A Regulatory Approach to the Safe Transport of Plutonium by Air

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INTRODUCTION

The safety of the transport of radioactive material presenting a high level of potential danger is based upon several lines of defence, a principle widely applied in nuclear safety :

- reliability of the conveyance, which partially conditions the probability of an accident,
- package design, which ensures safety functions are fulfilled in case of an accident,
- emergency planning to protect the public and the environment, should packages be damaged in an accident.

In the case of air transport, a strict application of regulatory requirements, as laid down by the International Civil Aviation Organization (ICAO), following IAEA recommendations, does not ensure that the second line of defence, the package design, is efficient enough. This is because the safety standards used for multimodal approval of package designs cover only a small fraction of conditions likely to be encountered in an aircraft accident.

However, risk assessment studies based upon worldwide statistics on aircraft crashes result in risk estimates lower than those corresponding to other transport modes. In spite of these satisfactory results, the low level of confidence formally attached to the package design, for air transport, cannot but lead to difficulties. Such difficulties, associated with the irrelevancy of the regulatory approval of package designs according to present safety standards, have already found expression in divergencies among various concerned countries as regards their approach to the question of air transport of radioactive material. Moreover, a substancial release of radioactive substances cannot be excluded in case of an aircraft crash ; the capacity of the various interested countries to cope with a possible accident, with serious radiological consequences, in a wide variety of possible situations, is therefore in question.

The above considerations, together with a possible increase in the volume of radioactive material shipment by air, have lead our country to make proposals in view of a revision of AIEA safety standards[1] in order to deal with the air transport of radioactive material presenting a high level of potential danger.

OBJECTIVES OF A MODIFICATION OF SAFETY STANDARDS

The main objective of a modification of AIEA safety standards is to limit the radiological consequences of accidents involving airplanes carrying radioactive packages with a high level of potential danger, priority being placed on packages containing plutonium. The second objective is to facilitate emergency planning and package recovery.

These objectives can be met through an appropriate upgrading of package designs with respect to additional requirements relevant to air transport accident conditions including specific mechanical and thermal tests. These requirements can be formulated in terms of :
amount of radioactive material above which an upgraded package shall be used, additional tests and acceptance criteria for the qualification of upgraded packages. For this purpose, a review of relevant safety objectives : protection of the public, protection of the environment, and protection of surviving persons, has been made, and has led to the following proposal :

a) protection of the public : in the vicinity of the accident scene, persons being not directly affected by the accident itself, could be either contaminated by radioactive substances or exposed to radiation emitted by failed packages. A typical case is, for example, an accident during landing or take-off, with individuals located a few hundred metres away. A dose equivalent to less than 50 millisieverts (5 rem) at 500 metres or more could be proposed as a criterion. This dose level is the same as that retained for the calculation of A_2 values in the AIEA explanatory document[3], but the distance is somewhat increased according to more probable situations. Possible exposure modes are described in the Q-system[3]. It can be noted here that a criticality accident would give rise, at such distances, to doses much less than the above-mentioned value. Therefore, the above criterion will essentially affect packages with a high radioactive content, whatever the amount of fissile material may be.

b) protection of the environment : land contamination may affect the public through inhalation of resuspended particles, direct exposure to deposits, or contamination in food chain. Simple countermeasures[2] would be sufficient in areas were the annual committed dose equivalent exceeds 1 millisievert (0.1 rem). Above 10 millisieverts (1 rem) per year, heavier countermeasures would be necessary. In this case, it could be considered that decontamination of an area of less than 1 square kilometre could be managed by any country affected by this problem, with the possible help of trained decontamination squads from abroad, without giving rise to unacceptable societal impact. The possible impact on a coastal environment, although less acute than the impact on land activities, must also be taken into account. It can be noted here that a criticality accident would not have a significant impact either on land or on coastal environment. This criterion too, aims at packages with high radioactive contents ; it will not affect packages containing low specific activity fissile material.

