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What Should "Damaged" Mean in Air Transport of Fissile Packages? CONF-951203--59

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## DISCLAIMER

**Overview***

It is likely that the ongoing process to produce the 1996 version of the IAEA Regulations for the Safe Transport of Radioactive Materials, IAEA Safety Series 6 (SS 6) will result in a more stringent package qualification standard for air transport of large quantities of radioactive materials (RAM) than is included in the 1990 version. During the process to define the scope of the new requirements there was extensive discussion of their impact on, and application to, fissile material package qualification criteria.

Since fissile materials are shipped in a variety of packagings ranging from exempt to Type B, each packaging of each type must be evaluated for its ability to maintain subcriticality both alone and in arrays and in both damaged and undamaged condition. In the 1990 version of SS 6 "damaged" means the condition of a package after it had undergone the "tests for demonstrating the ability to withstand accident conditions in transport," i.e., Type B qualification tests. These test conditions are typical of severe accidents in surface modes, but are less severe than air mode qualification test environments to be applied to Type C packages. As a result, questions arose about the need for a corresponding change in the 1996 SS 6 to define "damaged" to include the Type C test regime for criticality evaluations of fissile packages in air transport.

Since the process for revising SS 6 was changed for the 1985 edition, every change in SS 6 must have suitable justification. This was intended to provide the stable regulatory environment needed to maintain confidence in, and commitment to, the IAEA Regulations as the basis of national and international modal regulations. The justification for change should include consideration of regulatory consistency, safety assurance and operational impacts on regulated entities. While prevention of a criticality event in either routine, normal, or accident conditions of transport has always been a basic tenet of the Regulations (IAEA 1990c), the means to achieve this end for any packaging design is chosen by balancing a number of considerations. For instance, a change which results in the greatly stiffening qualification criteria for fissile packages could have impacts on the number of packages available for air transport and, hence, on nuclear industry operations. As a

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result, the risk and safety benefits of the change should be carefully considered against the potential impacts on the industry and the transport process itself. This paper examines justifications for a change to SS 6 to change definition of "damaged" to include the Type C qualification criteria for the purpose of criticality prevention in air transport. The following aspects of the issue are considered:

- Fissile Materials Affected
- Regulatory Features of a Change
- Packaging Types Affected
- Risk Reduction Aspects
- Safety Implications
- Cost Implications

**Fissile Materials Affected**

Table 1 provides a list of fissile materials and the quantities of each that could be shipped by the air mode in fissile packages of various types. Note that the last column contains the maximum

**Table 1: Package Content Limits and Exemption Limits for Various Fissile Materials**

| Fissile Isotope | A2 (TBq)* | Specific Activity (TBq/Kg) ** | Type C Lower Limit (Kg) | Type A Upper Limit (Kg) | Fissile Exemption Limit (Kg)* |
|---|---|---|---|---|---|
| Uranium-233 | 1.0E-03 | 3.6E-01 | 8.4E+00 | 2.8E-03 | 5.0E-01 |
| Uranium | | | | | |
| 90 % U-235 | 1.0E-03 | 2.2E-03 | 1.4E+03 | 4.6E-01 | 1.5E-02 |
| 20 % U-235 | 1.0E-03 | 3.7E-04 | 8.1E+03 | 2.7E+00 | 1.5E-02 |
| 10 % U-235 | 1.0E-03 | 1.8E-04 | 1.7E+04 | 5.6E+00 | 1.5E-02 |
| >5 % U-235 | 1.0E-03 | 1.0E-04 | 3.0E+04 | 1.0E+01 | 1.5E-02 |
| 5 % U-235 | unlim. | 1.0E-04 | NA | unlimited | 1.5E-02 |
| 1% U-235 | unlim. | 2.8E-05 | NA | unlimited | unlimited |
| Plutonium-238 | 2.0E-04 | 6.3E+02 | 9.5E-04 | 3.2E-07 | 1.0E+00 |
| Plutonium-239 | 2.0E-04 | 2.3E+00 | 2.6E-01 | 8.7E-05 | 5.0E-01 |
| Plutonium-241 | 1.0E-02 | 3.8E+03 | 7.9E-03 | 2.6E-06 | 2.0E-01 |
| Recycle Plutonium | 2.0E-04 | 4.0E+02 | 1.5E-03 | 5.0E-07 | 5.0E-01 |
| Recycle Uranium | | | | | 5.0E-01 |
| MOX Fuel (10%Pu) | 2.0E-03 | 4.0E+01 | 1.5E-01 | 5.0E-05 | 2.0E+00 |

