Equivalent Safety Basis for Evaluation of On-Site Packages for US DOE Facilities

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Abstract
Packages for transport of radioactive material within the boundaries of a Department of Energy facility (on-site) must conform to the requirements for packages shipped in normal commerce, or must provide equivalent safety. Present practice attempts to show that various accidents are incredible and consequently do not need to be addressed. An alternate approach is proposed in which equivalence is achieved if the frequency of severe on-site accidents, which could result in a release of radioactive material, is less than or equal to the frequency of Beyond-HAC accidents for packages in commerce. This is shown to be achieved if the rate of on-site accident is 0.14 per 100 MVM or lower. For equivalence to Normal Conditions of Transport, for on-site packages, appropriate, defensible Design Basis Conditions can be established and the ability of the package to meet the reduced requirements shown in the On-site Safety Assessment.

Background
Transport of radioactive materials has been safely and successfully performed for over 50 years. The success in this activity is the result of the integrity of the packages and the care with which they are moved. The standards for package integrity have been established by the IAEA. These standards with some changes have been adopted by the responsible agencies in the United States and incorporated into the Code of Federal Regulations (10 CFR 71 and 49 CFR 173), which has the authority of law. The regulatory standard establishes performance criteria for packages which will be used in normal commerce.

Transport of radioactive material within the boundaries of a facility is not subject to the same regulations that govern movements between facilities in normal commerce. The requirements are distinguished as on-site and off-site.

By order of the Department of Energy (DOE), on-site transport at DOE sites, which are government owned facilities, must be performed in accordance with the off site requirements (e.g., 10 CFR 71), or must provide "equivalent safety" (DOE Order 460.1a). In concept, this "equivalent safety" can be provided by determining the capabilities of the packaging and providing administrative controls which insure that the package is not exposed to conditions which could exceed its capabilities.

In practice this consists of establishing a set of design basis conditions (DBC) for normal transport conditions which may be less demanding than those required by regulation (10CFR71) for open commerce. Administrative procedures and supplementary measures are developed to insure that the package remains within these bounds. The combination package design requirements (to the design basis condition requirements) and administrative controls provides the required "equivalent safety".

Equivalence to the hypothetical accident condition (HAC) requirements is achieved by placing controls on the movement (vehicle speed, closing roads, limiting fuel, provision of escort vehicles) so that the accident risk is shown to be acceptably low by risk assessment. In present practice, this is achieved by imposing restrictions until the predicted frequency of occurrence of an accident is so low as to be considered incredible.

There are a number of older packages in use on-site at various facilities for which safety documentation has not yet been completed. These packages have been used successfully, historically, and are continuing in use under grandfather provisions, pending completion of the safety documentation. For US DOE facilities, the On-site Safety Assessment (OSA), or Onsite SARP, is the safety basis and corresponds to the Safety Analysis Report for Packaging (SARP) for a certified off site package. The OSA typically follows the same format as a SARP, and is comparable in scope. The authorization to use the package on site is based on an independent review of the OSA, paralleling the independent review of a SARP, which serves as the basis for issuing a Certificate of Compliance.

In order for these packages to continue in use, the OSA must show that the combination of the package and the associated administrative controls provides protection equivalent to that provided by a package conforming to 10 CFR 71. Here, protection indicates protection of the public, workers and environment from the hazardous effects of the contents.

Present Issue

In the absence of a suitable certified package for moving a given contents on site at a DOE facility, Order 460.1a allows the movement to be made in an on-site package providing equivalent protection. Typically, the on-site package does not fully meet all of the Normal Conditions of (NCT) or Hypothetical Accident Condition (HAC) requirements of the Code of Federal Regulations (10 CFR 71). Where requirements not fully met, 460.1a allows a corresponding set of less stringent requirements to be established, based on considerations of the actual physical challenges the package will encounter and consideration of benefits of administrative controls. The package is then shown to meet these reduced, design-basis conditions. At present, there is no consistently established basis for determining that equivalent protection is provided in an on-site package.

