Plutonium Transport by Air—The Role of Enhanced Severity Package Tests in Regulation

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INTRODUCTION

The UK legislation to ensure the safe transport of radioactive materials (ram) closely reflects the IAEA Transport Regulations (IAEA 1985), including the certification of packages essentially independent of transport mode. However, this has recently been called into question due to the proposed increase in frequency of flights of plutonium following the operation of the THORP (Thermal Oxide ReProcessing) Plant at Sellafield. A 1986 UK House of Commons committee report questioned the safety of the air transport of radioactive materials, and plutonium in particular. The uncertain situation is exacerbated by the significant differences between the IAEA and USA NUREG Regulations (US Nuclear Regulatory Commission 1978).

Considerations of this type led the UK Advisory Committee on the Safe Transport of Radioactive Materials, set up to advise the Secretary of State for Transport, to review the air transport of plutonium. The review concluded, inter alia, that the risk of health detriment to people in the UK from the air transport of radioactive materials is "extremely remote and acceptable" (ACTRAM 1988). It also suggested that some tightening of the IAEA Transport Regulations may be appropriate in the context of increased numbers of shipments in the future, and welcomed BNFL's actions in designing and testing packages to meet exceptionally severe accident conditions. At the request of ACTRAM, the UK Department of Transport identified the issue for inclusion in the IAEA Continuous Review of the Transport Regulations. Other Member states expressed concern and an IAEA review is now underway.

LITERATURE SUMMARY

SRD has examined the specification of test criteria for plutonium air transport packages (Brown et al. 1980). The severity of potential crash environments, and the response of the aircraft and package were assessed, and it was concluded, inter alia, that consideration should be given to additional package test criteria to ensure no "cliff-edge" effect beyond the current IAEA test conditions. Such criteria would limit the radiological consequences of the very severe accident environments possible in aircraft crashes. The report included a review of previous work, including that used as the basis for the USA NUREG Regulations.

SRD historical aircraft crash environment severity information has recently been updated to cover the period 1975-1985, with particular emphasis on the combination of severe fire and impact loadings (Wilkinson 1989). It was found that fire durations well in excess of the IAEA test 30 minutes have occurred following considerable ripping or tearing forces, but not following very severe direct impact. Extremely high temperatures due to, for example, burning aluminium have been reported but are likely to have been localised. It is generally not clear from accident reports to what extent a ram package would have been engulfed by the fires.

Evidence has been presented to a UK planning inquiry which included the evaluation of the safety of transporting plutonium dioxide by air (Brown 1986). Accident frequencies were assessed to be low and any radiological consequences to be very small. It was assumed that the packages to be used would be a future BNFL design, with proven margins well beyond the current IAEA test requirements.

Aircraft crash conditions have recently been investigated in France, and the resulting data applied using probabilistic methodology to plutonium air transport (Hubert el al. 1987). It is suggested that the IAEA tests cover a fraction of crashes which is relatively low by comparison with those covered for other modes.

IAEA REVIEW

An IAEA Technical Committee was convened in 1988 and examined information presented by several Member States. A consensus was achieved on a number of points, with others remaining to be evaluated and addressed at a further meeting planned for 1990. Consensus points which were subsequently endorsed by the IAEA Standing Advisory Group on the Safe Transport of Radioactive Material, and are now under consideration by the Agency, included proposals to introduce the following additional special provisions for the air transport of large quantities of ram shipped by air (not limited to plutonium):

- an impact test at 85 m s^{-1} and a one hour fire test (non-sequential)

- an acceptable release following these tests of A_2 per week
- quantities less than 3000 A_2 should be excluded from the special provisions.

Points requiring further consideration included the need for and specification of fireball, puncture, tearing, crush, burial and immersion tests, and external radiation and criticality aspects.

PROBABILISTIC SAFETY ASSESSMENT

Future UK Air Transport

After 1992 with the operation of the THORP plant it is anticipated that there could be fifteen flights per year to Japan and fifteen to Europe each carrying about 100 kg of plutonium dioxide (ACTRAM 1988).

