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**Review of Fissile Material Exemptions  
and General Licenses in 10 CFR Part 71**

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**Abstract**

Title 10 of the United States (US) Code of Federal Regulations (CFR), Part 71, Packaging and Transportation of Radioactive Material, includes requirements for the transport of fissile material in packages. These regulations provide requirements for packaging that is certified by the US Nuclear Regulatory Commission (NRC) to transport fissile material. The regulations also include provisions that allow for shipment in packages that are not required to be certified by the NRC. These provisions include criteria for exemptions from classification as fissile material (§71.15) and permit general licenses for limited quantities of fissile material and plutonium-beryllium special form sources (§71.22 and §71.23, respectively). These regulations are used frequently for a wide-variety of fissile material shipping operations and shippers must interpret the regulations for particular shipping situations.

The quantity of fissile material that presents a criticality safety risk depends on: 1) the mass, concentration, or isotopic distribution of the fissile material; 2) the system geometry and neutron reflection of the package from surrounding materials; and 3) other materials in the system that might absorb neutrons emitted from fission or moderate those neutrons to lower energies where the probability of them creating an additional fission is highest. These parameters were carefully considered in developing the requirements for the exemptions from the classification of fissile material and the requirements for general licenses for fissile material.

A reference NUREG/CR document, recently developed by Oak Ridge National Laboratory (ORNL) for the NRC, provides technical recommendations to fissile material licensees on how to apply the fissile material exemption and general license regulations. This paper will outline this NUREG/CR, including: 1) the technical basis, intent, and anticipated usage of each of the fissile material exemption and general license provisions; 2) the recent regulatory history of the Part 71 fissile material exemptions and general licenses, including the 2015 rulemaking effort; and 3) recommendations being formulated for a potential future revision to the regulations.

**1. Introduction**

Title 10 of the United States (US) Code of Federal Regulations (CFR), Part 71, *Packaging and Transportation*

of *Radioactive Material* [1], includes requirements for the transport of fissile material in packages. These regulations provide requirements for packaging that is certified by the US Nuclear Regulatory Commission (NRC) to transport fissile material. The regulations also include provisions that allow for shipment of fissile material in packages that are not required to be certified by the NRC. These provisions include criteria for exemptions from classification as fissile material (10 CFR 71.15) and permit general licenses for limited quantities of fissile material and plutonium-beryllium special form sources (10 CFR 71.22 and 10 CFR 71.23, respectively).

The objective of the fissile material exemptions in 10 CFR 71.15 and fissile material general licenses in 10 CFR 71.22 and 71.23 is to facilitate the safe transport of low-risk (e.g., small quantities or low concentrations) fissile material by exempting shipments of these materials from the packaging requirements and the criticality safety assessments required for fissile material transportation, and to allow the shipments to take place without specific Commission approval. The lower amount of regulatory oversight is acceptable for these shipments, because the exemptions are established so as to ensure safety under all credible transportation conditions.

A draft reference NUREG/CR document, under development by Oak Ridge National Laboratory (ORNL) for the NRC, will provide technical recommendations to fissile material licensees on how to apply the fissile material exemption and general license regulations. The next section will provide an outline of the NUREG/CR discussion of the technical basis, intent, and anticipated usage of each of the fissile material exemption and general license provisions. The third section will summarize the NUREG/CR discussion of the recent regulatory history of the Part 71 fissile material exemptions and general licenses, including the 2015 rulemaking effort [2]. The final section will discuss recommendations that are being formulated for an upcoming revision to the regulations in Part 71.

## **2. Fissile Material Exemption and General License Provisions**

The quantity of fissile material that presents a criticality safety risk depends on the other materials in the system that might absorb neutrons emitted from fission or moderate those neutrons to lower energies where the probability of them creating an additional fission is highest. Besides the absorption and moderation of neutrons, other parameters that must be considered to ensure criticality safety are: the mass, concentration, or isotopic distribution of the fissile material; and the system geometry and neutron reflection of the package from surrounding materials. These parameters were carefully considered in developing the requirements for the exemptions from the classification of fissile material and the requirements for general licenses for fissile material, as will be described in the draft NUREG/CR on technical recommendations for fissile materials exemptions and general licenses in 10 CFR Part 71, summarized in the following subsections.

### **2.1 10 CFR 71.15: Exemption From Classification as Fissile Material**

Fissile material is defined in 10 CFR 71.4 as the radionuclides  $^{233}\text{U}$ ,  $^{235}\text{U}$ ,  $^{239}\text{Pu}$ , and  $^{241}\text{Pu}$ , and refers to the nuclides themselves, not material containing these nuclides. Unirradiated natural uranium and depleted

uranium, and natural uranium or depleted uranium that has been irradiated in thermal reactors only, are not included in this definition. Material that meets the definition of fissile material, but also meets one of the six exemption criteria in 10 CFR 71.15, can be transported in packages that do not meet the fissile material transportation requirements of 10 CFR 71.55 or 10 CFR 71.59. For purposes of ensuring criticality safety, the exemptions consider that the material can be released from any packaging during transport, may reconfigure into a worst-case geometric arrangement, may combine with material from other transport vehicles, and may be subject to the fire and water immersion conditions assumed as part of the criticality safety assessment for package designs approved to transport fissile material. The following sections describe each of the six fissile exemption criteria in 10 CFR 71.15.

