U.S. NUCLEAR REGULATORY COMMISSION

Revision 1
March 1989

REGULATORY GUIDE

OFFICE OF NUCLEAR REGULATORY RESEARCH

REGULATORY GUIDE 7.8
(Tasks MS 527-4 and MS 804-4)

LOAD COMBINATIONS FOR THE STRUCTURAL ANALYSIS OF SHIPPING CASKS FOR RADIOACTIVE MATERIAL

A. INTRODUCTION

Section 71.71, "Normal Conditions of Transport," and Section 71.73, "Hypothetical Accident Conditions," of 10 CFR Part 71, "Packaging and Transportation of Radioactive Material," describe normal conditions of transport and hypothetical accident conditions that produce thermal and mechanical loads that serve as the structural design bases for the packaging of radioactive material for transport.

Initial conditions must be assumed before analyses can be performed to evaluate the response of structural systems to prescribed loads. This regulatory guide presents the initial conditions that are considered acceptable by the NRC staff for use in the structural analysis of Type B packages used to transport radioactive material in the contiguous United States.

Any information collection activities mentioned in this regulatory guide are contained as requirements in 10 CFR Part 71, which provides the regulatory basis for this guide. The information collection requirements in 10 CFR Part 71 have been cleared under OMB Clearance No. 3150-0008.

B. DISCUSSION

To ensure safe structural behavior of shipping casks used to transport radioactive material, specific load conditions must be established that will encompass the static, dynamic, and thermal loadings that may be experienced by the casks during transport. This regulatory guide presents initial conditions that can be used in addition to parts of §§ 71.71 and 71.73 of Part 71 to fully delineate thermal and mechanical load combinations for purposes of structural analysis. This guide should be used in conjunction with Regulatory Guide 7.6, "Design Criteria for the Structural Analysis of Shipping Cask Containment Vessels," for the analytical structural evaluation of the heavy (i.e., weighing several tons) casks used to transport irradiated nuclear fuel.

Regulatory Position 1.1 of this guide addresses initial environmental conditions. The external thermal environmental limits for which a shipping cask must be designed are stated in § 71.71 as being 100°F (38°C) in direct sunlight and -40°F (-40°C) in shade. The regulations specify that these two normal conditions are to be applied separately from the other normal conditions. For the other conditions of § 71.71 and for the hypothetical accident conditions, this guide presents a range of ambient temperatures from -20°F (-29°C) to 100°F (38°C) as a part of the initial conditions. In the contiguous United States, there is a 99.7 percent probability that any hourly temperature reading will fall within this range.[1]

Regulatory Position 1.3 addresses initial pressure conditions. The pressure inside the containment vessels and neutron shields of irradiated fuel shipping casks depends on several factors. These factors include prepressurization of the vessels, the cask

[1]M. B. Gens, *The Transportation and Handling Environment*, SD-DC-72-1386, Sandia Laboratories, Albuquerque, New Mexico, September 1972.

temperature distributions associated with the ambient temperatures and the decay heat of the irradiated fuel, and any gas leakage from such fuel.

Regulatory Position 1.5 addresses the possibility that fabrication and installation stresses may result during cask construction. These stresses depend on many different processes and should be considered when evaluating the casks.

Regulatory Position 1.6 states that the values for initial conditions given in this guide are maximums or minimums. However, intermediate values could possibly create a more limiting case for some cask designs. For example, a seal design might be more susceptible to leakage at a pressure less than the maximum internal pressure, or a local structural response might be greater during an impact test if the weight of the contents were less than the maximum.

Sections 71.71 and 71.73 of Part 71 outline requirements for packages used to transport Type B quantities of radioactive materials. However, some of these requirements do not pertain to irradiated fuel shipping casks because of the massiveness of the casks or because the requirements are not structurally significant to cask design. Casks that are designed to transport one or more commercial fuel assemblies weigh many tons because of the large quantities of structural and shielding materials used. This massiveness causes a shipping cask to have a slow thermal response to sudden external temperature changes such as those that might be produced by quenching after a thermal exposure. The NRC staff feels that the water immersion test of § 71.73 and the water spray test of § 71.71 are not significant in the structural design of large casks. Therefore, they are not discussed in this guide. (Note, however, that these conditions may be significant to criticality and other nonstructural aspects of cask design.)

Similarly, the corner drop and the compression tests of § 71.71 are not discussed because they pertain only to lightweight packages. The penetration test of § 71.71 is not considered by the NRC staff to have structural significance for large shipping casks (except for unprotected valves and rupture disks) and will not be considered as a general requirement.

