IRSN
INSTITUT
DE RADIOPROTECTION
ET DE SÛRETÉ NUCLÉAIRE

Enhancing safety

CONSIDERING CH_2 MODERATION FOR EXCEPTED FISSILE MATERIAL

presented by **G. SERT**
for
I. ORTIZ DE ECHEVARRIA, L. JUTIER and **S. EVO** (IRSN, FRANCE)

Looking to the future
PATRAM 2010

3rd – 8th October, 2010 – London, UK

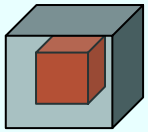
OVERVIEW

1. **Exceptions from the requirements for packages containing fissile material**
   - Regulations for the Safe Transport of Radioactive Material (2009 Edition)
   - Proposed new fissile exceptions
2. **Remaining issues with the new provisions**
   - Moderation issue: defined limits vs. presence of high density moderation
   - Examples
   - Comparison to requirements for approved package designs
   - Margins

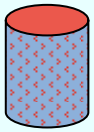
Exceptions from the requirements for packages containing fissile material

Regulations for the Safe Transport of Radioactive Material (2009 Edition)

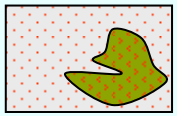
a)



M(fissile nuclides) / package < 15g



Restriction on fissile concentration for homogenous media



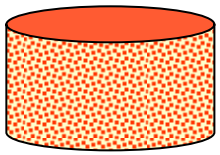
< 5g of fissile nuclides in any 10l

Consignment mass limit of fissile nuclides:

M(U-235) / X + M(Other FN) / Y < 1

Fissile Nuclide (FN)	FN mass mixed with substances having an average H density ≤ water	FN mass mixed with substances having an average H density > water
U-235 (x)	400 g	290 g
Other FN (Y)	250 g	180 g

b) & c)

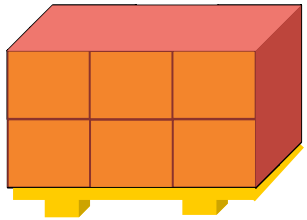


Infinite homogenous mixtures or solutions of uranium with very low enrichment in U-235

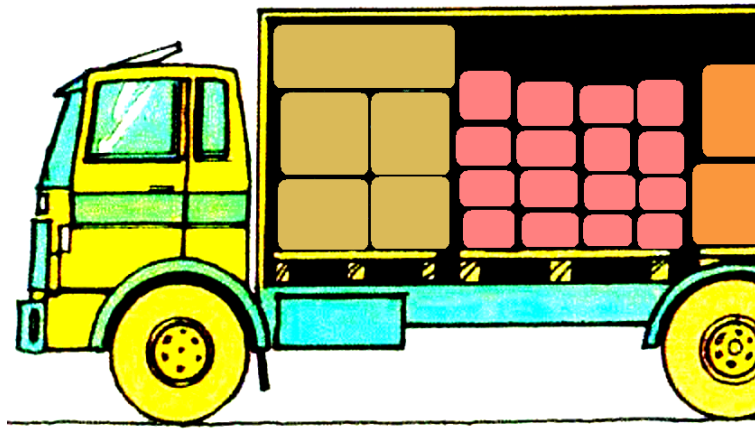
d)

M(Pu) ≤ 1kg (exclusive use)
Pu containing not more than 20% by weight of Pu-239 and Pu-241

The need to review regulations for fissile excepted packages



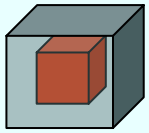
1 prepared consignment of fissile excepted packages



conveyance carrying several consignments

- Transport of coincident multiple consignments of fissile excepted packages on a single conveyance not prevented
- New shipment controls have been proposed to cover more than the single control of the fissile mass per consignment

Exceptions from the requirements for packages containing fissile material



M(fissile nuclides)/package < 15g

Consignment mass limit of fissile nuclides:

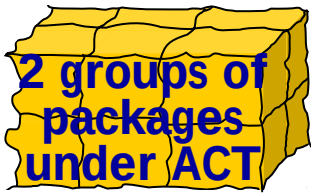
$M(U\text{-}235)/X + M(\text{other FN})/Y < 1$