* Based on SS 6 (IAEA,1990a)
** Derived from Table AIII-1 (IAEA,1990b)

exception quantity that could be unambiguously defined from para. 560a-f of SS 6 (exemption quantities could be larger than those shown if liquids are shipped and if certain requirements on mean density and hydrogen or nitrogen ratios were met). In para. 670 of the 1996 draft version of SS 6, the exemption quantities for uranium are close to the Type A quantity limits shown in Table A and are somewhat lower than those shown for the plutonium isotopes. Conclusions from this table are as follow:

- Plutonium containing packages shipped by air will be transported in Type C packages. Very small quantities (samples and the like) might be shipped in Type A or Type B packagings, but these would be excepted from the scope of the fissile packaging requirements. This results from the fact that exemption quantities from fissile package requirements are larger than the minimum quantity that must be shipped in a Type C package.
- U-233 in quantities larger than 0.5 kg but less than 8.4 kg shipped by air could be in Type B packagings. Samples less than 2.8 grams could be air shipped in Type A packages without triggering fissile package requirements. However, commerce in U-233 is at such a low level it seems unlikely that there will be any significant amount of this material shipped. Thus, U-233 shipments are not of great interest here.
- Unirradiated low-enriched uranium in packages shipped by air will be Type B(F) or Type A(F) packagings. UF6 samples would be Type A(F) or excepted. The usual UF6 cylinders, UO2 pellets, fresh fuel and feed material shipments would contain less than a Type C quantity and be shipped in Type B(F) or A(F) packagings.

**Regulatory Features of a Change**

In the current version of SS 6, para. 564b and the 1996 draft SS 6 (para. 683b) defines "damaged" to include the more limiting of:

1. being subjected to the normal conditions of transport plus immersion in 15 metres of water; or
2. being subjected to the normal conditions of transport plus the Type B test sequence followed by immersion in 0.9 metres of water.

Para. 562 requires that "...subcriticality is maintained under conditions *likely*[1] to be encountered during normal conditions of transport and in accidents". Later paragraphs indicate that in a "damaged" condition subcriticality must be maintained by the package. The "likely" recognizes that criticality events in accident environments more severe than those presented by the Type B test sequence are not foreclosed. The current draft of the 1996 revision of SS 6 specifically requires subcriticality for normal and accident conditions of transport.

From a regulatory viewpoint, it would seem that acknowledgment of the more severe accident environments in the air mode which are reflected in test conditions for Type C packagings would require these qualification tests to be included in the definition of "damaged" in a new para. 564 (para 683b in the 1996 draft) if a fissile package were to be transported by air. However, such a change might require that every type package be confirmed to be subcritical in isolation and in an array when subjected to the Type C test standards. Such a requirement is nontrivial in scope and expense for Type IP, A, and B packagings.

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[1] Emphasis added

In fact, the 1996 draft version of SS 6 recognizes the problem and adds a requirement only for those packages to be transported by air. The requirement is as follows:

> the package shall be subcritical under conditions *consistent with* the tests prescribed in (Type C test specification) assuming reflection by at least 20 cm of water but no water in leakage...

The meaning of the words "consistent with" is not clear and is open to Competent Authority interpretation. How this requirement will be elaborated in the Explanatory Material should be interesting considering there is no Competent Authority rulings to use as precedent. Presumably, a mode restriction will be included in Certificates of Compliance to differentiate those packagings that have been shown to maintain subcriticality alone and in arrays when subjected to the enhanced "damaged" criterion described above.

