IAEA-TECDOC-702

The air transport of radioactive material in large quantities or with high activity

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THE AIR TRANSPORT OF RADIOACTIVE MATERIAL
IN LARGE QUANTITIES OR WITH HIGH ACTIVITY
IAEA, VIENNA, 1993
IAEA-TECDOC-702
ISSN 1011-4289

Printed by the IAEA in Austria
April 1993

FOREWORD

With the publication of this TECDOC a landmark has been reached in the process of revision of the IAEA's "Regulations for the Safe Transport of Radioactive Material", Safety Series No. 6 and its supporting documents Safety Series Nos 7, 37 and 80.

It is for the first time in the history of the transport of radioactive material that the IAEA has prepared comprehensive text for one specific mode of transport only. So far the Regulations were essentially, as a matter of principle, mode-independent.

The development of mode-specific provisions for air transport of large quantities of radioactive material takes account of the more damaging accident environment for packages which have become involved in an aircraft crash as compared to other modes of transport.

The present TECDOC is a mixture of new regulatory provisions for the air transport of large quantities of radioactive material, explanatory and background material for these new provisions and other issues which have been discussed by the various technical committees, advisory groups and consultants that contributed to its development.

It represents the broad consensus that has been reached between IAEA Member States on the major fundamental issues related to air transport of radioactive material with high potential hazard. The most visible novelty in the TECDOC is the proposal to introduce a new package type, the Type C package.

The material contained in the TECDOC will be subject to further scrutiny by Member States and by cognizant international organizations. It is intended that the new regulatory provisions will be incorporated in the new, comprehensively revised Edition of the Regulations, due in 1996. To let the regulatory provisions proper stand out from background material it is printed in italics throughout the TECDOC.

EDITORIAL NOTE

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1. INTRODUCTION

1.1. PURPOSE

The safe transport of radioactive material is an important part of national and international radiation safety programme. The IAEA's "Regulations for the Safe Transport of Radioactive Material", Safety Series No. 6 [1], have been established as the basis for regulating the transport of radioactive material for national and international road, rail, air and water shipments. Through the widespread adoption of the IAEA's Regulations, a very high standard of safety in transport has been achieved.

In general, the IAEA has been able to sustain the multimodal applications of the Regulations. The mode-independent nature has not been maintained in a few cases because there are some differences in the conditions of transport among the land, air and water modes. For example, the IAEA has adopted specific packaging requirements for liquids transported by air.

The basis of the requirements in Safety Series No. 6 is that package performance requirements, operational procedures and approval and administrative actions are all structured on a graded hazard approach. For example, where the potential radiological hazard posed by the contents of a package is small, sufficient but minimal requirements and procedures are imposed, and as the potential radiological hazard increases additional packaging requirements and procedures are imposed to limit the probability of the occurrence and the direct effects of radiological hazards. Accordingly additional packaging requirements for high hazard materials must be considered.

Following the basic format of Safety Series No. 6, the following Sections provide recommendations for transporting radioactive material by air. These recommendations should be considered additional to the relevant requirements in Safety Series No. 6.

On the advice of the Standing Advisory Group on the Safe Transport of Radioactive Material (SAGSTRAM), the IAEA has prepared the recommendations with the assistance of Member States. The purpose of the recommendations is to provide guidance on the safe transport of radioactive material. This document should assist other organizations and Member States in providing adequate and harmonized requirements throughout the world.

For the purposes of this document, radioactive material in large quantities or with high activity means radioactive material that exceeds the limits shown in Section 4.2.2.

1.2. HISTORY

The Technical Committee Meeting on the Continuous Review of the IAEA Regulations held in 1987 [2] can be identified as a starting point for the discussion of mode-related aspects of the Regulations related to the transport of radioactive material in large quantities or with high activity. During this meeting a recommendation was directed to SAGSTRAM at its sixth meeting to consider the following aspects:

(1) Examine the level of risk posed by air shipments of plutonium and the concept that accidents with unacceptable consequences must be avoided;

(2) Examine potential regulatory measures to reduce both probability and consequence if shown to be necessary;

(3) Examine the risks and benefits (including security for these shipments) to obtain qualitative/quantitative understanding of the impact of possible regulatory changes; and

(4) Examine other air-shipped nuclides to determine which, if any, might be subject to additional regulation.

At its sixth meeting [3] SAGSTRAM considered the transport of potentially high hazard radioactive material by air to be the most important major regulatory issue currently identified:

> "The issue centered on the regulatory method of addressing high consequence/low probability accidents in the context of the increasing quantities of plutonium likely to be transported by air for security reasons, and the concern that some Member States have adopted or are considering adopting more stringent requirements for the air transport of plutonium than are provided for in the current IAEA Transport Regulations. The issue involves an examination of the underlying philosophy of the Regulations, the continued harmonisation of the Regulations on a national and international basis, and the essentially intermodal character of the Regulations to date. Following a general discussion of this subject, SAGSTRAM established a working group to bring forward a statement of the problems involved and to develop specific recommendations on further action the Agency might take to address these problems."

On the basis of the report of a Working Group, SAGSTRAM recommended that the IAEA convene a dedicated Technical Committee Meeting (TCM) in 1988 that would provide for technical input by Member States encompassing a risk/cost/benefit assessment, acceptability of potential solutions, and development of an approach to the problem. SAGSTRAM further recommended that a Consultants Services Meeting (CSM) be held to prepare for the TCM by gathering relevant information, undertaking preliminary technical analysis, developing the terms of reference for the TCM and preparing a working paper to be used as the basis of the TCM.

In accordance with this latter recommendation a CSM was held in Vienna, 15-18 March 1988. This CSM recommended that the TCM act to modify the qualification criteria and/or add requirements in Safety Series No. 6 for performance qualifications of packages that will be used for air shipment of large quantities of radioactive material. The new requirements would be consistent with transport regulatory philosophy and not present any internal inconsistency that will cause long term regulatory instability. The CSM also recommended that the TCM recommendations include an action plan that described how to achieve the regulatory change and the appropriate timetable.

During 5-9 December 1988 the Technical Committee [4] met to discuss the recommendations made by the CSM. The TCM focussed on the areas where additional requirements in packaging and operational and administrative controls were required. The result of this meeting was a series of recommendations for changes to the Regulations. These recommendations became the basis for or have been incorporated into the new regulatory provisions in this document. Unfortunately, there were a number of items on which no definitive conclusion could be reached.

Among these items was the exemption level for fissile materials. The TCM recommended to the IAEA that expert advice on a proper exemption level be obtained before the seventh meeting of SAGSTRAM. As a result a CSM was convened 1-2 February 1989 to develop recommendations on criticality safety in high-severity aircraft accidents. This CSM concluded that an exemption level of half of the minimum critical value for fissile nuclide concerned would be acceptable.

At its seventh meeting SAGSTRAM [5] discussed in detail the report of the TCM and the related CSM on criticality safety. Based on this discussion SAGSTRAM convened a small drafting group to prepare a set of recommendations. Based on these recommendations, SAGSTRAM tasked the IAEA to write to Member States for their comments on issues that had not been resolved at the TCM. The SAGSTRAM recommendations and the Member States' comments provided the material that was discussed at a second CSM on the mode related aspects of the Transport Regulations.

This CSM was held 4-7 December 1989 to review the work accomplished to date about the regulatory needs in assuring safety in possible high consequence accidents in air transport. To this end the CSM studied the responses from Member States on agreements and unresolved issues. Based on this study the CSM recommended future actions to be taken by the IAEA and developed the terms of reference for a subsequent TCM.

In addition, the CSM studied the role of probabilistic risk assessment techniques in the development of the Regulations. The consultants found that the role of PRA was indirect and that PRA can provide a quantitative analysis but is not primarily useful in the decision process. They concluded that the Regulations are not based solely on risk analysis but are developed more conservatively.

Further, during 7-11 May 1990 a Technical Committee Meeting [6] was convened to discuss the results of the CSMs and Member States responses. The goals of this TCM were to determine recommendations for specific performance and administrative requirements that should be applied to packages that will be used in the air transport of large quantities of radioactive material, and to develop text for a document detailing these requirements.

Moreover, this meeting achieved consensus on most issues. One of these concerned allowable radiation levels external to the package after the package had been submitted to the recommended tests. For consistency, the majority of the Member States represented at the meeting favoured restricting the allowable radiation level to that specified in para. 542 of the current Regulations. This decision has been included in this document.

Finally during 2-6 December 1991 an Advisory Group met in Vienna to give the finishing touch to this document by reaching consensus on most of the remaining, detailed issues related to the air transport of radioactive material [7].

Among the major issues in air transport reviewed at the Advisory Group Meeting were the following:

(1) overflight/flight plan notification;
(2) post-accident performance criteria and exemption levels;

(3) worst-orientation puncture test;
(4) quantity limits on aircraft;
(5) derivation of 100 000 A_2;
(6) super Special Form;
(7) test sequence for Type B and proposed new package for air transport;
(8) criticality safety following low dispersion accidents;
(9) fireball, burial and terminal velocity testing;
(10) crush test;
(11) unilateral/multilateral approval of package designs and shipments; and
(12) grandfathering.

The aforementioned meetings provided the basis for the recommendations and information contained in this document.

1.3. STRUCTURE

This report is divided into six sections. Section 2 provides the reasons for the regulatory changes. Section 3 details recommended additional packaging requirements. Section 4 details recommended operational and administrative requirements. The italicised text in Sections 4 and 5 represent the regulatory requirements as they would appear in the 1996 Revised Edition of the Regulations. Section 5 describes other areas considered during the discussion of this subject. Section 6 summarizes the overall conclusions. Finally, the Appendix provide additional information not specifically addressed in the report.

