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OVERVIEW OF IAEA MODIFICATIONS FOR EXCEPTIONS TO THE REQUIREMENTS FOR TRANSPORT OF FISSILE MATERIAL

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ABSTRACT

In 2012 the International Atomic Energy Agency (IAEA) published a revision to the IAEA Regulations for the Safe Transport of Radioactive Material [1]. This 2012 Edition of the Regulations, referred to as Specific Safety Requirement No. 6 (SSR-6), includes major revisions to the provisions that address the requirements for transport of fissile material. Identified safety concerns associated with provisions that allowed exceptions to the use of packages designed for transport of fissile material, as provided in the 1996 Edition of the Regulations [2] (and promulgated with minor changes thereafter), were the prime motivation for revisions that were under consideration by the IAEA and its Member States for over a decade. The revisions adopted by the IAEA in the 2012 Edition of the Regulations address the identified safety concerns by providing a graded approach with consistent assurance of criticality safety. Where possible, practical needs identified by industry as beneficial to efficiency and clarity in applying the regulations were addressed.

INTRODUCTION

The IAEA Regulations for Safe Transport of Radioactive Material have been in place for 50 years and have been consistently reviewed by Member State experts and revised by the IAEA as needed to address safety concerns. The Regulations have historically provided requirements for package design, package performance, and operations based, in part, on the type of radioactive material that would be included in the package. Fissile material is one classification of radioactive material, and Regulations have evolved [3] to provide specific requirements for packages certified for transport of fissile material.

With the 2012 Edition of the Regulations (hereafter referred to as the 2012 Edition), the IAEA has significantly revised the approach used to allow exceptions for transport of fissile material in packages other than those certified for such transport. Prior to the 1996 Edition of the Regulations (hereafter referred to as the 1996 Edition), the criteria for such exceptions indicated

that criticality safety would be ensured regardless of packaging and failed to control accumulations of packages or material. The adequacy of many of these criteria was challenged, particularly in regards to the unintended accumulation of material and assurance of continued adherence to the criterion under accident conditions of transport. Thus, with the introduction of the 1996 Edition, many of the exception criteria were constrained by an imposed limit on the total mass of fissile material that could be shipped in a consignment.

Rather than resolve the discussion on exceptions for transport of fissile material, the 1996 Edition seemed to introduce additional concerns. For example, imposing a mass limit on a consignment provides insufficient control for criticality safety since the approach did not prevent consignment accumulation or unintended mixing of multiple consignments during shipment. However, the imposition of a mass limit per consignment further highlighted concerns with industry's growing need for transport of what was perceived by many to be very low-risk fissile material (e.g., large volumes of waste products with very low concentrations of fissile nuclides). By 2009 the IAEA had accumulated over 100 proposals related to the development of improved criteria for exceptions to the transport of fissile material in certified packages [4].

Through extensive efforts on the part of many individuals and organizations representing many of the IAEA Member States, the 2012 Edition provides a significant modification to the approach implemented for exceptions to the requirements for transport of fissile material. Throughout the process, there was an effort to (1) ensure identified safety concerns were addressed, (2) strive for consistency in terms of the margin of safety provided with each exception, (3) seek industry input to understand the types of material perceived to be of sufficiently low risk to warrant an exception, and (4) minimize the impact of the transition from the 2009 Edition of the Regulations (hereafter referred to as the 2009 Edition) [5]. This paper provides a simplified overview of the requirements for packages certified for transport of fissile material and the categories of exceptions to these requirements that are allowed in the 2012 Edition, along with the bases for revising the 2009 Edition.

PACKAGES CERTIFIED FOR TRANSPORT OF FISSILE MATERIAL

Before discussing exceptions, it might be beneficial to quickly review the "standard" from which exceptions are allowed. Package designs certified for transport of fissile material must adhere to the requirements and provisions specified in paras. 673 and 676–686 of the 2012 Edition. These paragraphs specify the expectations that an applicant must demonstrate relative to subcriticality of individual packages and arrays of packages under normal conditions of transport (NCT) and accident conditions of transport (ACT). Packaging tests representative of NCT and ACT are referenced, and requirements that must be met and conditions considered are specified in these paragraphs. Key requirements are as follows.

