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A Review of the Risks and Risk Models for Transporting Very Radioactive Materials

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Abstract

This paper reviews how the risks of transporting very radioactive materials are modeled and how the resulting doses to the public compare with commonly experienced radiation doses like background radiation. Both routine, incident-free transportation and transportation accidents are discussed. Only transportation of used nuclear fuel and high-level radioactive waste is discussed.

Introduction

Thirty-five years ago the Nuclear Regulatory Commission responded to public concern about transportation of radioactive materials by estimating what the radiation impact of transporting such materials, including spent fuel, would be. The result was the Final Environmental Statement (EIS) on the Transportation of Radioactive Material by Air and Other Modes, NUREG-0170, published in 1977 (NRC, 1977). This EIS included transportation of all types of radioactive material by road, rail, air, and water, and concluded that:

- The average radiation dose to members of the public from routine transportation of radioactive materials is a fraction of the background dose.
- The radiological risk from accidents in transporting radioactive materials is very small compared to the non-radiological risk from accidents involving large trucks or freight trains.

Existing regulations were considered "adequate to protect the public against unreasonable risk from the transport of radioactive materials." In spite of these contentions, which have been verified repeatedly through the years, the transportation of radioactive materials is considered more dangerous than transportation of other hazardous materials (e.g. gasoline, chlorine, liquefied natural gas), which actually poses greater risks. This paper calculates the risks of radioactive materials transportation using a more refined model than was available in 1977 and that uses only data input by the analyst.

Routine Incident-free Transportation of Radioactive Materials

Routine, incident free transportation causes some radiation exposures because all loaded spent fuel casks emit some external radiation, though this is always within regulatory limits. The external dose and dose rate are measured, both on the cask surface and up to two meters from the cask to ensure that the cask complies with the regulation of 10 CFR Part 71. Figure 1 shows the external dose rate map of the GA-4 truck cask (GA, 1994) that results from such measurements.

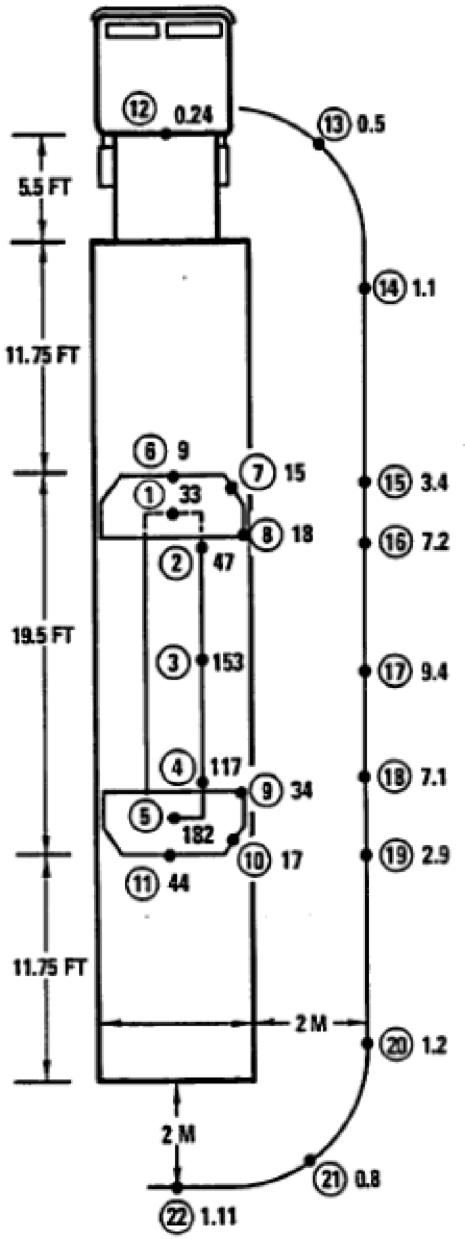

Figure 1. Total dose rate (mR/h) around GA-4 cask for normal conditions. (GA 1994)

The radiation dose from this external radiation to any member of the public during routine transportation, including stops, is barely discernible compared to natural background radiation, and is therefore exceedingly difficult to measure. Doses to the public are therefore modeled using the program and code RADTRAN (Neuhauser, et al, 2000; Weiner, et al, 2009) . The external dose rate at one meter from the cask – the "transport index" as defined in 10 CFR Part 71—is modeled as a virtual spherically isotropic source at the center of the cask. Figure 2 shows an example cask and the way the radiation to a member of the public is modeled.

This model has been experimentally validated (Steinman, et al, 1999) by measuring doses from a hot (0.5 Sv/hour) rail tank car at one, three, and 5 meters from the rail track, and shown to overestimate the dose slightly.