**Packaging Types Affected**

The "Requirements for Packages Containing Fissile Materials" at para. 559 (IAEA 1990a) apply to all package types. Thus, IPn (F), Type A(F), Type B(F), and, presumably in the 1996 SS 6, Type C(F) are potentially affected by any change to the damaged criterion.

IPn(F) and Type A(F) package designs, in general, would not be impacted by a new definition of "damaged". These packages would be used to ship quantities of fissile materials that meet one of the six exemption conditions in para. 560 that provide relief from meeting the remainder of the fissile package requirements. An exception to this generality are packages used for consignments of fresh nuclear fuel which can contain several hundred kilograms of fissile materials. From a containment standpoint, these package types are not required to withstand accident conditions . The only limit on distortion, containment or water exclusion ability or other characteristic of the packaging that is important to criticality control is gained as a result of meeting the "damaged" criterion in current regulations. Making the definition of damage more severe for these air transported packages by including the Type C qualification tests as part of the damaged definition is unlikely to be reflected in design changes in these packages. The severity of accident environments in air transport are too far beyond the relatively simple designs of these packages to expect more.

For Type C(F) packages a more severe damage standard also is not important, because the package must be designed to maintain containment, shielding and criticality control in the more severe environment in order to be certified as Type C.

Type B(F) packagings present the major impact area for the addition of more stringent damaged definition. While it is generally agreed that many Type B packages could sustain the enhanced environments of the Type C test regime and maintain criticality control, demonstration by test (full or scaled), reasoned analysis, or comparison with similar cases would be required. Looking at the quantities of materials that could be shipped in Type B(F) packages by air (see Table 1), it is clear that shipments of low enriched uranium (1% to 5% enriched) are most likely to be impacted by making the "damaged" definition more severe. It is unlikely that UF6 containers can be made resistant to the Type C impact environment. However, UF6 packages would not be candidates for routine shipment by air. This leaves shipments of low enriched UO2 pellets or feed materials as the shipments most likely to be impacted by inclusion of the Type C test in the "damaged" criterion

**Risk Reduction Aspects**

Risk evaluation requires construction of event sequences and the evaluation of their frequency and consequence. Risk metrics frequently used are the expected value and the frequency-consequence profile of absolute risk. For the purposes of this paper a more appropriate measure is relative risk, that is, a comparison of risk with and without the modified definition of damaged. Relative risk evaluation in this case is dominated by changes in frequency of occurrence of a criticality excursion. This is the case because we assume that the spectrum of consequences of a criticality event is basically the same for all similar accident sequences. These consequences are direct neutron radiation during the event and dispersion of nuclear material and fission products which affects nearby persons and requires cleanup and subsequent control of the event site. Looking at the various packaging types, the following may be observed:

- Type IF and AF packages are not required to retain containment in any accident situation and are unlikely to maintain criticality control features in severe aircraft accidents. In less severe aircraft accidents (close to Type B conditions) some are likely to maintain subcriticality because they must be qualified at Type B levels.
- Type C packages presumably will retain containment and subcriticality in an aircraft crash equal or less severe than the Type C qualification criteria.
- Type B(F) packages need more detailed consideration as indicated below.

Criticality can result from damage to individual packages or formation of arrays of damaged packages. For individual packages, containment failure could be considered as a surrogate for loss of criticality control elements. The relative risk reduction (resulting from containment failure) for air transported Type B versus Type C was shown to be about a factor of 10 to 20 (IAEA 1994).

Severe aircraft accidents have a very high potential for spreading cargo and parts of an aircraft over wide areas and would seem to preclude formation of arrays of fissile material that could reasonably be expected to form a critical arrangement. Since criticality for an array of packages requires loss of criticality control features in the package as well as coincidence of quantity, geometry, and reflection, one might expect an additional factor of 10 or more reduction in the frequency of criticality below that of simple containment loss on this basis. However, this contribution to the total risk is so small to start, the additional factor of 10 is not significant.

