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## **Recent Developments in Fissile Material Exemptions for Shipping Packages**

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## RECENT DEVELOPMENTS IN FISSILE MATERIAL EXEMPTIONS FOR SHIPPING PACKAGES

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### ABSTRACT

In February 1997 the Nuclear Regulatory Commission promulgated an emergency final rule regarding the shipment of limited quantities of fissile material. Background information is presented on criticality concerns that existed under the previous regulations, and changes effective in the new rule are summarized. Potential impacts of these changes on DOE shipments of fissile material are discussed. An update of developments based on public comment and any modifications to these rules will be presented in the meeting in September.

### I. INTRODUCTION

Regulations for the transportation of radioactive material, e.g., 10 CFR Part 71<sup>1</sup> and 49 CFR Part 173,<sup>2</sup> establish special requirements for shipping packages that contain fissile material. As defined by these regulations, fissile material includes <sup>233</sup>U, <sup>235</sup>U, <sup>238</sup>Pu, <sup>239</sup>Pu, and <sup>241</sup>Pu, or any combination of these nuclides.

To avoid overly burdensome controls on packages that do not have a criticality concern, three special exceptions are identified in the regulations. First, the definition of fissile material itself specifically excludes unirradiated natural and depleted uranium, or natural and depleted uranium that have been irradiated only in a thermal reactor. Second, certain packages or groups of packages—even though

they contain some fissile material—are exempt from further fissile material controls. Such packages contain small quantities, dilute concentrations, or low enrichments of fissile material. Third, under certain provisions, general licenses permit the shipment of fissile material in packages that do not need to meet the full set of standards typically required for shipment of fissile material. These provisions are also for small quantities, dilute concentrations, or low enrichments of fissile material, similar to packages that are fissile exempt.

This paper will specifically address fissile exempt packages, although for the most part similar issues are also applicable to the other exceptions listed above.

### II. REGULATIONS FOR FISSILE EXEMPTIONS

Exemptions are provided for packages that contain one of the following six categories of fissile material. Although the new regulations impose additional constraints, the categories themselves are essentially unchanged from the previous rule.

- (1) No more than 15 grams of fissile material,
- (2) Hydrogenous solutions or mixtures with an H/X of at least 5200 and a fissile concentration of no more than 5 grams per liter,

- (3) No more than 5 g of fissile material in any 10 liter volume,
- (4) Homogenous mixtures of uranium enriched to no more than 1%  $^{235}\text{U}$  by weight (plutonium and  $^{235}\text{U}$  content limited to 1% of  $^{235}\text{U}$  mass),
- (5) Liquid solutions of uranyl nitrate enriched to no more than 2%  $^{235}\text{U}$  by weight (plutonium and  $^{235}\text{U}$  content limited to 0.1% of  $^{235}\text{U}$  mass), or
- (6) No more than 1 kg of Pu, provided the mass of  $^{29}\text{Pu}$  and  $^{241}\text{Pu}$  does not exceed 20%.

### III. CONCERNS

Prior to the new rule, no additional constraints were imposed on the fissile material or other contents of the packages other than those listed in (1) to (6) in Section II above. During the past several years criticality personnel have postulated a number of situations in which the above limits might not be sufficient by themselves to prevent an arrangement of packages in a critical or nearly critical situation. Such concerns generally fell into one of three areas.

#### A. Mass Limits

If a shipment contains a very large number of very small packages, the total mass of fissile material in a conveyance will also be rather large. The minimum dimension of a package for shipment of radioactive material is only 10 cm (4 in.), and package dimensions might be further reduced under hypothetical accident conditions. Criticality issues for these packages depend on numerous details that one can assume about the packaging and its contents.

#### B. Concentration/Enrichment Limits-Low Absorption Moderation

Several of the fissile exemption categories listed above are similar to, or more restrictive than, typical subcritical limits for aqueous solutions reflected by water. For example, a fissile concentration of 5 g/10 liters is well below the necessary concentration to achieve criticality with an aqueous solution of either uranium or plutonium. Certain other moderating materials, however, have an absorption cross section significantly smaller than that of (ordinary) water. Provided the system is large enough to reduce leakage, mixtures or solutions with significant quantities of deuterium, beryllium, or carbon (without hydrogen) can be critical with concentrations of fissile

material less than 0.5 g/liter. Likewise, uranium enrichments less than 1% can also achieve criticality with such low absorbing materials.

