May 11, 2000

Mr. Richard W. Boyle
Radioactive Materials Branch
Office of Hazardous Materials
Technology
U.S. Department of Transportation
400 Seventh Street SW
Washington, DC 20590

SUBJECT: PROPOSAL FOR CHANGE TO 1996 EDITION OF THE IAEA'S REGULATIONS FOR THE SAFE TRANSPORT OF RADIOACTIVE MATERIAL

Dear Mr. Boyle:

Enclosed please find a proposal for change to the 1996 Edition of the International Atomic Energy Agency's (IAEA's) "Regulations for the Safe Transport of Radioactive Material." The proposed change pertains to regulatory exceptions for fissile materials and was prepared for the Spent Fuel Project Office by Oak Ridge National Laboratory. We request that you forward this proposal to IAEA for consideration at the Revision Panel Meeting, scheduled for September 4-8, 2000, in Vienna, Austria.

If you have any questions about this proposal, please contact Robert Lewis (301-415-8527), our technical manager for this project.

Sincerely,

/RA/

Susan F. Shankman, Deputy Director
Licensing and Inspection Directorate
Spent Fuel Project Office
Office of Nuclear Material Safety
and Safeguards

Enclosure: Proposal
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NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

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Enclosure: Proposal

Proposed Change to the 1996 Edition of the International Atomic Energy Agency Transport Regulations (ST-1) and/or its associated Guidance Documents (ST-2 and ST-3)
For Consideration by the September 2000 Revision Panel

Proposed Change Submitted by: (1)

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E-mail: parkscv@ornl.gov

Proposal Reference Number (2)
(to be assigned by the IAEA Secretariat)

Type of Change (3.1)

Minor Change ☐ Change of Detail ☐ Major Change ✔

Topic of Proposed Change (3.2)

(Provide brief summary statement on topic of proposed change with one or more key words associated with the topic)
➤Change **fissile material** definition to include additional nuclides that can present criticality safety concerns and revise exception criteria for packages containing **fissile material** to provide improved assurance that safety will not be compromised under accident conditions.

Principal Objective of Proposed Change (3.3) (Check boxes as appropriate)

✔ Necessary to provide adequate protection to health and safety of public and occupational workers
☐ Involves defining or redefining level of protection to health and safety of public and occupational workers
☐ Required for consistency within the Regulations
✔ Required as a result of advances in technology
☐ Needed to improve implementation of the Regulations
☐ Other (specify) _____

Paragraphs Affected and Proposed Text Changes to ST-1 (3.4)

(Provide new text for ST-1 and a listing of the paragraphs affected. Where appropriate identify where existing text is to be modified or deleted)
➤ **NOTE:** Nuclides marked with an asterisk in the following proposed definition are those considered by ANSI/ANS-8.15: Nuclear Criticality Control of Special Actinide Elements and represent the minimum list of nuclides that should be evaluated in extending the current definition of ST-1.

Para 222 [proposed] *Fissile material* shall mean protactinium-231, uranium-232, uranium-233*, uranium-234, uranium-235*, neptunium-235, neptunium-236, neptunium-237*, plutonium-238*, plutonium-239*, plutonium-240*, plutonium-241*, plutonium-242*, plutonium-244, americium-241*, americium-242m*, americium-243*, curium-242, curium-243*, curium-244*, curium-245*, curium-246, curium-247*, curium-248, berkelium-247, berkelium-249, californium-248, californium-249*, californium-250, californium-251*, californium-252, and californium-254 or any combination of these radionuclides. Excepted from the definition:

(a) *natural uranium* or *depleted uranium* which is unirradiated, and
(b) *natural uranium* or *depleted uranium* which has been irradiated in thermal reactors only.

NOTE: Tables 1-2 noted below in proposed para 672 are provided following the form.

Para 672. [proposed] *Fissile material* meeting one of the provisions (a) - (d) of this paragraph is excepted from the requirement to be transported in *packages* that comply with paras 673-682 as well as the other requirements of these Regulations that apply to *fissile material.*

(a) Each individual package contains not more than X grams of uranium-233, uranium-235, and plutonium-239 and there is no more than 1 gram of these radionuclides per Y grams of non-combustible, insoluble-in-water material in the packaging and contents. X and Y are provided in Table 1. All other

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radionuclides listed in para 222 shall not be present in quantities exceeding 1% by mass of the fissile material. Beryllium, graphite, and hydrogenous material enriched in deuterium may be present in the package, but shall not be included in determining the mass ratio for the package. The material can be packaged or unpackaged.