#### 2.1.1 10 CFR 71.15(a): Individual package containing 2 grams or less fissile material

Individual packages containing small quantities of fissile materials, such as environmental samples shipped frequently for testing purposes, contain such a low quantity of fissile materials that the risk of accumulating the number and type of packages needed to present a potential criticality hazard is negligible. The intent of 10 CFR 71.15(a) is to limit a single package in a consignment to a “de minimis” value of 2 total grams of  $^{233}\text{U}$ ,  $^{235}\text{U}$ ,  $^{239}\text{Pu}$ , or  $^{241}\text{Pu}$ . This exemption does not limit the accumulation of packages because the NRC judged it impractical in commerce to accumulate a sufficient number of individual packages to result in significant criticality safety concerns. Under normal conditions of transport, a cubic array of 84,853 1-liter packages containing only  $^{235}\text{U}$ , at near-optimal moderation, would be required for criticality to be possible [3].

Unlimited quantities of  $^{235}\text{U}$  samples could be shipped without any package requirements as a result of the  $A_1$  and  $A_2$  values being unlimited (10 CFR 71, Table A-1). For other fissile nuclides, Type A or Type B packaging requirements may apply due to the exempt material activity concentration limits in 10 CFR 71 Table A-2, or the  $A_1/A_2$  limits in 10 CFR 71 Table A-1. For example, normal form  $^{239}\text{Pu}$  quantities greater than 0.435 grams would need to be transported in a Type B package, due to the  $A_2$  limit, but would not require a criticality evaluation.

#### 2.1.2 10 CFR 71.15(b): Individual or bulk packaging containing 15 grams or less of fissile material

This exemption is for individual or bulk packaging containing 15 grams or less of fissile material, provided the package has at least 200 grams of solid nonfissile material for every gram of fissile material. Lead, beryllium, graphite, and hydrogenous material enriched in deuterium may be present in the package but must not be included in determining the required mass of solid nonfissile material.

The intent of this fissile material exemption is to allow larger per-package limits than the 2 gram limit in 10 CFR 71.15(a), provided a designated minimal amount of non-fissile packaging or other material is present. Single package subcriticality is assured by the small fissile material mass limit, and package accumulation does not result in criticality safety concerns due to the dilution effect of the required non-fissile mass. The exclusion of effective neutron reflectors (e.g., lead and beryllium) from the required non-fissile mass further reduces the

probability of inadvertent criticality from package accumulation.

An example that would meet this requirement would be a decommissioned glove box that contains 10 grams of  $^{239}\text{Pu}$  (including two times the measurement uncertainty) distributed uniformly on its interior surfaces. Provided the glove box had a total mass greater than 2000 grams, excluding any lead, beryllium, graphite, or hydrogenous material enriched in deuterium, it could be shipped as fissile exempt per 10 CFR 71.15(b). Note that in this example, the mass of  $^{239}\text{Pu}$  exceeds the  $A_2$  value, requiring the glove box to be shipped in a Type B package.

#### 2.1.3 10 CFR 71.15(c): Low concentrations of solid fissile material commingled with solid nonfissile material

This exemption provision is for low concentrations of solid fissile material commingled with solid nonfissile material, provided that: (1) there is at least 2000 grams of solid nonfissile material for every gram of fissile material, and (2) there is no more than 180 grams of fissile material distributed within 360 kg of contiguous nonfissile material. Similarly to 10 CFR 71.15(b), lead, beryllium, graphite, and hydrogenous material enriched in deuterium may be present in the package but must not be included in determining the required mass of solid nonfissile material.

The intent of this fissile material exemption is to allow large volumes waste or other material containing low concentrations of solid fissile material, commingled with a large amount of solid non-fissile material. The quantity of fissile material in this provision is not limited, but must be commingled such that no more than 180 grams is distributed within 360 kg (360,000 grams) of solid non-fissile material, resulting in a package matrix that has a homogeneous mixture of fissile material.

An example that would meet this requirement would be large volumes of soil contaminated with fissile materials, which meets the minimum fissile-to-nonfissile mass ratio of 1:2000. The requirement that the fissile material is "commingled" with nonfissile material would preclude shipment of surface contaminated equipment or piping, for example, where the fissile material may exist in localized sections within the equipment.

#### 2.1.4 10 CFR 71.15(d): Uranium enriched in $^{235}\text{U}$ to a maximum of 1 percent by weight

This exemption provision is for uranium enriched in  $^{235}\text{U}$  to a maximum of 1 percent by weight, with total plutonium and  $^{233}\text{U}$  content of up to 1 percent of the mass of  $^{235}\text{U}$ , provided that the mass of any beryllium, graphite, and hydrogenous material enriched in deuterium constitutes less than 5 percent of the uranium mass. Also, the fissile material should be distributed homogeneously and not form a lattice arrangement within the package. Systems containing homogeneous mixtures of uranium enriched to less than 1 percent will not be critical, irrespective of the mass or size of the system, provided other fissile materials are not present. 10 CFR 71.15(d) also limits the quantity of some less common moderating materials (beryllium, graphite, hydrogenous material enriched in deuterium) because the presence of these materials has the potential to reduce the minimum critical enrichment, increasing the potential for criticality with uranium of lower enrichment.