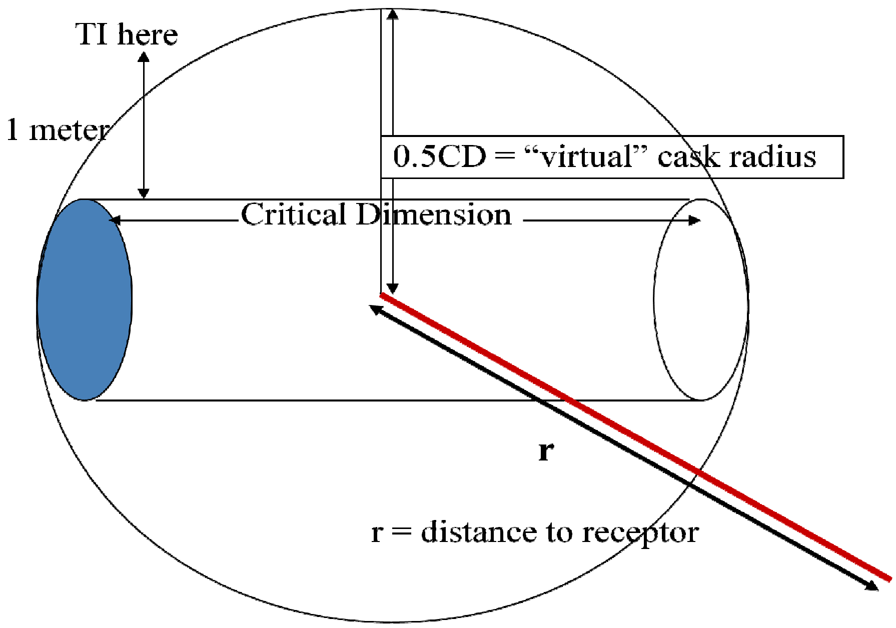

Figure 2. Model of a Type B cask in routine, incident-free transportation andparameters for calculating radiation dose to a member of the public.

The radiation dose to a member of the public near the route is proportional to $1/r^2$, where r is the distance of the receptor from the virtual source . For the usually observed distances (e.g., a highway lane width) the distance to the cask surface and to the virtual source at the center of the cask are essentially the same. The radiation dose to an inspector or anyone else within a cask length of the cask, the dose sustained is proportional to $1/r$.

The resulting dose to a member of the public along the route traveled by the cask is very small. The collective dose – dose to the resident population -- from routine transportation is the sum of all of these doses. Figure 3 shows the total dose to all of the exposed workers and members of the public for a particular sample route. The background radiation dose to exposed workers and members of the public during the time of the shipment is included in the figure.

As Figure 3 shows , the collective dose from the shipment is a negligible fraction of the collective background dose – the mostly external dose that everyone receives continuously. The data for this figure is from Dunagan and Weiner (2008). The background dose used for this calculation was 0.41 μSv/hour (3.6 mSv per year), the average U.S. background dose. Some higher elevations in the continental United States exhibit background doses at least twice as large.

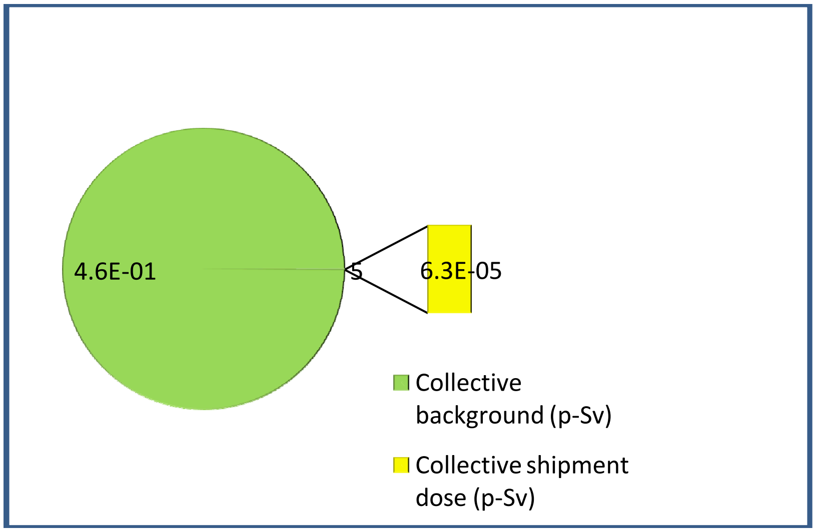

Figure 3. Collective Doses from Background and from a TRUPACT-II Shipment of Remotely Handled Transuranic Waste through an urban area (Person-Sv)

Transportation Accidents Involving Radioactive Materials

Three types of traffic accidents can occur when radioactive materials are transported;

1. An accident in which there is no effect at all on the radioactive cargo.
2. An accident in which there is a release of radioactive material.
3. An accident involving a lead-shielded cask in which there is no release of radioactive material but some of the gamma shielding provided by the lead shield is lost, and the external gamma dose rate is consequently increased.