C. REGULATORY POSITION

The load conditions given here are considered acceptable to the NRC staff for use in the analytical structural evaluation of shipping casks used to transport Type B quantities of radioactive materials. Table 1 lists the load combinations that should be used. Analyses should combine the initial conditions with both the normal conditions and the hypothetical accident conditions.

1. GENERAL INITIAL CONDITIONS TO BE USED FOR BOTH NORMAL AND HYPOTHETICAL ACCIDENT CONDITIONS

1.1. All initial cask temperature distributions should be considered to be at a steady state. The normal and hypothetical accident conditions should be considered to have initial conditions of ambient temperature at −20°F (−29°C) with no insolation and of ambient temperature at 100°F (38°C) with maximum insolation. Insolation should be in accordance with paragraph 71.71(c)(1). Exceptions to the above are made for the cold environment normal condition (which uses −40°F) and for the thermal accident condition (which considers the higher thermal initial condition but not the lower one).

1.2. The decay heat of the radioactive material should be considered as part of the initial conditions. Generally, the maximum amount of decay heat should be considered for the hot environment and no decay heat should be considered for the cold environment. These conditions should include the insolation considerations of Regulatory Position 1.1. In addition, the free-drop and vibration parts of the normal conditions and the free-drop and puncture parts of the accident conditions should consider the cases of maximum decay heat with an ambient temperature of 100°F (38°C) and of no decay heat with an ambient temperature of −20°F (−29°C).

1.3. The internal pressure used in evaluating normal and hypothetical accident conditions should be consistent with the other initial conditions that are being considered. Minimum internal pressure should be taken as atmospheric or, for designs where internal pressures are less than atmospheric, the appropriate negative value.

1.4. For commercial nuclear power plant fuels, the release of all the pressurized gases inside the irradiated fuel should be considered in determining the maximum resultant containment vessel pressure.

1.5. Fabrication[2] and installation stresses used in evaluating transportation loadings should be consistent with the joining, forming, fitting, and aligning processes employed during the construction of casks. Unless subsequent steps are taken to eliminate these stresses, they should be considered in determining the maximum resultant vessel stress.

---

[2]*Fabrication* means the assembly of the major components of the casks (i.e., the inner shell, shielding, outer shell, heads, etc.) but not the construction of the individual components. Thus, the phrase *fabrication stresses* includes the stresses caused by interference fits and the shrinkage of bonded lead shielding during solidification but does not include the residual stresses due to plate formation, welding, etc.

Table 1
Summary of Load Combinations for Normal and Hypothetical Accident Conditions of Transport

	Applicable Initial Condition								
	Ambient Temperature		Insolation		Decay Heat		Internal Pressure[2]		Fabrication Stresses[3]
	100°F	−20°F	Max.[1]	Zero	Max.	Zero	Max.	Min.	
NORMAL CONDITIONS (Analyze Separately)									
Hot environment: 100°F ambient temp.			X		X		X		X
Cold environment: −40°F ambient temp.				X		X		X	X
Increased external pressure: 20 psia		X		X		X		X	X
Minimum external pressure: 3.5 psia	X		X		X		X		X
Vibration and shock[4]: normally incident to the mode of transport	X		X		X		X		X
		X		X		X		X	X
Free drop: 1-foot drop	X		X		X		X		X
		X		X		X		X	X
ACCIDENT CONDITIONS (Apply sequentially)									
Free drop: 30-foot drop	X		X		X		X		X
		X		X		X		X	X
Puncture: drop onto bar	X		X		X		X		X
		X		X		X		X	X
Thermal[5]: fire accident	X		X		X		X		X

[1]See Regulatory Position 1.1.
[2]See Regulatory Positions 1.3 and 1.4.
[3]See Regulatory Position 1.5.
[4]See Regulatory Position 2.5.
[5]Evaluations should be made 30 minutes after start of fire and at postfire steady-state conditions.

1.6. It is the intent of this guide to specify discrete initial conditions that will produce bounding cases of structural response. Maximum or minimum values of initial conditions are given. However, if a larger structural response is suspected for an initial condition that is not an extreme (e.g., an ambient temperature between -20°F (-29°C) and 100°F (38°C)), intermediate initial conditions or other combinations of initial conditions should also be considered in the structural analysis.

2. NORMAL CONDITIONS OF TRANSPORT

Each of the following normal conditions of transport is to be applied separately to determine its effect on the fuel cask. These normal conditions are also to be combined with all the initial conditions as shown in Table 1.

2.1. Hot environment – The cask should be structurally evaluated for an ambient temperature of 100°F (38°C) in still air and with maximum insolation (see Regulatory Position 1.1). If the cask has mechanically operated auxiliary cooling systems, these systems should be considered to be inoperable during the hot environment condition.