The intent of this exemption provision is to allow shipment of low enriched uranium in homogeneous configurations. The homogeneity requirement is based on the fact that uranium enriched to less than 5 percent by weight is most reactive when it is in a heterogeneous configuration. For uranium enriched to not more than 1 percent, a large heterogeneous system or lattice arrangement would be required to approach criticality. However, it is conceivable that a heterogeneous system large enough to exceed the  $k_{\text{eff}}$  typically allowed for NRC-certified packages could fit on a large conveyance.

An example of a material that might meet this exemption would be waste uniformly contaminated with 0.95 percent enriched uranium. The exemption would be met provided  $^{233}\text{U}$  and Pu were present in quantities less than 1 percent of the  $^{235}\text{U}$  mass, and beryllium, graphite, or hydrogenous material enriched in deuterium are present in quantities less than 5 percent of the uranium mass.

#### 2.1.5 10 CFR 71.15(e): Liquid solutions of uranyl nitrate enriched in $^{235}\text{U}$ to a maximum of 2 percent

This exemption provision is for uranyl nitrate solutions enriched in  $^{235}\text{U}$  to a maximum of 2 percent by mass, with a total plutonium and  $^{233}\text{U}$  content not exceeding 0.002 percent of the mass of uranium, and with a minimum nitrogen to uranium atomic ratio (N/U) of 2. The material must be contained in at least a DOT Type A package, to ensure that the liquid is not released during normal conditions of transport.

The intent of this exemption is to allow shipment of low enriched uranyl nitrate solutions. The solution must be contained within a Type A package to ensure that the solution material will not convert to oxide form, combine with fissile material from other packages, mix with water, or form into an unfavorable geometry during a shipping accident. The total mass of  $^{235}\text{U}$  in the consignment is not controlled for criticality safety purposes; however, the mass of uranium in the solution is required if there is plutonium or  $^{233}\text{U}$  present, since the mass of other fissile nuclides is limited to 0.002% of the mass of uranium. Additionally, the ratio of atomic nitrogen to uranium (N/U) ratio is limited to 2 or more. This limit ensures that a minimum level of neutron absorption by the nitrogen is present in the fissile material package.

An example is a package containing 100 grams of uranium in uranyl nitrate solution. In this case, the  $^{233}\text{U}$  or plutonium content in the package cannot exceed 0.002 grams.

#### 2.1.6 10 CFR 71.15(f): Packages containing, individually, a plutonium mass of not more than 1000 grams

This exemption provision is for packages containing up to 1000 grams of plutonium, of which not more than 20 percent by mass may consist of  $^{239}\text{Pu}$ ,  $^{241}\text{Pu}$ , or any combination of these radionuclides. This fissile exemption does not constrain the total mass of fissile material in a consignment nor does it constrain the mass of commingled non-fissile material or moderating materials. It is intended primarily for shipment of the non-fissile isotopes of plutonium, such as  $^{238}\text{Pu}$  in heat sources.

The presence of the non-fissile plutonium isotopes provides significant parasitic neutron absorption, and

eliminates the potential for criticality. An example of this exemption would be a package containing 800 grams of  $^{238}\text{Pu}$  and 40 grams of  $^{239}\text{Pu}$  in a heat source. This would satisfy the overall plutonium mass limit of 1000 grams, and the requirement that not more than 20 percent of the plutonium mass consists of fissile plutonium isotopes. Note that, for radiological reasons, this material would need to be shipped in a Type B package, since the amount of material exceeds the  $A_2$  values for both  $^{238}\text{Pu}$  and  $^{239}\text{Pu}$ .

## 2.1 General Licenses in 10 CFR 71.22 and 10 CFR 71.23

The general license criteria in 10 CFR 71.22 (fissile material) and 71.23 (Pu-Be special form material) are intended to allow NRC licensees to ship small quantities of fissile material in packages that have been assigned a Criticality Safety Index (CSI) to ensure accumulation control for packages on a conveyance. These general license criteria require that the licensee have an NRC-approved quality assurance program, that the fissile material is present in at least a Type A package, and that the package contains no more than a Type A quantity of radioactive material.

### 2.2.1 10 CFR 71.22 General License: Fissile Material

The general license for the transportation of fissile material in 10 CFR 71.22 requires shipment in a Type A package, which maintains sufficient structural integrity under normal conditions of transport to preclude fissile material dispersing from the package. The CSI equation is derived to assure that at least two conveyances, shipped under non-exclusive use, would have to experience accident conditions before there was a potential for criticality. The CSI is calculated using the equation:

$$CSI = 10 \left[ \frac{\text{Grams of } ^{235}\text{U}}{X} + \frac{\text{Grams of } ^{233}\text{U}}{Y} + \frac{\text{Grams of Pu}}{Z} \right] \quad (1)$$

Where the denominators X, Y, and Z are determined one of two ways:

- Table 71-1 must be used if any of the following conditions exist:  $^{233}\text{U}$  is present in the package, plutonium mass exceeds 1 percent of the mass of  $^{235}\text{U}$ , the uranium is of unknown enrichment or greater than 24 weight percent enrichment, or substances having a moderating effectiveness (i.e., an average hydrogen density) greater than  $\text{H}_2\text{O}$  (e.g., certain hydrocarbon oils or plastics) are present in any form, except as polyethylene used for packing or wrapping; or
- Table 71-2 may be used if the package contains only  $^{235}\text{U}$  with known enrichment (the terms for  $^{233}\text{U}$  and plutonium are assumed to be 0).