c) protection of surviving persons : the chance of surviving of members of the crew or possible passengers of the plane should not be compromised by the presence in the plane of radioactive or fissile packages. One can claim here that an individual would have little chance of surviving in an accident in which a type B or a fissile package would be destroyed. In this regard, a study[4] performed by the US National Transportation Safety Board proposes a survival envelope defined by impact speeds, of 83 km/h at 90 degrees of impact angle, 110 km/h at 45 degrees, and 140 km/h at zero degree. Although these results concern general aviation, they can be considered as representative for our problem. A type B or a fissile package designed to remain tight or subcritical after an impact at a speed of 48 km/h, on an unyielding surface, at 90 degrees of impact angle, would not be affected at impact speeds below the survivable envelope. This has been verified, in particular, for existing plutonium package designs. As concerns accidents resulting in serious fires, survivability relies heavily on delays to evacuate the aircraft. These delays must be less than a few minutes. Therefore, upgrading type B or fissile packages with respect to a fire duration longer than 30 minutes would not improve survivability. From the above considerations, the upgrading of type B or fissile packages is not necessary to keep the chance of surviving of members of the crew or of passengers of the aircraft.

AMOUNT OF PLUTONIUM REQUIRING UPGRADED PACKAGE DESIGNS

The above-defined safety objectives have first been used to evaluate the amount of plutonium in an aircraft above which upgraded packages should be required.

The plutonium considered here comes from reprocessing of light water reactor spent fuel. Its main characteristics are the following :

- plutonium dioxide powder with AMAD equal to 10 µm,
- isotopic composition : Pu 238 (1,5 %), Pu 239 (55,1 %), Pu 240 (24,3 %), Pu 241 (13,25 %), Pu 242 (4,85 %), Am 241 (1,0 %),
- mass equivalent to A_2 : 8 mg plutonium.

It has been assumed that all non-upgraded packages would be destroyed in an aircraft accident and would release a fraction equal to 3.10^{-3} of their contents[3].

The impact on individuals and the environment of a given release of plutonium is taken from a CEPN study[2] which takes into account the chemical form and the particle size distribution of the plutonium compound.

Table 1 summarizes the results obtained.

Table 1 . Amount of plutonium in an aircraft, above which upgraded packages should be required, according to different safety objectives.

Safety objective	Protection of the public	Protection of the environment	Protection of surviving persons
Reference level	less than 50 mSv at 500 m or more	less than 10 mSv per year over an area of : 0,1 km^2 · 1 km^2 · 10 km^2	less than 500 mSv at 10 m or more
Plutonium content (A_2 unit)	2.0 10^5	1.6 10^4 · 2.1 10^5 · 2.7 10^6	unlimited
Mass of fissile material	unlimited	unlimited	unlimited
Nature of upgrading	upgrading of containment system	upgrading of containment system	no upgrading

These results show that, from the strict point of view of limiting the impact of an aircraft accident on individuals and environment, a maximum quantity of plutonium of the order of 200000 A_2 could be shipped in one aircraft as non-upgraded packages. Fixing a generally applicable limit to the activity content per package, above which an upgraded package should be required, looks somewhat arbitrary. For plutonium, we have suggested to use 3000 A_2 as this limit, because this figure, currently recommended by the AIEA as a reference for shipment requiring notification of the competent authority, can be interpreted as the lower limit of package contents presenting a high level of potential danger. Moreover, 30000 A_2, which represent for example ten packages of 3000 A_2 each, satisfy the above-mentioned maximum quantity of plutonium per conveyance with an appropriate safety margin.
In conclusion, from a regulatory point of view, it could be proposed to require upgrading of plutonium packages containing more than 3000 A_2. However, if the total activity content per conveyance was limited to 30000 A_2, corresponding packages could be exempted from upgrading. For plutonium having the characteristics already mentioned, these figures represent respectively 24 grams and 240 grams. Therefore, all packages used for shipment of plutonium from reprocessing and containing generally more than 10 kilograms of plutonium each, should be upgraded. If this method were shown to be applicable to other radionuclides, such as cobalt for example, the same figures would represent respectively 800 TBq (21000 Ci) and 8000 TBq (210 000 Ci) which are representative of quantities actually shipped. Therefore, for such radionuclides, the precise value of the exemption limit for package upgrading can have an important impact on practices.

ADDITIONAL REQUIREMENTS FOR THE QUALIFICATION OF UPGRADED PLUTONIUM PACKAGE DESIGNS

From the preceeding section, it follows that :

1) a package containing more than 3000 A_2 of LWR plutonium (i.e.24 g) must have its containment system upgraded with respect to additional mechanical and thermal tests relevant to conditions likely to be encountered in aircraft accidents,
2) no reenforcement of safety equipment devoted to the prevention of criticality is required, for any plutonium content,
3) no reenforcement of the radiation shields is necessary for a plutonium package with any plutonium content.

