COMMENTS ON THE REQUIREMENTS FOR PACKAGES CONTAINING FISSILE MATERIALS

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ABSTRACT

The Regulations for the Safe Transport of the Radioactive Material are in constant evolution. Draft amendments of the legal texts are regularly suggested by the Member States to improve the texts (cf. [3] for instance). This paper approaches two ambiguous points of the regulation (TS-R-1 [1]):

1. The need of a better specification of the configurations to be analyzed in the criticality studies for packages transported by air when the applicant does not realize the required test sequences;
2. The pertinence of the conditions imposed for the assessment of a 5N array of package under normal conditions of transport (absence of moderation between packages even if rain, fog or snow are usually considered as normal conditions).

INTRODUCTION

The release in 1996 of the new edition of the international regulation for the Safe Transport of Radioactive Material [1] brings new major changes, in particular in the transport by air of the radioactive materials.
Because the nature of this type of transport, the gravity of the accidents is very significant even if the risks are definitely smaller than by road or sea. The prevention, via the regulation, of such accidents must be consequently adapted: therefore the mechanical and thermal tests have been reinforced and an accidental situation has been added in the analysis of the criticality risks.
Following the assessment of some safety reports about the air transport of packages, we noticed that applicants did not treat correctly, in agreement with the paragraph 680 of the TS-R-1 [1], the criticality-safety of this kind of transport. The calculations showed in the first part of this paper are far from being exhaustive but demonstrate that the configuration of the spherical dry fissile medium reflected by 20 cm of water retained by applicants is not sufficient to cover the prescriptions of the paragraph 680. We focus here on non-irradiated media which are generally transported by air.

Then, in the second part of this paper, we discuss about the normal conditions in the paragraph 681 of the TS-R-1 [1] for the assessment of a 5N array of package.

1. “Warning” for the assessment of packages being transported by air

1.1 IAEA 1996 REGULATION – Air Transport

The last revised version of the IAEA Regulations for the Safe Transport of Radioactive Material [1], released in 1996, introduces a new concept of packaging for fissile materials transported by air: the type C package.

The type C package must follow different test sequences as specified in the paragraph 734 of TS-R-1 [1]. In fact, there are two test sequences, which are carried out on different specimens:

- ⇨ An impact test, at a velocity of at least 90 $m.s^{-1}$, on an unyielding fixed target;
- ⇨ Drop tests to estimate the mechanical resistance of the package followed by a one-hour thermal test.

These test sequences are more severe than those applied to the other types of package. In the same way, the criticality assessment has been made harder to prevent the criticality risk. Indeed, in addition to the fact that the applicant must demonstrate the sub-criticality of a single package in normal and accidental conditions (type B test sequences) and the sub-criticality of an array of packages in normal (5N) and accidental (2N) conditions of transport, a new additional configuration must be considered according to the paragraph 680 [1]:

- ⇨ Single package, following the type C test sequences prescribed in paragraph 734 of the TS-R-1 [1] and reminded previously, assuming reflection by at least 20 cm of water but without water penetration.

If type C test sequences are not performed by the applicant, then according to the paragraph 673 [1], conditions should be held and applied to the package to achieve the maximum neutron multiplication in the criticality assessment:

§673: " Where the chemical or physical form, isotopic composition, mass or concentration, moderation ratio or density, or geometric configuration is not known, the assessment of paras 677-682 shall be performed assuming that each parameter that is not known has the value which gives the maximum neutron multiplication consistent with the known conditions and parameters in these assessments ".

That can be done, for instance, by considering the most conservative geometrical configuration for packaging and its contents. Since the sphere is the most conservative form, the first idea is to retain the dry contents in the spherical form reflected by 20 cm of water as being the most pessimistic arrangement. Recently, some safety reports, based on this idea, have been submitted to the analysis of the French Safety Authorities (DSIN). It is to noticed that in all these reports, because the paragraph 680 of TS-R-1 [1] does not precise if hydrogenated or reflected materials already contained in the packages must be considered, the applicant does not think to take them into account.

Consequently, other configurations of an individual package in isolation which could lead to a more reactive situation should be analyzed, such as:

a) spherical volume of fissile contents surrounded by reflecting materials of the package and reflected by 20 cm of water;

b) a spherical mixture of fissile contents and moderating materials of the package surrounded by 20 cm of water.

These configuration have been submitted during the last revision panel of the Regulations and proposed to be included in the next version of TS-G-1 [2]. It is to be noticed that these configurations are not exhaustive and that, depending on the package and its materials, other configurations might be considered.