- "5 times N packages shall be subcritical for the arrangement and package conditions that provide the maximum neutron multiplication" (k-eff), consistent with NCT, and
- "2 times N packages shall be subcritical for the arrangement and package conditions that provide the maximum neutron multiplication," under ACT.

For each requirement, the "package conditions" must assume a range of specified contents for the package, and unknown values associated with the contents must be assumed such that the highest value of k-eff is obtained. Based on an assessment of these key requirements, the Criticality Safety Index (CSI) for each package is established to be

$$CSI = 50/N, \qquad \text{(Equation 1)}$$

where N is the smaller of the two values determined from the subcriticality assessments for NCT and ACT.

The CSI value is included in the package certificate issued by a competent authority and is used to provide a means of control over the accumulation of packages during transport. For example, if N = 5 for the purpose of determining the CSI per Equation (1), then CSI = 10 for the package. Per para. 525 of the 2012 Edition, the CSI for a conveyance of packages must be limited to 50 unless the package is loaded, transported, and unloaded by a single consignor under exclusive use, in which case a CSI up to 100 is allowed subject to competent authority approval (see Table 11 of the 2012 Edition).

Finally, packages certified by a competent authority will include a letter "F" as part of the type code on the certificate and must be shipped with a label that identifies the contents as having been classified as "FISSILE," consistent with shipping names and descriptions established by the United Nations (see Table 1 of the 2012 Edition). The label also must include the CSI value (see Fig. 5 of the 2012 Edition) and be consistent with the certificate issued by the competent authority.

TRANSPORT OF FISSILE MATERIAL IN PACKAGES NOT CERTIFIED BY A COMPETENT AUTHORITY

A key section of the 2012 Edition is entitled "REQUIREMENTS FOR PACKAGES CONTAINING FISSILE MATERIAL" and encompasses paras. 673–686. Paragraph 673 (a) provides a general expectation that all fissile material be transported so as to maintain subcriticality and (b) states that exceptions to requirements are provided in paras. 417, 674, and 675. The exceptions of paras. 674–675 are distinctly different from those of para. 417 in that fissile material transported consistent with paras. 674–675 is classified as "FISSILE" and subject to CSI control, while fissile material transported per the exceptions of para. 417 is not classified as "FISSILE" and is exempt from CSI control. For reference purposes, the exceptions provided in paras. 417, 570 (referenced by 417) and paras. 674–675 of the 2012 Edition are provided in the Appendix.

CSI Control with Exception from Competent Authority-Approved Packages

Paragraph 674 provides three provisions for consignors to transport fissile material and be excepted from the requirement to use packages that have been certified by a competent authority. These exceptions are permissible and safe based on the fact that the respective mass of fissile material is limited to ensure that 5N packages are subcritical under NCT and 2N packages are subcritical under ACT. The mass is limited by use of CSI control—implying that each package must be classified as "FISSILE" and labeled with the proper CSI to keep accumulation below the limiting safe mass values.

Determination of the CSI

For a package that has not been demonstrated to meet NCT, criticality safety must be ensured under optimal conditions for the fissile material that might be present in 5N packages; that is, the package integrity cannot be credited to survive NCT. To obtain a formula for the CSI, consider a mass of U-235 in a package such that

$$5Nz < Z\,, \qquad \text{(Equation 2)}$$

where z equals the mass of U-235 per package and Z is the limiting U-235 mass below which subcriticality in transport is ensured. Then substitution of Equation (2) into Equation (1) yields the following:

$$CSI = 50 \times 5 (z/Z) . \quad \text{(Equation 3)}$$

A further constraint imposed by the Member State experts was to limit the CSI per package to 10, thus providing consistency with the maximum radiological Transport Index (TI) allowed per package and ensuring dilution of the fissile material among various packages (i.e., the maximum mass per package is 1/25 of the safe subcritical mass, Z).