2. REASONS FOR REGULATORY CHANGE

2.1. BACKGROUND

2.1.1. Issues arising from air transport

The safety of the transport of radioactive material is based upon multiple lines of defence, a principle widely applied in nuclear safety. In transport these lines of defence are:

- Package design, which ensures that safety functions are fulfilled in all but the most severe accidents;
- Operation of the conveyance in accordance with regulations which partially conditions the probability of an accident; and
- Emergency planning to protect the public and the environment, should packages be damaged in a severe accident.

In the case of air shipments of radioactive material in large quantities or having high activity, application of the current regulatory requirements recommended in Safety Series No. 6 does not necessarily ensure that the strength of the line of defence related to package design is consistent with surface modes. This is so because the safety standards currently used for multimodal approval of package designs do not cover the same large fraction of possible conditions likely to be encountered in an aircraft accident as are encountered in sea or land mode accidents. However, risk assessment studies that consider both consequence and probability and that are based upon worldwide statistics on aircraft crashes and current package performance, result in risk estimates comparable to, or somewhat lower than, those corresponding to other transport modes.

Nevertheless the level of safety associated with air transport of radioactive material has been questioned. These questions, which are associated with the possible inadequacy of performance standards for regulatory approval of package designs for air transport, have already found expression in disparity among some countries regarding their approach to the question of air transport of plutonium. Since a release of radioactive substances cannot be excluded in the case of a severe aircraft crash involving current package designs, the capacity of any country to deal with fears of a possible accident with serious radiological consequences calls into question its ability to control risks to the public.

The above considerations, together with a possible increase in air shipments of radioactive material in large quantities or having high activity, have led to proposals for a revision of IAEA safety standards for the air transport mode.

2.1.2. IAEA response

The prime objective of revising IAEA safety standards for the air mode of transport is to limit the probability of serious radiological consequences of accidents involving aircraft carrying packages of radioactive material. A further objective is to facilitate emergency planning and to ensure package recovery.

These objectives would be met through an appropriate upgrading of package designs with respect to additional performance requirements relevant to air transport accident conditions, including specific mechanical and thermal tests. Package upgrading ensures decreased probability of release and enhanced structural integrity to permit safe package recovery. Operational requirements will enhance emergency planning. A review of the relevant safety objectives, the level of protection for the public and the environment, and emergency planning have resulted in the recommendations contained in this document.

2.2. PRESENT IAEA REGULATIONS

2.2.1. General requirements

The IAEA publishes Safety Series No. 6 "Regulations for the Safe Transport of Radioactive Material" and explanatory and advisory material in Safety Series Nos 7, 37 and 80 [8], [9], [10]. The Regulations are applicable to all modes of transport. They serve as a model for regulations implemented by Member States and for the regulatory documents promulgated by the international transport organizations. The latest amended edition of the Regulations was published in 1990 and publication of the next edition is planned for 1996. The Regulations include provisions for packages of the following types: Excepted packages; Industrial packages Types 1, 2 and 3; Type A packages; Type B(U) packages and Type B(M) packages.

2.2.2. Requirements for air transport

The Regulations contain some requirements specific to individual modes of transport. For air transport such special requirements appear in para. 433 (limit of radiation level under exclusive use and special arrangement), paras 473-475 (additional requirements for transport), para. 477(b) (transport by post), and paras 515-517 (additional requirements for packages).

All the relevant requirements of the Regulations are included in the "Technical Instructions for the Safe Transport of Dangerous Goods by Air" [11]. This document is issued by the International Civil Aviation Organization and is required to be used for international air transport.

3. RECOMMENDED ADDITIONAL PACKAGING REQUIREMENTS

3.1. INTRODUCTION

A basic tenet of the Regulations is the concept that the package is the primary element in assuring safety of the public. Existing package performance test requirements contained in Safety Series No. 6 have proven successful in assuring safety of the public during accidents that have involved radioactive material packagings. Fewer than 1 in 10 of Type A packages involved in quite severe accidents have failed. Only 1 or 2 Type B packages, *in toto*, have released contents in accidents during the 30 years that the Regulations have been implemented worldwide. The basis for this safety record is found in three fundamental principles that underlie the concept that the package is the primary factor in assuring the safety of the public:

- Performance tests provide much more rigorous challenge to packaging containment capability than is apparent from casual comparison to "real" accidents, that is, "engineered tests envelope real accidents";

- in accident environments just slightly above those required to meet the qualification tests, packagings should not fail and release their total content to the environment, i.e., packages are expected to "fail gracefully"; and

- given an accident, release of some or all of the package contents should occur in only a small fraction of all accidents, i.e., those accidents which entail, the most severe environments and are likely to produce containment failure. This is known as the "knee of the curve" concept.

Application of these same concepts to the problem of selecting appropriate performance tests for the large quantity air transport packaging is expected to provide comparable levels of safety and public confidence that are achieved today under existing regulatory requirements.

3.2. PERFORMANCE TESTING

3.2.1. Engineered tests envelope real accidents

Setting the level of a performance test in the Regulations is a process which takes account of the universe of accidents which have and could occur in a way that provides a repeatable and standardized process. While the particular tests imposed may not appear to mirror accident experience as seen by untrained observers, meeting the detailed specifications for the test and the criteria for passing can be shown to provide rigorous standards of performance for a package.

The 9 metre drop test in the current Regulations is a case in point. The drop yields an impact speed of about 50 km/h which is lower than that seen in rail and truck transport modes. As a result, this test has been widely criticized. What is unique in the test is the specification that the drop must be on an unyielding target, a situation in which all of the drop energy goes into deforming the package and not the target. But real accidents occur on real roads and rail links in which surfaces impacted are generally not like the unyielding target but are most likely to be other vehicles, soil, poles, and hard surfaces hit obliquely. That such details are important was indicated by a test performed in the USA in the mid-1970s

[12]. Two casks were dropped: one from 9 metres onto an unyielding surface, an identical cask was dropped 700 metres onto desert soil. The greater deformation was seen in the cask dropped 9 metres. That the drop test envelopes most accident impact environments is consistently shown by analysis of accident data. In fact, the drop test was set originally to mimic the damage seen in very severe accidents, not the typical speeds and targets in transport.

The fire test in the current Regulations is similar in its construction to the impact test. The test is actually a heat flux specification involving a fully engulfing fire in which fire temperature, duration, and emissivity/absorptivity are specified. The fire temperature (800^{0}C) is lower than that seen in the hottest areas of typical hydrocarbon fuel fires and below what particular fuels and circumstances in transport might produce. The fire duration (30 minutes) is shorter than many reported in accident accounts. The key element is that the fire fully engulfs the package for the entire duration, a condition seldom seen in real fires. Reported long duration fires generally have moved as they consume fuel and thus are not fully engulfing at any one location for a long period. High temperature fires generally are highly localized and thus allow a package to cool through thermal radiation from surfaces not immersed in the fire. The Caldecott tunnel fire in the USA [13], which is generally believed to be one of the most severe in transport, was analyzed and estimated to have approximated the heat flux required in the engineering test contained in the Regulations.

In both cases the engineering tests contained in the Regulations appear not to represent perceived accident reality. Deeper analysis reveals that the tests are representative and capable of producing the damage to a package in severe accidents. For the performance tests in the air mode the same basic process in defining performance tests was used and it should be expected that the 85 m/s impact speed and 1 hour fire will be criticized as not representing real environments, but aircraft accidents analysis indicates that coverage of a very large fraction of all accidents in the air mode is achieved.

3.2.2. Graceful failure

Package designs required to release no more than an A_2 quantity of radioactive material when subjected to performance testing might be assumed to release their total contents at just slightly more severe conditions. However, such eventualities are not expected. Rather it is expected that a package designed to meet the Regulations will limit releases to accepted levels until the accident environments are well beyond those provided in the performance standards and then only gradually allow increased release as accident environments greatly exceed the performance test levels, i.e., packages should "fail gracefully". This behaviour results from:

(1) The factors of safety incorporated into package designs;

(2) The capability of materials used in the package for a specific purpose, such as shielding, to mitigate loads when that capability is not explicitly considered in the design analysis;

(3) Material capability to resist loads well beyond the elastic limit;

(4) Reluctance of designers to use and of competent authorities to approve materials that have abrupt failure thresholds as a result of melting or fracturing in environments likely to occur in transport.

While all of these features of good package design are expected to provide the desired property of graceful failure, it is also true that there are only very limited data available on packagings tested to failure to see how release increases with severity of the accident environment. Limited test data and analyses that have been done indicate that graceful failure is a fact [14], [15], [16].

3.2.3. "Knee of the curve"

It would be relatively simple to specify a performance test for a package which would guarantee that no package would ever fail in an accident situation. Such a performance test would reduce public risk from transport of radioactive material or radiation exposure to zero, but would exact a tremendous economic toll from world economies. Packagings for surface modes designed under such a system would be much more massive than those currently in use and require many more shipments because of volume or mass limitations of conveyances.

It takes substantial additional material to accommodate the strength needed to resist impact speeds of 100 km/h or greater, or insulation needed to maintain low temperature in 3 or 4 hour fires. While such speeds or fire durations are within the scope of potential events in surface modes, current performance tests require impacts at about 50 km/h and fire duration of 30 minutes. The process of arriving at these performance criteria as well as those for the air mode relies on accumulations of accident data for the transport mode and a careful analysis to determine the point of diminishing returns or the "knee of the curve".