The CSI for a single package must be rounded up to the next decimal place, must be less than 10, and the sum of the CSIs must be less than 50 for a non-exclusive use conveyance, or 100 for an exclusive use conveyance. Additionally, a package using this general license must contain less than 500 total grams of beryllium, graphite, or hydrogenous material enriched in deuterium; a provision added to limit the potential for these materials to be

present as an effective reflector.

The general license mass limits used to calculate the CSI for single and multiple packages are based on the minimum subcritical mass for the materials of interest. The fissile mass limits in Tables 71-1 were derived based on calculations performed to determine the subcritical minimum critical mass of  $^{235}\text{U}$ ,  $^{233}\text{U}$ , and  $^{239}\text{Pu}$  [4]. The calculations considered water reflected and optimally-moderated spheres of  $^{235}\text{U}$ ,  $^{233}\text{U}$ , and  $^{239}\text{Pu}$ . For Table 71-1, column 1, the minimum subcritical mass values corresponding to a system  $k_{\text{eff}}$  of less than 0.95 for  $^{235}\text{U}$ ,  $^{233}\text{U}$ , and  $^{239}\text{Pu}$  are 614 grams, 437 grams, and 379 grams, respectively. For each fissile isotope, the minimum subcritical mass was reduced by a factor of 10, corresponding to a package CSI of 10, and rounded down to the following values for  $^{235}\text{U}$ ,  $^{233}\text{U}$ , and  $^{239}\text{Pu}$ : 60, 43, and 37 grams, respectively. The Table 71-1, column 2, data is applicable for fissile materials mixed with moderating substances having an average hydrogen density greater than water, such as polyethylene (not used for packing or wrapping materials) or hydrocarbon oils. The mass limits are lower for these waste matrices because these systems provide better moderation due to the greater hydrogen density in the matrix. The minimum critical mass of  $^{235}\text{U}$  homogeneously mixed with polyethylene is 527 grams [4]. The mass limit values in the second column of Table 71-1 were derived by reducing the column 1 values by the ratio of the critical minimum critical mass for a  $^{235}\text{U}$ /polyethylene system, 527 grams, to the minimum critical mass for a  $^{235}\text{U}$ /water system, 820 grams, which is equal to about 0.64 (for  $^{235}\text{U}$ , the 60-gram limit becomes  $60 \times 0.64$  or 38 grams, for  $^{233}\text{U}$ , the 43 gram limit is  $43 \times 0.64$  or 27 grams, and for Pu, the 37 gram limit is  $37 \times 0.64$  or 24 grams).

The mass limits for known enrichments in Table 71-2 begin at 60 grams at an enrichment of 24 weight percent  $^{235}\text{U}$ . This corresponds to the subcritical ( $k_{\text{eff}} = 0.95$ ) fissile material mass for fully enriched  $^{235}\text{U}$  [4], which is approximately 600 grams of  $^{235}\text{U}$ . This safe subcritical mass value is divided by 10 to derive a mass limit value in Table 71-2 for 24 weight percent  $^{235}\text{U}$  enrichment of 60 grams per package. The mass limit value for 0.92 wt. % enrichment is 1,800 grams, and corresponds to a minimum subcritical critical mass of 18,000 grams  $^{235}\text{U}$ . When measured enrichment values fall between values in the table, the licensee must use the next lowest mass limit available.

An example of a package that would meet this general license would be a shipment of 300 grams of graphite contaminated with 28.4 grams of uranium enriched to 20 weight percent. The package is Type A, the licensee has an NRC-certified Part 71 quality assurance program, there is less than 500 grams of graphite, and there is no plutonium,  $^{233}\text{U}$ , or substances with moderating effectiveness greater than  $\text{H}_2\text{O}$  present in the material. The CSI would then be:

$$CSI = 10 \left[ \frac{28.4 \text{ Grams } ^{235}\text{U}}{63 \text{ Grams}} \right] = 4.5; \quad (2)$$

which meets the limit of 10.

### 2.2.2 10 CFR 71.23 General License: Plutonium-beryllium special form material

The general license criteria in 10 CFR 71.23 applies to Pu-Be materials which meet the special form requirements of 10 CFR 71.75, ensuring that the material itself will maintain its integrity and will not disperse during normal conditions of transport or under hypothetical accident conditions. For the general license to apply, the package containing Pu-Be special form sources cannot contain more than a Type A quantity of radioactive material, and is limited to 1,000 grams plutonium with up to 240 grams being the fissile isotopes  $^{239}\text{Pu}$  and/or  $^{241}\text{Pu}$ . Note that this differs from the fissile exemption in 71.15(f) in that there is no requirement for nonfissile plutonium to be present (e.g., a special form source with less than 240 grams of  $^{239}\text{Pu}$ , with no or little nonfissile plutonium present, may meet this general license). The CSI for a package under this general license is determined by the equation:

$$CSI = 10 \left[ \frac{\text{Grams of } ^{239}\text{Pu} + \text{Grams of } ^{241}\text{Pu}}{24} \right] \quad (3)$$

The CSI for a single package must be rounded up to the next decimal place, must be less than 100, and the sum of the CSIs must be less than 50 for a non-exclusive use conveyance, or 100 for an exclusive use conveyance.