(b) Each individual package contains fissile material with the mass of all radionuclides listed in Table 2 being limited by the formula

$$\sum(m_i / M_i) < 1$$

where m_i is the grams of each radionuclide that is in the package and M_i is the excepted limit for each radionuclide. In addition, there must be no more than 1 gram of fissile material per 200 grams of non-combustible, insoluble-in-water material in the packaging and contents. Beryllium, graphite, and hydrogenous material enriched in deuterium may be present in the package, but shall not be included in determining the mass ratio for the package. The package shall meet the requirements of para 646.

(c) Uranium enriched in uranium-235 to a maximum of 1 percent by mass, and with total plutonium and uranium-233 content not exceeding 1% of the mass of uranium-235, provided that beryllium, graphite, and hydrogenous material enriched in deuterium constitute less than 0.1% of the fissile mass.

(d) Liquid solutions of uranyl nitrate enriched in uranium-235 to a maximum of 2% by mass, with a total total plutonium and uranium-233 content not exceeding 0.002% of the mass of uranium, and with a minimum nitrogen to uranium atomic ratio (N/U) of 2. The package shall meet the requirements of para 646.

(e) Packages containing, individually, a total plutonium mass not more than 1 kg, of which not more than 20% by mass may consist of plutonium-239, plutonium-241 or any combination of those radionuclides.

Paragraphs Affected and Proposed Text Changes to ST-2 (3.5)

(Provide a listing of the paragraphs affected, details on proposed change, and modified text to appropriate paragraphs in ST-2)

➤ Para 222.2 [replace]: The distinguishing characteristic of the nuclides named in the definition is that they are capable of maintaining a self-sustaining nuclear chain reaction. The nuclides U-233, U-235, Pu-239, and Pu-241 are typically considered to provide the greatest concern to criticality safety because of their potential for maintaining a self-sustaining nuclear chain reaction with thermal neutrons (neutrons with energies less than 0.3 eV as typically found in water-moderated systems) together with the quantities of these materials known to exist. Other nuclides included in the definition have the potential for criticality and have reported subcritical mass limits (Ref. ANSI/ANS-8.15) ranging from a few grams to tens of kilograms. Thus, although these nuclides do not all have the same potential for criticality under transport conditions, they are all included in the definition to assure that proper consideration is given to the safety issues that may arise from their transport in quantities that exceed the excepted limits of Table 2.

Para 222.3 [DELETE]
DELETE existing paras 672.2 - 672.4.
Re-number existing 672.5 to be new 672.9.
DELETE existing 672.6.
ADD Ref. 84 to list of references in existing 672.7 and re-number to be new 672.10.
NEW paras 672.2-672.8 are provided below.

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672.2 The principal parameters of concern in controlling the criticality safety of transportation packages are

1. type, mass, and form of the fissile material;
2. moderator-to-fissile material ratio (degree of moderation);
3. amount and distribution of moderator and absorber materials;
4. package geometry—internal and external; and
5. reflector effectiveness.

A package that is excepted from the requirements normally applied to packages containing fissile material will not be assessed relative to the above parameters. Thus, any control provided by the package geometry or the presence of any absorber/moderator materials cannot be relied upon in the assessment of the regulatory specifications. The effectiveness of water as a reflector and the abundance of it in nature has made water the reflector material of choice for evaluation of fissile material packages. Thus, exception specifications are limited to considering only the type, mass, and form of the fissile material, together with the presence of moderators.

672.3 The fissile exception criteria should provide assurance that the as-presented fissile-exempt package will not be affected by transport conditions to the detriment of the subcritcal parameter values upon which safety was based. Reference 1 concludes that, unless conveyance control is provided for excepted packages as a means to control accumulation of fissile material, the use of mass ratios (i.e., ratios of fissile-material mass to nonfissile-material mass) provide the most reliable assurance to maintain safety during normal and accident conditions specified by the regulations. The proposed mass ratios of 672(a)-(b) were developed to address the practical need for shipping material with low concentrations of fissile material but with control provided by presence of a more predictable nonfissile mass rather than a volume (which can contain noncombustible, insoluble-in-water material or no material at all). The mass-limited exceptions of para 672(a)-(b) provide criteria based on a ratio of the mass of fissile material per mass of nonfissile material. The nonfissile material considered in the ratio determination should be insoluble-in-water and noncombustible.

