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Assessment of Aircraft Accident Conditions in the Context of Test Requirements for Type C Packages Containing Radioactive Material

Final Report of a Coordinated Research Project on Accident Severity during the Air Transport of Radioactive Material (1998–2006)

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ASSESSMENT OF AIRCRAFT ACCIDENT CONDITIONS IN THE CONTEXT OF TEST REQUIREMENTS FOR TYPE C PACKAGES CONTAINING RADIOACTIVE MATERIAL

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IAEA-TECDOC-1965

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FINAL REPORT OF A COORDINATED RESEARCH PROJECT ON ACCIDENT SEVERITY DURING THE AIR TRANSPORT OF RADIOACTIVE MATERIAL (1998–2006)

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 2021

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FOREWORD

The production and use of radioactive material and the activities related to the production of nuclear power involve the transport of radioactive material through the public domain. In accordance with its statutory requirements, the IAEA publishes Regulations for the Safe Transport of Radioactive Material (the Transport Regulations), which undergo continuous review and are revised as necessary. The IAEA's Transport Regulations, which are prepared in consultation with experts from Member States, have been adopted, essentially in their entirety, in the regulations governing the transport of radioactive material published by international transport organizations and by many Member States. The Transport Regulations, inter alia, stipulate a set of package performance requirements intended to simulate serious accidents. Through the widespread adoption of the Transport Regulations, a very high standard of safety in transport has been achieved.

In 1996, the IAEA published IAEA Safety Standards Series No. ST-1, Regulations for the Safe Transport of Radioactive Material, which specified requirements for the safe transport of radioactive material for various transportation modes, including the specification of a new type of packaging (Type C) with enhanced performance requirements for air shipments. Type C package requirements apply to shipments of radioactive material by air with an activity greater than the specified limits.

In 1998, an International Civil Aviation Organization (ICAO) working group recommended that the IAEA Secretariat initiate a coordinated research project (CRP) to consider research on aircraft accident frequency and severities to validate Type C package test requirements. It further recommended that relevant issues be identified, including data collection, data analysis and treatment of results, and that the CRP results be incorporated into the review process for ST-1.

This publication represents the outcome of the original research conducted during this CRP, which concluded in 2006. The IAEA convened a meeting in 2014 of technical experts from Member States to review the methodology and conclusions of the CRP and to determine if they remained valid some ten years after completion of the study. The meeting, held in October, was attended by 27 technical experts from 14 Member States (Austria, Canada, China, France, Germany, Greece, Italy, Japan, Republic of Korea, Pakistan, Poland, Russian Federation, Sweden and the United States of America) and 6 international organizations (European Commission/Joint Research Centre, International Federation of Air Line Pilots' Associations, International Maritime Organization, International Organization for Standardization, World Nuclear Transport Institute and United Nations Economic Commission for Europe).

The experts concluded that the methodology, data rationalization and conclusions of the report remained valid and, as such, the report could be published without further need of revision. The experts also recommended that Member States be encouraged to record and review data on transport accidents to assist in future reviews of such accidents and their influence on regulatory requirements for the transport of radioactive material. Since the research under the CRP was conducted, the Transport Regulations have been revised and published in 2009, 2012 and 2018. During these review and revision processes, there were no submissions by Member States to revise the requirements relating to the performance requirements for Type B or Type C package designs, evidencing that there has been no new research or analysis of accidents that would provide a challenge to the research, analysis or conclusions reached in this CRP. Furthermore, there is no indication that there have been changes in the types of aircraft involved in aviation, or in the types and severity of accidents involving aircraft that would contradict the findings of this CRP.

This review of accident data is expected to continue on a regular basis to ensure that the IAEA's Transport Regulations remain current and to ensure that package designs perform as required in an accident.

The IAEA officers responsible for this publication were A. Nandakumar and E. Reber of the Division of Radiation, Transport and Waste Safety.

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1. INTRODUCTION

1.1.BACKGROUND

The safe movement of radioactive material by air requires compliance with the IAEA's Regulations for the Safe Transport of Radioactive Material, 2018 Edition ((IAEA Safety Standards Series No. SSR-6 (Rev. 1)) [1]. These regulations include a set of package performance requirements intended to simulate serious accidents (paras 726-737 of the Transport Regulations). Through the widespread adoption of the Transport Regulations, a very high standard of safety in transport has been achieved.

The basis of the requirements stems from a graded approach. For small hazards, sufficient but minimal requirements are imposed. As radioactivity increases, additional packaging requirements limit the probability of occurrence and the effects of the hazard.

In 1996, the IAEA published Regulations for the Safe Transport of Radioactive Material (IAEA Safety Standards Series No. ST-1 [2], subsequently revised and published as TS-R-1 (2005 Edition) [3]). These regulations specified requirements for the safe transport of radioactive material for various transport modes, including the specification of a new packaging type with enhanced performance requirements (Type C) for air shipments. Type C package requirements apply to shipments of radioactive material by air with an activity greater than $3000A_1$ or $100\,000A_2$, whichever is lower, for the special form radioactive material; or $3000A_2$ for all other radioactive material. The requirements concerning Type C packages in the Transport Regulations in force at the time of publication, i.e., in SSR-6 (Rev. 1) [1], are the same as those that were considered by the CRP.

One of the test requirements for a Type C package is that the specimen shall be subjected to an impact on an unyielding target of not less than 90 m/s. The derivation of the 90 m/s impact speed was a long and intensively discussed issue, since 1988, during the IAEA's revision process of the Transport Regulations. It was derived from the studies in United Kingdom (1980), France (1989) and the USA (1990) on accident impact probabilities based on the best accident data available at that time. Analysis of these studies showed that there was a range of equivalent, perpendicular impact velocities from 85 to 100 m/s onto an unyielding target for 90–95% of all severe aircraft accidents. Beyond this range, even large increases in impact test velocities produced relatively small improvements in safety. It was noted that such impact velocities onto an unyielding target covered a larger range of airspeed impacts due to mitigating factors of target hardness, impact angle, energy absorbed by the conveyance, over performance, and subsequent 'graceful failure' of real packages designed to IAEA standards. Considering that this range of impact velocities had limited influence on the resulting level of safety and that different kinds of uncertainties were present in different studies; the value of 90 m/s was accepted as providing a level of safety for the Type C package in air transport equivalent to that for Type B packages in surface transport.

1.2.OBJECTIVE

Since significant changes in the Transport Regulations were likely to raise concerns, with the changes concerning the air transport of radioactive material being no exception, the IAEA Secretariat conducted a coordinated research programme (CRP) on aircraft accident frequencies and severities to investigate the validity of Type C package test requirements. The research also focused on data collection, data analysis, and treatment of results, with these results being incorporated into the review process of the IAEA Transport Regulations. The methodologies and data rationalization from the original CRP are being published in order to: document the results of the CRP; establish a historical record of the basis of prior review processes; and to provide a clear framework for future review processes.

1.3.SCOPE

This publication represents the outcome of the research conducted during this CRP, focusing on the high speed accident environment. The results are expected to lead to increased knowledge in the post-crash survivability of packages containing high activity radioactive material.