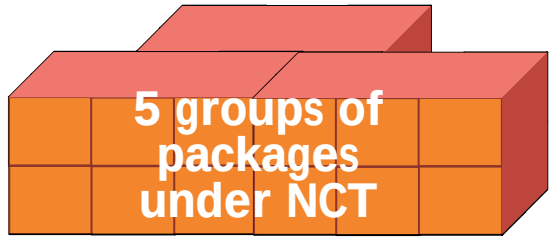
Fissile Nuclide (FN)	FN mass mixed with substances having an average H density > water	FN mass mixed with substances having an average H density ≤ water
U-235 (x)	290 g	400 g
Other FN (Y)	180 g	250 g

Regulations for the Safe Transport of Radioactive Material (2009 Edition)

Draft Safety Requirement DS437

It has been proposed to revise this exception to strengthen these mass limits by requiring the use of a Criticality Safety Index (CSI) → To be consistent with the safety level required for approved package designs:





SUBCRITICAL

Draft Safety Requirement DS437

To introduce CSI for these packages ⇒ two types of situations:
- packages with mechanical and thermal qualifications in NCT (§ 672 b & c)
- packages without mechanical or thermal qualifications (§ 672 a)

Paragraph 672 a

CSI=50x5x[M(U-235 in package (g))/Z+M(Other FN in package (g))/Y]

Paragraph 672 b

CSI=50x2x[M(U-235 in package (g))/Z+M(Other FN in package (g))/Y]

To ensure fissile material distribution throughout the consignment (several packages) ⇒ CSI package ≤ 10

CSIpackage ≤ 10

- If CSI consignment = 50 then fissile material is divided out in at least 5 packages

Fissile Nuclide (FN)	U enrichment in mass percent of U-235 not exceeding	General Use	Limited use
U-235 (Z)	1.5	2000	2400
	5	770	1000
	10	550	810
	20	470	700
	100	360	540
Other FN (Y)	Not applicable	230	350

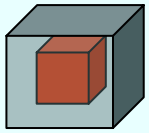
Mass limits of U as a function of U-235 enrichment ⇒ more flexibility

To make transition

Paragraph 672 c : 15 g of fissile nuclides/package
- **smallest external dimension of package ≥ 10 cm after NCT tests**
- **consignment mass limit = paragraph 672 b**

Moderator materials presents in packages are taken into account :
- "general use" (polyethylene authorised)
- "limited use"

Exceptions from the requirements for packages containing fissile material



M(fissile nuclides)/package < 15g

Consignment mass limit of fissile nuclides:

M(U-235)/X + M(Other FN)/Y < 1

Fissile Nuclide (FN)	FN mass mixed with substances having an average H density > water	FN mass mixed with substances having an average H density ≤ water
U-235 (x)	290 g	400 g
Other FN (Y)	180 g	250 g

Regulations for the Safe Transport of Radioactive Material (2009 Edition)

Draft Safety Requirement DS437

Fissile nuclide (FN)	U enrichment in mass percent of U-235 not exceeding	Maximal mass per package CSI = 10 (No NCT test)	
		General use	Limited use
U-235	1.5	80 g	96 g
	5	30.8 g	40 g
	10	22 g	32.4 g
	20	18.8 g	28 g
	100	14.4 g	21.6 g
Other FN	Not applicable	9.2 g	14 g

Paragraph 672 a

CSI=50x5x[M(U-235 in package (g))/Z+M(Other FN in package (g))/Y]

Paragraph 672 b

CSI=50x2x[M(U-235 in package (g))/Z+M(Other FN in package (g))/Y]

Fissile Nuclide (FN)	U enrichment in mass percent of U-235 not exceeding	General Use	Limited use
U-235 (Z)	1.5	2000	2400
	5	770	1000
	10	550	810
	20	470	700
	100	360	540
Other FN (Y)	Not applicable	230	350

Points to be discussed:

- Demonstration of resistance of the packages to NCT tests validated only by the consignor
  - ↳ weak point for paragraphs 672(b)-(c) to obtain an equivalent safety level than the one for certified packages

- The presence of moderator materials with a hydrogen density greater than water and the way they are taken into account