The OSA consists of analyses that support the ability of the package to meet the shielding, criticality and containment requirements for the specified contents. In addition, the OSA includes analyses of the structural, thermal and materials aspects of the design that are essential to support the shielding, criticality and containment analyses.

The challenge for demonstrating that an on-site package provides a level of safety equivalent to an off-site package is to establish an objective basis for comparison of the on-site protection with the regulatory basis (10 CFR 71).

Aspects of evaluation of equivalence

In order to demonstrate that the package meets the "equivalent safety" standard, the On-site Safety Assessment must present tests or analyses which support the performance of the package and define the supporting administrative controls.

The analysis of the performance of the package in the packaging sense (i.e. with respect to 10 CFR 71), involves determining:

The level of containment the package achieves
The level of shielding provided.
Confirmation that subcriticality is assured.

In addition, the performance analysis identifies specific points of non-compliance.

The assessment also details the administrative controls needed to provide the required additional measure of safety (beyond the package performance) to compensate for the points of non-compliance and achieve a level equivalent to 10 CFR 71.

This, in turn, poses the question: How can the contribution of administrative control of conduct of operations to the package safety basis be demonstrated?

Risk assessment based equivalence for accidents

Probabilistic Risk Assessment (PRA) provides an objective method for evaluating equivalence. This approach is the accepted method for nuclear facilities and is endorsed by IAEA and other regulatory agencies [1].

To show that:

On-site risk ? Off-site risk,

We must show that:

Frequency of on-site accidents resulting in release
? frequency of off-site accidents resulting in release.

For purposes of developing a basis for evaluating "equivalent safety", it is first recognized that a package may not survive a beyond-HAC event. (i.e., containment is breached so that loss of contents occurs, shielding breaks down, or water [moderator] enters the containment boundary.)

Accidents occurring off site which result in release from certified packages must be more severe than the events represented by the regulatory Hypothetical Accident Condition (HAC) test sequence. Such events are judged to be sufficiently infrequent as to be an acceptable risk and are not addressed by the regulations.

An acceptable basis for safety assessments for on-site movements would be to show that any accident, resulting in release, was incredible for the particular on-site movement. This approach is frequently used in on-site package safety analyses. However, Department of Transportation (DOT) accident statistics show that beyond-HAC accidents are not incredible events [2 – 7]. To hold on-site moves to this standard is to exceed the requirement for equivalent safety and to impose an unwarranted burden on these on-site movements.

It is proposed that the frequency of Beyond-HAC events become the standard for equivalent safety, with respect to accidents.

Proposed Alternate Basis

The level of safety for accidents achieved by off-site packages (certified to 10 CFR 71[8]) can also be achieved by on-site packages moved in accordance with supplementary administrative controls if the frequency of on-site accidents would not exceed the frequency of Beyond-HAC accidents for the off site moves.

It is postulated that, in a hypothetical accident scenario, the transporter is slowed from its pre-accident speed prior to package impact. That is, energy is dissipated in the initial stages of the accident event by braking, crushing of minor obstacles, deformation of body work and transporter structure, so that at the time the package itself experiences impact, it is traveling at a speed comparable to the regulatory test velocity (i.e., about 48 km/h (30 mph) at the termination of the 9 m (30 ft drop)). In this context, it would be conservative to assume that the transporter was traveling at highway speed greater than 90 km/h (55 mph) at the moment of initiation of the accident. The required accident frequency for use in the equivalent safety evaluation would be the frequency for accidents occurring at speeds above 90 km/h (55 mph). For this analysis, accidents occurring at 98 kph (60 mph) or above are considered. This is conservative because it reduces the reference frequency used for comparison.

Data on frequency of severe accidents, in which the vehicle is subjected to high speed impact, is not directly available. However, data on fatal accident distribution by posted speed limit is available (BTS Table 3-12).