For multiple fissile nuclides and using a fractional equivalency for the reactivity, one can show that Equation (3) can be expanded to produce the following formula:

$$CSI = 50 \times 5 (z/Z + y/Y) , \quad \text{(Equation 4)}$$

where y is the mass per package of other fissile nuclides and Y is the safe subcritical mass for other fissile nuclides (besides U-235).

For a package that has been demonstrated to meet NCT but has not been certified to meet ACT, the package cannot be credited for ACT and 2N packages under optimum conditions must have a safe subcritical mass. The corollary equation to Equation (4) becomes

$$CSI = 50 \times 2 (z/Z + y/Y) . \quad \text{(Equation 5)}$$

To restrict the maximum CSI of Equation (5) to 10, the mass of fissile nuclides per package can never be more than 1/10 of the safe subcritical mass under optimum conditions.

Determination of Safe Subcritical Mass

Equations (4) and (5) provide an approach for shipping limited quantities of fissile mass with accumulation control that is consistent with the method used for packages certified for transport of fissile material. From here the challenge facing the Member State experts was to determine consensus values for Z and Y.

Reference 6 discusses the general approach and summarizes the analysis methodology used to obtain limiting values for the mass of fissile nuclides that the experts agreed would provide an adequate safe margin of subcriticality. The minimum mass of fissile nuclides needed for criticality will be a mixture of fissile nuclides in hydrogen. (As the lightest element, hydrogen is optimum at slowing fission neutrons from their initial high energy to thermal energies where the probability for subsequent fission interaction with a fissile nuclide is highest.) Water is the common material to assume for optimal (i.e., to minimize critical mass) mixing of fissile nuclides, but substances like polyethylene, which can be present as a packaging material, have a higher density of hydrogen than water and can produce a somewhat lower critical mass. It follows then that fissile nuclides mixed with water and separately with polyethylene provide the two systems that need to be assessed to determine the fissile nuclide mass values below which one can ascertain that a 5N (for NCT) or 2N (for ACT) group of packages will be safe.

The criticality safety experts from numerous Member States worked to obtain consensus values for the minimum critical mass and the mass determined to be subcritical for uranium with U-235 enrichments between 1.5 wt% and 100 wt% and for Pu-239 (acting as conservative surrogate for "all other fissile nuclides"). Literature references, consensus standards, and independent analyses by many of the experts were used to obtain candidate values of Z and Y for both polyethylene- and water-moderated systems (surrounded by 20 cm of water reflection) [6]. The potential complexity (and confusion) of having different values based on the presence of polyethylene or water led to further deliberations that yielded the one set of values for Z reported in Table 13 of the 2012 Edition and reported here in Table 1 along with the value for Y. These Z and Y values were selected to be approximately 15–20% lower than the consensus set of limiting safe subcritical values for water-moderated systems.

Table 1. Values of safe subcritical mass for calculation of CSI

Enrichment[a]	Mass (g)
Uranium enriched up to 1.5%, U (1.5)	2200
Uranium enriched up to 5%, U (5)	850
Uranium enriched up to 10%, U (10)	660
Uranium enriched up to 20%, U (20)	580
Uranium enriched up to 100%, U (100)	450
Other fissile nuclides	280

[a] If a *package* contains *uranium* with varying enrichments of uranium-235, then the value corresponding to the highest enrichment shall be used for Z.

The missing step in the discussion above is confirmation that the use of Equation (5) together with the selected Z and Y values not only ensured safety for 2N packages under ACT but also criticality safety for 5N packages under NCT. Again, Reference 6 provides a discussion of the extensive set of nearly 75,000 array configurations (with various content arrangements, packaging materials, and non-fissile media) that demonstrated that all conceived 5N arrays of packages under NCT would be subcritical if constrained to the allowed mass per package of Equation (5) for a CSI = 10. Heterogeneous and homogeneous arrangements were considered for the low-enriched uranium systems since the uranium critical mass for low-enriched heterogeneous systems (e.g., lattices or units of uranium) can be lower than that for homogeneous mixtures. For simplicity, packages were assumed to have no external dimension less than 30 cm in order to properly assess optimum moderation for low-enriched uranium systems [6].