672.4 Moderators such as beryllium, carbon, and deuterium are not as effective as hydrogen (i.e., the mass to obtain criticality will be smaller with a water-moderated system). However, their neutron absorption properties are much lower than that of hydrogen, such that the limiting concentration of fissile material required to obtain criticality is much lower than for water. The mass-limited exceptions of para 672(a)-(b) enables the only restriction related to beryllium, carbon, and deuterium be that these moderators not be used in the nonfissile mass determination.

672.5 Mass ratios as required by 672(a)-(b) are often easier for users to determine than values related to volume or volumetric concentration, and they are judged to provide an improved assurance for subcriticality under hypothetical accident conditions (i.e., assurance that desired volumes are maintained during accident conditions is much more difficult than assurance that insoluble, non-combustible mass values are maintained). The non-fissile mass can be any part of the package, i.e. the contents or packaging. Given an array of such packages in an accident, it is anticipated that rearrangement of the contents and packaging material for the

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array would be such that sufficient mixing of the fissile and non-fissile masses would be maintained. An increased mass allowance for packages that meet the normal conditions of transport (option 3 of Table 1) gives consideration to the fact that there is some packaging performance criteria that has been met and that such criteria justifies a reduction in the required mass ratio (or increase in fissile material mass). See Appendix G of Ref. 1 for more discussion and justification of each exception.

672.6 The mass limits provided in Tables 1 and 2 are based on referenced work that seeks to determine subcritical limits for the nuclides included in the fissile material definition. Reference 1 provides the justification for the values of Table 1 and the values of Table 2 are selected to be 1/50 of the subcritical mass as reported in ANSI/ANS-8.15: Nuclear Criticality Control of Special Actinide Elements and Ref. 2.

672.7 The enrichment limit of 1 wt% U-235 in subpara. (c) is a rounded off value slightly lower then the minimum critical U-235 enrichment for infinite homogenous mixtures of uranium and water published by Paxton and Pruvost [84]. Beryllium, deuterium, and carbon are not allowed because the combination of these moderators and material with uranium enriched to 1 wt% U-235 could be a potential criticality safety concern if the material is transported in a lattice configuration.

672.8. The exception limit for subpara (d) provides for uranyl nitrate solution to have a content enriched in U-235 to no more than 2% by mass of uranium. This limit is slightly lower than the minimum critical enrichment value reported by Paxton and Pruvost [84]. The exception for uranyl nitrate solutions as provided in para 672(d) incorporate packaging standards to meet the tests of para 646. These standards are judged to be adequate to assure the uranyl nitrate is protected from adverse conditions that might affect the potential for criticality.

REFERENCE 1: C. V. Parks, C. M. Hopper, and J. Lichtenwalter, *Assessment and Recommendations for Fissile-Material Packaging Exemptions and General Licenses Within 10 CFR Part 71*, NUREG/CR-5342 (ORNL/TM-13607), July 1998.

REFERENCE 2: J. Anno and G. Sert, *French Participation at ANS/ANSI 8/15 Working Group Updating Criticality Data on ^{237}Np Criticality and Transportation Proposals*, Presented in the Proceedings of the International Conference on Nuclear Criticality ICNC'99, Vol. I, p. 447 (September 1999).

Paragraphs Affected and Proposed Text Changes to ST-3 (3.6)
(Provide a listing of the paragraphs affected, details on proposed change, and modified text to appropriate paragraphs in ST-3)
➤None currently recommended.

Justification for Proposed Change (3.7)
(Provide details on justification for the proposed change. For a proposed major change, include an assessment of how it affects risk and a value impact. Use additional pages as needed)
➤
This proposed change addresses both the definition of *fissile material* and the criteria for excepting packages from the requirements for packages containing *fissile material.*