To define the severity of the various tests, a study of the available data on airplane accidents has been performed, the severity level being chosen in order to encompass a large proportion of forseeable accidents, similar to the one corresponding to land transport accidents when using multimodal standards. Therefore, taking into account safety margins inherent to design rules, a package designed to withstand these tests might in reality be capable of resisting accident conditions yet more severe. The proposed tests are being discussed within the framework of the revision process of the AIEA safety standards. The present French proposal is summarized in Table 2

Table 2. Additional requirements for the qualification of upgraded plutonium package designs containing more than 3000 A_2.

Additional test	Test characteristic	Acceptance criterion
Impact on unyielding target a/	90 $m.s^{-1}$	Release rate lower than A_2 per week
Dynamic crush for packages weighing less than 500 kg	500 kg at an impact speed of 90 $m.s^{-1}$	Release rate lower than A_2 per week
Burial	24 hours in adiabatic conditions	Release rate lower than A_2 per week
Fire	800°c, 1 hour (consider also fire ball)	Release rate lower than A_2 per week
Immersion b/	200 m	No rupture of the containment system

Remarks : a) the value adopted for the impact speed encompasses 85 to 95 % of accident conditions (see Fig. 1) ;

b) this test aims at protecting coastal environment in the short term.

The above tests should be applied individually : in particular, it appears unnecessarily restrictive and scarcely consistent with available data on airplane accidents to combine a maximum fire with maximum mechanical loading.

The proposed acceptance criteria for the qualification of upgraded package designs with respect to these tests are the same as those used for multimodal approval. These criteria easily satisfy the safety objectives defined above. The acceptance criterion for the release rate after the mechanical or thermal tests could have been chosen less stringent than A_2 per week : from the discussion in the previous section, an instantaneous release of 9 A_2 (equal to 3000 A_2 times 3.10^{-3}) would have still been consistent with the exemption limit. However, there are several reasons for not relaxing the acceptance criterion : firstly, design specifications in terms of strain or temperature limitations on vital components are relatively insensitive to a relaxation of the acceptance criterion, secondly it would be hard to explain that a package is upgraded if, at the same time, the tests were strenghtened whereas the acceptance criterion was relaxed.

As concerns the prevention of a criticality accident, the safety objectives defined in the previous section do not require that provisions assuring subcriticality of packages be reinforced with respect to mechanical loading or thermal conditions relevant to aircraft accident conditions. Therefore, the action of firemen could be hindered, when fighting fires of duration longer than half an hour, because of doubts about the subcriticality of fissile packages. In principle, situations of this type correspond to a relatively moderate mechanical loading, so that the main question is the resistance to fire of components important for subcriticality. Taking into account the relatively high probability of such situations, we propose to recommend that any fissile package to be used for air shipment of fissile material be upgraded in order to remain subcritical after having been exposed to a fire of 800°C during 1 hour. This supplementary requirement should be added to Table 2.

On the contrary, in case of a serious crash, there is no necessity for a rapid intervention at the aircraft itself because the main release has already occurred. The main problem is the recovery and the security of damaged packages. Because more time is available in this case, special provisions can be taken against possible criticality accidents when proceeding to the collecting and storing of damaged fissile packages. The same question can be raised in the case where packages would have to be recovered from the bottom of the sea after an undefinite delay. To make recovery operations less problematic we propose that the packages used for the air transport of fissile material be designed without having recourse to controlled moderation.

CONCLUSION

The proposal presented in this paper as an input to a major revision of AIEA safety standards concerning the transport by air of radioactive material presenting a high level of potential danger is founded on a logical approach including :

- consensus that present safety standards for the transport of RAM by air are not entirely satisfactory in that the level of safety assigned to the package design is insufficient,

- definition of safety objectives relevant to the particularities of airplane accidents : this permits to clarify the relative importance of the various possible radiological impacts of an accident through dispersion of radioactive substances, direct exposure to a broken package or criticality burst,

- application of the above objectives to the case of plutonium resulting in the following requirements : above a content of 3000 A_2 the package containment system should be reinforced with respect to both mechanical and thermal accident conditions ; no reinforcement of the package radiation shield is necessary,

- selection of tests uncompassing a large proportion of forseeable accident conditions, in continuity with the principle used for land transportation ; and selection of acceptance criteria, identical to those used for the qualification of type B package designs, compatible with the above-mentioned safety objectives,

- proposal for special requirements applicable to fissile packages aiming at facilitating package recovery.