Hopefully, the above discussion provides some clarification regarding the exception provisions of paras. 674(a) and 674(b) of the 2012 Edition, which allow limited quantities of fissile nuclides to be transported based on the CSI definitions of Equations (4) and (5), respectively, and the assumptions described (e.g., regarding package integrity). Considering pure U-235, Equation (4) and Z = 450 from Table 1 indicate that a maximum (CSI = 10) of 18 g per package could be transported under para. 674(a). The provision of para. 674(b) using Equation (5) would allow 45 g of U-235 per package; however, the smallest external dimension of the package must be at least 30 cm. To provide a provision for packages that meet NCT similar to para. 674(b) but have

external dimensions down to 10 cm, para. 674(c) was included. Safety under NCT for the provision of 674(c) was based on lessons learned from the results of the 75,000 analyses noted above and is ensured by limiting the mass per package to 15 g and always using the Z = 450 value in the CSI evaluation per Equation (5). The purpose of this added provision was to ascertain that previously loaded packages (using the 15-g exception of previous versions of the Regulations) that meet NCT, but have external dimensions less than 30 cm, could be accommodated.

For each of the provisions (a)–(c) of para. 674, the quantities of beryllium, deuterium, and allotropic forms of carbon are restricted to the mass of fissile nuclides in the package. Per 674(d) of the 2012 Edition, some allowances are provided for relaxing this restriction based on demonstrated need and safety assessments performed by industry and reviewed by the Member State experts.

Special Case Exception Provision for Plutonium

The Regulations have historically included a special exception provision for plutonium whereby up to 1 kg of plutonium did not have to be shipped in a package certified for transport of fissile material provided not more than 20% of the plutonium mass consisted of fissile nuclides (e.g., Pu-239 and Pu-241). This historic exception has been included in the 2012 Edition as para. 675 but with the new requirement that the package be classified as "FISSILE" and a CSI be provided on the package label to ensure accumulation control. Shipment of these quantities of plutonium would require a Type B certificate, indicating the package would meet NCT. Thus, the CSI formula for this exception is

$$\text{CSI} = 50 \times 2 \text{ (grams of plutonium/1000)} . \quad \text{(Equation 6)}$$

An allowance for uranium up to 1% of the plutonium mass is provided.

Exception from Classification as FISSILE and CSI Control

Historically, exceptions regarding the transport of fissile material in packages approved by a competent authority to contain fissile material were assumed to be safe based on the inherent characteristics included in the IAEA provisions. These exceptions were not classified as "FISSILE" and there was no accumulation control other than a limit placed on each consignment. Given that there was no CSI control over accumulation, the provisions that limited the mass per consignment (see para. 417a of the 2009 Edition) were challenged and were subsequently removed in the new 2012 Edition, and as discussed above, the special provision for plutonium with no more than 20% fissile nuclides was modified to require CSI control.

Two historic exceptions not included in the 2012 Edition because of insufficient control for criticality safety, were of significant concern to industry. These two exceptions were for shipment of up to 15 g of fissile nuclides in a package and shipment of fissile material provided there was no more than 5 g of fissile nuclides in any 10 L volume of material. Although safe in a vast majority of situations, accumulation of multiple packages with up to 15 g per package could in some cases present a challenge to criticality safety. Depending on the material media and the potential for redistribution, the limit of 5 g of fissile in any 10 L volume created the possibility of configurations that could approach criticality [7,8]. Industry identified a continuing need for the shipment of both very small quantities and larger masses of fissile material in forms judged to pose a very low risk for potential criticality. Competent authorities concurred with these needs, and the Member State experts sought to address the issue while ensuring that criticality safety

was maintained in a manner consistent with that of packages certified to transport fissile material.