3.3. SUPPORTING DATA

3.3.1. Basic data

Data on which to base accident analyses have been obtained from reports on the particulars of accidents that are filed by officials on the scene and those involved in subsequent investigations. Some of the data are based on actual measurements. Other data are derived by analysis of data and inferences based on a notion of how the accident probably progressed. Some data are also based on the observations of untrained individuals and casual observers of the accident and its aftermath. Each accident report is evaluated and converted to some basic characteristics such as impact speed, character of the impacted mass, deceleration, fall height, fire duration, fire temperature, cargo exposure and other variables. Figures 1 to 4 indicate what such data look like in a format that shows frequency of occurrence as derived from accident reports, with speed shown as a fraction of cruising speed or stall speed for the aircraft involved in each accident.

3.3.2. Data analysis

Basic data is useful, but it does not include the effects of the character of the accident and the environment likely to have been experienced by the cargo involved. For instance, the damage to conveyance and the cargo could be very different if the conveyance impacted a small car, a soft bank or a bridge abutment. To account for this effect, it is normal to translate the actual impact velocity into an effective head-on impact velocity onto a surface that itself absorbs none of the energy of the impact. Such a surface is called an unyielding surface. Thus all of the available energy ends up in deformation of the conveyance and the cargo (radioactive material package). Since the analyst is interested in the cargo, it is normal to assume that the conveyance absorbs no energy; this assumption leads to conservative

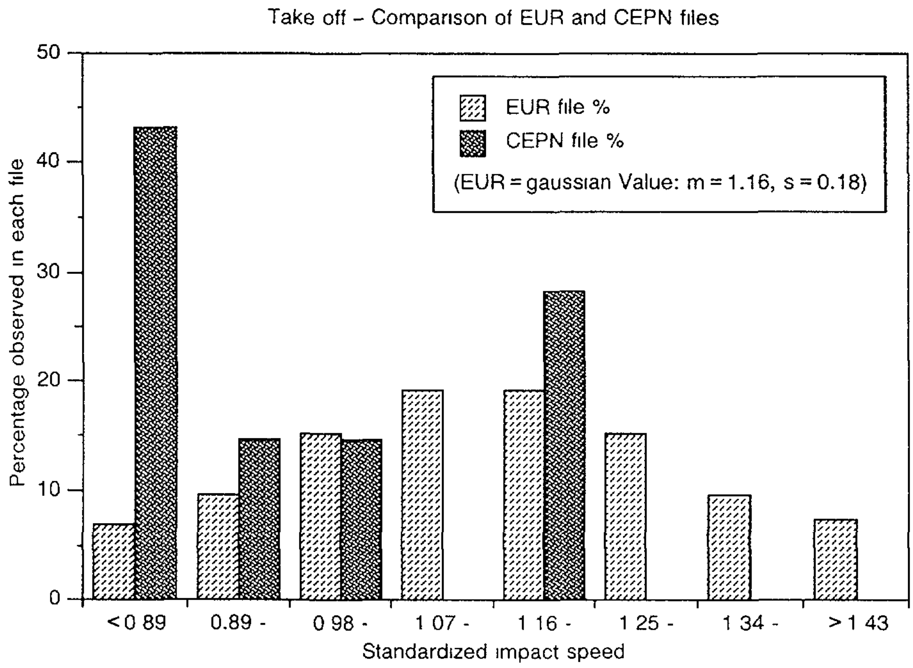

FIG. 1. Impact speed distribution in take-off accidents.

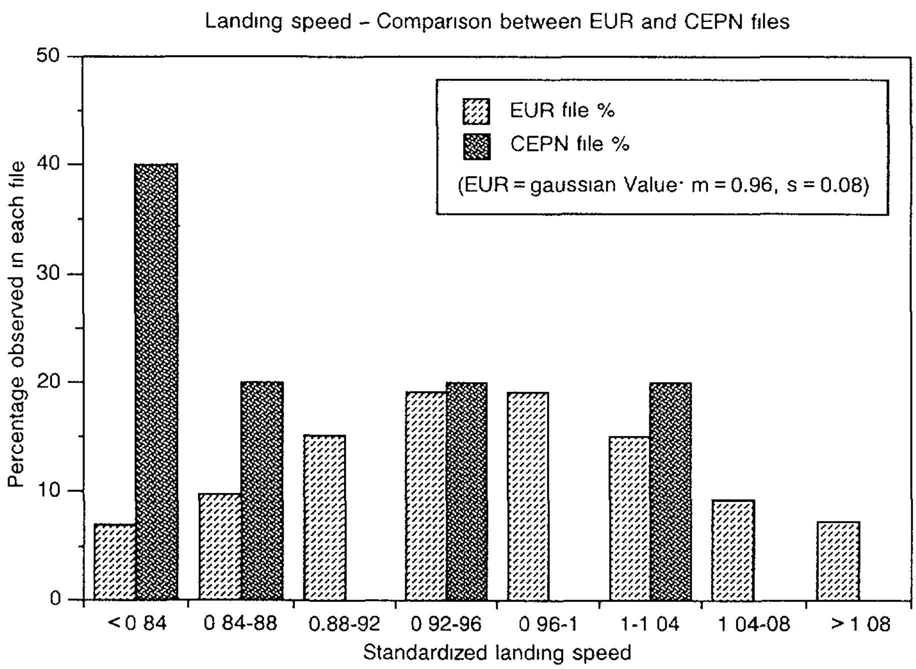

FIG. 2. Impact speed distribution in landing accidents.

analysis. With the assumption that the cargo impacts at the speed of the conveyance, the translation to effective impact onto an unyielding surface requires an effective impact speed which is lower than actual, how much lower depending on the relative strength of the cargo compared to that of the actual impacting surface. For a "hard" package and "soft" target (for example, spent fuel flask on water) the ratio of actual to effective velocity might range from 7 to 9. For similar hardness in package and surface, the ratio might be 2 or more. For concrete roadways and runways the velocity ratio could range from 1.1. to 1.4. There are very few surfaces for which the ratio would be 1.

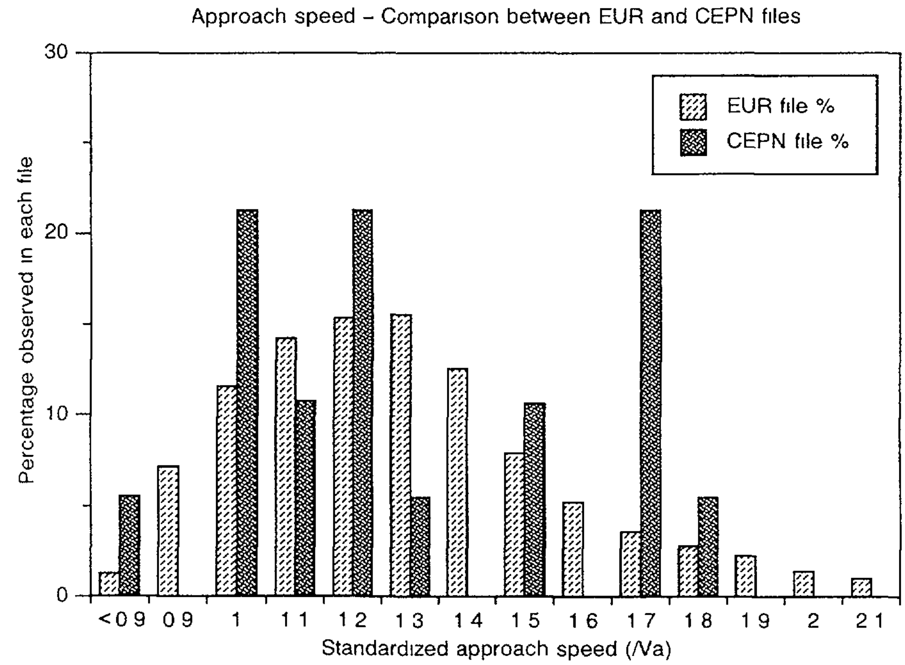

FIG. 3. Impact speed distribution in approach phase accidents.

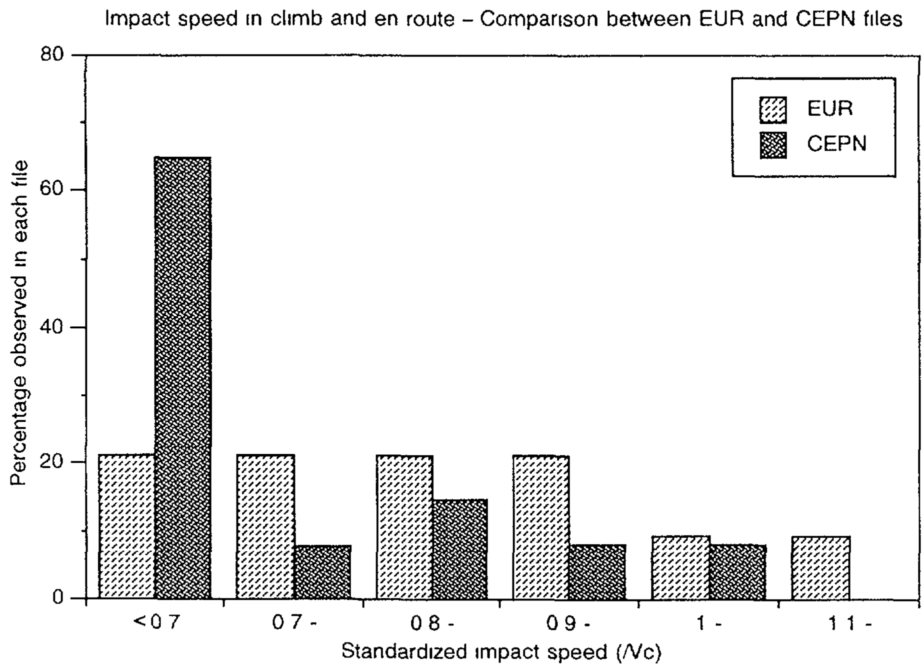

FIG 4. Impact speed distribution in climbing and en route accidents.