Accident Frequency

SRD significant crash (airframe write-off and at least one fatality) probabilities for aircraft of mass in excess of 20 t are 2×10^{-7} per take-off, 5×10^{-7} per landing and descent, and 5×10^{-10} per km in flight. Thus the predicted future plutonium flight crash frequency is 1×10^{-4} a^{-1}.

Release Magnitude

Some packages have been tested under extreme conditions, well beyond the current IAEA Regulation requirements (ACTRAM 1988, Brown et al 1980, Hubert et al 1987 and McSweeney and Johnson 1977). For example, impacts at speeds of 50 - 120 m s^{-1} result in package damage but not in large releases, 6% of a surrogate powder being the reported maximum. It is therefore conservative to assume a 10% release in 10% of crashes.

Only about 0.05% of BNFL plutonium dioxide product is of respirable size, the majority of the mass being particles with diameters 15-35 µm (ACTRAM 1988). The respirable release given a crash would thus be of the order of 5 grams on the basis of these assumptions.

Radiological Consequences - Atmospheric Release

The latent cancer probability for an individual located 100 m from the accident, making an allowance for wind direction, for a ten gram respirable release of a typical isotopic mixture is 0.007 for average weather conditions (Brown 1986).

The expected number of latent cancer fatalities for a ten gram respirable release in UK conditions is 0.9 (Brown 1986).

Risks - Atmospheric Release

The probability of an aircraft crash at sea is conservatively neglected in the assessment of risks from crashes on land in this section. The radiological risk to a hypothetical individual assumed to be located 100 m from the accident is 4×10^{-8} a^{-1}. The reduction in risk due to the probability of accident occurrence anywhere along the route is also conservatively neglected. This hypothetical individual risk may be compared with the value of 10^{-6} a^{-1} generally considered to be broadly acceptable, provided benefits accrue and proper precautions are taken (Health and Safety Executive 1988).

The expected number of latent cancer fatalities, conditional upon the occurrence of the crash, is 0.5. The expected number of latent cancer fatalities per year is 5×10^{-6}. This figure may be compared with the expected number of fatalities in the ground population due to impact by wreckage from all civil aircraft flights over the UK of about 0.5 a^{-1}. Of course the benefits derived from these flights are in no way comparable, but the rates serve to illustrate the very small magnitude of the radiological risk.

Alternative Scenario

Plutonium dioxide powder from an alternative source has a respirable fraction up to about 10% (McSweeney and Johnson 1977). A package with little margin to failure beyond the IAEA test requirements may fail in 50% of serious aircraft crashes.

Applying these alternative hypothetical data to the anticipated future UK air movements (and neglecting non-stochastic health effects) results in an individual risk of 4×10^{-5} a^{-1}, an expectation number of latent fatalities given the release of 90, and an annual expectation number of fatalities of 0.005 a^{-1}. In our view further evaluation would be necessary to justify risks of this magnitude.

Crash at Sea

It is expected that any packages sinking on the Continental Shelf would be recovered without loss of plutonium. However, illustrative calculations have been performed to evaluate the radiological consequences (largely through the consumption of seafood) resulting from 1 kg of plutonium dioxide dissolving over a period of 100 years. The time integrated collective dose to the UK population is up to about 12 man Sv (Brown 1986). This is negligible in comparison with the UK population collective dose due to "basic unavoidable" radiation of natural origin (cosmic, terrestrial γ and internal excluding radon and thoron) of about 50000 man Sv a^{-1}.

Conclusions

A much simplified and abbreviated assessment of risks is presented in this section. However, it is sufficient to show clearly that current and foreseeable future UK plutonium air transport risks are extremely low. However, this is due largely to the low aircraft crash probability, the sound design of packages in current use leading to capabilities to retain significant fractions of the ram in accident severities well beyond IAEA test conditions, and the form of the ram in limiting the radiological consequences of releases. These mitigating factors are not controlled by the IAEA Transport Regulations, and it is conceivable that the latter two in particular will not always hold.

PACKAGING PHILOSOPHY

A fundamental tenet of IAEA Transport Regulation philosophy is to place primary reliance on the packaging to ensure safety, which implies a high probability that a Type B package will survive severe accidents intact.

Air transport is different from other modes particularly in that the significantly greater speeds provide the potential for crash conditions of extreme severity.