1.4.STRUCTURE

Following this introduction, Section 2 focuses on the test requirements for Type C packages. Section 3 comprises a comparative study of flight data recorder test requirements and Type C package test requirements. Section 4 presents a collection of aircraft accident data. In Section 5, an analysis is presented of the mechanical impact accident environment, while Sections 6 and 7 analyse the thermal accident environment and water immersion accident environment, respectively. Section 8 examines accident sequences, while Section 9 looks at aircraft accident rates. Section 10 estimates the transportation risk for the air transport of packages with large quantities of radioactive materials, while Section 11 presents a final discussion and conclusions. Appendix I is a comparative study of Type C package and flight data recorder test requirements, while Appendix II presents a reproduction of the questionnaire used to gather information on air accidents that was developed for this CRP and distributed by ICAO. Appendix III lists the States which responded to the questionnaire. Appendix IV discusses equivalent impact velocity, while Appendix V analyses aircraft accident data. Appendix VI analyses the thermal environment in accidents, while Appendix VII describes selected accidents involving fire. The report concludes with a list of definitions and terminology.

2. TEST REQUIREMENTS FOR TYPE C PACKAGES

The parameters of interest based on these standards are primarily test performance requirements for package designs that characterize severity levels associated with aircraft accidents. Packaging must comply with the requirements of para. 669 of Ref. [1], which are identical to those of para. 667 of Ref. [3], following the cited tests and test sequences specified. The following is a brief discussion of the specifications for Type C packaging. Details of each requirement can be found in the IAEA Regulations for the Safe Transport of Radioactive Material, SSR-6 (Rev. 1) (2018 Edition) [1]. Prior to the introduction in 1996 of Type C packages in the IAEA Regulations (ST-1 [2]), Type B(U)/(M) packages were permitted to carry radioactive material by air subject to the limit on the radioactive contents specified in the Competent Authority approval certificate. However, ST-1 [2] introduced limits on the activity content in Type B(U)/(M) packages if they are being transported by air. The relevant para. 433 from the IAEA Transport Regulations [1] is reproduced below.

"433. *Type B(U)* and *Type B(M) packages*, if transported by air, shall meet the requirements of para. 432 and shall not contain activities greater than the following:

(a) For *low dispersible radioactive material* — as authorized for the *package design* as specified in the certificate of *approval*,
(b) For *special form radioactive material* — $3000A_1$ or 10^5A_2, whichever is the lower;
(c) For all other *radioactive material* — $3000A_2$."

The Transport Regulations provide that, if activities in excess of the specified limits had to be transported by air, then Type C packages shall be deployed for the purpose. This requires the package performance to be evaluated against tests simulating serious accident conditions of air transport. The relevant paragraphs from the Ref. [1] concerning tests for Type C packages are described in Section 2.1.

2.1.TESTS FOR TYPE C PACKAGES

"734. Specimens shall be subjected to the effects of each of the following test sequences:

(a) The tests specified in paras 727(a), 727(c), 735 and 736, in this order;
(b) The test specified in para. 737.

Separate specimens are allowed to be used for each of the sequences in (a) and for (b)."

The requirements for the testing of packaging designs are summarized in Table 1.

TABLE 1. PACKAGING TESTING SPECIFICATIONS

Severe accident environment	Testing performance specifications	Para. in SSR-6 (Rev. 1) [1]
Mechanical impact	9 m drop	727(a)
	500 kg flat plate falling from 9 m	727(c)
	250 kg probe falling from 3 m (or drop on probe from 3 m)	735
	impact of 90 m/s	737
Thermal environment	Engulfing fuel/air fire of 800°C for 1 h	736
Water immersion environment	Under 15 m of water for 8 h	729
	Under 200 m of water for 1 h	730
Sequence of accident environments	9 m drop 500 kg crush 250 kg puncture-tearing 800°C fire for 1 h	734(a)

3. COMPARATIVE STUDY OF FLIGHT DATA RECORDER AND TYPE C PACKAGE TEST REQUIREMENTS

3.1. INTRODUCTION

A major regulatory issue raised during the development of the IAEA Transport Regulations [2] was the impact test velocity requirement of the newly designated Type C package. Several international bodies suggested that the impact test velocity requirement of 90 m/s for the Type C package, intended for the air transport of large quantities of radioactive material, may be less stringent than the aircraft flight data recorder (FDR) or cockpit voice recorder (CVR) impact test requirements.

FDRs were used for comparison purposes with Type C package test requirements because they have been used extensively in millions of flights and are subjected to similar tests. The primary differences between testing specifications for FDR and Type C packages are in survivability and usage following testing. The purpose of an FDR is to record aircraft parameters and other flight information prior to an accident so that the information may be used to assist in determining the possible cause of the accident. Therefore, the primary crash survival requirement for the FDR is that following crash survival tests, the recorder should be capable of preserving and replaying the data recorded in the memory module. It has been found that very few FDRs have been damaged to the extent that it was not possible to retrieve the data.

For a Type C package for the transport of radioactive material, the primary objectives of the package are to retain sufficient shielding of the radiation at the surface of the package and restrict the leakage of the radioactive contents to very stringent regulatory quantities. In general, this requires that there be less physical damage to a packaging designed for radioactive material when compared with an FDR following testing.

The project undertaken by Bosik Consultants Limited (BCL) under contract for the Canadian Nuclear Safety Commission (CNSC) (then called the Atomic Energy Control Board) [4] investigated this issue with the objective of obtaining a better understanding of the differences between the impact test requirements of a Type C package and an FDR. The tests were conducted at the National Research Council of Canada Flight Impact Simulator Facility in Ottawa, Canada.

The primary objective of this project was to better understand:

- The differences between Type C packages and the FDR accident condition test requirements;
- If the test standards for Type C packages and the FDR could be compared;
- How a Type C package would behave if tested to the FDR impact test requirements.

The project involved:

- Testing of the FDR to Type C package mechanical test requirements (9 m drop, dynamic crush, puncture-tearing and impact at 90 m/s);
- Testing of the internal components of a Type B package (in the absence of a Type C package) to the impact test requirements of an FDR.

The FDRs which were studied included those based on an old design (i.e. 1000*g*) as well as those meeting the current requirements (3400*g* and solid state designs). An FDR rated for 3500*g* was propelled at 90 m/s, impacting onto an essentially unyielding target. A second recorder was tested for the other series of mechanical tests required for the Type C package to withstand accident conditions. This consisted of the 9 m drop test, followed by the dynamic crush test (500 kg mass drop from a height of 9 m onto the specimen) and then the puncture test (250 kg probe drop from a height of 3 m above the intended impact point of the specimen). The enhanced thermal test was not performed.

A test was then carried out on the internal components of a Type B package without the outer drum and wooden inserts, known as the overpack, in accordance with the FDR impact shock test performance specification. The impact shock test specification for FDRs requires that an impact shock be applied so that the energy content of the impact shock is equivalent to a half-sine wave shock of 6.5 ms duration and a peak acceleration of 33 342 m/s^2 (3400*g*). This acceleration pulse is equivalent to an impact velocity of 138 m/s.

Based on the test results, FDRs may not survive the Type C test requirements; however, Type C packages would likely survive the FDR crash survival testing requirements.

3.2. DISCUSSION OF RESULTS

Appendix I presents the results of tests on an FDR using the Type C package impact testing requirements and the results of impact tests done on a Type B package without an overpack in accordance with the FDR impact shock test specification.