Small Quantities of Fissile Material

Extensive discussions and thoughtful exercises were conducted by the Member State experts who sought to determine an exception limit for very small masses of fissile nuclides based on some equivalency with CSI-controlled packages. In a strict quantitative sense, such an exception was not possible; rather, risk-based judgment on unintended errors or inadvertent mixing during shipment had to be carefully considered in determining the value of the very small quantity of fissile material per package that would be excepted from CSI control. Values of less than a gram to several grams were proposed, and industry input was sought to best understand the types of such shipments that were currently in commerce. The key identified need was for shipment of samples to support various activities including environmental sampling, research, and testing.

The approach agreed to by the Member State experts was to use the same general approach of the 2009 Edition—a limit on the quantity of fissile nuclides per package provided in para. 417 combined with a mass limit on the consignment provided for in para. 570. However, compared to the 2009 Edition, the 2012 Edition [see para. 417(d) and para. 570(d)] provides a significant restriction on both the allowed mass per package (from 15 g to 2 g) and the mass per consignment (from 400/250 g for uranium/plutonium to a uniform 15 g for all fissile nuclides). Therefore, it would take 2 g of U-235 per package, 7 packages per consignment, and an accumulation of 30 consignments before the 450 g safe subcritical mass of Table 1 is even approached. The low probability and consequential risk associated with such an accumulation was judged, in comparison to the 5N/2N criteria for controlled packages, to provide a sufficient margin of safety for transport. Plutonium greater than about 1 g would have to be shipped in a certified Type B package, mitigating concerns about the lower number of consignments (6) needed before approaching the 280 g safe subcritical limit of Table 1 for plutonium.

One area of concern expressed early by industry was the long-established commercial practice of shipping sample bottles with UF_6 having uranium enrichments less than 5 wt% U-235. Using a ratio of the values for U (5) and U (100) in Table 1, it was judged that the excepted fissile mass could be increased to 3.5 g per package [see para. 417(c) of the 2012 Edition]. For this situation, the mass per consignment was raised to 45 g per para. 570(c) of the 2012 Edition. At 3.5 g per package, it would take 12 packages per consignment and 20 consignments to approach the 850 g safe subcritical mass for U (5) identified in Table 1.

Unpackaged Material

Provisions for unpackaged material in the 2009 Edition limited the quantity of fissile nuclides to the excepted package limit of 15 g and indicated this value should also be the consignment limit. The approach for unpackaged material was modified with the 2012 Edition [see para. 417(e) and 570(e)] in that unpackaged fissile material was seen as requiring exclusive-use shipment approval; however, the allowed fissile nuclide mass was raised to 45 g.

Exception Based on Fissile Material Characteristics

Compared to the 2009 Edition, the 2012 Edition carries forward only two exceptions where neither CSI control nor use of competent-authority-approved packages is required These exceptions are for homogeneous systems of uranium enriched to less than 1wt% U-235 [para. 417(a) of the 2012 Edition] and uranyl nitrate solutions enriched to less than 2 wt% U-235 [para. 417(b) of the 2012 Edition]. After discussions for nearly a decade, the Member State

experts could not reach consensus on other general characteristics of fissile material that could be excepted from CSI control. The approach most discussed was one proposed by the United States, where a ratio of nonfissile-to-fissile solid mass is used to provide mass dilutions that are judged sufficient for exception by the US competent [9]. In light of concerns raised about a mass ratio exception and concerns from industry that such an approach might not be suitable for all perceived needs for shipping low-risk material (e.g., low-reactivity material such as process waste), it was decided that the best option was to provide flexibility, per para. 417(f), so that each Member State could approve fissile material for exception to classification as "FISSILE". Such material would be subject to multilateral approval (see para. 805 of the 2012 Edition) and subject to the requirements of para. 606 of the 2012 Edition (e.g., ensured subcriticality under NCT and ACT conditions).

