1986, when approval for use of the RAL waste cask was actively being sought, this accident criteria was determined to be unacceptable. It was brief and lacking in detail to the extent that the requesters and the approvers would probably never reach a consensus on an accident criteria that the two already fabricated casks could meet even with modification.

During the request for approval procedure, many referrals were made to the current Federal criteria (10 CFR 71) for interstate radioactive shipments. This criteria establishes performance requirements for shipping casks which can be satisfied by testing or by analysis. These performance requirements have been internationally accepted as simulating damage to shipping casks that could occur in most, severe credible accidents. The impact, fire, and water-immersion tests are considered in sequence to determine their cumulative effects on one package. The impact tests include both free drop and a puncture test. In the free drop test, the cask drops 30 feet onto a flat, horizontal, unyielding surface so that it strikes at its weakest point. In the puncture test, the cask drops 40 inches onto a 6-inch diameter vertical steel bar at least 8 inches long, the cask striking the bar at the cask's most vulnerable spot. After the impact and puncture tests, the cask is totally engulfed in a 1475°F thermal environment for 30 minutes. With respect to initial conditions, impact tests are conducted and the fire test is started at a temperature between -20°F and 100°F which is most unfavorable for the feature being tested. In the water-immersion tests, the previously-tested cask is completely submerged under at least 3 feet of water for 8 hours (for a fissile material shipping cask only) and a new cask is completely immersed under 50 feet of water for 8 hours. The acceptance criteria requires no escape of radioactive material exceeding a total amount A_2 in one week, and no external radiation dose rates exceeding one rem per hour at one meter from the external surface of the package. A_2 is the maximum activity of radioactive material, other than special form radioactive material, permitted in a Type A package. The A_2 values are tabulated in 10 CFR 71. These criteria are much more specific than the criteria of DOE Order ID 5480.1.

BASIS FOR FEDERAL CRITERIA

The 10 CFR 71 criteria are almost identical in substance to internationally accepted standards and have been in effect for about 20 years. These criteria have recently been justified (Fischer et al, 1986). A major part of that report was directed toward demonstrating what broad classes of accidents and their associated loadings are enveloped by the loadings implied in the current regulatory standards. Obviously, there are numerous variables involved in defining cask loadings and response. Also there is a broad range of possibilities and interrelationships for each of the variables. Both mechanical and thermal loads generate response states for a cask that could result in damage to the cask. By using the 10 CFR 71 criteria and by knowing the basis of that criteria, a new set of reduced criteria (similar to 10 CFR 71 in format) was developed for the INEL site specific conditions that would provide "equivalent safety".

THE PROPOSED INEL ACCIDENT CRITERIA

The following modifications to the of 10 CFR 71 hypothetical accident conditions are proposed because:

- (a) The cask will never be transported (with radioactive contents) outside the boundaries of the INEL,

- (b) the transport vehicle will not be traveling at legal highway speeds (i.e., 35 MPH speed restriction),
- (c) the shipment will be accompanied by a Security escort, and
- (d) with the exception of about two miles, the roads traveled are not used by the general public.

Free Drop

- 10 CFR 71: A free drop through a distance of 30 feet onto a flat essentially unyielding horizontal surface, striking the surface in a position for which maximum damage is expected.
- Proposed: A free drop through a distance of 15 feet onto the flat typical INEL desert soil or a distance of 10 feet onto a flat 6-inch-thick asphalt pavement at an ambient temperature of -20°F, striking the surface in a position for which maximum damage is expected.

Puncture

- 10 CFR 71: A free drop through a distance of 40 inches striking, in a position for which maximum damage is expected, the top end of a vertical cylindrical mild steel bar mounted on an essentially unyielding horizontal surface. The bar shall be 6 inches in diameter, with the top horizontal and its edge rounded to a radius of not more than one-quarter inch, and of such length as to cause maximum damage to the package, but not less than 8 inches long. The long axis of the bar shall be perpendicular to the unyielding horizontal surface.
- Proposed: The parameters are the same except the free drop would be 20 inches instead of the 40 inches. Also, the initial condition would be 70°F in place of -20°F or 100°F.