FDRs have a higher impact test velocity requirement as compared with the Type C package requirements. However, in this test programme, when subjected to the Type C impact test requirements, the FDR was severely damaged to the extent that it was unlikely that the recorded data could have been retrieved. On the other hand, the Type B package tested without the overpack survived the FDR impact test specification requirements with only minor deformation.

For the tests carried out in this project, the peak forces acting on the FDR when impacting the rigid plate at the Type C impact of 90 m/s were found to be approximately three times greater than that required for the FDR specification.

For impacts onto the essentially rigid target all of the kinetic energy of the package is absorbed by deformation of the package. For impacts onto real yielding targets the kinetic energy is absorbed by deformation of the target as well as by deformation of the package. The severity of damage is therefore seen to be greater when the specimen is subjected to the Type C impact test requirements.

3.3. CONCLUSION

The study showed that the test requirements and acceptance criteria for FDR and Type C package were different and no direct comparison of the impact test criteria could be made. The acceptance criterion for a radioactive material package is a very low level of leakage of the contents, whereas FDRs must allow retrieval of the data contained on the recording media.

The target hardness has a major influence on the survivability of the test specimen. The impact velocity for the performance specification of the FDR is higher than that for the Type C packages. However, the FDR specification does not require all the impact energy to be absorbed by the FDR. Because of the Type C impact of 90 m/s onto an unyielding target, the peak acceleration of the specimen was determined to be about three times more than that required for the FDR specification. The level of damage was therefore seen to be greater when the specimen was subjected to the Type C requirements.

Based on the test results, the FDR may not survive the Type C test requirements. However, a Type C package would likely survive the FDR crash survival testing requirements. It should be noted that a Type C package differs significantly in size, mass and stiffness and the test may not be applicable to other designs.

4. AIRCRAFT ACCIDENT DATA COLLECTION

An extensive effort was made in this CRP to collect, review, and record pertinent worldwide aircraft accident data for use in developing levels of severity in accident environments. This effort included three phases of activity. The first phase was a review of the complete set of worldwide accident data to identify those accidents that best represented commercial aircraft operations and severe accident environments. The second phase involved collecting detailed data from aircraft accident reports, accident files and accident investigation organizations of States where the accident occurred. The third phase included the development of an accident database to evaluate severity in accident environments.

4.1.IDENTIFICATION OF REPRESENTATIVE AIRCRAFT ACCIDENTS

The preliminary review of worldwide aircraft accidents since the end of World War II identified over 5000 accidents involving all types of aircraft and aircraft operations. Given the time and resources available, it was not possible to evaluate this large number of accidents to derive data pertinent to the objectives of the CRP. Therefore, the CRP concentrated on identifying accidents representative of modern aircraft and involving the most severe accident environments.

Accidents involving large commercial aircraft were considered to result in the most severe accident environments since these types of aircraft are normally used in cargo operations, have operating envelopes in the upper velocity range, and carry large amounts of fuel. Therefore, the evaluation of the data was limited to those accidents involving civilian commercial aircraft operation for two aircraft weight classes: (1) aircraft with a maximum takeoff weight between 27 001 and 272 000 kg; and (2) aircraft with a maximum takeoff weight over 272 000 kg. These weight ranges correspond to ICAO Category 4 and Category 5, respectively, as defined in the ICAO Accident Database Report (ADREP) database. All types of aircraft are considered: jets; turboprops; and reciprocating engines driven fixed wing aircraft.

Additionally, those accidents that resulted in the destruction of the aircraft were identified. Accidents involving fatalities or serious injuries without related destruction of the aircraft were not considered. However, aircraft accidents were not restricted to those events that occur during normal flight operations; accidents during ground operations were also included. Applying these criteria to the overall number of aircraft accidents resulted in a reduction of the number of accidents relevant to the project to about 800 — still too many accidents to evaluate, given the time and constraint on resource. Further screening reduced the number of accidents for detailed evaluation to a more manageable level.

It was concluded that the most recent accidents would be most relevant when considering the type of aircraft most likely to be used in cargo operations. The more recent accidents are also the best candidates to have more complete information in their accident report and the best potential for obtaining additional information from the accident investigators. Therefore, initial efforts at collecting and evaluating data concentrated on accidents that have occurred since 1990. Considering that the accident rate (for aircraft destroyed) for aircraft with a maximum certificated takeoff mass greater than 27 000 kg is about 35 accidents per year, it seemed reasonable to give the highest priority to 336 accidents that occurred between 1990 and 2000. If additional accidents were required for the analysis, then the previous ten year period could be included. If necessary, this could be extended further to another ten year period, going back to 1970.

Since the 336 accidents since 1990 still represent a very large number to be considered, the CRP participants agreed to use a 'coarse filter' for prioritizing the large number of accidents and for developing a better understanding of the most serious air transport accidents. It was recognized that the application of this coarse filter would concentrate on only the most serious impact accidents in the spectrum of accidents involving total aircraft loss. The coarse filter was defined by using a normal impact velocity, as discussed in Section 5, of greater than 60 m/s. The normal impact velocity compares the recorded data to the relationship between calibrated air speed, altitude and true airspeed. This coarse filter would identify the accidents of greatest interest to the CRP. The filter was tested by applying it to 21 accidents involving total aircraft loss in the United Kingdom, or involving aircraft registered in the United Kingdom (5700 kg or above) but occurring outside the United Kingdom between 1 January 1980 and 30 September 2000. Based on the accident summaries, this method eliminated 14 of the 21 accidents. Most of the remaining seven accidents are expected to have 'normal' impact speeds of less than the 90 m/s test required for Type C packages.

The application of the accident selection criteria and coarse filter resulted in the identification of approximately 135 accidents that have occurred between 1990 and 2000 involving aircraft with a certificated takeoff mass greater than 27 000 kg and with impact velocities greater than about 60 m/s. However, limiting the evaluation to high speed accidents also eliminates accidents involving fire and immersion. In particular, other evaluations have shown that recorded accident fire duration varies inversely with impact velocity. This behaviour is due to the fact that higher speed impacts tend to disperse the available fuel, leading to a shorter fire duration, while lower speed impacts tend to result in the available fuel collecting into pools or structures where the fuel is more slowly consumed. Therefore, data concerning fire and immersion from all of the aircraft accidents that occurred between 1990 and 2000 needed to be considered.

4.2.AIRCRAFT ACCIDENT DATA COLLECTION

Actual data reported in accident reports are not readily comparable to test requirements for packaging. The emphasis of accident investigations and reports is to investigate the cause of the aircraft accident and, particularly for passenger flights, to address safety related issues. These recorded data had to be supplemented with additional data that can be used to derive parameters that are comparable to packaging requirements. This additional information had to be collected to the extent possible from the accident investigators of the particular accident since they could have information that might not have been provided in accident reports.

To facilitate the collection of additional information, two data questionnaires were developed to gather information that can be used to derive accident parameters if such parameters are not readily available in the accident reports, or to verify or clarify the information that is recorded. The first questionnaire addressed information concerning impacts. The second questionnaire addressed information concerning fire and immersion.

The ICAO ADREP database was used as a 'test' to fill out these questionnaires. From this test it was observed that additional information was needed before the intended analyses concerning packaging requirements could be carried out. The questionnaires were adjusted by requesting more detailed information about the impact location, firefighting efforts, and weather conditions.