Conversion of the data given above to effective impact velocity is performed in order to normalize the accident environment for impact in a standard format that removes much of the variability of the accident scenarios but at the same time preserving the stress on the cargo. Figure 5 shows the impact speed data shown above converted to effective normal velocity on an unyielding target.

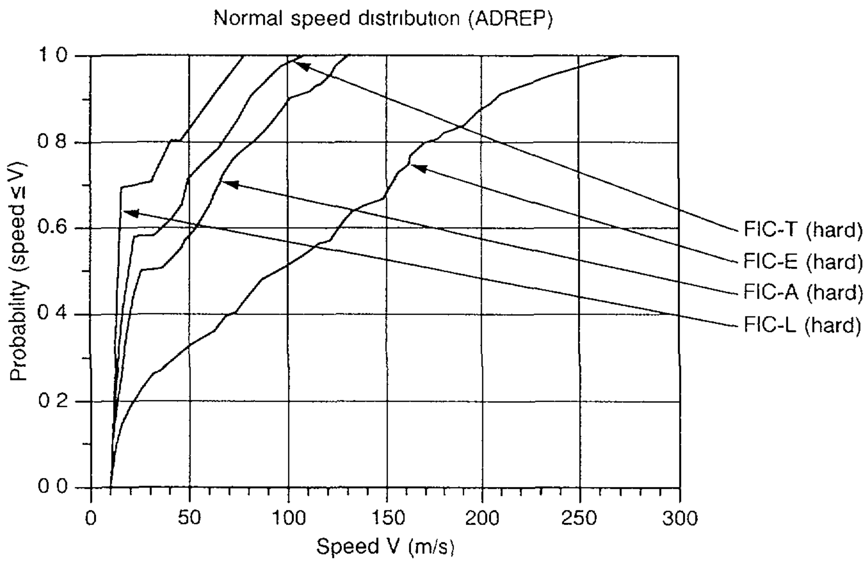

FIG. 5. Normal impact speed distribution.

3.3.3. "Knee of the curve"

Examination of the curves in Figure 5 indicates a common behaviour of curves depicting accident environment occurrences. As the speed of impact increases, the number of occurrences decreases. This means that very severe accidents are very unlikely. When the data are plotted in a format that shows the probability of exceeding a given impact velocity as shown in Figure 6, that scarcity of severe accidents shows up as a distinct bend or "knee" in the curve. This area of the curve is of interest because it indicates where increased levels of strength or fire protection built into a package begin to have less effect on the probability of failure. Designing a package for protection against successively higher impact velocities lower than those at the knee produces noticeably larger fractions of accidents resisted. But above the knee a similar increase in design velocity protection yields much smaller increases in the fraction of resisted accidents. This is the point of diminishing returns for the protection built into the package.

Requiring package design to protect against velocities much higher than the knee generally means a more massive, more complicated, and more expensive package design which achieves little increase in the protection afforded the public. In addition, it is to be expected that a design that survives impact at a speed at or above the knee will survive many accidents at speeds above the knee because of the conservatism contained in the analysis of accident data and the conversion of that data into effective impact speed onto an unyielding target. Moreover, the fact that a package is designed for graceful failure means that, at these extremes of the curves, the total consequence of packaging failure will be much less than if there were immediate and complete failure of containment.

3.4. AIR CRASH PERFORMANCE TEST SPECIFICATION

Given the more demanding environment of aircraft accidents, and the emphasis that is placed on the package design for overall safety, it is important that additional packaging requirements (general conditions and tests) be examined to preserve a level of protection in air transport accidents that is comparable to that provided in the Regulations for surface modes transport accidents.

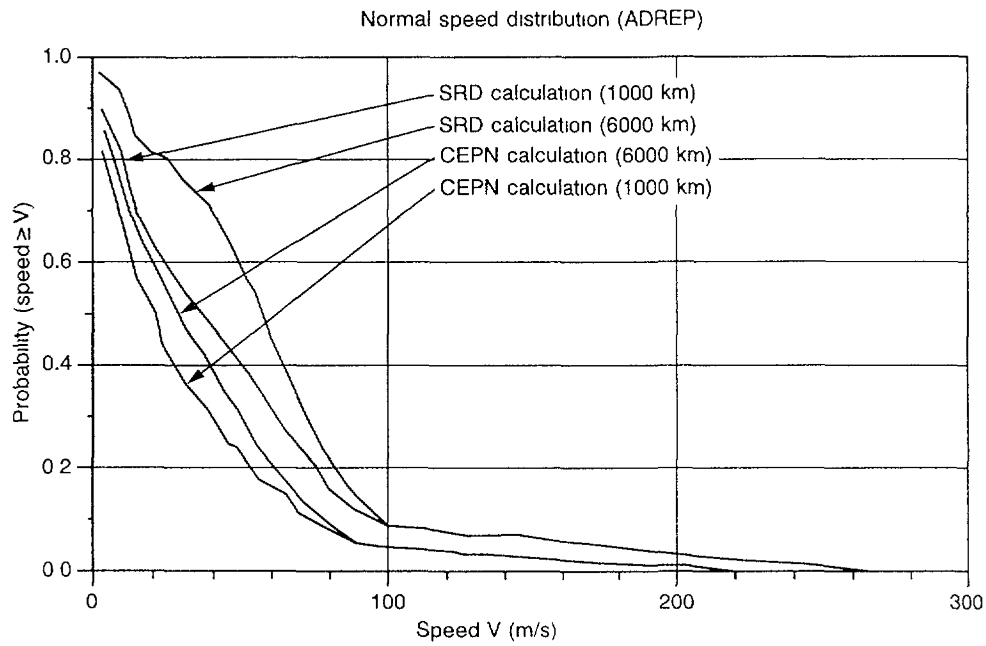

FIG.6. Equivalent impact speed distributions for two journeys.

Looking at potential accident environments in air transport, there is a consensus on the list of possible accident scenarios that are worthwhile considering. It is necessary to select tests and assign quantitative figures to test parameters and also to reduce the number of tests in order to arrive at a practical regulation while still addressing the list of scenarios. The following tests and other package design requirements are considered to represent the best approach to recognizing the more demanding environment of aircraft accidents. These tests and package design requirements are additional to those required for Type B packages.

Packages conforming with these design requirements will be denoted in the following as Type C packages (see also Section 4.2.7). In addition, it is required that the Type C package first must be qualified as a Type B package. Thus the performance tests that are proposed here must be in addition to those tests for Type B qualification. However, Type C tests could be combined with Type B tests provided the sequence and condition of Type B test requirements are met or exceeded.

Each package design must be evaluated with respect to the general conditions, described in Sections 3.4.1 to 3.4.3 that may result from a transport accident.

Fireball, burial and terminal velocity are general conditions of transport accidents that must be evaluated to ensure safety for a package design. It is recommended that guidance be provided for evaluation of these general package design conditions but that the Regulations not require tests for these general conditions.

3.4.1. Fireball condition

The design of the outermost surface of the package and of any underlying material intended to provide thermal insulation shall be such that the capability of the package to satisfy the requirements of the enhanced thermal test specified in para. xxx (Section 3.5.2 of this report) will not be impaired if the package, following performance of the enhanced puncture/tearing test specified in para. xxx (Section 3.5.3 of this report), were followed by exposure of the package to 3000°C black body radiation for a period of 5 seconds.

Surveys have shown that "fireballs" of short duration and high temperature occur commonly in the early stages of aircraft fires generally followed by a ground fire [17]. Whilst the heat input to the package arising from fireballs is insignificant, there is a need to ensure that the potential damage to the thermal insulation of the packaging is limited such that the package remains capable of enduring a prolonged fire which may ensue. Account should be taken of melting, burning or other loss of the thermal insulant or structural material upon which the insulant depends for its effectiveness.

There was a discussion of the 3000°C temperature being excessive. Data indicate a temperature of 1500°C to be more appropriate [18]. For analytical demonstration it is recommended to consider the fireball condition followed immediately by a 1 hour 800°C ground fire using appropriate analytical methods. The result of this analysis will fulfill this requirement as well as the thermal test described in Section 3.5.2 and the general design criteria defined in Section 3.5.6 of this report.

3.4.2. Burial condition

For Type C packages containing radioactive material having a relatively high heat generation rate (greater than xxx W/m^2), it is necessary for air transport to evaluate by analysis the result of burial (e.g., by impact in dry soil).

One of the potential post-crash environments is package burial. Packages involved in a high-velocity crash may be covered by debris, or buried in soil. If packages whose contents generate heat become buried, an increase in package temperature and internal pressure may result.

It is suggested that the effects of package burial be considered because they could be more severe than those of the fire test under certain circumstances.

In defining the burial environment it is necessary to specify appropriate parameters. There are two options available:

(a) assuming adiabatic conditions for 24 hours, or
(b) assuming the burial environment for a period of 7 days.

3.4.3. Terminal velocity condition

The purpose of a terminal velocity condition would be to demonstrate that the package design would provide protection in the event that the package is ejected overboard from the aircraft. This situation could arise as a result of mid-air collision or in-flight airframe failure.

It is noted that Type C package requirements already include an impact test on an unyielding surface at a velocity of 85 m/s. This test provides a rigorous demonstration of package integrity for cargo overboard scenarios. While the free fall package velocity may exceed 85 m/s, it is unlikely that the impact surface would be as hard as the unyielding surface specified in the impact test.