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Fissile Material Definition. During the revision process for the 1996 Edition of the Regulations, the Working Group on Criticality Safety (and subsequent approval bodies) concurred with a Member State request to remove ^{238}Pu from the list within the *fissile material* definition. The reason for the removal was that ^{238}Pu can not maintain a self-sustaining chain reaction with thermal (low-energy) neutrons and is thus no different from a host of other nuclides which typically require large mass accumulation and/or special conditions to achieve criticality. The minutes of the Working Group indicate that the decision was to delete ^{238}Pu from the list to create a consistent set of nuclides (^{233}U, ^{235}U, ^{239}Pu, and ^{241}Pu) that were considered those most prominently used in transport and presented the greatest criticality concern. The current advisory material of para 222.3 indicates that there are numerous other nuclides that have the potential for achieving criticality and that due care should be exercised when such nuclides were transported in mass quantities that could create a concern. However, based on recent experience from some Member State regulatory authorities (e.g., the UK and France) and the expected practice based on changes observed in the nuclear industry (e.g., actinide burners, advanced reprocessing techniques, defense-related applications, nuclide production for medical and industrial applications, etc.), the need for considering a broader definition of fissile material (inclusion of ^{238}Pu and other similar nuclides) is more evident than it was during the revision process leading to the 1996 Edition of the Regulations.

The current definition of ST-1 does not include all nuclides which are truly fissile (able to self-sustain a nuclear chain reaction with thermal neutrons), nor does it include all the nuclides that can pose a criticality concern due to their ability to maintain a self-sustaining nuclear chain reaction with neutrons that are not thermal. Transport of selected ones of these nuclides in quantities that can present a potential criticality concern have been or are being considered. Reference 2 presents an initial investigation of the nuclides that should be considered together with some proposed mass limits presented as excepted quantities. This current change proposal recommends he definition be expanded to include a broader list of nuclides capable of maintaining a self-sustaining nuclear chain reaction. Further discussion with Member States and industry may be needed to define exactly how broad the list should be in order to include all nuclides of concern for transport (i.e, eliminate those nuclides which are so esoteric that they are inconsequential to concerns of criticality safety in transport). The proposed definition includes all nuclides that can maintain a self-sustaining chain reaction and will likely need to be reduced based on input provided by Member States relative to practical potential for transport. As a minimum, the nuclides with an asterisk are recommended for inclusion in the definition.

Extension of the list of nuclides included in the fissile material list will assure that licensees, shippers, and regulators provide adequate attention to package contents that may present a potential threat to criticality safety. Only a very small number of selected packages worldwide have been judged to need a criticality safety evaluation when contents did not meet the current definition. Thus, given that appropriate exception criteria are applied, the impact of the extension is judged to be minimal based on current transport practice and needs. However, the value provided by this minimal impact may be enormous based on the prevention of a potential criticality in future transport given the current evolution of processes involving special actinide elements.

Exception Criteria. During the revision process for the 1996 Edition of ST-1, there was an IAEA Member

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State concern regarding uncontrolled accumulation of packages containing excepted quantities of fissile material. This concern led to a detailed review and discussion of the exception criteria - both within the IAEA revision process and within Member States.[3-6] The discussion within the revision process eventually led to a decision point whereby conveyance control was provided via labeling with a criticality safety index (CSI, based on fraction of accepted fissile mass allowed on the conveyance) or the ad hoc control provided by limiting the fissile material mass in a consignment and restricting the presence of select moderators with very low neutron-absorption properties (i.e., "special" moderators). The latter option was chosen as the preferred option because it avoided the necessity and potential confusion of additional labeling. However, subsequent to the issuance of ST-1, experience in the US has 1) identified concerns regarding the potential for inadequate criticality safety in certain shipments of excepted quantities of fissile material (beryllium oxide containing low-concentration of high-enriched uranium), 2) identified multiple examples where fissile-excepted consignments were accumulated on a conveyance in quantities which exceeded the excepted fissile material limits (demonstrating that the ad hoc control provided by a consignment limit was insufficient), and 3) demonstrated continued confusion among licensees regarding what constitutes a "lattice" or "essentially homogeneous" material as required for 672(b).

Licensees in the US have also expressed concern that the consignment restrictions are far too limiting based on the subcritical characteristics of the exemption criteria and the small risk of hypothetical accident conditions rearranging the fissile material to a form that would cause a criticality concern. The limit on the Be and D_2O currently allowed in a fissile-excepted material under para 672(a) is also overly restrictive.[1,5] However, the technical need for some limit is valid unless the quantity of fissile material per conveyance is controlled or criteria are implemented to mitigate the potential effect of their presence. The reason for this conclusion is that criteria such as the current 5-g-per-10-L criteria of para 672(a)(iii) assumes a water-moderated system; much lower concentrations would be needed if the fissile material was mixed with significant quantities of Be, C, or D_2O.