The first type of accident is by far the most common; more that 99.9% of the accidents predicted by the model are of this type. This is the only type of accident in which a Type B cask carrying very radioactive material has been involved. This result is not surprising, since such casks are designed to withstand accidents, because it is recognized that a truck carrying radioactive material is a likely to be in an accident as any other truck of similar size and weight.

Figure 4 shows the tests that Type B casks are designed to withstand;

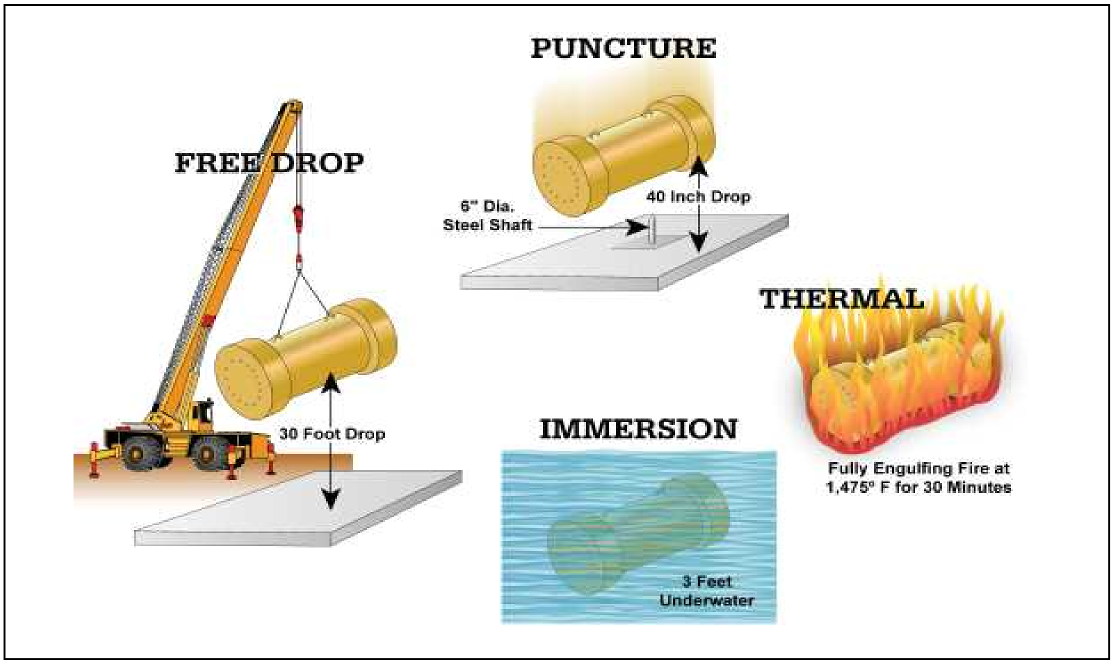

Figure 4. The four tests for Type B casks (courtesy of Earl Easton, USNRC)

Every cask used is not tested. The cask must withstand the tests without a leak or breach, but it would come through the test series dented, discolored and sooty from the fire, and mechanically weakened. The tests are designed to destroy the cask. Full-size and smaller scale prototype casks and critical features of the cask, like pressure welds, are tested. New cask design and structure are also compared to the design and structure of similar certified casks, and applicants for certification are required to show the results of tests with prototypes. New cask designs are modeled using models that have been benchmarked by physical tests. Physical testing of prototypes and components, comparison with existing certified casks, and modeling by benchmarked thermal and structural models are all used to determine that a cask meets the test requirements. The test series does not guarantee zero release, and is not intended to. 10 CFR 71.51 allows release of certain amounts of each radionuclide and certain radioactive emissions from Type B casks in the event of an accident, because the amount of such releases is deemed not to harm either human health or the environment.

If the cask is subjected to mechanical and/or thermal stresses greater than those of the test series, a release of radioactive materials could occur. The model of such an accident involving used nuclear fuel assumes, very conservatively, that all of the fuel rods in the casks are damaged, and the fraction released is a fraction of the radioactive inventory. The dose to a receptor that results from such a release depends on the amount of released material dispersed, the height above the ground at which the released material becomes available for dispersion, and the ambient meteorology (wind, insolation, etc.). Release from a Type B cask in a traffic accident can only be through the seals as a result of seal failure. As a consequence, any material released either would be gaseous or would consist of particles small enough to be dispersed.