1.2. INFLUENCE OF THE REFLECTING MATERIALS OF THE PACKAGE

In the (a) configuration described before, it is considered that the reflecting materials contained in the packages could be rearranged in such a way (around the fissile medium), that it would make the single configuration more reactive. In this section, the reflector effect is highlighted. The minimal thickness necessary to reduce the critical mass by studying different fissile media surrounded by steel - MOX assemblies, fuel rods in $UZrH_2$ or fuel with high enriched uranium (or plutonium) is determined. Metal fissile media have been chosen because they have a strong reactive potential and are conservative of real media like uranium strongly enriched, fuel plates containing UAl, U_3Si_2-Al and all mixed oxide assemblies, etc.
The calculations were performed with CRISTAL, the more recent French package for criticality-safety studies. This package includes different codes and calculation roots: standard (APOLLO 2 Pij – MORET4, a multigroup Monte Carlo Code), reference (TRIPOLI 4, a point wise Monte Carlo Code). APOLLO 2 allows also Sn calculations in this study by using a 20-group structure build from JEF2 libraries, a S8 (or more) quadrature and a P3 approximation for H_2O anisotropic scattering.

In order to determine the influence of steel and according to the (a) configuration, calculations were carried out for each fissile medium by considering a dry homogeneous fissile medium of spherical geometry, reflected by a stainless steel ring of variable thickness (x cm) and 20 cm of water.

The following conservative fissile materials have been chosen:

- Uranium metal strongly enriched (93,5% and 95% ^{235}U);
- Plutonium metal (100% ^{239}Pu);
- Mixed oxide (PuO_2-UO_2) with a plutonium content of 40% and the following isotopic vector: ($^{239}Pu/^{240}Pu/^{241}Pu/^{242}Pu$) = (71%/17%/11%/1%);
- $UZrH_2$ (8% of uranium with 20% in mass of ^{235}U).

The influence of the steel is evaluated, by calculating critical masses and masses of medium to obtain a keff = 0,95, using the APOLLO 2-Sn code.

The curves fissile mass versus steel thickness are given in Charts 1 and 2 for plutonium metal and $UZrH_2$ media. In the left region of the curves, the steel, due to its small thickness, is not effective enough and let high energy neutrons pass through to be moderated in water and then return in steel to be absorbed: the critical mass increases. From thicknesses, around 2 to 3 cm, the tendency is reversed and the steel reflection increases: the critical mass decreases.

Table 1 - Minimal steel thickness to obtain a critical mass lower or equal than without steel

Fissile medium	**Critical mass without steel reflector (only 20 cm of water) (kg)**	**Minimal thickness of steel to obtain a critical mass lower or equal (cm)**
U metal – 93,5% and 95% ^{235}U	23.01 and 22.48	9.0
Pu metal – 100% ^{239}Pu	5.39	6.0
MOX (40% Pu/(U+Pu) – Isotopic vector: 71/17/11/1 – 1,2% of ^{235}U)	87.26	8.0
$UZrH_2$ (8% of uranium with 20% in mass of ^{235}U)	3.57	10.0

For each studied fissile material (except for plutonium metal), it appears in Table 1 that below a steel thickness of 8 to 10 cm, the critical mass is not reduced. In the case of packages containing steel, the applicant must ensure that the total amount will never allow obtaining an 8 cm spherical ring around the fissile media in an accidental situation. According to our knowledge, the packages devoted to the transport of fresh fuel will rarely contain such a quantity of steel.

Furthermore, other reflecting materials could be considered having similar effect. Therefore, the applicant must keep in mind that reflecting materials have a great importance in the assessment of the most reactive case for an individual package in isolation.