The use of fissile-to-nonfissile mass ratios as the criteria for mass-limiting exception quantities 1) removes the uncertainty related to potential change of form and concentration under normal or accident conditions; 2) eliminates the need for a restriction on low-absorbing moderators such as Be, D2O, and graphite; and 3) removes the consignment restriction on fissile mass and puts the criteria strictly on a package basis. The nonfissile material considered in the ratio determination should be insoluble-in-water and noncombustible. Mass quantities of Be, C, and D_2O should be excluded from consideration as nonfissile material for the purposes of determining the ratio value. Mass ratios are often easier for users to determine than values related to volume or volumetric concentration, and they are judged to provide an improved assurance for subcriticality under hypothetical accident conditions (i.e., assurance that desired volumes are maintained during accident conditions is much more difficult than assurance that insoluble, non-combustible mass values are maintained).

In addition, the exception for uranyl nitrate solutions as provided in para 672(c) should be revised to incorporate packaging standards to meet the tests of para 646 in order to provide adequate protection against potential chemical changes that might affect the potential for criticality.

The exception for uranium enriched to no more than 1 wt % ^{235}U as provided in 672(b) should be modified to

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remove the requirement for homogeneity and prevention of a lattice arrangement. Instead, a moderator criteria restricting the mass of Be, C, or D_2O to less than some percentage of the fissile mass should be provided. Ref. 1 suggest a value of 0.1% as the percentage of fissile mass, but it would be more appropriate (and relatively straightforward) to perform analyses that provide a technical basis for excepting ranges (limiting the 1 wt% ^{235}U total mass and/or the total fissile-to-moderator ratio) of these specific fissile/moderator mixtures. Such a change is needed in this provision because conditions such as "essentially homogeneous"and "lattice arrangement" are extremely difficult to define in a concise and clear manner.

To provide acceptable mass-limiting quantities for the new nuclides added to the fissile material definition, the proposed change is to rely on exception mass values based on the same fraction of the critical mass value as that represented by the 15-g value for the existing nuclides in ST-1. Unfortunately, the 15-g value is an agreed upon value for nuclides which have subcritical mass limits varying by a factor of about 3 (i.e, ANSI/ANS-8.15 provides a subcritical mass limit of 200 g for ^{241}Pu and Ref. 1 provides a 614-g subcritical value for ^{235}U in water at k = .95). However, with only a few differences noted in Table 2, this proposed change recommends an excepted mass limit equal to 1/50 of the subcritical mass value be applied in the regulations for all nuclides included in the **fissile material** definition excluding ^{233}U, ^{235}U, and ^{239}Pu. The more conservative fraction of 1/50 is recommended because for nuclides other than ^{233}U, ^{235}U, and ^{239}Pu there is a distinct lack of critical experiment data, limited knowledge of the behavior of these added nuclides under different moderation and reflection conditions, and largely varying uncertainty in the cross-section data. Thus it is likely that criticality safety specialists will need to concur with the appropriate set of subcritical mass values that should be used for the added nuclides. In addition, for simplicity, consideration may be given to adopting exception mass limits that apply to multiple nuclides (similar to the use of a common 15-g value for ^{233}U, ^{235}U, and ^{239}Pu).

Note the above recommendation discontinues the use of the 15-g exception limit for ^{241}Pu and recommends a new exception limit as given in Table 2. This proposal is made because ^{241}Pu was not originally considered in the basis used to develop the 15-g value; because the subcritical mass for ^{241}Pu is much lower than that for ^{233}U, ^{235}U, or ^{239}Pu; and because the availability of ^{241}Pu in pure form is much more likely now than when the exception limits were first conceived.

The final step in developing exception criteria for the nuclides of Table 2 is to determine the fissile-to-nonfissile ratio that is appropriate. Given the A1 and A2 values of most of these nuclides, it is likely that they will be placed in packages that meet the standards of para 646. Thus, for initial consideration, it is proposed to include these additional nuclides within the regulatory text appropriate for the 1:200 ratio with packages that satisfy tests for normal conditions of transport (e.g., satisfy para 646).

The impact of modifying the fissile exception criteria is difficult to evaluate. Although mass ratios are conceptually easier to obtain, this is a major departure from current practice. However, the change provides substantial value in a more rigorous and defensible safety position that removes hard-to-regulate and hard-to-define terminologies and conditions. The impact of the excluding (essentially) graphite from the 1 wt% enrichment exception may be significant and requires further study. However, there is substantial confusion about what defines "lattice" and "essentially homogeneous" as used in the current exception. Work may be needed to justify allowance of a higher quantity of graphite in order to remove the "lattice" restriction.