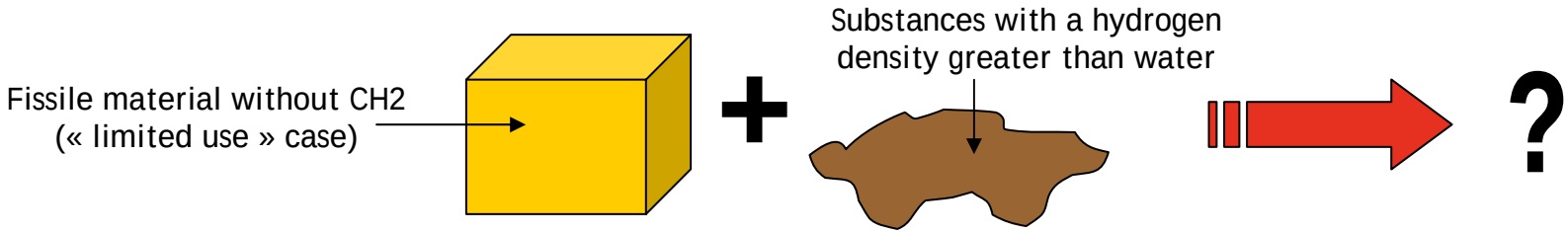
THIS PRESENTATION

Calculation of CSI in case of restrictions

General use and limited use:

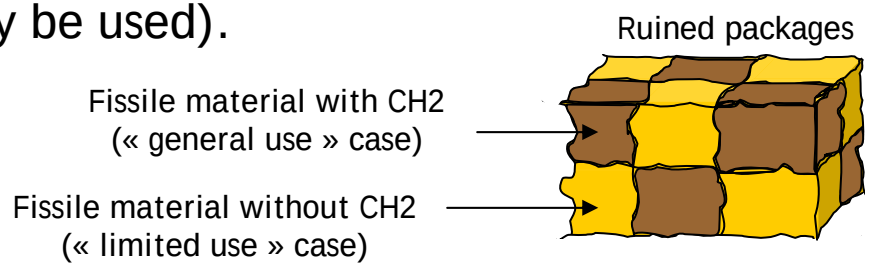
"Limited use" case for the calculation of CSI ⇒ Packages containing materials with a hydrogen density less than water

↳ Lower mass limits must be considered if materials with a hydrogen density greater than water are present in packages



Scenario number 1:

A consignment can be constituted by packages coming from "general use" case and "limited use" case, but since packages do not necessarily survive the ACT (drop tests, fire test and water immersion test) or even NCT, scenarios of ruined packages cannot be excluded ⇒ Subcritical mass for a group of packages could be exceeded (in current regulations only one column per consignment may be used).

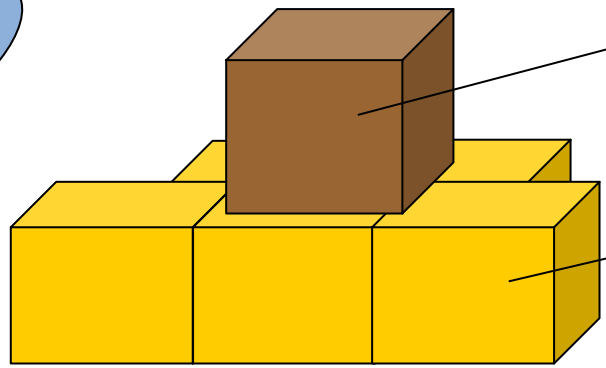


↳ Examples of consignments

Calculation of CSI in case of restrictions

Consignment of packages without demonstration that packages survive NCT tests

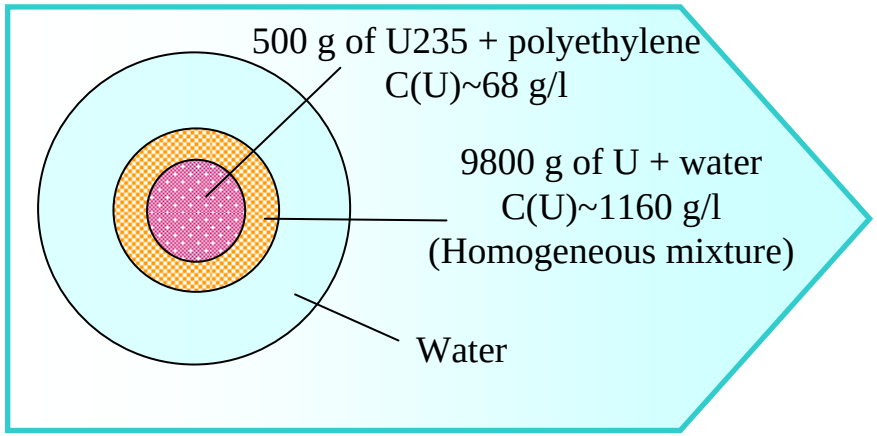
Example 1



1960 g of U (1.5% U-235 enrichment) with polyethylene (CSIpackage=3.7)