The guidance material for completing the impact information questionnaire and the questionnaire are given in Appendix II. Using these questionnaires and the ADREP database, a list of accidents involving aircraft with a maximum certificated takeoff mass greater than 27 000 kg and resulting in total destruction of the aircraft was generated. This list of 336 accidents since 1990 included information on the date of the accident, the State that investigated the accident and a summary report for each accident.

The number of potential high speed impact accidents was identified as 135 by applying the coarse filter to the 336 accidents. Information readily available from the ADREP database was used to partially complete the impact parameter questionnaire for these potential high speed impact accidents.

For fire accidents that were not included in the potential high speed impact accidents, information readily available from the ADREP database was used to partially complete the simplified specific fire/immersion accident questionnaire for these additional fire accidents.

For water immersion accidents that were not included in the potential high speed impact accidents, information readily available from the ADREP database was used to partially complete the simplified specific fire/immersion accident questionnaire for these additional immersion accidents

These lists of accidents were then sorted into the States where the accident occurred and the partially completed questionnaires were used to gather additional information needed for the evaluation of packaging test requirements. To gather as much data as possible, the partially completed questionnaires, along with the guidance material, were sent to the accident investigation units of the ICAO Member States in which the severe aircraft accidents had occurred. The States that responded to the questionnaire are listed in Appendix III. The CRP participants followed up on the questionnaires sent to their respective States.

4.3.SUMMARY NOTE ON DATA COLLECTION

At the outset, the CRP noted that there was data on 5000 aircraft accidents post World War II. Upon determination of the aircraft categories and the period for which the data could be relevant to the CRP, the number of related aircraft accidents was 336. In two events, two aircraft were involved, thus the number of aircraft in the data base was 338. The criterion of high impact velocity, i.e. an impact velocity greater than 60 m/s, resulted in 135 accidents available for consideration. In response to the questionnaires sent to various States, 66 data sets were collected. Correcting for events involving two aircraft yielded 64 accidents. Of these, one incident related to an aircraft of a category considered not relevant to the study. Of the remaining 63 accidents, 10 occurred (two in the United Kingdom and eight in the USA) during periods outside the range of dates considered in the study. Thus, the sample size matching the selection criteria was 53 accidents. Due to the low probability of water immersion accidents, the analysis of water immersion was extended to the 64 accident database. A complete listing of the impact data is given in Appendix IV.

5. ANALYSIS OF THE MECHANICAL IMPACT ACCIDENT ENVIRONMENT

The assessment of the severity of the mechanical impact accident environment as a result of an aircraft accident is limited to analysing loading due to impact forces only. Although puncture and crush loading may also be present during an aircraft accident, this evaluation of the impact environment assumes that the dominant forces are due to the impact loads and, therefore, the puncture and crush environments were not evaluated.

In this section, data are corrected for normal impact velocity and for equivalent impact velocities for a real target. These data can be compared to the impact testing requirements for Type C packaging impacting on an unyielding surface. The equivalent impact velocity represents the velocity at which a package impacting an unyielding surface would experience the same damage as a package impacting the real surface at the actual impact velocity. Aircraft impact surface type data and the methods used for the derivation of equivalent velocities are given in Appendix IV.

5.1.AIRCRAFT PARAMETERS THAT AFFECT IMPACT LOADING

Impact load, as defined in this section, is the force or loading imparted to the aircraft by the surface of impact in an accident. The impact velocity by itself does not define impact loading. The various parameters that may affect this loading are velocity and orientation of the aircraft at the time of impact, angle of impact and the characteristics of the impacted surface. Additionally, the angular orientation of the aircraft at the time of impact with respect to the surface, i.e. roll, yaw and pitch axes as shown in Fig. 1, can also affect the impact load.

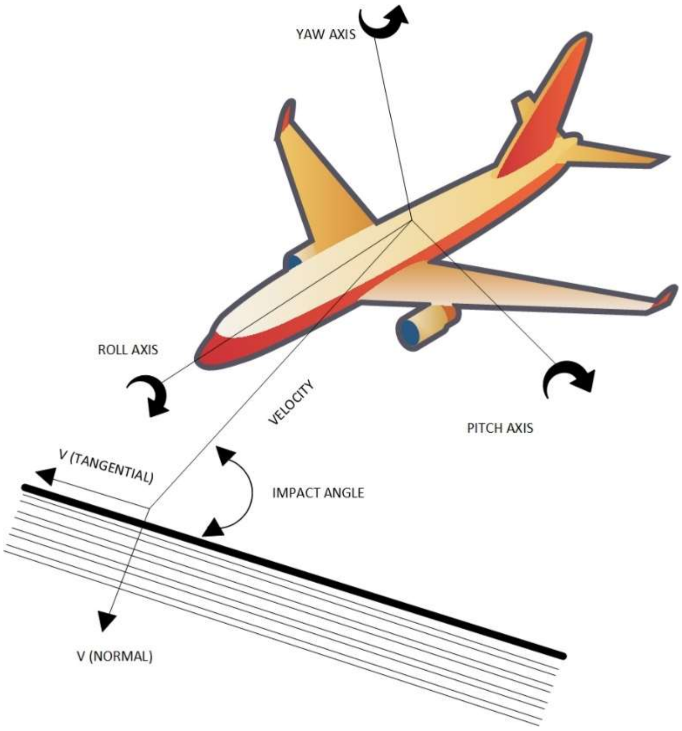

FIG. 1. Aircraft orientation at impact.

The impact loads or forces affecting packaging in the cargo area of an aircraft will depend upon the transmission of the initial impact forces through the airframe. The strength of the airframe and the energy absorbing capacity of the airframe structure will affect this transmission of forces. For simplicity, this analysis assumes that the impact velocity of the aircraft is imposed on the package, not considering the possibility that the aircraft would absorb some energy that would not be imposed upon the package. This assumption provides a conservative analysis of impact forces.

5.2.COLLECTED IMPACT VELOCITIES

The probability density for the impact velocities is shown in Fig. 2. It should be noted that the plotted impact velocity is not corrected for angle of impact. This figure was obtained by sorting the impact velocities into velocity bins, with each bin having a width of 10 m/s and plotting the bin’s central value (i.e. 10 m/s, 20 m/s, 30 m/s, etc.) versus the probabilities that the impact velocity is within that bin.

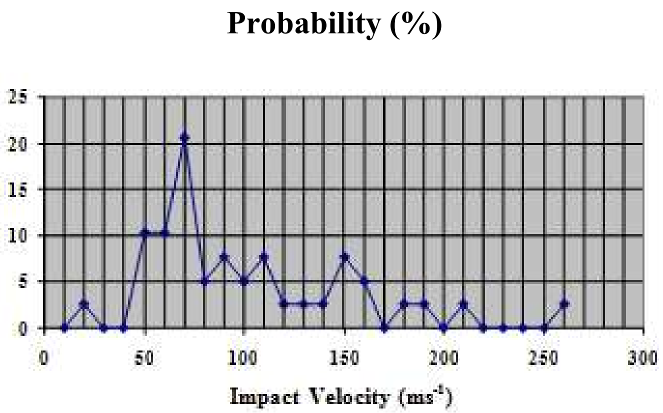

FIG. 2. Probability density for collected impact velocity.