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Further discussion justifying the need for changes to the exception criteria can be found in Ref. 1.

REFERNCES

1. C. V. Parks, C. M. Hopper, and J. Lichtenwalter, *Assessment and Recommendations for Fissile-Material Packaging Exemptions and General Licenses Within 10 CFR Part 71*, NUREG/CR-5342 (ORNL/TM-13607), July 1998.

2. J. Anno and G. Sert, *French Participation at ANS/ANSI 8/15 Working Group Updating Criticality Data on ^{237}Np Criticality and Transportation Proposals*, Presented in the Proceedings of the International Conference on Nuclear Criticality ICNC'99, Vol. I, p. 447 (September 1999).

3. H. Okuno and T. Sakai, "Criticality Safety Studies Related to Advisory Material for the IAEA Regulations," pp. 217–223 in Proceedings of PATRAM 98 The International Conference on the Packaging and Transportation of Radioactive Materials, Vol. 1, May 10–15, 1998, Paris, France.
4. N. J. Barton and C. K. Wilson, "Review of Fissile Exception Criteria in IAEA Regulations," pp. 9–15 in Proceedings of the 5th International Conference on Nuclear Criticality Safety, Vol II, September 17–21, 1995.

5. M. K. Shaeffer et al., *Recent Developments in Fissile Material Exemptions for Shipping Packages*, pp. 214–218 in Proceedings of the Criticality Safety Challenges in the Next Decade, American Nuclear Society, Chelan, Wash., September 7–11, 1997.

6. D. Mennerdahl, *Fissile Package Design Basis: Regulations or Analysis?*, pp. 449–456 in Proceedings of The 11th International Conference on the Packaging and Transportation of Radioactive Materials (PATRAM'95), Las Vegas, Nev. (1996).

Number of Continuation Sheets Used: 3

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Continuation Sheet No:
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Table 1 Proposed fissile-except mass ratios to replace current criteria of para 672(a)

Package limit for combination of ^{233}U, ^{235}U, and ^{239}Pu (X)	Mass of nonfissile material per gram of ^{233}U, ^{235}U, and ^{239}Pu (Y)
15 g	200
350 g	2000
350 g	200[a]

[a]Packaging required to satisfy standards of para 646.

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Proposed Change Submitted by: (1) **Name: C. V. Parks** **Address: PO Box 2008,** **Oak Ridge National Laboratory** **Oak Ridge, TN 37831-6370** **Telephone: 865-574-5280** **Telefax: 865-576-3513** **E-mail: parkscv@ornl.gov**	**Proposal Reference Number (2)** *(to be assigned by the IAEA Secretariat)*

Table 2 Mass limits for excepting radionuclides from the requirements for packages containing fissile material per 672(b)

Radionuclide, i	Exception mass limit in grams, M_i
Protoactinium-231	1600[b]
uranium-232	23[b]
uranium-233	15[a]
uranium-234	720[b]
uranium-235	15[a]
neptunium-235	0.0008[d]
neptunium-236	0.04
neptunium-237	400[a]
plutonium-236	50[b]
plutonium-238	60[a]
plutonium-239	15[a]
plutonium-240	300[a]
plutonium-241	4[a]
plutonium-242	80[a]
plutonium-244	1.5[d]
americium-241	320[a]
americium-242m	0.26[a]
americium-243	500[a]
curium-242	0.00000008[d]
curium-243	1.8[a]
curium-244	60[a]
curium-245	0.6[a]
curium-246	100[c]
curium-247	18[a]
curium-248	0.002[d]
berkelium-247	0.00002[d]
berkelium-249	0.000005[d]
californium-248	0.0000001[d]
californium-249	0.2[a]
californium-250	36[b]
californium-251	0.1[a]
californium-252	37[b]
californium-254	3×10^{-9}[d]

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[a]Limits based on 1/50 fraction of subcritical limits from ANSI/ANS-8.15 (1981).
[b]Limits based on 1/100 fraction of critical estimates from TRANSSAC-III WP 22 (Anno, Bagarry) April 1998.
[c]Limits based on 1/200 fraction of critical estimates from TRANSSAC-III WP 22 (Anno, Bagarry) April 1998.
[d]Trace quantity fissile exempt limit set due to lack of data (Excepted package limits - $0.001A_2$).