Thermal

- 10 CFR 71: Exposure to a thermal test in which the heat input to the package is not less than that which would result from exposure of the whole package to a (thermal) radiation environment of 1475°F for 30 minutes with an emissivity coefficient of 0.9, assuming the surfaces of the package have an absorption coefficient of 0.8. The package shall not be cooled artificially until 3 hours after the test period unless it can be shown that the temperature on the inside of the package has begun to fall in less than 3 hours.
- Proposed: Exposure for at least 15 minutes to a heat flux not less than that of a thermal radiation environment of 1475°F with an emissivity coefficient of at least 0.9. For purposes of calculation, the surface absorptivity must be either those values which the package may be expected to possess if exposed to a fire, or 0.8, whichever is greater. The cask may be subjected to artificial cooling at any time following the 15 minutes heat flux exposure. The effects of solar radiation may be neglected.

Water Immersion

- 10 CFR 71: Immersion in water to the extent that all portions of the

package to be tested are under at least 50 feet of water (or equivalent pressure) for a period of not less than 8 hours.

Proposed: Not applicable.

Acceptance Criteria

10 CFR 71: There would be no escape of radioactive material exceeding a total amount A_2 in one week, and no external radiation dose rate exceeding one rem per hour at one meter from the external surface of the package.

Proposed: It must be shown by analysis that the RAL waste shipment cask, as constructed or modified and prepared for use, when subjected to the proposed criteria, will not leak radioactive material (solid, liquid, or gaseous). The cask should be allowed to bend, distort or crack, but if the integrity of the inner 30-gallon drum is maintained, it should be considered as withstanding the forces of the maximum credible accident. Additionally, it must be analytically calculated that any reduction of shielding integrity would not be sufficient to increase the external radiation dose rate to more than one rem per hour at one meter from the external surfaces of the cask.

JUSTIFICATION OF THE PROPOSED CRITERIA

The route the truck transporting this cask will travel is well defined. It is 8.6 miles of two-lane asphalt paved highway. The roadside ditches are typically three feet to five feet deep, except at one curve where the embankment slopes away for an elevation drop of 10 to 12 feet on the outside of the curve. No bridge abutments or bare lava rock outcroppings that might present unyielding surface problems at impact are present. All intersections are at grade-level with one crossing a U.S. highway. Five different accident possibilities were considered. The most severe accident likely to occur was determined to be a fully head-on collision between the escorted cask transport truck traveling at 35 miles per hour and a large waste hauling truck returning from the RWMC traveling at 55 miles per hour. Knowing the route, the roadside hazards and the most severe accident likely to occur, a comparison to the basis for the 10 CFR 71 requirements was made.

The 10 CFR 71 basis report (Fischer et al., 1986) presents justification for the 10 CFR 71 criteria. By comparing the basis report accidents to the INEL accident, a logically derived accident criteria can be developed for the INEL intrasite shipments.

Free Drop

Mechanical loads include forces on the cask caused by impact with a surface or hard object, puncture by sharp objects, and crushing by heavy objects. Impact loads are the dominant mechanical loads and have the greatest potential for causing significant structural damage to a spent fuel cask. The following loading parameters affect cask response and potential damage: impact velocity, cask orientation, and hardness of the object impacted. The distribution of potential cask velocities can vary depending on the specifics of the accident scenario. Accident scenarios may include collisions, fall from heights, a combined collision and fall, or train accident at a grade crossing. Most accident reports give the truck velocity just prior to the accident which makes it difficult to estimate cask impact velocity. One-half of the trucks involved in accidents were traveling at 30 miles per hour or

less. The other one-half were traveling between 30 and 60 miles per hour. Of the bridges surveyed, which is believed to be typical of all roads, 95.6% were 50 feet or less in height and 83.5% were less than 30 feet in height. Accident scenarios involving train-truck collision at grade crossings indicate that in 72.5% of the accidents the train was traveling at less than 30 miles per hour. Impact angle is the angle between the cask velocity and the plane of the surface struck. A 90° impact angle defines the accident as head-on and an impact angle close to 0° defines the accident as a sideswiping impact. For cask orientation, historical records do not contain significant information on the orientation of the cask with respect to the object impacted. For hardness of the objects impacted, accident surveys indicate that about 65% of the accidents involve collision with a moving object such as another truck, automobile, animals, etc., about 9% involve collision with a fixed object such as bridge railing, abutment, etc., about 25% involve driving off the road, overturning, or jackknife and about 1% is fire only. In the case the truck runs off a bridge, about 78% involve impacting rocks and railways, 20% involve water and about 2% involve soil and rock. Only three accident scenarios have been determined to cause mechanical loads high enough to damage a spent fuel cask: collision with trains, columns and abutments; trucks running off bridges and over embankments; and trucks running into slopes.