The allowance for 240 grams of fissile plutonium per package compared to the maximum general license allowance of 37 grams of fissile plutonium per package has been made because of the increased confidence that the fissile plutonium in the special form capsules would not escape during an accident and reconfigure into an unfavorable geometry. The basis of the 240 gram  $^{239}\text{Pu} + ^{241}\text{Pu}$  mass limit in the package is the minimum subcritical mass of 379 grams for  $^{239}\text{Pu}$  ( $k_{\text{eff}} = 0.95$ ) [4]. Using the same basis as for the fissile material general licenses for moderators with a hydrogen density greater than water, the fissile Pu mass limit is equal to 64% of the critical mass value of 379 grams and rounded down to 240 grams. The presence of any non-fissile plutonium isotopes, up to 760 grams, will provide significant parasitic neutron absorption, and eliminate the potential for criticality.

Provision 10 CFR 71.23(c)(1) requires that each package contents contain no more than a Type A quantity. Note that the  $A_1$  value (special form) for some plutonium nuclides will limit their masses to less than the limits given in this general license provision.  $A_1$  values will limit  $^{241}\text{Pu}$  to 11 grams,  $^{236}\text{Pu}$  to 1.52 grams,  $^{237}\text{Pu}$  to 0.045 grams, and  $^{238}\text{Pu}$  to 15.8 grams. All other nuclides of plutonium have  $A_1$  values in excess of the 10 CFR 71.23 mass limits.

An example of a package that would meet this general license would be a shipment of a special form Pu-Be source containing 8.7 grams of  $^{239}\text{Pu}$  and 1.5 grams of  $^{241}\text{Pu}$ , with 4.3 grams of nonfissile  $^{240}\text{Pu}$ . The package is Type A, and the licensee has an NRC-certified Part 71 quality assurance program. The CSI would then be:



$$CSI = 10 \left[ \frac{8.7 \text{ grams of } ^{239}\text{Pu} + 1.5 \text{ grams of } ^{241}\text{Pu}}{24 \text{ grams}} \right] = 4.3; \quad (4)$$

which meets the limit of 100.

### **3. Recent History of Part 71 Fissile Exemptions and General Licenses**

The fissile exemption and general license criteria have existed in some form in 10 CFR Part 71 for several decades. Significant changes have occurred over the past 18 years. These changes will be discussed in detail in the draft NUREG/CR on technical recommendations on fissile material exemptions and general licenses, and are summarized in the following subsections.

#### **3.1 1997 Direct Final Rule**

Responding to licensee-identified concerns regarding the potential for inadequate criticality safety in certain exempted quantities of fissile material (specifically beryllium oxide containing a low concentration of high-enriched uranium), the NRC initiated an emergency rulemaking of 10 CFR Part 71. The primary criticality safety concern was that fissile material mixed with select moderators with very low neutron absorption properties (e.g., beryllium or graphite), can achieve criticality at a lower critical mass concentration than that which was allowed in the fissile exemptions (i.e., 5 grams of fissile material in 10 liters).

Thus NRC initiated rulemaking actions to limit the consignment mass for fissile material exemptions and also restrict the presence of beryllium, deuterium, and graphite. The NRC issued an emergency final rule on February 10, 1997 [5], to revise the regulations on fissile material exemptions and the general licenses that apply to fissile material. The NRC determined that good cause existed to publish this final rule without notice and opportunity for public comment. Further, the NRC also determined that good cause existed to make the final rule immediately effective. Notwithstanding the final status of the rule, the NRC provided for a 30-day public comment period.

#### **3.2 2004 Part 71 Rulemaking**

The NRC subsequently published in the Federal Register on October 27, 1999 [6] a response to the comments received on the emergency final rule discussed above and a request for information on any unintended economic impacts caused by the final rule. Based on the public comments on the emergency final rule, the NRC staff contracted with Oak Ridge National Laboratory (ORNL) to review the fissile material exemptions and general license provisions, study the regulatory and technical bases associated with these regulations, and perform criticality model calculations for different mixtures of fissile materials and moderators. The results of the ORNL study were documented in NUREG/CR-5342, *Assessment and Recommendations for Fissile-Material Packaging Exemptions and General Licenses Within 10 CFR Part 71* [4].

The ORNL study confirmed that the emergency final rule was needed to provide safe transportation of packages

with low-absorption moderators that are shipped under the general license and fissile material exemptions, but concluded that the regulations may be excessive for shipments where water moderation is the only concern. The ORNL study recommended that the NRC revise the fissile material exemptions and general licenses in 10 CFR Part 71 to:

- Move fissile exemption and general license requirements to a more appropriate part of the rule,
- Provide a nonfissile-to-fissile mass ratio approach for some exemptions,
- Limit select low-absorption moderators consistently across the exemption and general license provisions,
- Require Type A package standards for the low-enriched uranyl nitrate solution provision,
- Remove the requirement for homogeneity and prevention of a lattice arrangement for uranium enriched to no more than 1 weight percent,
- Separate the Pu-Be general license requirements from the consolidated fissile material general license requirements, and
- Revise the general license mass limits to provide similar safety equivalence provided by certified packages per the criteria of 10 CFR 71.55 and 10 CFR 71.59.

Based in part on the recommendations in NUREG/CR-5342, the NRC revised the fissile material exemptions and general licenses in 10 CFR Part 71, in a rulemaking that was final in 2004 [7].

### 3.3 2015 Part 71 Rulemaking

The 2004 rulemaking described above changed the provisions of 10 CFR 71.15(d) to remove the restriction that, to qualify for the fissile material exemption, uranium enriched in  $^{235}\text{U}$  is distributed homogeneously throughout the package and does not form a lattice arrangement within the package. The terms homogeneity and lattice arrangement were not clearly defined, and a restriction on beryllium, graphite, and hydrogenous material enriched in deuterium would be sufficient to prevent criticality in all but a very large repeating array of low-enriched uranium that was judged impractical for transport scenarios.