The bin probability is the number of crashes with the impact velocity within that bin divided by the total number of crashes:

$$P_{bin} = \sum N_{x< v \leq +10} / N_T \tag{1}$$

where:

P_{bin} = bin probability;
$N_{x< v \leq +10}$ = number of crashes with impact velocity with the 10 m/s bin;
x = bin boundary, starting with 5 m/s;
N_T = total number of crashes.

The cumulative probability of the collected impact velocities is shown in Fig. 3. This figure is obtained by summing the probabilities of the velocity bins for those bins that have a value less than or equal to the chosen velocity, V:

$$f(v) = \sum P_{bin} (v \leq V) \tag{2}$$

For a chosen velocity, this figure presents the probability that the velocity will be at that value or less. For example, there is about a 60% probability that the collected impact velocity will be 100 m/s or less. Stated another way, there is a 40% probability that the collected impact velocity is greater than 100 m/s. This is the velocity at impact at whatever angle and in many cases not a perpendicular impact; this is a high speed subset of the data.

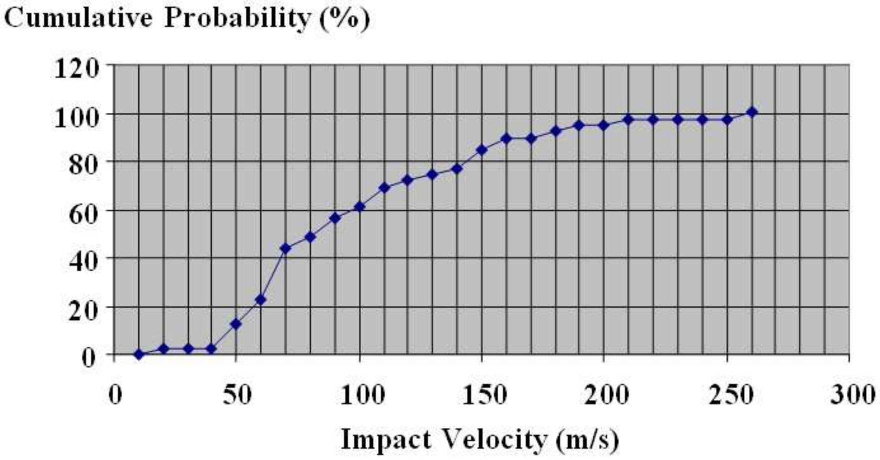

FIG. 3. Cumulative probability distribution for collected impact velocity.

Figure 2 indicates that given an accident, the most probable impact velocity occurs between 50 and 80 m/s. Figure 3 indicates that there is a 90% probability that the impact velocity given for an accident is less than or equal to ~160 m/s. That is, there is a ~10% probability that the impact velocity is greater than 160 m/s.

In 135 of the 336 accidents, i.e. 40.2%, the data indicated that the impact velocity exceeded 60 m/sec. Additionally, assuming that the results presented above are representative of these 135 accidents, the probability that the collected impact velocity is greater than ~160 m/s can be estimated to be about 4%. Translating these results to the 90 m/s impact velocity, the probability that the collected impact velocity is above 90 m/s is about 19.3%. That is, there is about a 19% probability that the impact velocity will be greater than 90 m/s. However, this evaluation does not take into account the impact surface condition nor the impact angle. Therefore, the equivalent impact velocity, i.e. the velocity of impact normal to an unyielding surface – would be lower.

5.3.EQUIVALENT IMPACT VELOCITIES

As mentioned above, the primary factors affecting aircraft impact loads are the impact velocity, the impact angle, and the characteristics of the impacted surface. To take into consideration the effect of the impact angle, the collected impact velocity is converted to the normal impact velocity. This velocity is then adjusted to relate the impact load encountered in a real accident to an equivalent load encountered when impacting an unyielding surface. The collected impact velocities are provided in Appendix IV. This equivalent impact velocity is the velocity of impact normal to an unyielding surface that would produce the same impact loading or damage as the collected impact velocity on the identified impact surface for that accident. For example, using Table 21 in Appendix IV, a 100 m/s, 60° impact onto a mixed surface (vehicles on the ground, structures, tall vegetation, etc.) would result in the same impact loading as a 74 m/s vertical impact onto an unyielding surface.

The factors used to adjust the collected surface impact velocity were derived from statistical data and evaluations from several sources. For each type of impacted surface, mean and 90th percentile values were derived. The methods and derivation of the factors used to adjust the collected impact velocity are provided in Appendix V. Additionally, impact angle information was not provided for 10 out of 39 accidents. A conservative approach was adopted for these accidents with no adjustment to the collected impact velocity made to account for the angle of impact.

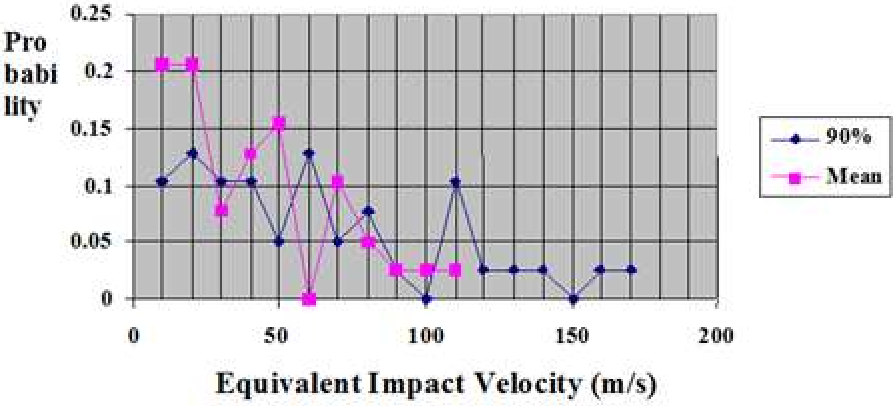

FIG. 4. Probability density for equivalent impact velocity.

The probability density for the equivalent impact velocities, given an accident, is shown in Fig. 4 for both the mean and 90th percentile surface impact adjustment factors. This figure was obtained in the same way as the value in Fig. 2. Figure 4 indicates that when the collected impact velocity is adjusted for surface hardness and impact angle, the most probable equivalent impact velocity is less than 60 m/s for the 90th percentile. Due to the uncertainties with the correction factors, the data are given based on mean (best estimate) value for equivalent velocity factors and also based on conservative 90th percentile values.

The cumulative probability of the equivalent impact velocities onto an unyielding target, given an accident, is shown in Fig. 5 for both the mean and 90th percentile surface impact adjustment factors. This figure shows that for the mean adjustment factors there is about a 5% probability that the equivalent impact velocity is above 90 m/s, and for the 90th percentile surface impact adjustment factors, there is about a 22% probability that the equivalent impact velocity is above 90 m/s. Accounting for the sample of collected data and assuming the results are representative of the sample, there is about a 2% probability that the equivalent impact velocity given an accident will be above 90 m/s for the mean surface impact adjustment and about a 9% probability that the equivalent impact velocity given an accident will be above 90 m/s for the 90^{th} percentile surface impact adjustment.

The CRP attempted to derive a well based cumulative probability distribution of equivalent impact velocities to arrive at a technical basis for 90 m/s test conditions. Because of limited data available to the CRP participants, a simplified approach had to be adopted.