Applying the preceding data to the INEL, the previously described route survey indicates no train crossings, no columns or abutments, no bridges to run off and no slopes to run into. The only accident scenario remaining is a truck running over an embankment. (The energy of impact of the head-on collision is dissipated in the deformation of the vehicle and in the breaking of the cask securing mechanism, therefore, eliminating the head-on collision as causing high mechanical loads.) Since the vehicle speed is restricted to 35 miles per hour for radioactive shipments at the INEL, the transport vehicle has only 34% of the kinetic energy of the over-the-highway vehicle. The potential energy of the proposed 15 foot drop test is 50% of that of the 10 CFR 71 required 30 foot drop test. The balance of the energy is accounted for in the strain energy absorbed by the impacted surface.

Puncture

The puncture test is only significant if puncture can occur at some location other than at the impact limiter. Impact limiters are typically made of crushable material surrounding the extremities of a cask. For large casks they usually are removable and on smaller casks they are integral with the cask. (If the puncture occurs at an impact limiter, the damage from the 40 inch (drop) puncture test will always be less than the damage from the 30 foot drop test.) In some accidents, such as rail grade crossings accidents, the impact limiter on the cask can be bypassed and the side of the cask can be struck directly. This may occur when the cask impacts a train sill or a small bridge column. However, on heavily constructed spent fuel casks, of which the RAL Waste cask is similar, it has been found that the puncture test is relatively insignificant compared to the 30 foot drop test.

At the INEL, considering the travel route, it is very difficult to conceive a puncture accident occurring. Consequently, it was determined not to eliminate the puncture test, but to decrease the impact energy by 50%.

Thermal

The thermal response of a cask is determined by fire duration, flame temperature and fire location with respect to the cask. Historical accident data is lacking for fire duration and flame temperature. It is known that

fire only accidents are only 1% of all accidents. Since fire is involved in only 2.4% of all collision accidents and since collision accidents are 74.1% of all accidents, fire is involved in collision only 1.8% of all accidents. It is also known that the heat load to the cask decreases as the distance between the cask and fire increases. At 31.5 feet, a fire is considered to have negligible effect on a cask. High thermal loads caused by fires can cause the cask containment seals to deteriorate and leak or the lead shield to melt. Flame temperatures for the open burning of hydrocarbon fuels ranges from 1400 to 2400⁰ F. Other materials tend to burn at lower temperatures.

Considering, the low percentage of fire involvement in accidents, the shortness of the INEL transport route, the close proximity of the fire station, and the two-way communications present in the Security escort vehicles, the magnitude of the fire is maintained but the duration of the fire is reduced from 30 to 15 minutes.

Water Immersion

Since at the INEL, the route of cask transport crosses only one potential waterway, a flood control canal, which has never been used and future use is expected to be much less than once a year, it is justified to consider water immersion not applicable.

CONCLUSION

By considering the route, travel restrictions and comparison to the basis for the national criteria, site specific accident criteria can be developed for radioactive material shipping casks that provide equivalent safety to nationwide shipments. Spent fuel, radiological waste, and other casks have sufficient design margins such that significant radiological consequences will not occur even at loading conditions which exceed those specified in regulations. The proposed accident criteria for use at INEL for the RAL Waste Transfer cask is safe, appropriate, and does provide equivalent safety as required by local regulations.

REFERENCES

- "Safety Requirements for the Packaging of Fissile and Other Radioactive Materials", DOE Order ID 5480.1, Chapter III, U. S. Department of Energy, Idaho Operations Office , December 27, 1982.
- Office of the Federal Register, Title 10, Code of Federal Regulations, Part 71, "Packaging and Transportation of Radioactive Material", Office of the Federal Register, Washington, DC, January 1984.
- Fischer, L.E., Chou, C.K., Gerhard, M.A., Kimura, C.Y., Martin, R.W. Mensing, R.W., Mount, M.E., and Witte, M.C. (1986), "Shipping Container Response to Severe Highway and Railway Accident Conditions, Volume 1: Main Report", Report Numbers: NUREG/CR-4829, Vol. 1; UCID-20733, Vol. 1, Lawrence Livermore National Laboratory.