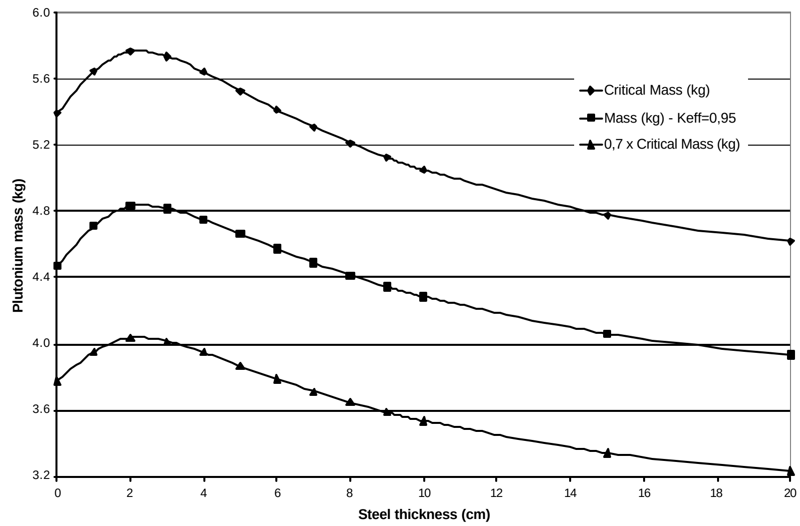

Chart 1 - Masses for plutonium metal strongly enriched (100% ^{239}Pu) reflected by x cm of steel and 20 cm of water

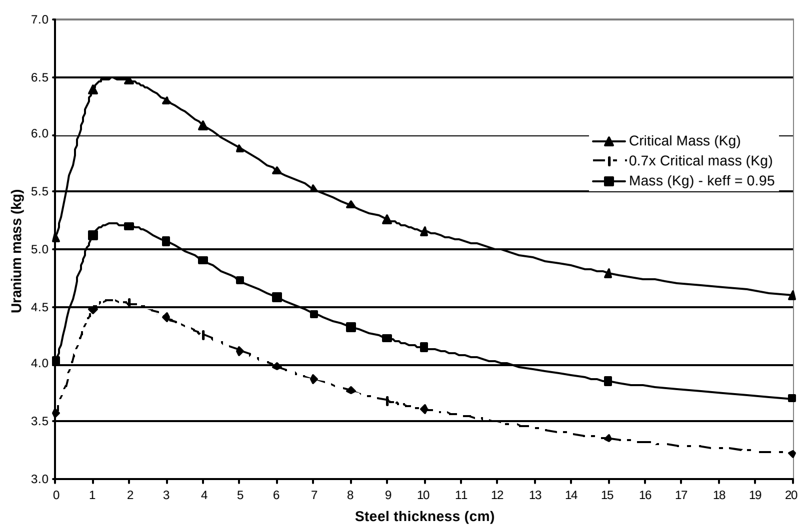

Chart 2 - Spherical masses for the heterogeneous medium U-ZrH_2 in the air reflected by x cm of steel and 20 cm of water

1.3 THE MODERATING MATERIALS OF THE PACKAGE

As we have seen in 1.1 section, and according to the paragraph 673 [1], if type C test sequences are not realised by the applicant, most penalizing conditions should be held and applied to the package in the criticality assessment. Besides, no water penetration (paragraph 680) means that no supplementary moderation has to be taken into account, but it does not mean that hydrogenated materials of the package like wood, polythene, compound or a mixture of these elements and the fissile materials should not be considered (that corresponds to the (b) configuration evoked previously in the paragraph 1.1) in the assessment of criticality risks for an air transport.

This leads us to consider two different possibilities depending on the type of package:

1. package without poison material;
2. package with poison material.

In all considered configurations, calculations are carried out with CRISTAL and 7 kg of metal uranium enriched to 100% in ^{235}U is used as the reference medium.

1.3.1 Configurations with the hydrogenated materials of the package

It is not easy for the applicant to evaluate precisely the amount of hydrogenated materials contained into the package. A possibility could be to determine the maximum quantity of hydrogen (or water) deduced from criticality calculations and to verify if it is lower than the estimated mass of the hydrogenated materials of the package. To illustrate that concept, calculations were performed for both water and polythene as moderator mixed with the fissile medium.

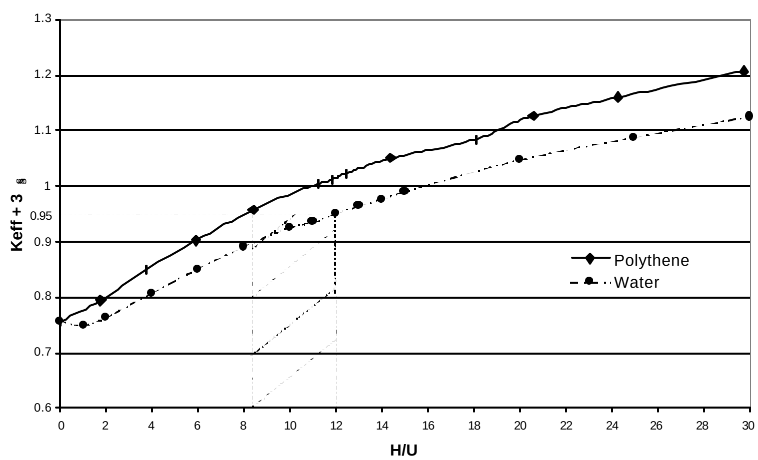

Chart 3 - Reactivity of a sphere of uranium metal 100% ^{235}U (7 kg) reflected by 20 cm of water and moderated by water or polythene