Reference 8 provides a very good perspective on the challenges and uncertainties that must be faced by industry and the competent authorities in order to issue a certificate for fissile material to be excepted from classification as "FISSILE". Guidance material has been prepared in order to help clarify what applicants need to consider in preparing their safety case. However, implementation of this provision will involve exploring unchartered territory for industry and competent authorities until more experience is gained and some initial certificates are issued. Industry in the UK has indicated interest in pursuing such a certificate, and reference 10 provides some examples of potential waste streams that might be good candidates for consideration. The UK competent authority has shown a willingness to carefully evaluate a thoroughly prepared application.

EXCEPTION FROM DEFINITION AS FISSILE MATERIAL

The 2009 and 2012 Editions properly define fissile material as material containing fissile nuclides, which are defined as U-233, U-235, Pu-239, and Pu-241. Excluded from the definition of fissile material is natural uranium or depleted uranium that is unirradiated or that has been depleted in thermal reactors only. In the 2012 Edition, the definition was expanded to exclude material with less than 0.25 g of fissile nuclides. This exclusion was added in recognition that many materials have trace quantities of fissile nuclides and that the intent of the Regulations is not to have such materials governed under the requirements set forth for fissile material. Another clarifying point provided with the 2012 Edition is that the exclusions cited are valid only if there is no other material with fissile nuclides in the package, or in the consignment if shipped unpackaged. This last clarification was added recognizing that some criticality safety assessments for packages containing fissile material had not considered the potential impact the presence of the fissile nuclides within natural or depleted uranium in the contents or packaging design (e.g., depleted uranium as shielding) could have on reactivity.

CONCLUSIONS

The 2012 Edition of the IAEA Regulations addresses long-standing safety concerns regarding exceptions related to transport of fissile material while providing additional flexibility for industry and Member States to address the transport of limited quantities of fissile material and low-risk (e.g., low-reactivity) fissile material. The Regulations now have four clear categories for the transport of fissile material: packages certified to contain fissile material, exceptions from use of certified packages, exceptions from "FISSILE" classification (or exception from CSI control), and exceptions (or exclusions) by definition. Hopefully, the historically used terminology "fissile excepted" will slowly be replaced in vocabulary and texts with words that better define and clarify the categories of exceptions noted above.

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APPENDIX

(Extracted from Reference 1)

417. *Fissile* material and *packages* containing *fissile material* shall be classified under the relevant entry as "FISSILE", in accordance with Table 1 unless excepted by one of the provisions of subparagraphs (a)–(f) of this paragraph and transported subject to the requirements of para. 570. All provisions apply only to material in *packages* that meets the requirements of para. 636, unless unpackaged material is specifically allowed in the provision:

(a) *Uranium* enriched in uranium-235 to a maximum of 1% by mass, and with a total plutonium and uranium-233 content not exceeding 1% of the mass of uranium-235, provided that the *fissile nuclides* are distributed essentially homogeneously throughout the material. In addition, if uranium-235 is present in metallic, oxide or carbide forms, it shall not form a lattice arrangement.
(b) Liquid solutions of uranyl nitrate enriched in uranium-235 to a maximum of 2% by mass, with a 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.
(c) *Uranium* with a maximum *uranium* enrichment of 5% by mass of uranium-235 provided:
    (i) There is no more than 3.5 g of uranium-235 per *package*.
    (ii) The total plutonium and uranium-233 content does not exceed 1% of the mass of uranium-235 per *package*.
    (iii) Transport of the *package* is subject to the *consignment* limit provided in para. 570(c).
(d) *Fissile nuclides* with a total mass not greater than 2.0 per *package*, provided the *package* is transported subject to the *consignment* limit provided in para. 570(d).
(e) *Fissile nuclides* with a total mass not greater than 45 g, either packaged or unpackaged, subject to the limits provided in para. 570(e).
(f) A fissile material that meets the requirements of paras 570(b), 606 and 802.