The assumption is made that accidents severe enough to result in fatalities are severe enough to challenge a RAM Package, when they occur at high speeds. So, the fatal accident statistics are at least an indicator of the severe accident. Even if a multiplier greater than 1 is required to correct the relationship between these rates, the conservatisms incorporated into the analysis allow for considerable range in the multiplier.

It is also assumed that the accidents in zones posted above 90 km/h (55 mph) actually involve speeds close to, or above, the posted limit. It is recognized that vehicles involved in accidents in zones posted at 90 km/h (55 mph) may actually have been exceeding the posted limit. However, including accidents in 90 km/h (55 mph) zones increases the total frequency of accidents which are considered an acceptable risk by the regulations. Omitting those occurring in zones posted at 90 km/h (55 mph) or less is, therefore, conservative.

Using BTS Table 3-12 data summarized in Table 1, Fatal accidents by Posted Speed Limit, the fraction of fatal accidents occurring in zones posted at, or above, 98 km/h (60 mph) can be determined. In the following evaluation, the number in the table for which the posted speed was “unknown” are included in the total for those in the 98 km/h (60 mph), and above, zones. The total in the 98 km/h (60 mph), or above, is divided by the total number of fatal accidents to obtain the fraction occurring in zones posted at 98 km/h (60 mph), or above.

For example, for 1990; Number in $\geq$ 98 km/h = 3144
Total fatal accidents = 39836

Fraction in > 90 km/h = 3144/39836 = 7.9%

The fraction of severe high speed accidents (over 90 km/h) of all severe accidents is then taken to be equal to this number, i.e., 7.9%.

Table 2 summarizes BTS Table 3-11 data for total accidents per 100 Million Vehicle Miles (MVM) and fatal accidents per 100 MVM (for all highway vehicles).

The number of accidents in zones posted at, or above 98 km/h (60 mph) per 100 MVM is the product of the following terms:

(Severe accidents in zones > 90 km/h / total severe accidents)
X
(total severe accidents / 100MVM)

= (severe accidents > 90 km/h / 100MVM)

As noted above, for this evaluation accidents occurring at 55 mph are omitted. The assumption that Beyond-HAC accidents require higher speed than 55 is believed to be conservative. The combined results for 1990-1995 are given in Table 3. The corresponding rate for low speed accidents, 41 kph (25 mph) are also given in Table 3.

This analysis shows that a conservative value for the average severe accident frequency for speed ranges of 98 km/h (60 mph), or above, for the period 1990 through 1995, is about 0.14 per 100 Million Vehicle Miles (0.14 per 100M VM). Assuming a normal distribution for the accident frequency, the one-sided normal tolerance limit at 99% confidence is 0.075 per 100M VM. The overall accident rate is 220 per 100M VM, for the same period.

Proposed approach

Recognizing that a certified off-site package cannot be expected to withstand a Beyond-HAC event, it is assumed that an on-site package may be vulnerable to any significant accident.

We achieve equivalence if we show that, with sufficient additional operational controls, the frequency of on-site accidents resulting in a release is equal to the frequency of exposure of off site packages to Beyond-HAC accidents.

That is, if the package has no ability to withstand an accident, it must be transported in such a way that the frequency of accident is equal to, or less than, the frequency of off site accidents exceeding HAC. In quantitative terms, the on-site accident rate must by shown to be 0.14 per 100M VM or lower.

If the package has some ability to withstand an accident, it requires less administrative control on how it is moved to insure that the frequency of accident resulting in release is within the frequency of off-site beyond-HAC accidents.

Design Basis for Accident Conditions

Establishing a justification for not performing HAC tests or analyses does not obviate the need for evaluation of the package for its ability to withstand a credible accident. Performance of a process hazards review provides a structured means of identifying the evolutions in the employment of the package which place it at greatest risk. Examples of such hazards include dropping the package during handling, or vehicle roll-over. The package must be analyzed for its ability to withstand such events. If necessary, further mitigating actions may be specified, to enable the package to survive (e.g., limiting the lift height allowed during handling).