It is also noted that the probability of aircraft accidents of any type is low and that the percentage of such accidents that involve mid-air collisions or in-flight airframe failures is very low. If such an accident were to occur to an aircraft carrying a Type C package, damage to the package could be mitigated if the package remains attached to airframe wreckage during descent, which would tend to reduce the package impact velocity.

Although a direct head-on-mid-air collision is possible, it is more likely that a less severe collision angle would occur. Further, most mid-air collisions of large aircraft involve smaller, general aviation aircraft. In such collisions, the large mass of the aircraft carrying the cargo would serve to protect and contain its packages.

Finally, terminal velocity tests may not be practicable, considering the large drop height and target alignment, wind effects and available target sizes.

It is recommended that there be no terminal velocity for Type C packages in the Regulations at this time. However, it is recommended that terminal velocity impacts on realistic surfaces be considered for the general design criteria of this type of package.

3.5. RECOMMENDED TESTS AND THE BASES FOR THE TESTS

3.5.1. Impact test

The specimen shall be subjected to an impact on a target at a velocity of not less than 85 m/s, at such an orientation as to suffer maximum damage. The target shall be as defined in para. 618.

In specifying the conditions for the test it was taken into account that the combination of the specified velocity perpendicular to, and onto, an unyielding target in the most damaging attitude will produce damage conditions to the specimen equivalent to that which might be expected from impacts at much higher speeds onto real surfaces and at more common angles [19], [20], [21].

In particular, the impact velocity for the test was derived from frequency distribution cumulative probability studies which show that an increase in velocity beyond 85 m/s will increase only insignificantly the fraction of accidents protected against [22], [23], [24].

3.5.2. Fire test

The thermal test shall consist of the exposure of a specimen fully engulfed, except for a simple support system, in a hydrocarbon fuel/air fire of sufficient extent and in sufficiently quiescent ambient conditions to provide an average emissivity coefficient of at least 0.9, with an average flame temperature of at least 800°C for a period of 60 minutes, or shall be any other thermal test which provides the equivalent total heat input to the package. The fuel source shall extend horizontally at least 1 m, and shall not extend more than 3 m, beyond any extenal surface of the specimen, and the specimen shall be positioned 1m above the surface of the fuel source. After cessation of external heat input, the specimen shall not be cooled artificially and any combustion of materials of the specimen shall be allowed to proceed naturally. For demonstration purposes, the surface absorptivity coefficient shall be either 0.8 or the value which the package may be demonstrated to possess if exposed to the fire specified; and the convective coefficient shall be that value which the designer can justify if the package were exposed to the fire specified. With respect to the initial conditions for the thermal test, the demonstration of compliance shall be based upon the assumption that the package is in equilibrium at an ambient temperature of 38°C. The effects of solar *radiation may be neglected prior to and during the tests, but must be taken into account in the subsequent evaluation of the package response.*

This fire test has the same design criteria as those specified in para. 628 of the Regulations, with the exception of the duration, which, in this case, is 60 minutes. Statistical data on fires supports the conclusion that the 60 minutes thermal test exceeds most severe fire environments that a package would be likely to encounter in an aircraft accident.

The presence of certain materials in an aircraft, e.g. magnesium, could result in an intense fire. However, this is not considered to be a serious threat to the package because of the small quantities of such material that are likely to be present, and the localized nature of such fires. Similarly, aluminium in large quantities is present in the form of fuselage panels. These panels will have melted away within a few minutes. It was not considered credible that aluminium will burn and increase package heat load greatly.

It is recommended that this test not be sequential to the impact speed test that is described in Section 3.5.1. The Type C package will be subjected to Type B sequential impact and fire tests which provide protection against moderate accidents which could involve both impact and fire. In severe accidents, high speed impact and long duration fires are not expected to be encountered simultaneously because high velocity accidents cause fuel dispersion. Accordingly, it is recommended that the fire test be conducted non-sequentially.

3.5.3. Puncture/tearing test

(a) *The specimen shall be subjected to the damaging effects of a solid probe made of mild steel, which shall have the shape of the frustum of a right circular cone; be 30 cm long; measure 20 cm in diameter at the base and 2.5 cm in diameter at the end; and shall have a mass of 250 kg. The orientation of the probe to the surface of the specimen shall be so as to produce maximum damage.*

(b) *For packages having a mass of 250 kg or more, the base of the probe is to be placed on a flat, essentially unyielding, horizontal surface and the package dropped from a height of three metres onto the probe, striking in the position expected to result in maximum damage at the conclusion of the test sequence.*

(c) *Packages having a mass less than 250 kg are to be placed upon a flat, essentially unyielding, horizontal surface and subjected to the probe falling from a height of three metres and striking in the position expected to result in maximum damage at the conclusion of the test sequence.*

(d) *This test is to be followed by the fire test described in para. xxx (Section 3.5.2).*

It is recommended that a puncture/tearing test for Type C packages be introduced into the Regulations. The purpose of this test is to impose damage on the package that is similar to that caused by puncture or tearing in actual accidents. The occurrence of puncture and tearing situations is generally felt to be significant (McSweeney [25] quotes a probability of 0.06). The environment is qualitatively and quantitatively difficult to describe [25], [26]. Puncture can be associated with parts of the airframe and cargo. In an accident, it is also possible to encounter a puncture probe on the ground although this may be considered to be of less importance.

A consequence of puncture can be an accidental opening of the package, but this would have a very low probability of occurrence. A stronger concern would be, however, that of damage to the thermal insulation capability of a package, which would result in unsatisfactory behaviour should a fire follow impact.

Taking into account all these considerations, a puncture test was felt to be desirable. The design of the test implies the definition of a probe (having two diameters and a length), a target (assumed to be unyielding as in the current Regulations), a mass, and an impact speed. In order to specify the probe, one possibility was to refer to components of the aircraft, such as an I-beam as has been incorporated in some tests or test proposals, but it was preferred to adopt a more conventional geometric object (i.e., a cone). This shape is considered to be one that could cause considerable damage; a height of fall in the range of a few metres is representative of the collapse of structures, or bouncing within the aircraft.

Failure in engines can generate unconfined engine fragments at a rate which deserves consideration (about 20 events/year). Loss of the aircraft is only one among many possible consequences of the emission of missiles, which can be quite energetic (up to 10^5 J). However, the probability of a fragment hitting a package has been found to be very low in specific studies (about 10^{-6} per flight [27], [28]) and penetration probability, although not estimated, would be lower. Thus on a probability basis, it was considered unnecessary to define a test to cover engine fragment damage.

3.5.4. Crush test

The specimen shall be subjected to a dynamic crush test by positioning the specimen on the target so as to suffer maximum damage by the drop of a 500 kg mass from 9 m onto the specimen. The mass shall consist of a solid mild steel plate 1 m by 1 m and shall fall in a horizontal attitude. The height of the drop shall be measured from the underside of the plate to the highest point of the specimen. The target on which the specimen rests shall be as defined in para. 618.

A crush test whose parameters are the same, at a minimum, as those specified in para. 627(c) of the Regulations should be required of Type C packages with a mass less than 500 kg regardless of density.

Should an air crash occur, packages cannot be considered to be free projectiles. Interaction with the environment can result in puncture (see Section 3.5.3) or crush situations, whenever the interacting object does not have penetrating properties.

Crush situations can result from a "dynamic piling" of an array of packages (e.g., in ISO-type containers) or from random shocks with other packages, other elements of the cargo or with parts of the structure of the aircraft. Crushes can be dynamic, quasi-static or static (e.g., collapse of the structure).

The likelihood of a crush situation is significant. For packages having a high mass, the impact test ensures that they can withstand a very energetic crush. There is more concern about light packages because, for these, the energy absorption ability required to pass the impact test may be small in comparison with the kinetic energy of the rest of the masses involved; however, the relative stiffness of the rest of the cargo with respect to the package must also be considered.

Therefore, at low speeds it is possible that a light package could fail, with consequences for possible survivors. However, the proposed test addresses light packages, random interactions (but not piling), and dynamic crush (but not static load due to structural failure).

The specification of the test as shown above implies a definition of the mass limit below which the test is to be applied, the shape and speed of the impacting object, and the target. The crush test is conceived so as to replace the impact test for light packages, and continuity should be ensured between the two tests.

After detailed consideration, the restriction of the crush test to packages of less than 500 kg does not appear to be justifiable since packages considerably large than 500 kg could be present on aircraft. Therefore a crush test requirement should be applied to all packages but a technical justification for not carrying it out may be made for packages of mass greater than 500 kg.

In order to take account of the crushing of a Type C package by another package of greater mass it is recommended that the International Civil Aviation Organization (ICAO) should include in the air mode regulations an operational requirement that Type C packages should be stowed aft of any package of greater mass than the Type C package itself.

3.5.5. Immersion test

The specimen shall be immersed under a head of water of at least 200 m for a period of not less than one hour. For demonstration purposes, an external gauge pressure of a least 2 MPa (20 kgf/cm^2) shall be considered to meet these conditions.

The concept of an immersion test was raised in the context of an air accident over a body of water in which a package could be submerged for a period of time pending recovery. Large hydrostatic pressures could be applied to the package depending upon the depth of submersion. It is conceivable that submersion could follow impact, even an impact on land. Of primary concern is the possible rupture of the containment vessel in inland waters or near the coastline. Another concern is recovery of the package before severe corrosion develops.

Sequential Type B tests provide protection against impact followed by shallow immersion. The 200 m depth recommended above corresponds approximately to the continental shelf where studies indicate that radiological impacts could be important [29], [30]. Recovery of a package from this depth would be possible and often desirable. The immersion test specified in para. 630 of the Regulations is desirable. The acceptance criteria for the immersion test is no rupture of the containment system.