20 g of U (100% U-235)/package without polyethylene (CSIpackage=9.3)

To be consistent with the objective of the regulations, 5 consignments of ruined packages should be subcritical



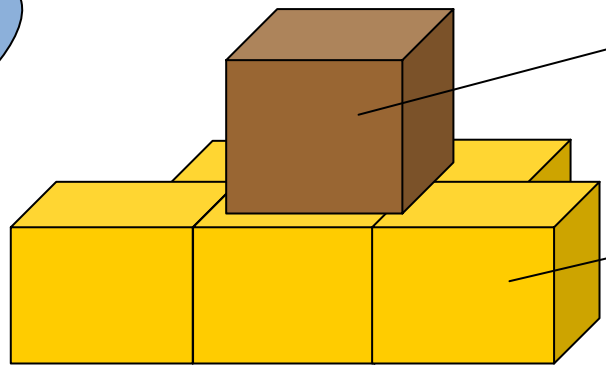
For a mass of polyethylene of 7 kg (1.4 kg/consignment)

Keff > 1 (~1.025)

Calculation of CSI in case of restrictions

Consignment of packages with demonstration that packages survive NCT tests

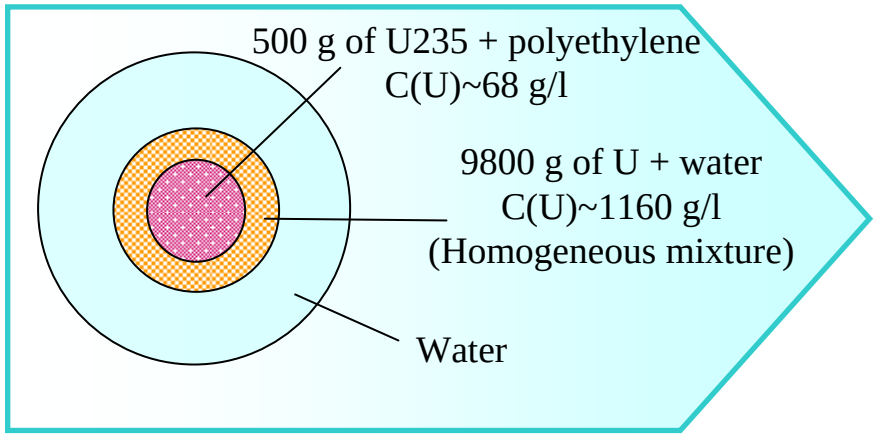
Example 2



4910 g of U (1.5% U-235 enrichment) with polyethylene (CSIpackage=3.7)

50 g of U (100% U-235)/package without polyethylene (CSIpackage=9.3)

To be consistent with the objective of the regulations, 2 consignments of ruined packages should be subcritical



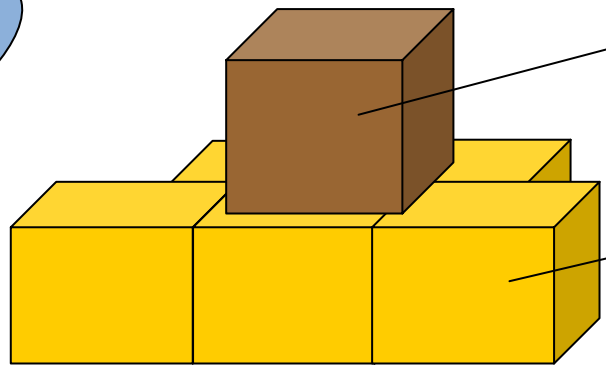
For a mass of polyethylene of 7 kg (3.5 kg/consignment)

Keff > 1 (~1.025)