Dispersion of released material is modeled using Gaussian dispersion. Doses are not modeled closer to the source than 100 meters, since the Gaussian dispersion model greatly overestimates the dose closer to the source. Figure 5 (Dunagan and Weiner, 2008) shows the modeled dose to the maximally exposed individual from radioactive material released in the presence and absence of a fire. The release in this case was from an RH-72B cask carrying the maximum inventory of remote-handled transuranic (RH-TRU) waste to the Waste Isolation Pilot Plant. The heat from the fire lofts the plume, so that ultimate dispersion is from an elevated plume.

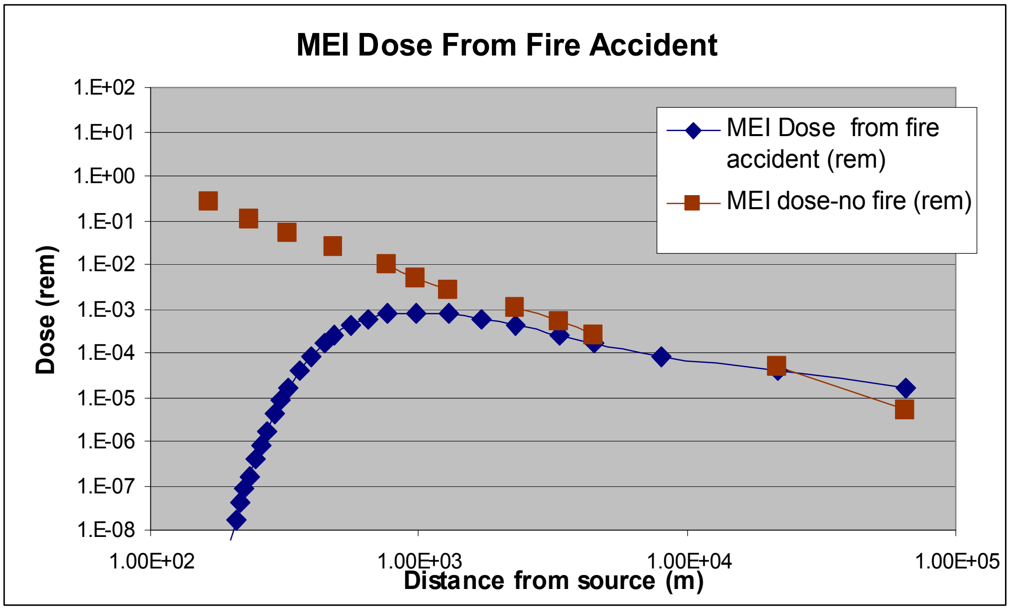

Figure 5. MEI doses from an accident that involved a fire and one that did not involve a fire. (Dunagan and Weiner, 2008, Figure 9).

The maximum dose shown in Figure 5 is approximately one rem (0.01 Sv); a significant dose. Under similar assumptions the maximum MEI dose from a truck shipment of four used PWR assemblies would be at least an order of magnitude larger: 10 rem (0.1Sv). However, the risk from such an accident must include the probability of the accident. The average probability of a heavy truck accident in the U.S. is about 2×10^{-6} per km, or about 6/1000 for a trip across the United States (DOT, 2008). Because Type B casks are designed to withstand accidents, the probability of release of radioactive material is at most about 2×10^{-5} (Sprung, et al, 2000, p.7-74). The net probability of such an accident is thus about 10^{-7}, and the "dose risk" (the risk that the MEI would sustain such a dose) is about 10^{-6} rem (10^{-8} Sv). In fact, no such accident has ever been observed; this result is based entirely on a model.

Some Conclusions

The statements in the 1977 EIS, which were based on necessarily relatively crude models have been substantiated by refined analyses:

- The average radiation dose to members of the public from routine transportation of radioactive materials is a fraction of the background dose.

- The radiological risk from accidents in transporting radioactive materials is very small compared to the non-radiological risk from accidents involving large trucks or freight trains.

People living along transportation routes are receive background radiation continuously, and far in excess of any ionizing radiation from a routine shipment of very radioactive material like spent fuel, or even from 100 contiguous shipments.

An accident that would result in release of radioactive material has not been observed in the U.S. and is very unlikely to happen.

Although an elevated release of radioactive material can affect more people that a grpound-level release, since its footprint cover a larger area, the material is more dilute, and both the average and maximum individual doses are less than from a ground-level release.

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