As the sea represents a relatively soft impact surface, it is deemed sufficient that the immersion test be an individual demonstration requirement, i.e., non-sequential. Additionally, the test should provide a demonstration of package recoverability.

It is recommended that an immersion test for Type C packages be incorporated into the Regulations. The design criteria for this test should be consistent with para. 630 of the Regulations. This test provides for standards of immersion equivalent to 200 m for a period of not less than one hour. It is noted that this test is an issue for multimodal consideration.

3.5.6. Acceptance criteria

558 a (To contain general requirements for design referring to earlier paras)

558 b A package shall be so designed that material limits will not be exceeded under the general conditions of transport accidents. Especially in the fireball and burial conditions the temperatures of the container contents and of the safety related components (moderator, seals, etc.) shall not reach values which would cause criticality and or the failure of the containment system.

558 c A package shall be so designed that, if it were subjected to the tests in paras 626 to 629 and those in paras xxx (Section 3.5.1 of this report) to paras xxx (Section 3.5.2 of this report). It would meet the requirement of paras 542 and 548 (not excluding requirements of para. 627c when density is >1000 kg/m^3*).*

It is recommended that these acceptance criteria for Type C packages be located close to para. 558. When a Type B package is subjected to the hypothetical accident tests, the primary criteria to confirm that the package has survived the test are:

(1) That the containment boundary limits release to less than an A_2 quantity in the week following the test; and

(2) That the shielding restricts radiation levels to less than 10 mSv/h at 1 metre.

These criteria were considered and accepted for the Type C package. However, issues were raised indicating that there was a potential inconsistency between the concepts used for the acceptance criteria and the exemption levels.

A lengthy discussion defined the following features of the issues:

(a) In accident situations, ICRP 40 [31] does not prescribe any particular action if the resulting radiation dose is less than 50 mSv ;
(b) Using the Q-system scenario, account must be taken of the possibility of a person remaining within 1 metre of the package for 30 minutes;
(c) Using a combination of these hypotheses, (50 mSv, 30 minutes at 1 metre), a limiting dose rate of 100 mSv/h at 1 metre may be acceptable; and
(d) This figure is ten times higher than that prescribed for Type B packages, but can be justified due to the very low probability of air accidents.

Nevertheless, for consistency with the requirements for Type B packages it was recommended that in the case of air accidents involving Type C packages, the 10 mSv/h limit at 1 metre be retained.

3.5.6.1. Allowed release

In the Q system, the A_2 quantity derived for other than Special Form radioactive material is taken as the minimum value which leads to an "acceptable" individual dose under a specific set of exposure scenarios. As a result the A_2 quantity is accepted as the largest amount of radioactive material that can be shipped in a Type A package which does not have significant accident resistance. While a Type B package does have the capability to resist severe accident forces, and may have somewhat different release conditions from that in the

Q system scenarios, it has been accepted that limiting the release from a Type B package, after subjecting it to the accident conditions of transport tests, provided for acceptable consequence mitigation in hypothetical accident situations. It is also accepted that the probability of such an accident was rather low in surface modes. This principle is carried forward into the acceptance tests for the Type C package.

Whilst there was some discussion on multiples of A_2 as candidate allowed releases at the early meetings related to development of the current Type C package concept, there was little movement towards selecting another value. In general, the Member States who were represented at the Technical Committee Meeting on Mode-Related Aspects in 1990 and those who replied to the IAEA's circular letter of 8 August 1989 (see Appendix), supported the level of a single A_2 as the allowed release standard. Few specific reasons were offered for supporting the current release level, but, presumably, the link to the Q system and existing acceptance standards for Type B tests were seen as being possible situations and, thus, were excellent precedents for the decision to use 1 x A_2/week as the acceptance criterion.

Consequently, the accumulated loss of radioactive contents in a period of one week shall not be more than 10 A_2 for krypton-85 and not more than A_2 for all other radionuclides.

3.5.6.2. Allowable external radiation

There are two fundamentally different approaches to the specification of the allowable maximum external radiation level for a package following the Type C package tests. These are discussed below:

(a) Consistency with the Regulations

Para. 542 of the Regulations specifies a maximum allowable external radiation level for Type B packages following the accident condition tests.

The goal for introducing the Type C package is to ensure similar levels of protection for the surface and air modes given that an accident occurs. To achieve this goal it is necessary to ensure the same external radiation level following the Type B accident condition and the Type C tests. Therefore, the external radiation level following the Type C package tests should not exceed that specified in para. 542 of the Regulations.

It is acknowledged that the probability of accident conditions occurring relative to the Type C package tests is, in practice, extremely low. However, the introduction of the Type C package is based on the requirement for the package to survive an acceptably high fraction of accidents (equal to the corresponding survivability fraction for surface mode accidents), and not on any requirement for an equal level of risk for the surface and air modes. It is therefore not appropriate to relax the allowable level of the Type B accident condition tests to compensate for the lower accident occurrence probability applicable to Type C packages.

It is also acknowledged that the Q system described in Safety Series No. 7 assumes a higher external radiation level following the complete loss of shielding from a Type A package. This represents a degree of inconsistency in the current scheme of radiation protection which requires justification. Nevertheless, it is considered that the testing of the Type C package is closer in concept to the testing of the Type B package, and therefore that the Type B external radiation acceptance level should be adopted.

(b) ICRP dose limit basis

The dose rate limit for Type B packages after an accident is 10 mSv/h at 1 metre from the outside surface of the package.

Although maintaining an A_2 per week release rate limit for air packages is feasible in terms of design requirements, the same may not be true of the dose rate limit for which the severity of the mechanical and thermal tests has an extremely strong influence at design level. Furthermore the limit proposed must be as realistic as possible and should consider the very low probability of a severe air accident.

This dose rate limit must be determined with due allowance for the hazard for any surviving passengers and emergency teams needing to enter the wreck.

The following basic scenario is proposed: presence of 1 hour (maximum duration of search for survivors), 10 metres from packages remaining in the cargo bay, with a maximum dose of 50 to 500 mSv. This dose, tolerable for concerted action, corresponds to the level beyond which ICRP proposes evacuation of the public.

The data result in a tolerable dose rate of 50 to 500 mSv/h at 10 metres from the surface of the package. Due to the possible presence of a number of packages a limit of 10 to 100 mSv/h at 10 metres can be adopted.

(c) Compromise proposal

Following a discussion of proposals (a) and (b), a third approach was suggested, and this was to set an intermediate allowable radiation level of 10 mSv/h at 10 metres from the surface of the package.

A lengthy consideration of proposals (a), (b) and (c) could not achieve consensus approval of one proposal. Nevertheless, the majority favoured proposal (a) based on consistency with requirements for Type B accident conditions in the current Regulations. The majority expressed the view that the introduction of a higher allowable radiation level following the Type C package tests could not easily be justified. Nevertheless, certain Member States felt that a higher value could be justified.

3.5.6.3. Demonstration of compliance

It is recommended that the method of compliance demonstration for the Type C package be consistent with the general design criteria described in para. 601 of the Regulations. The basis for this recommendation is that it is accepted that package design can be shown to meet performance requirements by many methods, such as actual testing, scale model testing or computation. This widely accepted provision in the Regulations allows the inclusion of tests that may be relevant for some packages while engineering judgment and common sense may suggest that a certain test is not needed for other packages in order to demonstrate that a requirement is met.

Attention is drawn to the difficulty in using analytical models to evaluate package response in the more demanding tests, e.g. fire and high-speed impact. It would be consistent with the philosophy of assessment of package response to tests and calculation, to enable analytical evaluation provided it is verified, accurate or sufficiently conservative. It is recognized, however, that the new test requirements may require a re-examination of this recommendation.

4. RECOMMENDED OPERATIONAL AND ADMINISTRATIVE REQUIREMENTS

4.1. BACKGROUND

The Regulations emphasize the need for strong packagings to prevent the release of radioactive materials and excessive radiation levels to the environment. Special performance requirements have been developed to ensure that these goals are achieved. Indeed, packaging standards alone achieve containment and shielding in over 97% of the accidents likely to occur for the highway mode of transport [32].

However, safety does not depend on packaging standards alone. Other methods are important components to overall safety. These methods include operational and administrative requirements. These methods do achieve a greater level of safety but at a cost of time and expense to the shippers and carriers. For this reason operational and administrative requirements are usually applied with a graded approach. The graded approach requires, among other things, that the hazard posed by the radioactive material, the activity of the radioactive material, and transport package be examined to determine the additional level of controls that need to be adopted. Excepted packages require few controls while the transport of other materials may require a sufficient number of additional controls to ensure a high probability of survival during transportation. Air transport of high hazard materials does require additional operational and administrative requirements to control the release of materials.

Operational requirements generally include those controls taken by shippers and carrier after commencement of transport to ensure that the desired level of safety is achieved during the entire transport process. Actions such as tie-downs, stowing provisions, segregation considerations, and notification requirements will achieve this goal. For air transport where the package may be subjected to extraordinary environments during a crash, operational requirement serve at least two purposes: to reduce the forces experienced by the package; and to provide information through notifications that can be used by emergency personnel responding to an incident.

Administrative actions generally occur prior to actual transport. Requirements on type of radioactive materials, quantity of radioactive materials, the form of the materials, the criticality considerations and other areas must be considered. Analogous to operational requirements, administrative requirements ensure that the proper packaging is selected prior to transport.

The following sections describe additional recommended operational and administrative requirements for the shipment of high hazard radioactive material.