Level of administrative control required

Reference to the DOT Bureau of Transportation Statistics data, shows that restricting the travel speed to below 41 kph (25 mph) reduces the severe accident rate to 0.097 per 100M VM. This is well within the 0.14 per 100M VM (and close to the 0.075 per 100M VM tolerance limit) needed for equivalent accident safety, and is recommended as a conservative on-site transit speed limit.

Equivalent Safety for Normal Conditions

Risk assessment enables avoiding full Hypothetical Accident Condition tests or analyses. However, Normal Conditions of Transport (NCT) are encountered on-site just as they are encountered off site. The most direct means of achieving equivalent safety for on-site packages under NCT conditions is to conform to the regulatory requirements. Where the regulatory requirement is unduly restrictive, or unachievable, for on-site application, an appropriate, defensible reduced requirement should be established and the ability of the package to meet this reduced requirement shown in the OSA. The establishment of such Design Basis Conditions (DBC) is specifically permitted in the applicable DOE Order on Packaging and Transportation Safety, 460.1A.

These Design Basis Conditions are developed by considering each of the requirements of 10 CFR 71.71 in turn and providing a comparable requirement for the applicable on-site conditions. This is illustrated in the following example Design Basis Conditions for the various NCT requirements.

The requirements for Normal Conditions of Transport, given in 10CFR71.71(c),are:

Requirement: (c) (1) Heat - imposes solar energy flux for package in 311° K (100°F) still air.

This requirement may be reduced by basing insolation on local meteorological data (an established practice for on-site packages assessments). In addition, administrative controls on the movement, or provision of solar shielding, can limit exposure to high ambient temperatures and to solar irradiation.

Requirement: (c) (2) Cold - imposes 233°K (-40°F) ambient temperature criterion.

This requirement may be reduced by use of local meteorological data. For example, at the Savannah River Site, the coldest days are seldom below 267° K (+20°F).

Requirement: (c) (3) – imposes reduced external pressure (to 24 Kpa [3.5 psi]).

This requirement may be reduced by use of local meteorological and geographical data. For example, the peak elevation at the Savannah River Site is on the order of 90 m (300 ft), so that elevation changes are not significant.

Requirement: (c) (5) Vibration in Transport – imposes evaluation of vibration.

If required, reduction in vibration may be obtained by administratively controlling the speed of the vehicle. The 40 km/h (25 mph) limit, imposed to meet the accident equivalency requirement, would significantly reduce vibration in transport.

In addition, on-site moves are, by definition, of limited duration, so the exposure to vibration in terms of number of cycles is correspondingly limited.

Requirement: (c) (6) Water Spray – requires exposure to water spray.

This requirement is applicable to cardboard and similar packages, whose structural properties would be affected by being wet. It is not applicable to packages constructed of waterproof materials.

Requirement: (c) (7) - Imposes Free Drop criteria, based on package weight.

This is typically the most difficult NCT test to satisfy, but is important because it is an indication of the general structural integrity of the package. If a package cannot meet the regulatory criterion, engineered or administrative controls must be imposed to limit the height from which the package could fall. Alternatively, or in addition, shock absorbing material may be placed beneath the package, during any movement that could result in a drop.

In some cases, the Safety Analysis Reports for the facilities where the package is loaded or unloaded from the truck will envelope the package drop event.

Requirement: (c) (8) Corner drop – requires dropping package on corners.

This requirement applies to relatively small packages, constructed of fiberboard or wood, or used for fissile materials.

Requirement: (c) (9) Compression – imposes ability to withstand stacking loads.

The compression requirements may reasonably be relaxed if the controls on the package movement prevent stacking or otherwise placing such loads on the package.

Requirement: (c) (10) Penetration – requires ability to withstand penetration.

This requirement postulates that the package is speared by a 6 Kg, 3.2 cm diameter rod. The requirement may be reasonably relaxed if the actual use environment is controlled so the such an event is prohibited.