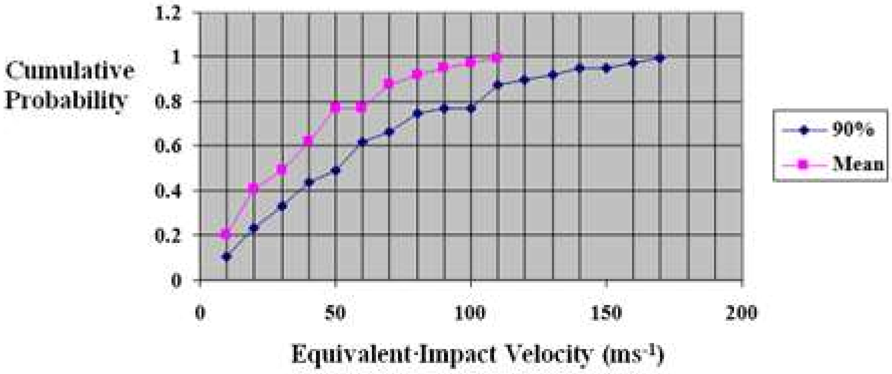

FIG. 5. Cumulative probability distribution for equivalent impact velocity.

An alternative method for computing equivalent impact velocities is to consider the probability that an aircraft will crash into a particular type of surface type. From the data collected, the probability that a crash will involve a certain type of surface can be derived as:

$$P_{\text{surface i}} = N_{\text{surface i}} / N_{\text{Total}} \tag{3}$$

where

$P_{\text{surface i}}$ = the probability of impacting surface of type i;
$N_{\text{surface i}}$ = the number of impact into surface of type i;
N_{Total} = the total number of impacts.

An overall surface adjustment factor can then be derived as the sum of the products of the probability of impacting surface i and the adjustment factor for surface i:

$$P_{\text{Overall}} = \sum P_{\text{surface i}} \times K_{\text{surface i}} \tag{4}$$

where

P_{overall} = overall surface adjustment factor;
$P_{\text{surface i}}$ = the probability of impacting a surface of type i;
$K_{\text{surface i}}$ = adjustment factor for unyielding surface i.

Using the normal impact velocity data, P_{overall} is calculated to be 0.83 using $K_{\text{surface i}}$ for 90th percentile values. Using this overall impact surface adjustment factor; the probability density and cumulative probability of the equivalent impact velocities, given an accident, are shown in Figs 6 and 7, respectively.

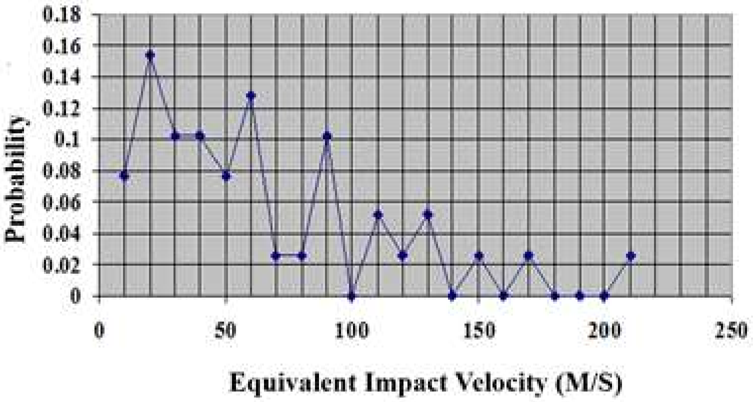

FIG. 6. Probability density for equivalent impact velocity using an overall probability factor.

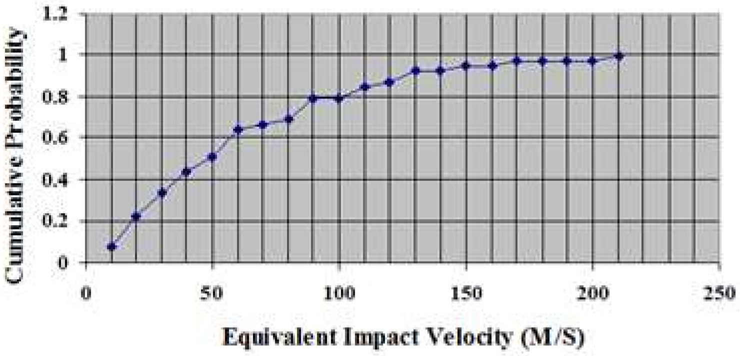

FIG. 7. Cumulative probability distribution for equivalent impact velocity using an overall probability factor

Figure 6 indicates that the most probable equivalent impact velocity using an overall probability factor to adjust for surface hardness and accounting for impact angle is less than 60 m/s. Figure 7 indicates that, given an accident, there is an 80% (i.e. 0.8 on the scale) probability that the equivalent impact velocity will be equal to or less than 90 m/s using an overall probability factor based on 90th percentile surface hardness adjustments and accounting for impact angle. Accounting for the sample of collected data and assuming the results are representative of the sample, there is an 8% probability that the equivalent impact velocity will be greater than 90 m/s, given an accident. In conclusion, the analysis provided in this section suggests that, depending on the method selected to calculate equivalent impact velocity, the probability of a normal impact on an unyielding surface exceeding 90 m/s may vary from 2 to 20%.

5.4.STATISTICAL ANALYSIS OF THE DATA WITH RESPECT TO THE IMPACT ENERGY

The purpose of this discussion is to further evaluate the probability of impact velocity exceeding 90 m/s for the accidents considered in this study. Two different approaches were considered:

- The first approach considered only those events for which data were extracted from completed questionnaires;

- The second approach considered all the events, assuming that there is no correlation between the energy of impact of an event and whether or not the related questionnaire has been completed. The validity of this assumption and the possibility of a bias is discussed hereinafter.

The second approach is interesting because it benefits from all the events, and is not restricted to data obtained in the first approach. It leads to the following conclusions (see Appendix V):

- The most probable value of an impact exceeding 90 m/s is close to 11%;
- A probability of an impact exceeding 90 m/s by about 10–14% cannot be rejected with a good confidence level;
- A probability of an impact exceeding 90 m/s by less than 8% or more than 18% can be rejected with a good confidence level.

5.4.1. Consideration of bias

With regard to the assumption made for the second approach, the subset of 53 events considered is representative in terms of repartition of the different flight phases, except for the landing accidents (5 landing accidents out of 53 events, i.e. 9.4%, as compared with 87 out of 336, i.e. 25.9%). As discussed in Appendix V, the probabilities of high energy impacts outside the range of ≤ 10% and ≥ 26%, based on the first approach, may be excluded with a confidence level of 90%. According to the whole database, the probability of an accident occurring during the landing phase would be less than 23%.

On the other hand, the 53 events for which a questionnaire is available correspond to a distribution for which the landing phase contributes less than 16% of the total number of accidents, with the probabilities greater than 16% being excluded with a confidence level of 90% (see Section 8).

There is also a deficit of landing accidents in the 53 event subset. The landing phase does not correspond to a high speed phase nor does it involve an uncontrolled descent from high altitude. As a consequence, this deficit of landing events cannot lead to an underestimation of the number, and also the probability, of high energy impact accidents. From that point of view, the results should also be conservative.