4.2. BASES FOR THE RECOMMENDATIONS

4.2.1. Inclusion of all nuclides

The basis of design and use of existing packages for radioactive material is to provide a safe level of radiological protection regardless of the nuclide being transported. Early discussions about the Type C package were limited to plutonium, but it was noted that there are many nuclides which have high radiological and chemical toxicities and which may be transported by air in very large quantities. Hence, it was concluded that the Type C package should, as for Type A and Type B packages, be applicable for all nuclides.

4.2.2. Exemption levels

The limit above which the Type C package standards shall apply are as follows:

Type of radioactive material	Exemption level	Example: Am-241
Special form	3000 A_1, but not more than 100 000 A_2 for the nuclide in special form	20 TBq (100 000 A_2)
Other forms	3000 A_2	0.6 TBq (3000 A_2)

For mixtures of radionuclides, it would be necessary to refer to the rules shown in paras 304 - 306 of Safety Series No. 6.

One method of justifying the 3000 A_2 level was by the use of risk analysis techniques based on limited tests carried out on a representative Type B packaging [33]. A rough graph showing release levels vs. log energy (velocity of crash in m/s) showed releases up to 5% of contents at impact speeds a factor of 5 to 10 above the speed achieved in the 9 metre drop test and releases a factor of 10 lower for speeds a factor of 2 to 5 higher than the IAEA regulatory test.

EXEMPTION LEVEL	RELEASE
3000 A_2	100 A_2 - 10 A_2
300 A_2	10 A_2 - 1 A_2
30 A_2	1 A_2 - 0.1 A_2
3 A_2	0.1 A_2 - 0.01 A_2

With an estimated release fraction of 3×10^{-3} to 3×10^{-2} at impact speeds somewhat above 85 m/s, release levels of 10 to 100 A_2 were estimated to correspond to the upper limit of release from a Type B package in such an accident. It was accepted that this level of release was a reasonable boundary between "serious" and "high consequence" accidents. This determined the exemption level of 3000 A_2.

Using a different approach whose safety objective is the protection of the public, the environment and surviving persons, the same exemption limit of 3000 A_2 was reached. Thus, there is some consistency in these estimates.

With regard to the exemption level for special form radioactive material, it follows from the Q system that 3000 A_1 was adopted as the exemption limit for such material in parallel to the 3000 A_2 exemption level. However, for certain alpha emitters the ratio A_1 to A_2 can be as high as 10^4, which would lead to effective potential package loadings of

~3 x 10^7 A_2 not in dispersible form. This was seen as an undesirably high level of content particularly if the special form was partially disrupted in a very severe accident. It was assumed that the similarity between the special form impact tests and the Type B impact tests, implies that special form may be expected to provide a comparable 10^2 reduction in release as indicated above for Type B package allowing the source to increase by a factor of 100 to 300 000 A_2. The value of 100 000 A_2 was taken as a conservative estimate.

Radioactive material in a non-dispersible form or sealed in a strong metallic capsule presents a minimal contamination hazard, although the direct radiation hazard still exists. Additional protection provided by the present special form definition is considered to be sufficient to ship special form material by air in a Type B container up to an activity of 3000 A_1 but not more than 100 000 A_2 of the special form nuclide. French studies indicated that some special form material approved under current standards may retain its containment function under test conditions for air accidents (85 m/s impact and 1 h fire).

4.2.3. Non-dispersible form

For the air transport of radioactive material above the 3000 A_1 and 100 000 A_2 exemption limits, the concept of non-dispersible form could be a useful alternative to the Type C package by defining a "super special form" which could be transported by air in a Type B package in unlimited quantities. At present there is no proposal to introduce this concept of non-dispersible form because it was not possible to evaluate its potential practical application and needs. However, it was agreed that the concept could be addressed in the near future. A first proposal is that super special form means a solid radioactive material or a sealed capsule containing a radioactive material of a nature such that after tests with an impact of 85 m/s on a rigid surface and a 1 h fire (non-sequential), less than 3000 A_2 of material in inhalable form is released. To limit the hazard from external radiation for such super special form in Type B packages a dose rate limit equivalent to contents of 3000 A_1 for Co-60 has been suggested.

4.2.4. Criticality

The following recommendations made by a Consultants Service meeting when applied to all package types in air transport, were considered to provide adequate protection against accidental criticality:

(i) It is essential that in the case of fissile material consignments by air there should be adequate protection against accidental criticality;

(ii) It is assumed that the same enhanced severity tests recommended by TC-675 for packages whose contents exceed 3000 A_2 (i.e., a mechanical impact of 85 m/s and a thermal test of 1 hour duration, performed with different specimens and not cumulatively) should be applied, in general, to packages of fissile material in order to establish the "worst-damaged" condition;

(iii) The acceptance criteria for fissile packages after subjection to the enhanced severity tests should consist of the requirement of para. 566 of the Regulations which ensures that an individual package in isolation is subcritical.

Although the formation of arrays of packages in a high-severity accident is not considered to be a conceivable eventuality, the provisions of para. 567 must nevertheless be met in order to define the number, N, to ensure subcriticality of a consignment of packages;

(iv) However, in view of the nature of the damaging effects envisaged in high-severity accidents, it is not considered appropriate, in applying (iii) above, to allow any relaxation against accidental leakage of water into or out of the containment system, such as is provided in para. 565 of the Regulations for the standard "damaged" condition of para. 564. In the case of the "severely-damaged" condition, acceptance for the single isolated package should require subcriticality with the moderation of the contents by water which results in maximum neutron multiplication;

(v) It is pointed out that all packages of fissile material whose contents do not satisfy the general exception clauses of para. 560 of the Regulations must comply with the existing requirement for fissile package designs, as provided for in paras 561-568 inclusive.

4.2.5. Marking and labelling

In para. 438 the following sub-section (d) should be added:

(d) In the case of a Type C package design, with "Type C"

Para. 439 should be modified to read as follows:

439. Each package which conforms to a Type B(U), Type B(M) or Type C package design shall have ....

As far as marking and labelling is concerned, only minor additions to the current provisions described in Section IV of the Regulations are necessary in order to include the new Type C package in the existing system. Due to the inclusion of an air accident resistant package paras 438 and 439 have to be extended.

Paras 440-442 of the Regulations, which describe labelling, require no change.

4.2.6. Operational controls and requirements

The present Regulations have no requirements for operational controls that are specific to air transport. Indeed, para. 474 states that "packages subject to operational controls during transport..... shall not be transported by air". This paragraph refers to operational controls in the sense of attention to the package being needed during transport.

The United States of America has, in NUREG-0360 [20], imposed a number of "operational controls" for the transport of plutonium by air. The term "operational controls" is used in NUREG-0360 in a sense different to that intended by para. 474. For purposes of the Regulations, it would be preferable to consider these controls as "operational requirements". These requirements concern: stowage location, tie-down system and segregation from other dangerous goods. The need to adopt some, or all, of these requirements was carefully considered. While some of them might be desirable, it was felt that existing rules and regulations were probably adequate. It was also felt that this type of requirement falls within the responsibility of ICAO, and that that organization should consider whether further restrictions need to be applied.

Para. 456 of the Regulations requires the consignor to give prior notification of the shipment of certain packages. It was felt that this notification for packages of higher activity should also be required for Type C. Thus it is recommended that para. 456 be extended by adding:

(d) Type C packages

This paragraph requires notification to the competent authority of each country "through or into which the consignment is to be transported". This is intended to include countries of transit, but not necessarily to those being overflown (see para. 113). It was suggested that the concept of overflights requires clarification and should be reviewed for the next edition of the Regulations. However, prior notification of overflights would be difficult in practice. Planned routings are sometimes changed just before flight according to current weather conditions, and/or during flight on the instructions of air traffic control.

It was considered whether there was a need to include information on the flight plan when Type C packages are on board an aircraft. However, there was seen to be no safety need as such information would be readily and quickly available on other documentation, not only for Type C packages, but for all types of dangerous goods.

In the event of an aircraft accident in which a Type C package is involved, there should be no significant release of radioactivity as these packages are designed to withstand accident conditions. Thus initial emergency response actions can be the same as for other aircraft accidents. (Note: Emergency response actions would not be the same if higher post-accident radiation levels were allowed.) However, in most cases it will be desirable to locate and recover the package for safety and other reasons. To assist in locating the Type C package consideration could be given to the possibility of fitting each with a transmitting device.

It was suggested that some overall limit in terms of a maximum number of A_1 and/or A_2 per aircraft be imposed. However, as any such limit, if found desirable, would also apply to Type A and Type B packages it was not considered further. In any case it was felt that the number of Type C packages carried on one aircraft would already be severely limited by the requirements of Table XI of the Regulations (TI limits for freight containers and conveyances), the limits on transport index per aircraft compartment, the segregation distances from crew and passengers, the limits on total weight and the restrictions on weight distribution.

4.2.7. Package identification

At present there are no packages designed specifically to standards for air transport under the IAEA Regulations. Type A or Type B packages can be transported by air if, in addition to meeting the Type A or Type B requirements, they also fulfill the additional requirements that are specified in paras 515-517 and 433 of the Regulations.

The applicable identification system is detailed in para. 724 ("Competent Authority identification marks").

At TC-675.2 the new package was first referred to as an "Air Qualified Package" and there was a suggestion that it be referred to for short as an AQP-package. However, this name was not found to be appropriate since it might lead to misunderstanding because current packages which fulfill the requirements of paras 515-517 are in practice sometimes referred to as air qualified packages. Further, it was concluded that the package is a new type of package and therefore should be assigned an appropriate type code consistent with the current Regulations.

It was concluded that "Type C package" would be an appropriate type code.

The question was addressed as to whether or not Type B(M) packages as well as Type B(U) packages could form the basis of a Type C package design. It was agreed that only a Type B(U) package should form the basis for the Type C design. Multilateral approval would not therefore be required.