#### C. Concentration Limits-Low Density Moderation

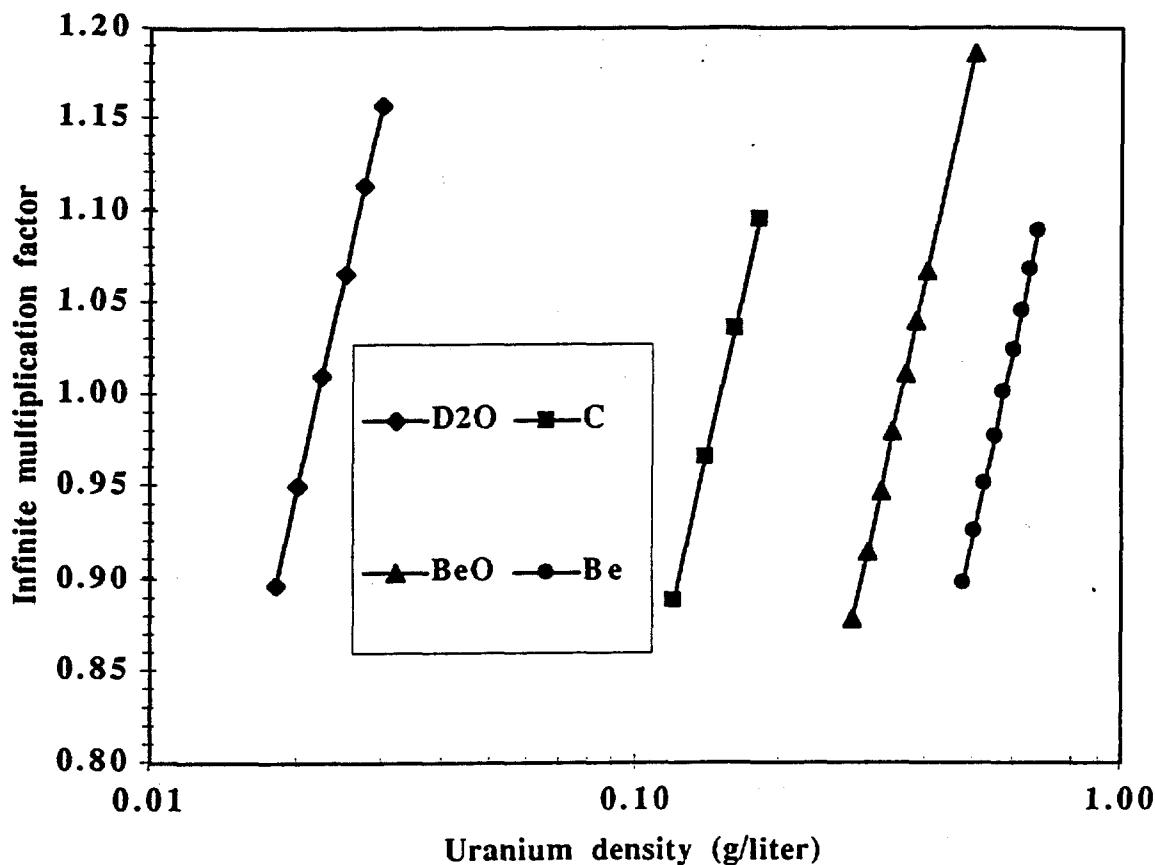
As indicated in the previous concern, the fissile exemption because of low concentration is based on substantial absorption by non-fissile materials. Even if moderating materials have absorption cross sections somewhat larger than those of beryllium, deuterium, or carbon, a critical reaction is in principle achievable provided the density of the moderator is very low and the system is large enough to overcome leakage. Note that in an infinite homogeneous system, the multiplication factor depends on the relative densities of the materials, rather than the absolute densities.

In summary, each concern described above is generally characterized by large volumes, lack of absorbing impurities, and/or the presence of very selective materials. These conditions have generally been considered not to be applicable to actual shipping packages.

### IV. RECENT DEVELOPMENTS

Rewards to the fissile exemptions have been considered during the past several years as part of the normal revision process for the International Atomic Energy Agency transportation regulations. In September 1996, however, an NRC licensee involved in processing operations for down-blending strategic materials notified the Commission of calculational examples in which criticality was possible even though the limits for fissile exemption were satisfied. These examples were representative of the concern on Concentration Limit-Low Absorption Moderation, as discussed above. They addressed a very large (sea-land) package containing only a low concentration (0.5 g/liter) of highly enriched uranium and beryllium oxide.

Because the package identified was so large, demonstration of this concern can be simplified by considering the effect in an infinite system. Figure 1 illustrates the multiplication factor ( $k_{\infty}$ ) for an infinite homogenous mixture of  $^{235}\text{U}$  in several special moderating materials. Each of these materials is characterized by a relatively low atomic weight to enable reasonably good moderation and, perhaps more important, an absorption cross section much lower than that of ordinary water. Note that the density of



**Figure 1** Multiplication factor as a function of the density of  $^{235}\text{U}$  in an infinite homogeneous system of special moderating material

$^{235}\text{U}$  is plotted on a logarithmic scale. Calculations were performed on a personal computer using the CSASIX module of SCALE 4.3.<sup>3</sup> Because no benchmarking or other validation of these calculations was attempted, the results should be considered for illustrative purposes only. Nevertheless, the results of these calculations clearly demonstrate that the multiplication factor for a large system can be greater than unity for highly enriched fissile concentrations significantly less than 5 grams per 10 liters (0.5 g/liter).