Calculation of CSI in case of restrictions

Consignment of packages with demonstration that packages survive NCT tests

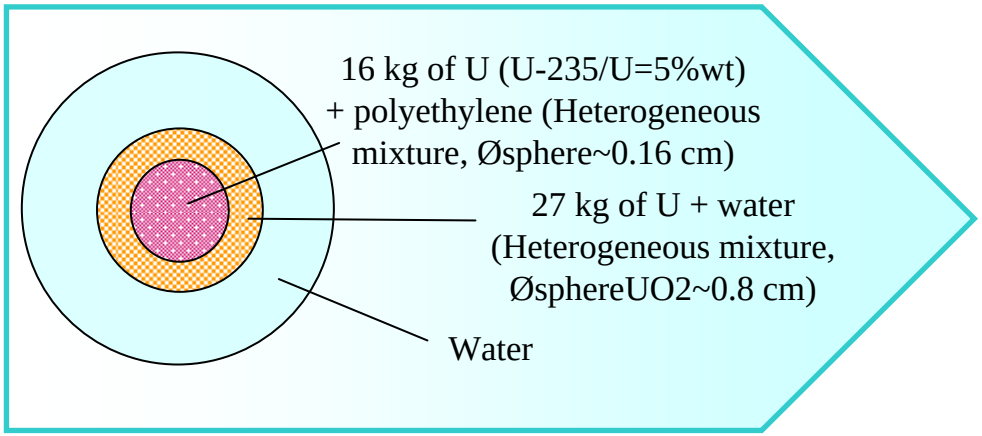
Example 3



13.3 kg of U (1.5% U-235 enrichement) with polyethylene (CSIpackage=10)

1.6 kg of U (5% U-235 enrichment)/package without polyethylene (CSIpackage=8)

To be consistent with the regulations, 2 consignments (ruined packages) have to be subcritical



For a mass of polyethylene of 9.8 kg (4.9 kg/consignment)

Keff > 1 (~1.012)

Calculation of CSI in case of restrictions

Unacceptable keff values obtained
+
Calculations performed are not exhaustive but, to have a subcritical keff value, the mass of polyethylene per consignment has to be lower than 500 g

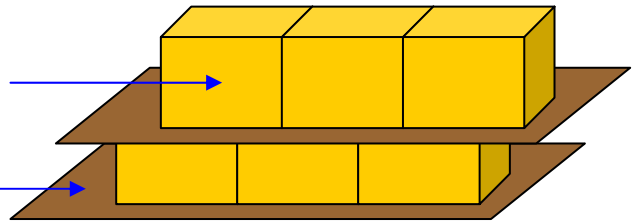
Scenario number 2:

Many transport equipments contain HDPE (retention trays, containers, bottles, pallets, etc.). For approved package designs:

- they are not often taken into account (because of demonstration of NCT and ACT regulations tests)
- hydrogenous moderation between damaged packages has to be considered

Fissile material without CH2
(« limited use » case)

Transport facility with HDPE



These materials should be considered when there is no demonstration that packagings do not release their contents (excepted fissile packages)

- This problem already exists in current regulations but it is necessary to damage, in most cases, more packages (15 g of fissile nuclides/package) than in the current revision of the regulations to reach a critical configuration

Comparison to requirements for approved package designs

In paragraph 682(c) : *"the fissile material that escapes from each damaged package shall be arranged in the configuration and moderation that results in the maximum neutron multiplication with at least 20 cm of water reflection"*

- It is expected the release of only a little quantity of fissile material
- This paragraph provides a severe restriction to consider the possible configurations for fissile material escaping from the containment system and the chemical or physical changes
- Scenario consisting in gathering fissile materials in packages complying with the requirements of paragraph 672 is not less credible than the one for packages containing fissile materials for which paragraph 682(c) is applicable.

Considerations of paragraph 682(c) should be :

- taken into account for packages according to paragraph 672(b) or (c) that can be ruined under accident conditions
- extrapolated to arrays of packages according to paragraph 672(a) since fissile materials can escape from the containment system for packages even in normal conditions