The identification mark of the Type C package would fit into the system of para. 724, and it is recommended that an addition to the listing under item (c) of para. 724 be made as follows:

Type C package design (CF for fissile material)

As far as the definition of the new Type C package is concerned (para. 134 of the Regulations) it is suggested that item (e) be added, to have the following meaning:

(e) Type C package is a packaging fulfilling all the requirements of a Type B(U) package and in addition thereto the requirements of paras xxx to paras xxx (Section 3 of this document).

4.2.8. Competent authority approval

Competent authority approvals are required in the existing Regulations for packages and shipments as stated in para. 701. The approval procedure for Type B(U) packages is laid down in paras 704-706. Packages carrying fissile material in quantities above certain limits need multilateral approval (paras 710-712). Shipment approvals are required for transport involving certain Type B(M) packages, fissile material in certain cases and special use vessels (para. 716). The contents of approval certificates for package designs is outlined in para. 729.

The new Type C package should fulfill Type B(U) requirements and in addition successfully withstand the new Type C tests. In practice this will mean that Type C unilateral package approval will follow the rules of approval given in the existing Regulations for Type B(U) packages.

It is recommended to add "*and Type C*" to the heading above para. 704, and in paras 704 and 706.

4.2.9. Grandfathering

Grandfathering, the continued use of packagings manufactured to approved designs under a previous regulatory regime, is addressed in paras 713 and 714 of the 1985 Edition of the Regulations.

As was the case with previous issues of the Regulations, the solutions for grandfathering of existing packages have been proven, in practice, to be rather difficult. In the case of the replacement of an existing design by a new upgraded design, grandfathering will most certainly be an extremely sensitive issue.

The next edition of the Regulations and its supporting documents is scheduled for publication by 1996. This will provide the first occasion to introduce the new testing and acceptance criteria for the Type C packages. Until that time, organizations wishing to transport radioactive material by air can only do so in accordance with conditions based on the 1985 edition of the Regulations. Clearly, individual states have the option to forbid this if they wish.

It is proposed that the date of entry into force of those regulations requiring a Type C package be three years following publication of the next revision of the Regulations (i.e. 1 January 1999 assuming current timescale is maintained for publication of Safety Series No. 6 by 1 January 1996).

The question of whether or not, and under what conditions, grandfathering may be applied with respect to Type C packages must be addressed by the review procedure associated with the 1996 Edition of the Regulations. For the present, it is recommended that the design and development of Type C packages should proceed as rapidly as is technically possible. It should be borne in mind that the Revision Panel, in developing the 1996 Regulations, might decide that the concept of grandfathering is incompatible with the introduction of this new package type.

5. OTHER ITEMS CONSIDERED

SAGSTRAM at its 6th meeting considered the transport of large quantities of radioactive material by air as the current most important major regulatory issue. The discussion focused on the regulatory method of addressing accidents involving the increasing number of plutonium shipments. Because these accidents are considered to be high consequence/low probability, issues involving the underlying philosophy of the Regulations and the essentially multimodal character of the Regulations must be reviewed.

5.1. RISK BASED CONSIDERATIONS

The underlying philosophy of the Regulations involves minimizing the probability of a release of radioactive material during transport and the protection of the public from actual releases. Although this philosophy minimizes the risk, it is not in itself a risk assessment based philosophy. However, probabilistic risk assessment (PRA) may be useful in determining the overall need for the Regulations. The application of PRA to regulation formation was reviewed and support was expressed for the position reached at the seventh SAGSTRAM meeting that PRA has applications in understanding the level of risk, but that these applications are limited in the actual process of setting test levels and details of the Regulations.

In a similar manner, to avoid the proliferation of regulations based on mode of transport, the Regulations attempt to maintain a multimodal character. The main benefit is efficiency of regulation. For example, if separate package requirements for each mode of transport were developed, the complications are obvious. However, since all modes of transport are not the same, special circumstances may demand that specific requirements be developed.

5.2. MODE SPECIFICITY IN THE REGULATIONS

The Regulations have been maintained in a state of being almost mode independent for some time. SAGSTRAM has expressed the concern that the effort to provide regulations in the air mode could set a precedent for mode specific requirements elsewhere in the Regulations. Were such an event to occur, the proliferation of requirements could increase the number of regulations to be enforced as well as the number of different possible packages for shipment, and thus raise complexity, cost and likelihood of dangerous errors in shipment.

What, then, is the likelihood of occurrence of this cascade effect of mode specific regulations? It was considered that such an event is unlikely, provided that the response of the IAEA to the regulatory initiative is appropriately limited in scope to those areas already covered in other modes and for which the air mode is demonstrably unusual. This is already the case in the Regulations; the only real difference between the air mode and the other modes of transport relates to the pressure difference that can occur across package boundaries in high altitude flight.

Thus, to minimize the "modal cascade", the new air regulation should address those accident environments already addressed in the Regulations for which there is a clear difference in the air mode, in the probability of the accident environment or in its severity. If new environments are defined for protection in the air mode that can also exist in the surface modes, the tendency will be to attempt to incorporate such protection for the surface modes. If there is a neglected failure mechanism, its effect is probably justified and such a modal cascade might not be objectionable. But given the positive experience with the Regulations over 30 years it seems unlikely that there are many hidden features of accidents that current regulations do not protect against.

Under the conditions defined above, the incorporation of higher speed impact is clearly justified. This is the accident environment which has great potential to exceed the capability of ordinary Type B packagings. Similarly the thermal impact to packagings in the air mode has the potential to be somewhat greater than in surface modes as a result of the amount and proximity of fuel to the packages, the potential for burning of aircraft structural materials and the potential for fires in areas where no effective fire-fighting can be provided in short time. In addition, a fuel fire in an aircraft crash, instead of being a relatively rare event as it is on road and rail, is the dominant scenario.

Other accident environment-related tests and proposed features of the air transport regulations were examined for existence in the current Regulations and for well defined justification for a difference in treatment in the air mode. There was a general belief that the new provisions for air transport of radioactive material in large quantities or with high activity as presented in this report will not lead to a modal cascade of regulations.

6. CONCLUSION

The process for developing additional regulatory language for the air transport of radioactive material in large quantities or having high activity has been moving forward for approximately four years. This document is a significant milestone in that process because it provides the first draft of regulatory text for possible inclusion in Safety Series No. 6. The draft text contained herein is, however, only a limited indicator of progress. Many other aspects of the regulatory framework that will circumscribe air shipments in which low probability/high consequence accidents are of concern were discussed and resolution is left to questions of wording and the testing for compatibility with the remainder of Safety Series No. 6 and the international air transport regulatory community.

However, there are significant issues that remain. These issues include those dealing with how to include special form material; how (or whether) to pursue an exemption criterion based on non-dispersibility; and the post-test acceptance criteria for shielding. The latter item seems to be calling into question the general question of post-test radiation levels for any package/mode and hence may not be a specific question in the Type C package test requirements.

Progress in accommodating mode related issues affecting the Regulations will continue with further technical meetings and the Revision Panels that will be convened in 1993 and 1995. In the interim, this report indicates the broad areas of international agreement and the IAEA commitment to pursuing rational and technically defensible modifications to the Regulations to meet the demands of changing international transportation environments.

Appendix

IAEA CIRCULAR LETTER OF 8 AUGUST 1989

INTERNATIONAL ATOMIC ENERGY AGENCY
AGENCE INTERNATIONALE DE L'ENERGIE ATOMIQUE
МЕЖДУНАРОДНОЕ АГЕНТСТВО ПО АТОМНОЙ ЭНЕРГИИ
ORGANISMO INTERNACIONAL DE ENERGIA ATOMICA

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DIAL DIRECTLY TO EXTENSION
COMPOSER DIRECTEMENT LE NUMERO DE POSTE

The Secretariat of the International Atomic Energy Agency presents its compliments to the Ministries of Foreign Affairs of Member States of the Agency and has the honour to inform them that the Seventh meeting of the Standing Advisory Group on the Safe Transport of Radioactive Material (SAGSTRAM), which was held in Vienna from 10 to 14 April 1989, considered the issue of mode-related aspects of the Agency's Regulations for the Safe Transport of Radioactive Material and recommended that special regulatory provisions be required for the transport of large quantities of radioactive material by air.

In particular SAGSTRAM identified and recommended acceptance of some specific provisions on which consensus agreement had been reached in earlier meetings. These provisions are listed in the Appendix to this letter.

SAGSTRAM also identified some items on which a consensus does not yet exist. It recommended that these should be addressed by an Advisory Group meeting (AGM) scheduled to take place in 1990. The items so identified are also listed in the Appendix to this letter with some further considerations which SAGSTRAM advised should be referred to the AGM. As one of the preparations for the AGM, SAGSTRAM advised that Member States' views on these listed items should be solicited in advance by mail.

The Secretariat accordingly now invites Member States to submit comments on the items listed in the Appendix. Information is requested on any significant impacts that would result from adoption of the proposed provisions; in particular, what materials and shipments would be affected by them and what would be the expected magnitude of the effects. This information is being sought because SAGSTRAM noted that recent consideration of the problems of transport by air has so far centred on the special case of plutonium.

Member States are cordially invited to provide any additional justification of the proposed regulatory provisions which they may have available. In this respect the suitability of the proposed exemption level of activity is particularly of interest.

Additional information on accidents involving fires in all transport modes would also be welcomed.

It would be much appreciated if responses to this enquiry could be provided to the Agency by 29 September 1989.

The Secretariat of the International Atomic Energy Agency avails itself of this opportunity to renew to the Ministries of Foreign Affairs the assurances of its highest consideration.

8 August 1989

Attachment

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93-00493