Caution must however be exercised in comparing in detail the results from different assessments of the fractions of accidents expected to be covered by test conditions. In some cases more minor accidents are included in the data set, resulting in higher predictions of fractional cover.

A recent USA assessment calculates that at least 99.4% of road and rail accidents are less severe than the IAEA Type B test requirements (Fischer et al 1987). Corresponding lower bound figures of about 98-99% have been derived by SRD (Appleton et al 1989).

For air transport impact conditions, SRD and Sandia calculate that about 50% of significant accidents are less severe than the IAEA 13 m s^{-1} test, and the corresponding CEPN figure is about 20% (Brown et al 1980, McClure 1977 and Hubert et al 1987). Sandia calculate that some 96-99.5% of aircraft fires are less severe than the IAEA Type B test, and SRD and CEPN data indicate 75-80% of fire durations (taking no account of engulfment) to be less than the IAEA test 30 minutes.

Considerable uncertainty exists with these assessments, but the difference between air and other modes, particularly for impact, is clear.

SAFETY CRITERIA

Current IAEA Transport Regulations

The current Type B test requirements assure package survival in a fraction of severe aircraft accidents which we judge to be too low to be consistent with the regulatory philosophy, notwithstanding the current very low associated risk levels.

It is accepted that the introduction of special requirements for the air transport of large quantities of ram has the disadvantage of further eroding the mode independence of the Regulations. This is an inevitable consequence of seeking to specify packaging to survive a large majority of possible accidents, which we judge an admirable feature and likely to inspire public confidence.

Zero Risk

The USA NUREG plutonium air transport regulations were developed to satisfy a Public Law demanding a package which would not fail under crash conditions. In discussion, the NRC note that it is not possible to guarantee no failure under any circumstances (US Nuclear Regulatory Commission 1978).

Recognising that zero risk is unachievable, it is necessary to employ package test conditions which represent more severe environments than all but a small fraction of extreme accidents.

IAEA Review Principal Proposals

The principal additional test proposals currently tabled in the IAEA review process are a 85 m s^{-1} impact and a non-sequential one hour fire.

The 85 m s^{-1} impact is expected to cover 98%, 90% and 60-90% of significant crashes by SRD, Sandia and CEPN respectively (Brown et al 1980, McClure 1977 and Hubert et al 1987). A one hour fire is expected to cover 98.5-99.9% of fire severities by Sandia, and 84% and 80-90% of fire durations by SRD and CEPN respectively. Again uncertainties, differing assumptions and differing transport conditions lead to differences in calculated probabilities.

It appears that these review proposals cover a fraction of aircraft crashes which is significantly greater than the current test requirements. The fraction is probably a little less than is covered by the current tests for road and rail. We judge the proposals to be reasonable and adequate. We consider the probably slightly lower cover than for road and rail to be acceptable, in view of the very low level of absolute risk associated with air transport. In addition, because of the shape of the impact probability distribution, a significant and unjustified increase in test speed would be required to assure equal cover with road and rail.

IAEA Review Additional Proposals

We judge these to be worthy of investigation but to be of secondary importance. However, instances of severe puncture/tearing forces followed by long duration fires are known, and it is felt that this situation in particular deserves further consideration.

CONCLUSIONS

Anxiety expressed in the UK and elsewhere has led to an IAEA review of the air transport regulations for ram and plutonium in particular, and the tabling of proposals for special mode-specific provisions. These proposals include non-sequential tests of impact at 85 m s^{-1} and a one hour fire for large quantities of ram.

Risks for UK air transport of plutonium are very low and are not considered to be of concern. However, this is largely due to the low aircraft crash probability, package design without "cliff-edge" effects just beyond current test conditions, and forms of ram which limit the radiological consequences of any release, rather than directly to IAEA Transport Regulation packaging requirements.

Notwithstanding these low risks, the proposals for special provisions in the IAEA Transport Regulations are endorsed, in order to maintain the reliance on the packaging to provide the principal safety assurance, and as a step towards the maintenance of international regulation harmonization.

The impact and fire test conditions proposed are judged to give assurance of packages surviving an acceptably high fraction of potential aircraft accident environments.

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