Subsequent to the 2004 rulemaking, the U.S. Department of Energy (DOE) identified a planned shipment of large quantities of low-enriched fissile material that would qualify for the exemption at 10 CFR 71.15(d). Analyses performed by the DOE indicated that large arrays (i.e., multiple conveyances) of heterogeneous uranium with enrichment of one percent by weight of  $^{235}\text{U}$  could exceed a  $k_{\text{eff}}$  of 0.95 when optimally moderated by water. Because such a shipment, as analyzed, could both qualify for the fissile material exemption for low-enriched fissile material and have a  $k_{\text{eff}}$  greater than 0.95, the NRC decided that additional restrictions on low-enriched fissile material shipped under the fissile material exemption at 10 CFR 71.15(d) are warranted to provide similar safety equivalence provided by certified packages per the criteria of 10 CFR 71.55 and 10 CFR 71.59.

The NRC restored the former lattice arrangement and homogeneous distribution provisions in the 10 CFR 71.15(d) exemption requirement [2]. The revised provision excludes from the exemption's scope situations where fissile "lumps" or lattice arrangements of fissile material are present within the package. The 10 CFR 71.15(d) exemption language continues to exclude large quantities (less than 5 percent of the uranium mass) of low-absorbing moderators (beryllium, graphite, or hydrogenous material enriched in deuterium). These requirements will preclude fissile material arrangements in packages that can potentially result in criticality at  $^{235}\text{U}$  enrichments less than 1 weight percent.

Heterogeneous systems are generally defined as any mixtures of fissile and moderator materials with uniformly distributed fissile material particles larger than  $\sim 0.1$  mm [8]. Additionally, the IAEA Safety Guide TS-G-1.1, *Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material* [9], contains a description of essentially homogeneous materials as "those in which the particles in the mixture are uniformly distributed and have a diameter no larger than 127 microns (0.127 mm)." Lattice arrangement means a fixed, repeating configuration of separate fissile material lumps. A nuclear fuel assembly is an example of a lattice arrangement.

For the exemption in 10 CFR 71.15(d), small volumes of heterogeneity may exist, provided that a significant fraction of fissile material is homogeneous and mixed with non-fissile material, or lumps of fissile material are in a largely irregular arrangement. Further, heterogeneous effects in a package due to large fissile material lumps/particles or lattice arrangements of fissile material would only affect criticality safety in a regular or near-optimal configuration over a large volume. Large quantities of fissile material (kilograms of  $^{235}\text{U}$ ) and regions of heterogeneity on the order of a cubic meter in size are necessary before a system could adversely affect the validity of the 1 weight percent  $^{235}\text{U}$  enrichment limit for this fissile exemption.

#### **4. Potential Revisions to Fissile Material Exemptions and General Licenses**

In the process of completing the 2015 rulemaking effort for the fissile material exemptions, some potential opportunities for improvement were identified in the fissile material exemptions, the fissile material general licenses, and the Pu-Be special source material general license provisions in 10 CFR Part 71. Some of these potential changes to be considered in the future include:

- Making a clearer connection between fissile material exemption and general license packaging requirements and those for Type A or B radioactive material quantities,
- Revising the 10 CFR 71.22(3)(5)(i) requirement that no  $^{233}\text{U}$  is present in the package, when a restriction to less than 1 percent of the  $^{235}\text{U}$  mass, similar to that for plutonium in 10 CFR 71.22(3)(5)(ii), would likely suffice,
- Revising the wording for the general licenses in 10 CFR 71.22 and 10 CFR 71.23 to allow shipment in a Type B package, as some mass limits for plutonium isotopes greatly exceed a Type A quantity.

Additionally, the NRC has initiated a rulemaking for the purpose of making 10 CFR Part 71 compatible with IAEA transportation regulations in SSR-6, *Regulations for the Safe Transport of Radioactive Material* [10], to the extent practical. The IAEA updated the regulations in SSR-6 in 2012, and the NRC must consider which of the regulation changes to adopt in 10 CFR Part 71. Some of the provisions in the 2012 revision to SSR-6 that are not in 10 CFR Part 71 are:

- Additional fissile exception/exemption criteria in paragraph 417:
  - Up to 3.5 grams <sup>235</sup>U per package, up to 5.0 weight percent enriched, with a consignment limit of 45 grams <sup>235</sup>U,
  - Up to 2.0 grams fissile material per package, with a consignment limit of 15 grams, and
  - Up to 45 grams fissile material, packaged or unpackaged, shipped exclusive use,
- The addition of a “competent authority-approved” fissile exception, for exceptions that are different than those existing in paragraph 417,
- The addition of a CSI determination in paragraph 674, analogous to the CSI determination in 10 CFR 71.22 and 71.23, but with different mass values, and
- The addition of a CSI determination for accumulation control of previously fissile-excepted packages containing up to 1000 grams plutonium, with fissile plutonium isotopes limited to less than 20 percent of the total plutonium mass.

The NRC is coordinating this rulemaking with the U.S. Department of Transportation (DOT), and will also consider potential fissile material transportation requirement changes in DOT regulations, which are not reflected in NRC regulations.