Comparison to requirements for approved package designs

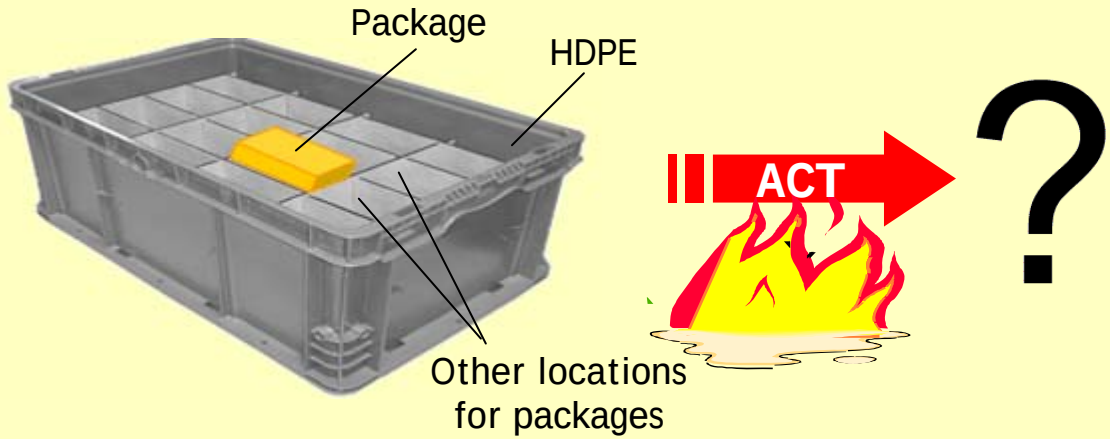
According to paragraph 682(a) : a hydrogenous moderation has to be considered between the damaged packages of an array

- The maximum neutron multiplication of an array of a sufficient number of packages is generally obtained for moderations lower than water
- As fissile material generally remains in the confinement system of the packages, moderation between packages often reduces their interactions

Since the confinement of the fissile material in not required in paragraph 672, the maximum neutron multiplication may not be obtained for moderation between packages lower than water.

Transposing paragraphs 682(a) and (c) to the proposed paragraph 672, the worst assumptions regarding the geometric arrangement of fissile material and moderation conditions should be made, taken into account all moderating components, at least, of the consignment

Comparison to requirements for approved package designs



Obviously, the assumptions about location of fissile and moderating materials should be prudent if the packaging could disappear after a fire for example

Discussion of margins

In the proposed paragraph 672, the consignor :

- is responsible for :

→Determining the characteristics of contents,

→Preparing the packages

→Verifying the minimal external dimension of packages after the regulatory tests

- will validate that the fissile material in each package is not under-estimated
- will decide which column of table M apply for each package

The verification of the behaviour of packages under the regulatory tests defined in paragraphs 672(b) and (c) may not be within the competence of the consignors

Both paragraphs should be improved to maintain the expected safety level.

Margins evaluation

In the current regulations:

Some errors concerning the mass of each package could be acceptable because of :

- the uranium enrichment in U-235 is not taken into account,
- the dissemination of the fissile material throughout the consignment in packages of 15 g,
- the consignment mass limit considered when it is constituted by at least one package with substances having hydrogenous densities greater than water is the lowest one.

In the proposed paragraph:

- the limit of fissile mass per package can be higher because uranium enrichment is considered
- fissile material can be less distributed through the consignment because the consignment mass limit can be reached with only 5 packages

If the underestimation of the fissile mass of each package remains low, the error could be acceptable

But, the possibility to mix packages with substances having hydrogenous densities greater than water and packages with substances having hydrogenous densities equal or lower than water without restricting the consignment mass limit to the lowest one is completely different from current regulations and lead to increase criticality risk significantly

Conclusion

Summary

It is not desirable:
-to mix packages whose CSI is obtained from "general use" case and from "limited use"
-to mix packages from "limited use" with non-radioactive packages or transport facilities or materials containing substances having a hydrogen density greater than water

When the CSI of packages, applying to proposed paragraph 672, is calculated for a "limited use" case, at least a limit of mass of polyethylene per consignment is necessary. Calculations performed show that the mass of polyethylene per consignment has to be lower than 500 g to be subcritical.

- The limit of 20 g of material with a hydrogen density greater than water in a package applying to the case of "limited use" proposed in current revision of the regulations is not sufficient.
- Since many transport facilities are made of HDPE, it could be not easy to comply with this consignment limit.

Proposal

Restrict the use of table M to the values of the column "general use".
Option: redefining the mass values in this column to lighten the impact of this recommendation.

As for HDPE transport equipments, the current regulatory provisions are also concerned. This issue could also be addressed for approved package designs.

Thank you for your attention