6. ANALYSIS OF THE THERMAL ACCIDENT ENVIRONMENT

The stresses imposed by the thermal accident environment are due to thermal loading generated by fires internal to the aircraft prior to impact and by fires generated by the impact. High thermal loads can lead to increased package internal pressure and deterioration of packaging seals, leading to loss of package containment.

Factors related to the magnitude and frequencies of aircraft thermal loads include: fire temperature; fire duration; fire size; and package location relative to the fire.

6.1.CHARACTERISTICS OF AIRCRAFT ACCIDENT FIRES

Aircraft accidents of ICAO mass categories 4 and 5 resulting in their destruction are likely to include a severe fire in the sequence of events. In-flight fires are short compared with ground fires (ground operation, impact, or landing) since these fires either lead to an immediate attempt of an emergency landing or to a loss of control and impact. Accidents which involve the destruction of the aircraft but without fuel spill or fuel dispersion from ruptured tanks are rare. Apart from aircraft accidents with immersion, fuel spill or fuel dispersion mostly results in ignition of the kerosene, e.g. through the hot parts of the engine. Temperatures in large fuel fires typically exceed the IAEA regulatory fire temperatures of 800°C. Hence, kerosene fires are of great relevance with respect to the thermal impact on a package, although these fires are relatively short compared with the burning of other combustible material of the aircraft structure or of its cargo load.

When an aircraft impacts onto the surface at high speed, clouds of fuel mist are generated during the disintegration of the tank structure. Small scale impact experiments with enclosed and free surface fluid volumes representing wing tanks have shown that, for an impact speed of about 60 m/s, virtually no pool development takes place and at 90 m/s less than 50% of the impacted fuel will be found at the surface as a thin fluid film [5]. Even less fuel will probably cover the surface when ignition of the fuel mist occurs.

Vapour above a fuel pool will not ignite at normal temperatures, since the flash point of standard civil aviation jet fuel (Jet A or Jet A-1) is above 38°C. Through additional heating or through fragmentation of the fuel surface into small droplets, the fuel vapour pressure can exceed the lean limit and ignition of the fuel is likely.

The rate of spread of the fire in the case of fuel vapour or fuel droplet clouds is much faster than on a pool surface, resulting in rapid consumption of the fuel cloud in a fireball of only a few seconds duration. Dispersion and ignition experiments have shown that the fireball development of dispersed kerosene is comparable to boiling liquid expanding vapour explosion (BLEVE) [5]. BLEVE events occur when tanks of liquefied combustible gas burst due to an engulfing fire. The immediate vaporization of the heated fuel results in a rapid combustion process. When the available dispersed aviation fuel mass M is known, the fireball duration t and maximum fireball radius R may be obtained from the relations:

$$t = 4.63M^{0.177} \qquad (t \text{ in s}, M \text{ in t})$$

$$R = 26M^{0.33} \qquad (R \text{ in m}, M \text{ in t})$$

In the past, several attempts were made to reduce the generation of fuel clouds by anti-misting agents. These developments culminated in a full scale experiment in 1984 (Controlled Impact

Demonstration) using a remote controlled B-720 aircraft with approximately 35.5 t of anti-misting kerosene on board, which was a failure. When the aircraft landed with gears up and passed wing cutters at the ground, leaking fuel ignited to form a large fireball. Subsequently, the engulfing fire, which was fed by the leaking fuel, resulted in complete destruction of the aircraft.

Maximum temperatures obtained from radiation measurements in large kerosene fireball experiments reach 1300°C [6]. Due to the short duration of this phenomenon, the possible thermal impact to a package qualified as a Type C package is negligible. Nevertheless, a large fireball is an ignition source for all other combustible materials and for the remaining fuel spill. In impact scenarios with high or medium impact velocities, a large area of spilled fuel is to be expected. Only for low impact velocities will the break-up of the fuel tank be small enough to feed a small area spill fire of long duration. On the other hand, an intense kerosene fire will further damage the tank structure, resulting in a speed-up of fuel spill and fuel burning.

Typical fuel consumption rates of large open kerosene pool fires are in the range of 4–6 mm/min [7]. The major factors influencing the burning rate are the pool diameter and the wind speed. A typical fuel level sinking rate of 5 mm/min would for instance mean that a kerosene pool of 5 cm depth would be consumed within 10 min. Large fuel spill areas are probable with corresponding thin fuel layer depths, especially in high speed impacts.

Hence, a kerosene fire is likely to be short compared with the total fire duration associated with an aircraft accident. Nevertheless, temperatures of large pool fires exceed 800°C. Experiments with a mock fuselage section in a large JP-8 fuel pool fire have shown typical local maximum temperatures of 1100–1200°C [7]. Therefore, 1100°C is a reasonable upper estimate for average temperature conditions in a large aircraft fuel fire on a horizontal sealed surface. Kerosene seeping into the soil will burn much slower (dirt fire) and with much lower temperatures compared with a pool fire [5]. A simple comparison of radiative heat transfer from a fire with 800°C and 1100°C, respectively, to a cool package shows a factor of approximately 2.7 for a fire of equal duration (see Appendix VI). A similar factor for an equivalent fire duration is found when the thermal response of the package is taken into account. In other words, the thermal impact of a fully engulfing fire at an average temperature of 1100°C lasting 10 min is approximately equivalent to a fully engulfing fire of temperature 800°C lasting 27 min in terms of the thermal energy input into the package.

Ignition of other combustible materials inside the aircraft will be immediate if the fuselage breaks into sections. But even when the hull initially remains intact after an impact, an outside fuel fire will burn through the fuselage in a few minutes, depending on the skin thickness and the acoustical and thermal insulation material [8].

The combustible materials in an aircraft (e.g. seats, insulation, baggage, cargo) have lower heat release rates than hydrocarbon liquids. Fire-resistant and non-flammable material is used in aircraft construction as far as possible. Flammable material with high heat release rates and fire temperatures is rather localized or limited to the transport of special cargo. Temperatures involved in non-kerosene fires are therefore comparable with the IAEA regulatory fire temperature of 800°C. The total mass of non-kerosene combustible material in an aircraft is much lower than the maximum fuel load. Hence, the relatively slow pyrolysis compared with fuel fires is a major reason for long duration fires in aircraft accidents. In some cases, secondary fires of surrounding material (e.g. wood) can prolong the initial impact of the fire.

6.2.STATISTICAL ANALYSIS

The following analysis is based on 53 returned data sets of the questionnaire (see Appendix VI). Many of these data sets contain incomplete information and, in some cases, even questionable information about the fire. To avoid, as far as possible, the use of estimated values to fill gaps or remove unrealistic data, only obvious corrections or supplements of database values were made. Information reported as a range is converted to a centered average and reported estimates of upper or lower bounds are taken as is. Despite the deficits of the database, the information about the fire environment in the 53 data sets allows a rough analysis of major trends and dependencies.

Fire type is divided into ground operation fire, in-flight fire and fires resulting from impact. There are five accidents without a fire and two with no indication of whether there was fire or not, leaving 46 accidents with fire information, 43 of them finally resulting in an impact fire. Table 2 shows the number of incidents for each fire type and additional information about mean and median fire duration. In addition, the respective standard deviations for both average measures of fire duration are given. Note that one accident with a post-landing fire is treated as a post-impact fire.