The results (see Chart 3) show that for a H/U > 12 (3,2 kg of water), the reactivity exceeds 0,95 (For 36 kg of metal uranium enriched at 20% in ^{235}U, the limit of water will be 8,2 kg). So, in that case, the applicant must ensure that the total amount of hydrogenated materials contained in the package does not exceed an equivalent of 3,2 kg of water (8,2 kg in the case of uranium metal enriched at 20%). Moreover, a careful attention to the nature of the moderator should be considered. Thus, if polythene or other plastic materials, for which the hydrogen concentration is greater than in water is present in packages, then the assessment must take it into account.

Another recommendation concerns the hydrogenated materials distribution within the fissile medium. The distribution of the moderator is important, although it has not been considered in safety reports. This effect can be illustrated by considering a heterogeneous distribution of the moderator inside the reference medium represented on figure 1.

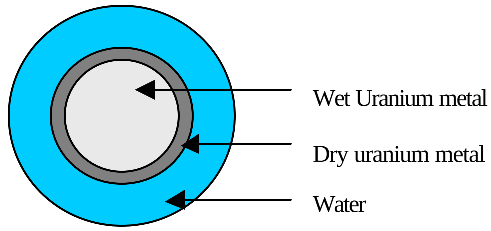

Figure 1 – Heterogeneous distribution of fissile medium

Calculations were carried out with the CRISTAL code for various masses of wet uranium metal. The results are gathered in Table 2. With such a distribution, the moderator effect is reinforced (the moderation ratio is higher) and the reflector effect, with the presence of dry fissile located in the outside ring, is increased. So, the minimal quantity of water necessary to exceed the reactivity criterion (keff + $3\sigma \leq 0{,}95$) is slightly decreased with a limit at around 2,7 kg of water. Consequently, for this case precisely, the total quantity of hydrogenated material in the package must not exceed an equivalent of 2,7 kg of water.

Table 2 – Reactivity of a medium, moderated heterogeneously and reflected by 20 cm of water

Wet Fissile Mass (kg)	6.5	6	5	4	**2**	**1**	0.5
H/U	13	14	16	19	**35**	**70**	160
Water Mass (kg)	3.24	3.22	3.06	2.91	**2.68**	**2.68**	3.06
Keff + 3s (s = 200 pcm)	0.95614	0.95593	0.94856	0.94699	**0.94156**	**0.94338**	0 .94953

1.3.2 Configurations with resins, compound and neutronic absorbers

Although the paragraph 673 of TS-R-1 [1] precise to consider in the criticality assessment the most pessimistic conditions, it seems realistic to take into account the neutronic absorber in the calculations since its loss due to an accident is very improbable.
Furthermore, it seems realistic to take account of all components included in the neutronic absorber (especially hydrogen) and not only the poisoned components. So, we proposed to consider the presence of neutronic absorber under its natural chemical form (compound or resin) in the calculation model (except if neutronic absorbers are affected by the thermal test).
At last, concerning the neutronic absorber distribution in the calculations model, it is recommended to choose a heterogeneous distribution, more conservative than a homogeneous one.
In this present case, the neutronic absorber must not be mixed with fissile material because the poisoned isotopes should become more efficient. This leads to the following configuration: a spherical volume of fissile (7 kg) surrounded by neutronic absorber and 20 cm of water and moderated by various quantities of water coming from hydrogenated materials of the package (Chart 4).

In this configuration the presence of poison involves a decrease of about 0.1 on the keff compared to the configuration without poison (see Chart 4).