2.2. Cold environment – The cask should be evaluated for an ambient temperature of -40°F (-40°C) in still air and with no insolation. The case of no internal heat load and minimum internal pressure should be considered. The possibility and consequence of coolant freezing should also be considered.

2.3. Increased external pressure – The cask should be evaluated for an external pressure of 20 psia (140 kilopascal).

2.4. Minimum external pressure – The cask should be evaluated for an external pressure of 3.5 psia (24.5 kilopascal).

2.5. Vibration and fatigue – The cask should be evaluated for the shock and vibration environment normally incident to transport. This environment includes the vibratory motion produced by small excitations to the cask-vehicle system and also intermittent shock loads produced by coupling, switching, etc., in rail transport and by bumps, potholes, etc., in truck transport. Repeated pressurization loads and any other loads that may contribute to mechanical fatigue of the cask should be considered.

Factors that may contribute to thermal fatigue should also be considered. These factors should include the thermal transients encountered in the loading and unloading of irradiated nuclear fuel from the cask and any restraint against thermal expansion that may be provided by the tiedown system.

Although there are a number of different load combinations that could occur during normal transport and for which separate fatigue analyses may be performed, this evaluation should be based on the most unfavorable initial conditions for the specific design consistent with a credible spectrum representing the life-cycle for normal shock and vibration environments. Table 1 identifies the cases that the staff believes are the most unfavorable.

2.6. Free drop – The cask (assuming a weight of over 30,000 pounds (13,600 kg)) should be evaluated for a 1-foot free drop onto a flat unyielding surface; it should strike the surface in a position that is expected to inflict maximum damage. Impacts with maximum and minimum weights of contents should be considered.

3. HYPOTHETICAL ACCIDENT CONDITIONS

The following hypothetical accident conditions are to be applied sequentially to the same cask in the order indicated (dropped, then punctured, then exposed to fire) to determine the maximum cumulative effect. These hypothetical accident conditions are also to be combined with the initial conditions as shown in Table 1.

3.1. Free drop – The cask should be evaluated for a free drop through a distance of 30 feet (9 m) onto a flat unyielding horizontal surface. It should strike the surface in a position that is expected to inflict maximum damage. Impacts with the maximum and minimum weights of contents should be considered.

In determining which position causes maximum damage, applicants should consider impact orientations in which the cask strikes the impact surface on its top end, top corner, side, bottom end, and bottom corner and the center of gravity of the cask is directly over the point of impact. If the design of the cask is such that an intermediate oblique orientation could be more damaging, the applicant should also evaluate the impact of the cask in those orientations. These latter evaluations should include impacting on appurtenances that are part of the cask design such as those used for handling, tiedown, or for other functions during transport.

3.2. Puncture – The cask should be evaluated for a free drop of 40 inches (1 m) onto a stationary and vertical mild steel bar of 6 inches (0.15 m) diameter with its top edge rounded to a radius of not more than 0.25 inch (6 mm). The bar should be of such a length as to cause maximum damage to the cask; however, it should not be less than 8 inches (0.2 m) long. The cask should hit the bar in a position that is expected to inflict maximum damage, and impacts with maximum and minimum weights of contents should be considered.

3.3. Thermal – The cask should be evaluated for a thermal condition in which the whole cask is exposed to a radiation environment of 1,475°F (800°C) with an emissivity coefficient of 0.9 for 30 minutes. The surface absorption coefficient of the cask should be considered to be 0.8. The structural response of the cask should be considered up to the time when the temperature distributions reach steady state. The possibility and consequence of the loss of fluid from the neutron shield tank should be considered for casks that use this design feature.

Table 1 summarizes the loading combinations given above.

D. IMPLEMENTATION

The purpose of this section is to provide information to applicants and licensees regarding the NRC staff's plans for using this regulatory guide.

Except in those cases in which an applicant or licensee proposes an acceptable alternative method for complying with specified portions of the Commission's regulations, the NRC staff will use the methods described in this guide in evaluating applications for new package designs and requests for existing package designs to be designated as Type B packages for all applications and requests.

REGULATORY ANALYSIS

A draft regulatory analysis was published with the second proposed Revision 1 to Regulatory Guide 7.8 (Task MS 804-4) when the draft guide was published for public comment in September 1988. No changes were necessary, so a separate regulatory analysis for the final guide has not been prepared. A copy of the draft regulatory analysis is available for inspection and copying for a fee at the Commission's Public Document Room at 2120 L Street NW., Washington, DC, under Task MS 804-4.

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE, $300

FIRST CLASS MAIL
POSTAGE & FEES PAID
USNRC

PERMIT No. G-67