The densities of the special moderating materials used in the calculations for Figure 1 were essentially 100% of their nominal value. Decreasing their density causes less parasitic absorption and thus further increases the multiplication factor of the system. Such results are consistent with examples presented by the above licensee to the NRC. In fact, as

mentioned in Section III.c above, even materials that are not generally considered to be special moderators can show similar effects if their density is sufficiently low. Although not shown in Figure 1, calculations of  $^{235}\text{U}$  at 0.5 g/liter in an infinite homogeneous mixture of  $\text{SiO}_2$  at 10% of its nominal density indicated a  $k_{\infty}$  equal to approximately 1.29.

#### V. RULE CHANGES

In December 1996 the NRC issued Information Notice 96-63<sup>4</sup> to alert all licensees of potential safety issues regarding shipments using the fissile material exemption and general license provisions of 10 CFR Part 71. In February 1997 the NRC promulgated an emergency final rule<sup>5</sup> amending these provisions.

Regarding the fissile material exemptions, the new rule included two additional constraints on the

contents of the packages. First, the packages may not contain any special moderating materials—defined as beryllium, graphite, or material enriched in deuterium—that exceed 0.1% of the fissile mass. This limit applies to all six categories of exempted material listed in Section II above. Second, for categories (1) through (3), in addition to the mass or concentration restrictions on each package, the total fissile material in a consignment by the shipper is limited to 180–400 g, depending on the type of fissile material and whether the hydrogen density of other materials in the package is less than or greater than that of water. (Detailed specifications for the total allowed fissile material are provided by a table in the rule.)

Although this paper deals essentially only with the changes to the fissile exemptions, the changes to the general license provisions in Part 71 are similar. In particular, the restriction of 0.1% for special moderating materials has been added to the two general license provisions that did not already exclude such moderators.

The new regulations became effective on the date of their publication (February 10, 1997). The NRC provided, however, a period for public comment until March 12 and indicated that it would revise the rule if necessary.

## VI. IMPACT OF RULE CHANGES

Because these changes were issued less than three weeks prior to the submission date for this paper, a thorough assessment of their impact on DOE shipments of fissile material has not been completed. Nevertheless, two primary areas of potential impact have been identified.

### A. Limits on Mass of Special Moderators

The allowed quantities of special moderating materials are very small. If a package containing radioactive material from a waste stream includes only trace amounts of both fissile and special moderating material, the package might not qualify as fissile exempt, even though it is clearly of no criticality concern. For example, if the contents include beryllium at a concentration of 1 ppb, the package is not fissile exempt if the fissile concentration is only 0.9 ppm. On the other hand, increasing the fissile concentration to 1.1 ppm satisfies the fissile exemption (assuming all other regulatory conditions are satisfied).

As noted above, the concerns expressed to the NRC involved very large packages. The quantity of special moderating material was many tens of metric tons and exceeded the fissile material mass by several orders of magnitude. The criticality concern was not due to the presence of very small quantities of special moderating material.

### B. Consignment Limit on Fissile Mass

For the fissile exempt categories (1) through (3), the total fissile mass in a consignment by the shipper is limited to 400 g or less, depending on the type of fissile material and the hydrogen density of the contents. This limitation has the potential to result in three significant impacts.

First, under the old rule, when a package was closed and prepared for shipment, a final determination could be made as to whether it qualified as fissile exempt. No further accounting of its fissile material was necessary for this purpose. Under the new rule, the small quantity of fissile material present in the package must be considered when a group of packages is prepared for consignment. (Under both the old and new rules the packages are not labeled to indicate fissile material contents.)

Second, the limit on total fissile mass has the potential to reduce significantly the number of packages that can be included in a fissile exempt shipment. For example, a 55-gallon (210-liter) drum with a fissile concentration of approximately 5 g per 10 liters would contain about 100 g of fissile material, and a fissile exempt shipment would be limited to only a few drums.

Third, determination of the actual fissile material will probably have to be much more accurate to satisfy the limit on total material per shipment. For example, in many cases the shipper has good justification that the fissile material concentration in a package is less than 5 g in any 10 liter volume. On the other hand, determining that the concentration is actually 1 g or 2 g per 10 liters can be significantly more difficult. As shown above, merely using the upper allowable limit can overly restrict the number of packages in the consignment.

The significance of these potential impacts, or others not yet identified, on DOE shipments is expected to be evaluated in the near future. Additional information, including any modifications to the rule,

will be updated in the presentation at the meeting in September.

## VII. REFERENCES

1. *U.S. Code of Federal Regulations*, "Packaging and Transportation of Radioactive Material," Part 71, Chapter 1, Title 10, "Energy."
2. *U.S. Code of Federal Regulations*, "Shippers-General Requirements for Shipments and Packagings," Part 173, Chapter 1, Title 49, "Transportation."
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