The NRC will publish an Issues Paper, which will describe in detail each of the changes the NRC intends to make to 10 CFR Part 71, in November in the *Federal Register* (Rulemaking ID #3150-AJ85 and Docket ID NRC-2016-0179). This paper will give the justification for each of the changes, and justification for each of the IAEA SSR-6 regulations that the NRC does not intend to adopt, and solicit feedback from stakeholders. The Issues Paper will be discussed at a public meeting at the NRC on December 5-6, 2016. The public will have additional opportunities for comment on this proposed rulemaking after the rule and its associated regulatory basis are drafted.

## 5. Conclusions

This paper outlined a reference NUREG/CR document, under development by Oak Ridge National Laboratory (ORNL) for the NRC, which will provide technical recommendations to fissile material licensees on how to apply the fissile material exemption and general license regulations. Section 2 summarized the technical basis, intent, and anticipated usage of each exemption and general license provision, which will be detailed in the reference NUREG/CR. Section 3 summarized the recent history of 10 CFR Part 71 rulemaking, which will also be detailed in the reference NUREG/CR. Finally, Section 4 summarized potential changes to 10 CFR Part 71

being considered for an upcoming rulemaking, and announced opportunities for public comment during the rulemaking process.

## References

1. Code of Federal Regulations, Title 10, Part 71, *Packaging and Transportation of Radioactive Material*, January 1 (2015).
2. *Federal Register* / Vol. 78, No. 95, Thursday, May 16, 2013 / Revisions to Transportation Safety Requirements and Harmonization With International Atomic Energy Agency Transportation Requirements.
3. International Atomic Energy Agency, *Consultant Services Meeting (CS-41) – Development of Exceptions from the Regulations for Transport Packages Containing Fissile Material – Discussion of Fissile Exemption Criteria Proposed by the United States*, Paris, France, March 15-17 (2004).
4. C.V. Parks, C.M. Hopper, and J.L. Lichtenwalter, *Assessment and Recommendations for Fissile-Material Packaging Exemptions and General Licenses Within 10 CFR Part 71*, NUREG/CR-5342, (ORNL/TM-13607), U.S. Nuclear Regulatory Commission, Oak Ridge National Laboratory (1998).
5. *Federal Register* / Vol. 62, No. 27, Monday, February 10, 1997 / Rules and Regulations 10 CFR Part 71, Fissile Material Shipments and Exemptions.
6. *Federal Register* / Vol. 64, No. 207, Wednesday, October 27, 1999 / Fissile Material Shipments and Exemptions; Response to Comments and Request for Information.
7. *Federal Register* / Vol. 69, No. 16, Monday, January 26, 2004 / Compatibility with IAEA Transportation Safety Standards (TS-R-1) and Other Transportation Safety Amendments.
8. R. A. Knief, *Nuclear Criticality Safety – Theory and Practice*, American Nuclear Society, La Grange Park, IL (1998)
9. International Atomic Energy Agency, *Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material Safety Guide*, TS-G-1.1 (Rev. 1), Vienna, Austria (2008).
10. International Atomic Energy Agency, *Regulations for the Safe Transport of Radioactive Material*, SSR-6, Vienna, Austria (2012).

## Appendix A

### Text of 10 CFR 71.15, 10 CFR 71.22, and 10 CFR 71.23

#### **10 CFR 71.15 Exemption from classification as fissile material.**

Fissile material meeting the requirements of at least one of the paragraphs (a) through (f) of this section are exempt from classification as fissile material and from the fissile material package standards of §§ 71.55 and 71.59, but are subject to all other requirements of this part, except as noted.

- (a) Individual package containing 2 grams or less fissile material.
- (b) Individual or bulk packaging containing 15 grams or less of fissile material provided the package has at least 200 grams of solid nonfissile material for every gram of fissile material. Lead, beryllium, graphite, and hydrogenous material enriched in deuterium may be present in the package but must not be included in determining the required mass for solid nonfissile material.
- (c) (1) Low concentrations of solid fissile material commingled with solid nonfissile material, provided that:
  - (i) There is at least 2000 grams of solid nonfissile material for every gram of fissile material, and
  - (ii) There is no more than 180 grams of fissile material distributed within 360 kg of contiguous nonfissile material.(2) Lead, beryllium, graphite, and hydrogenous material enriched in deuterium may be present in the package but must not be included in determining the required mass of solid nonfissile material.
- (d) Uranium enriched in uranium-235 to a maximum of 1 percent by weight, and with total plutonium and uranium-233 content of up to 1 percent of the mass of uranium-235, provided that the mass of any beryllium, graphite, and hydrogenous material enriched in deuterium constitutes less than 5 percent of the uranium mass, and that the fissile material is distributed homogeneously and does not form a lattice arrangement within the package.
- (e) Liquid solutions of uranyl nitrate enriched in uranium-235 to a maximum of 2 percent by mass, with a total plutonium and uranium-233 content not exceeding 0.002 percent of the mass of uranium, and with a minimum nitrogen to uranium atomic ratio (N/U) of 2. The material must be contained in at least a DOT Type A package.
- (f) Packages containing, individually, a total plutonium mass of not more than 1000 grams, of which not more than 20 percent by mass may consist of plutonium-239, plutonium-241, or any combination of these radionuclides.