Conclusion and Recommendations

To show equivalence with respect to accidents, it is not necessary to show that an event is incredible. Equivalence is established if it is shown that the possibility of an event is less than or equal to the possibility of an off-site Beyond-HAC accident. The proposed criterion of 0.14 accidents per 100M VM is conservative. This can be achieved by limiting the speed of movement to below 41 kph (25 mph).

Accident performance will be evaluated for the worst credible accident identified by a process hazards review. If necessary, mitigating actions can be specified.

To show equivalence with respect to Normal Conditions of Transport, it is recommended that the NCT requirements be met whenever possible. Where this cannot be achieved, reasonable, defendable reductions in the NCT requirements can be established. The package performance can then be evaluated against these modified requirements.

Disclaimer

The views and opinions of the author, expressed herein, do not necessarily state or represent those of the US Department of Energy, or Westinghouse Savannah River Company.

References

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3. Gross, M. and Feldman, R.N., *National Transportation Statistics*, Table 3-10, "Motor Vehicle Fatalities and Vehicle-Miles and Associated Rates by Highway Functional System", U.S. Department of Transportation, DOT-VNTSC-BTS-96-4,(1996).

4. Gross, M. and Feldman, R.N., *National Transportation Statistics*, Table 3-11, "Motor Vehicle Fatalities, Injuries , Accidents and Vehicle-Miles and Associated Rates", U.S. Department of Transportation, DOT-VNTSC-BTS-96-4,(1996).

5. Gross, M. and Feldman, R.N., *National Transportation Statistics*, Table 3-12, "Motor Vehicle Fatal Accidents by Posted Speed Limit", U.S. Department of Transportation, DOT-VNTSC-BTS-96-4,(1996).

6. Gross, M. and Feldman, R.N., *National Transportation Statistics*, Table 3-19, "Truck Fatalities , Injuries, Accidents and Vehicle-Miles and Associated Rates by Truck Size", U.S. Department of Transportation, DOT-VNTSC-BTS-96-4,(1996).

7. U.S. Department of Energy Order 460.1A, Oct. 2, 1996.

8. Title 10, United States Code of Federal Regulations, Part 71 – Packaging and Transportation of Radioactive Materials.

9. Montgomery, D. C., Introduction to Statistical Quality Control, John Wiley & Sons, (1985).

Table 1. Excerpted Data for Bureau of Transportation Statistics Table 3-12, Motor Vehicle -Fatal Accidents by Posted Speed Limit

Year	41 km/h (25 mph)	98 km/h (60 mph)	105 km/h (65mph)	113 km/h (70 mph)	Over 113 km/h	Unknown	Total
1990	2234	18	2175			951	39836
1991	2097	9	2078			800	36937
1992	1911	4	2002			665	34942
1993	1895	9	2155			651	35780
1994	1890	13	2173			608	36254
1995	1848	16	2324	38	10	820	37221

Table 2. Excerpted Data from Bureau of Transportation Statistics Table 3-11, Motor Vehicle Fatalities, Injuries, Accidents and Vehicle Miles and Associated Rates.

Year	Fatalities/100MVM	Accidents/100MVM
1990	2.1	302
1991	1.9	282
1992	1.7	267
1993	1.7	266
1994	1.7	275
1995	1.7	273

Table 3.Fraction of Severe Accidents in Zones >90 km/h (55 mph) Per 100 MVM

Year	41 km/h (25 mph)	Severe Accidents >90 km/h	Total Severe Accidents	% >90 km/h	Total Severe Accidents per 100 MVM	Severe Accidents >90 km/h per 100MVM	Severe Accidents <41 km/h per 100MVM
1990	2234	3144	39836	7.89	2.1	0.166	0.118
1991	2097	2887	36937	7.82	1.9	0.149	0.108
1992	1911	2671	34942	7.64	1.7	0.130	0.093
1993	1895	2815	35780	7.87	1.7	0.134	0.090
1994	1890	2794	36254	7.71	1.7	0.131	0.089
1995	1848	3208	37221	8.62	1.7	0.147	0.084
					Average =	0.143	0.097