570. *Fissile material* meeting one of the provisions (a)–(f) of para. 417 shall meet the following requirements:

(a) Only one of the provisions (a)–(f) of para.417 is allowed per *consignment*.
(b) Only one approved *fissile material* in *packages* classified in accordance with para. 417(f) is allowed per *consignment* unless multiple materials are authorized in the certificate of *approval*.
(c) *Fissile material* in *packages* classified in accordance with para. 417(c) shall be transported in a *consignment* with no more than 45 g of *fissile nuclides*.
(d) *Fissile material* in *packages* classified in accordance with para. 417(d) shall be transported in a *consignment* with no more than 15 g of *fissile nuclides*.
(e) Unpackaged or packaged *fissile material* classified in accordance with para. 417(e) shall be transported under *exclusive use* on a *conveyance* with no more than 45 g of *fissile nuclides*.

674. *Packages* containing *fissile material* that meets the requirements of para. 674(d) and one of the provisions of para. 674(a)–(c) are expected from the requirements of paras 676–686.

(a) *Packages* containing *fissile material* in any form provided that:
    (i) The smallest external dimension of the *package* is not less than 10 cm.
    (ii) The *CSI* of the *package* is calculated using the following formula:

CSI = 50 × 5 × {[mass of uranium-235 in *package* (g)]/Z
+ [mass of other *fissile nuclides*[1] in package (g)]/280}
where the values of Z are taken from Table 13.

(iii) The *CSI* of any package does not exceed 10.

(b) *Packages* containing *fissile material* in any form provided that:

(i) The smallest external dimension of the *package* is not less than 30 cm.

(ii) The *package*, after being subjected to the tests specified in paras 719–724:
- Retains its *fissile* material contents;
- Preserves the minimum overall outside dimensions of the *package* to at least 30 cm;
- Prevents the entry of a 10 cm cube.

(iii) The *CSI* of the *package* is calculated using the following formula:
CSI = 50 × 2 × {[mass of uranium-235 in *package* (g)]/Z
+ [mass of other *fissile nuclides*[1] in package (g)]/280}
where the values of Z are taken from Table 13.

(iv) The *CSI* of any *package* does not exceed 10.

Table 13. Values of Z for calculation of CSI in accordance with para. 674

Enrichment[a]	Z
Uranium enriched up to 1.5%	2200
Uranium enriched up to 5%	850
Uranium enriched up to 10%	660
Uranium enriched up to 20%	580
Uranium enriched up to 100%	450

[a] If a *package* contains *uranium* with varying enrichments of uranium-235, then the value corresponding to the highest enrichment shall be used for Z.

(c) *Packages* containing *fissile material* in any form provided that:

(i) The smallest external dimension of the *package* is not less than 10 cm.

(ii) The *package*, after being subjected to the tests specified in paras 719–724:
- Retains its *fissile* material contents;
- Preserves the minimum overall outside dimensions of the *package* to at least 10 cm;
- Prevents the entry of a 10 cm cube.

(iii) The *CSI* of the *package* is calculated using the following formula:
CSI = 50 × 2 × {[mass of uranium-235 in *package* (g)]/450
+ [mass of other *fissile nuclides*[1] in package (g)]/280}.

(iv) The maximum mass of *fissile nuclides* in any *package* does not exceed 15 g.

[1] Plutonium may be of any isotopic composition provided that the amount of plutonium-241 is less than that of plutonium-240 in the *package*.

(d) The total mass of beryllium, hydrogenous material enriched in deuterium, graphite and other allotropic forms of carbon in an individual *package* shall not be greater than the mass of *fissile nuclides* in the *package* except where their total concentration does not exceed 1 g in any 1000 g of material. Beryllium incorporated in copper alloys up to 4% by weight of the alloy does not need to be considered.

675. *Packages* containing not more than 1000 g of plutonium are expected from the application of paras 676–686 provided that:

(a) Not more than 20% of the plutonium by mass is *fissile nuclides*.
(b) The *CSI* of the *package* is calculated using the following formula:
CSI = 50 × 2 [mass of plutonium (g)/1000].
(c) If *uranium* is present with the plutonium, the mass of *uranium* shall be no more than 1% of the mass of the plutonium.