**§ 71.22 General license: Fissile material.**

- (a) A general license is issued to any licensee of the Commission to transport fissile material, or to deliver fissile material to a carrier for transport, if the material is shipped in accordance with this section. The fissile material need not be contained in a package which meets the standards of subparts E and F of this part; however, the material must be contained in a Type A package. The Type A package must also meet the DOT requirements of 49 CFR 173.417(a).
- (b) The general license applies only to a licensee who has a quality assurance program approved by the Commission as satisfying the provisions of subpart H of this part.
- (c) The general license applies only when a package's contents:
  - (1) Contain no more than a Type A quantity of radioactive material; and
  - (2) Contain less than 500 total grams of beryllium, graphite, or hydrogenous material enriched in deuterium.
- (d) The general license applies only to packages containing fissile material that are labeled with a CSI

which:

- (1) Has been determined in accordance with paragraph (e) of this section;
- (2) Has a value less than or equal to 10; and
- (3) For a shipment of multiple packages containing fissile material, the sum of the CSIs must be less than or equal to 50 (for shipment on a nonexclusive use conveyance) and less than or equal to 100 (for shipment on an exclusive use conveyance).

- (e) (1) The value for the CSI must be greater than or equal to the number calculated by the following equation:

$$CSI = 10 \left[ \frac{\text{Grams of } ^{235}\text{U}}{X} + \frac{\text{Grams of } ^{233}\text{U}}{Y} + \frac{\text{Grams of Pu}}{Z} \right]$$

- (2) The calculated CSI must be rounded up to the first decimal place;
- (3) The values of X, Y, and Z used in the CSI equation must be taken from Tables 71-1 or 71-2, as appropriate;
- (4) If Table 71-2 is used to obtain the value of X, then the values for the terms in the equation for uranium-233 and plutonium must be assumed to be zero; and
- (5) Table 71-1 values for X, Y, and Z must be used to determine the CSI if:
  - (i) Uranium-233 is present in the package;
  - (ii) The mass of plutonium exceeds 1 percent of the mass of uranium-235;
  - (iii) The uranium is of unknown uranium-235 enrichment or greater than 24 weight percent enrichment; or
  - (iv) Substances having a moderating effectiveness (i.e., an average hydrogen density greater than H<sub>2</sub>O) (e.g., certain hydrocarbon oils or plastics) are present in any form, except as polyethylene used for packing or wrapping.

**Table 71-1. Mass Limits for General License Packages Containing Mixed Quantities of Fissile Material or Uranium-235 of Unknown Enrichment per § 71.22(e)**

Fissile material	Fissile material mass mixed with moderating substances having an average hydrogen density less than or equal to H <sub>2</sub> O (grams)	Fissile material mass mixed with moderating substances having an average hydrogen density greater than H <sub>2</sub> O <sup>a</sup> (grams)
<sup>235</sup> U (X)	60	38
<sup>233</sup> U (Y)	43	27
<sup>239</sup> Pu or <sup>241</sup> Pu (Z)	37	24

<sup>a</sup> When mixtures of moderating substances are present, the lower mass limits shall be used if more than 15 percent of the moderating substance has an average hydrogen density greater than H<sub>2</sub>O.

**Table 71-2. Mass Limits for General License Packages Containing Uranium-235 of Known Enrichment per § 71.22(e)**

Uranium enrichment in weight percent of <sup>235</sup> U not exceeding	Fissile material mass of <sup>235</sup> U (X) (grams)	Uranium enrichment in weight percent of <sup>235</sup> U not exceeding	Fissile material mass of <sup>235</sup> U (X) (grams)
24	60	5.5	102
20	63	5	108
15	67	4.5	114
11	72	4	120
10	76	3.5	132
9.5	78	3	150
9	81	2.5	180
8.5	82	2	246
8	85	1.5	408
7.5	88	1.35	480
7	90	1	1,020
6.5	93	0.92	1,800
6	97		

**§ 71.23 General license: Plutonium-beryllium special form material.**

- (a) A general license is issued to any licensee of the Commission to transport fissile material in the form of plutonium-beryllium (Pu-Be) special form sealed sources, or to deliver Pu-Be sealed sources to a carrier for transport, if the material is shipped in accordance with this section. This material need not be contained in a package which meets the standards of subparts E and F of this part; however, the material must be contained in a Type A package. The Type A package must also meet the DOT requirements of 49 CFR 173.417(a).
- (b) The general license applies only to a licensee who has a quality assurance program approved by the Commission as satisfying the provisions of subpart H of this part.
- (c) The general license applies only when a package's contents:
  - (1) Contain no more than a Type A quantity of radioactive material; and
  - (2) Contain less than 1000 g of plutonium, provided that: plutonium-239, plutonium-241, or any combination of these radionuclides, constitutes less than 240 g of the total quantity of plutonium in the package.
- (d) The general license applies only to packages labeled with a CSI which:
  - (1) Has been determined in accordance with paragraph (e) of this section;
  - (2) Has a value less than or equal to 100; and



(3) For a shipment of multiple packages containing Pu-Be sealed sources, the sum of the CSIs must be less than or equal to 50 (for shipment on a nonexclusive use conveyance) and less than or equal to 100 (for shipment on an exclusive use conveyance).

(e) (1) The value for the CSI must be greater than or equal to the number calculated by the following equation:

$$CSI = 10 \left[ \frac{\text{Grams of } ^{239}\text{Pu} + \text{Grams of } ^{241}\text{Pu}}{24} \right]$$

(2) The calculated CSI must be rounded up to the first decimal place.