Less severe accidents (but still greater than the Type B environments) might not disrupt criticality control features in individual packages or achieve a high degree of dispersion of packages in the wreckage, but individual package criticality control features are much less likely to be disrupted. This is true because the package is required to maintain subcriticality in Type B accident environments and the tendency for packagings not to fail catastrophically at slightly above their design thresholds. Thus, at lower air accident intensities, no significant risk reductions might be achieved.

The overall result is that no more than a factor of two reduction in relative risk of criticality might be expected by requiring Type C qualification for air transported fissile packages. While this is a relatively large reduction in potential criticality events from Type B's in air transport, it must be scaled by the number of Type B(F) packages relative to all fissile packages shipped by air to put it in terms of absolute risk. Given the limited number of fissile materials that must be shipped in Type B(F) packagings and that are likely to be shipped by air, the relative reduction in risk seems likely to be very small.

**Safety Implications**

The public and involved regulators perceive that the addition of Type C criteria for air transport of large quantities of RAM increases safety in transport. Transport professionals and regulators know that the actual change in overall risk resulting from that change is almost imperceptible in the total risk from RAM transport or even from the risk resulting from air shipments of RAM. Yet the IAEA has acted to institute such changes, in part, to meet the perception that air transport of plutonium is much less than a safe process. This perception has been generated, in part, by prior U. S. action to respond to safety concerns expressed in congressional initiatives by Representative Scheuer and Senator Murkowski, for example. Failure to institute similar changes in the criteria for air transported fissile materials is likely to be perceived by the public and others as illogical, inconsistent, and deferring to the nuclear industry. It is this perception of unmitigated risk that leads to questions about the safety provided by adhering to the regulations.

**Cost Implications**

The principal costs associated with requiring the demonstration of subcriticality of Type B(F) packagings under the conditions of aircraft accidents will result from three sources:

- Design - Accommodating enhanced fire duration is unlikely to be onerous given the fact that the Type B test currently required with preexisting damage implies thermal input only slightly less than that of the Type C fire. A key factor for thermal protection is likely to be the end point temperature of package contents. A UF6 package may burst if the temperature gets too high, but may not present a criticality problem (depending on the violence of the burst and the dispersion of the UF6 in the fire cloud). More difficult will be designs to accommodate the Type C impact test without highly distorted package geometry and loss of criticality control features.

- Confirmation - Testing full scale or sub scale configurations is always expensive. The additional costs above a Type B test sequence are likely to be 50% to 100% because the sites at which such tests can be performed are so limited. Of course confirmation can be achieved by analysis. The cost of such an approach is, again, probably a 50% to 100% increment over the same process for confirmation of subcriticality in Type B test conditions.

- Package Capacity Penalties in Operation - It seems likely that meeting the more stringent qualification tests will require greater volume and mass per unit product shipped. This will translate into higher costs for transport in any transport mode where the tariff structure is related to mass or volume moved. It may be possible to avoid such costs through use of facility-owned or leased conveyance fleets.

These costs will be minimized if the requirement is put in place for air transported packages only. However, avoidance of the cost by eschewing air transport may distort normal shipping patterns and entail other cost penalties resulting from time value of money, security during longer duration transport, and other factors.

**Overview**

On the basis of regulatory logic (perhaps an oxymoron) and safety considerations, it would seem prudent to require "damaged" for fissile packages in air transport to mean that produced by the Type C test regimen. Notwithstanding this logical basis, from a cost basis such a decision will lead to somewhat higher costs to the shipper both in package development, operational practice, and complications in marking of packages qualified for air transport of fissile materials. The return on this investment will be a very small decrease in absolute risk. The results from imposing this regulatory change, taken with the fact that relatively few shipments are likely to be affected by the change, suggests that changing from the current definition of "damaged" is largely unnecessary.

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