This method is applicable to radionuclides other than plutonium. Application to shipment of cobalt sources and fissile material with unlimited A_2 are necessary to evaluate the impact of a generalization of the requirements established for the transport of plutonium by air.

REFERENCES

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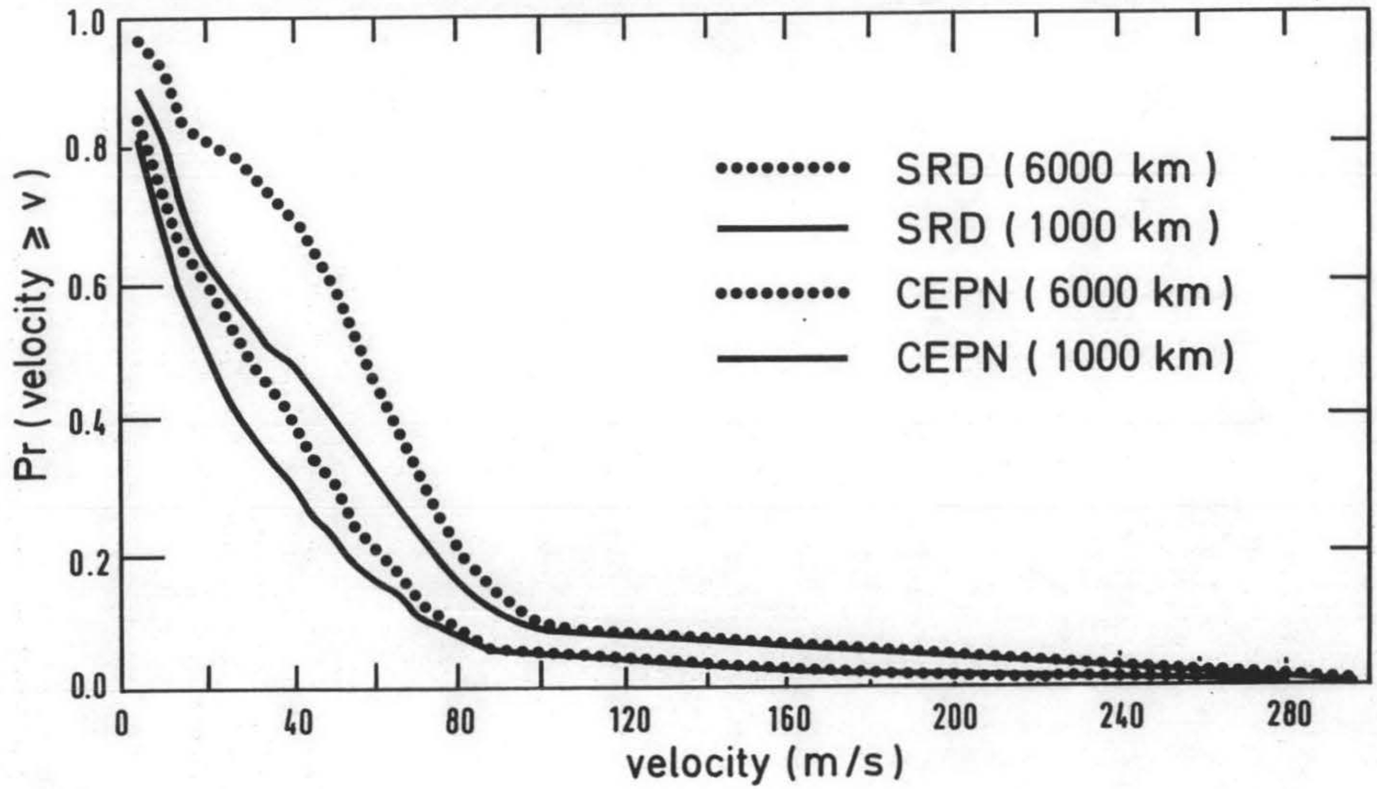
FIG.1 **C C D F for HARD TARGET EQUIVALENT VELOCITIES**

(10 % of hard soils in approach or en route phase, 50 % otherwise)



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