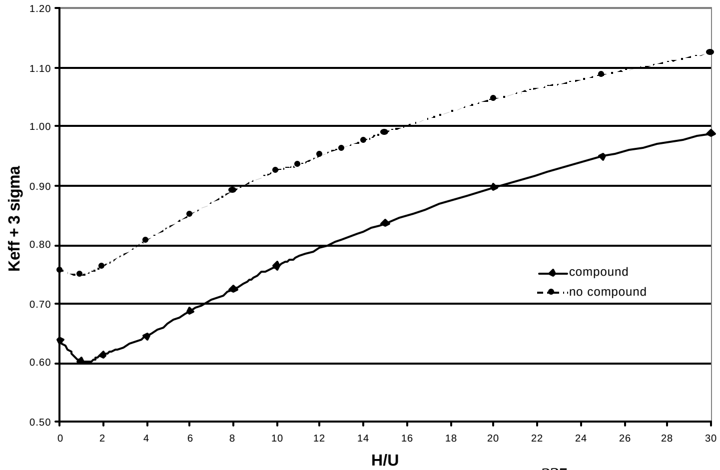

Chart 4 - Reactivity of a sphere of Uranium metal (100% ^{235}U) moderated by water and reflected by compound and 20 cm of water

2. Observations on the assessment of package arrays under normal conditions of transport

§ 681 of ST-1 [1] - *A number "N" shall be derived, such that five times "N" shall be subcritical for the arrangement and package conditions that provide the maximum neutron multiplication consistent with the following:*

*"(a) **There shall not be anything between the packages**, and the package arrangement…"*

The application of this requirement involves that no moderation (except moderation included into the packages) should be considered in the criticality evaluation for the packages that remain watertight after the tests for the normal conditions of transport.

Nevertheless, rain, fog, snow, presence of wood (pallets) or polythene (plastic sheets) between packages can be met under normal conditions of transport and constitute external moderators.
The following configuration (see fig. 2) has been chosen to illustrate this inaccuracy of the regulatory.

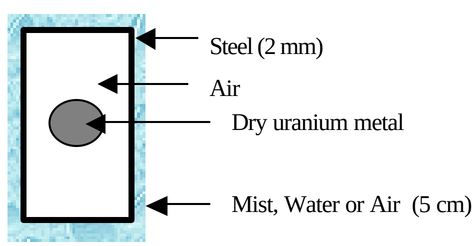

Figure 2

The configuration studied consists of a container loaded with uranium metal enriched in ^{235}U to 100% in mass (note that this kind of container can be used for the transport of UF_6).

Different calculations of a 5N array of package (with N = 25) were performed, putting 5 cm of water, mist or just air, between the packages. The results are gathered in Table 3.

Table 3 – keff versus different conditions of moderation between packages

Mass of ^{235}U	**Moderator between the packages (thickness: 5 cm)**	**keff + 3s (s = 0.001)**
7 kg	No (only air)	**0.63717**
	Water	0.60407
	Mist (water with a low density: 0,1)	**0.64918**
14 kg	No (only air)	**0.81923**
	Water	0.76300
	Mist (water with a low density: 0,1)	**0.83269**

These results show that, when there is no other hydrogenated materials inside the package (it means no hydrogenated resin, no penetration of water), the presence of **mist** between packages increases the reactivity. This study is not exhaustive and these results depend on the geometry of the package and the type of fissile material but they show **that moderation between packages has to be taken into account for normal conditions as well as for accidental conditions**.

CONCLUSION

The new AIEA 96 Regulations introduce new concepts as the type C package. Sometimes, these new features are not clear enough. Amendments, as those suggested by the Member States [3], should be integrated to enlighten applicants on the way to lead their criticality assessment.

In particular, as this paper emphasizes, it would be useful to precise the different configurations to be analyzed, when test sequences are not carried out, in the assessment of the additional configuration described in the paragraph 680 of the Regulations [1].
Thus, at least three distinct configurations should be studied: the dry content alone, reflected by 20 cm of water, the dry content surrounded by reflecting materials of the package and 20 cm of water and finally the content mixed with moderating materials of the package and reflected by 20 cm of water. Nevertheless, these configurations are not exhaustive because they depend on the packaging and its content but they could by used as a guide to fulfill the requirements of the regulation as far as air transport is concerned.

For the assessment of an array of packages, an optimal moderation between the packages should be studied for normal conditions as well as for accidental conditions of transport. As it has been shown, the presence of mist between the packages in normal conditions of transport for watertight packages could lead to a more reactive configuration.

REFERENCES

[1] Regulations for the Safe Transport of Radioactive Materials – 1996 Edition – N° TS-R-1 – International Atomic Energy Agency, IAEA safety standards series.

[2] Advisory material for the regulations for the safe transport of radioactive material (1996 edition) IAEA safety standards series N° TS-G-1.

[3] Proposed Change to the 1996 Edition of the IAEA Transport Regulations (ST-1) and/or its associated Guidance Documents (ST-2 and ST-3) – RUSSIA/00/03 and SWEDEN/00/02.