TABLE 2. BASIC STATISTICAL ANALYSIS OF REPORTED FIRE DURATION DATA

	Ground operation fire	In-flight fire	Impact fire	All fires
Total accidents	1	8	43	46
Accidents with fire duration information	1	5	28	29
Range (min)	20	1–18	1.5–1440	1.5–1440
Median (min)	—	6.00	195	180
Standard deviation from median (min)	—	8.29	367	363
Mean (min)	—	8.20	258	251
Standard deviation from mean (min)	—	7.92	361	358

Note: There is some double counting with accidents involving both in-flight fires as well as post impact fires.

The ground operation and inflight fires are rather short compared with the duration of the impact fire. Due to the small number of inflight fires, the average duration of all fires is only slightly shorter than the average impact fire duration. The rather high average impact fire duration is mainly due to two fires with a duration reported to be 24 h, which dominate the cumulative probability distribution of the total fire duration in Fig. 8.

These two accidents are the Cameroon Airlines Boeing 737-200 crash in Douala (Cameroon) on 3 December 1995 and the El Al Israel Airlines Boeing 747-100 crash in Amsterdam on 4 October 1992. Figure 8 is based on 29 data sets with fire duration information.

In the case of the Cameroon Airlines crash, the given fire duration is inaccurate. From the official accident report it is known that the fire started at impact during the night time in a mangrove swamp which was not accessible in terms of for immediate help and firefighting. The remaining fires, which also included a secondary fire of the surrounding vegetation, were extinguished the following day using fire drenchers. Hence, the total fire duration has been much shorter than 24 h, although no exact duration is known. Nevertheless, the fire was severe enough to destroy both FDRs.

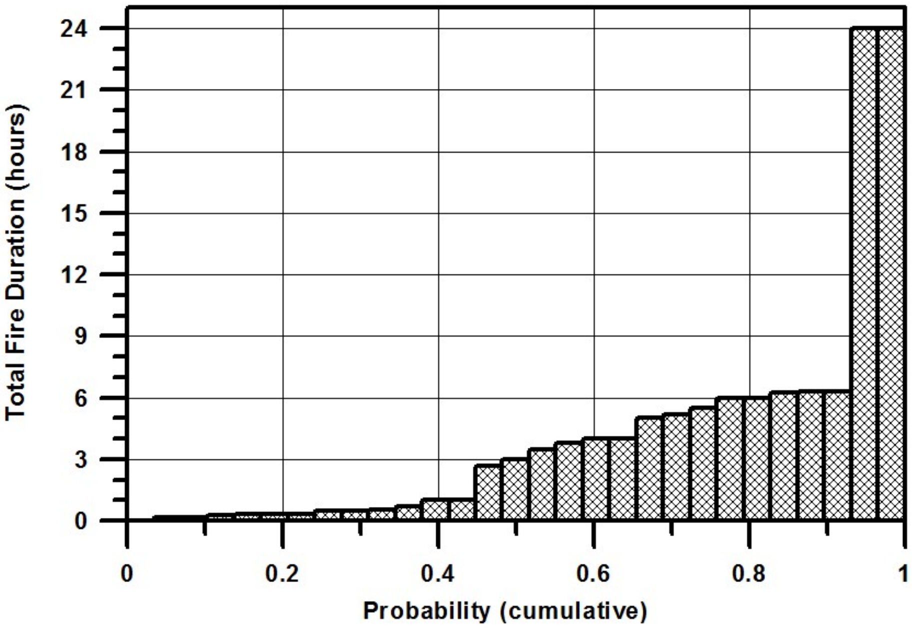

FIG. 8. Cumulative probability distribution of reported total fire duration (ground operation + inflight + impact fire duration, 29 accidents).

The second accident with long fire duration took place in Amsterdam, where a Boeing 747 cargo plane crashed into an apartment building. Further details on this accident are given in Appendix VII. In this case, the time for containing the fire is reported as additional information. The reported fire duration until fire containment was only 151 minutes compared with 24 h until the fire was extinguished. As there was an extensive secondary fire of the apartment building, a large difference between both fire duration values occurred.

Since the thermal effects of a fire on a Type C package are significant only if the fire is severe, the more appropriate parameter for characterizing the fire condition is the time to contain a fire. It is assumed that, once contained, the fire no longer presents a significant thermal loading condition to a package. Hence, where available from the data, it would be desirable to describe the fire duration in terms of the time to contain (i.e. control) the fire rather than the time to extinguish the fire.

Unfortunately, only ten data sets include information which allows a comparison of fire containment times and fire extinguishing times. It is therefore impossible to derive a reliable probability distribution of fire duration until containment from the database. In six of these cases the ratio is simply 1 (e.g. accidents without fire-fighting activities). Other reported ratios of the time to extinguish to the containment time are between 1.8 and 9.5 (Amsterdam crash). To give a rough estimate of the fire duration in terms of time for fire containment, Fig. 9 shows an adjusted fire duration using the individual factors, where available, or an average factor of 2.2. It should be kept in mind that this procedure provides a better estimate of the fire duration which is relevant for a package. On the other hand, the level of uncertainty is increased compared with Fig. 8.

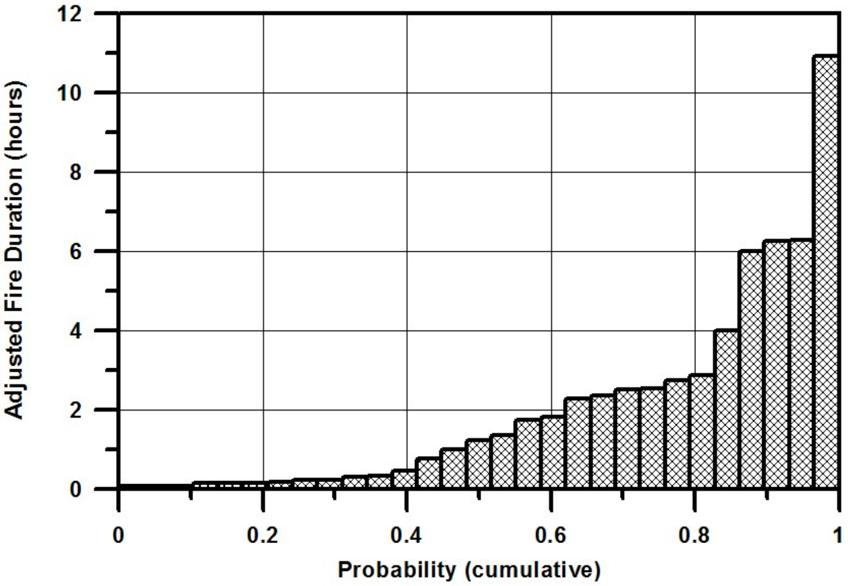

FIG. 9. Cumulative probability of adjusted fire duration using known or estimated relations between fire containment time and fire extinguishing time (29 accidents).

As already mentioned, the impact fire duration depends on many parameters such as impact velocity, cargo load, fuel load, surface type, and availability of other combustible material for secondary fires. Database information about the combustible material involved is given in Table 3. Aviation fuel is quoted as dominating combustible material in approximately 75% of all reported fires.

TABLE 3. INFORMATION ON COMBUSTIBLE MATERIAL INVOLVED IN IMPACT FIRES

	No impact fire	No impact fire information	Material unknown	Aviation fuel	Other aircraft fluids	Cargo, baggage	Others
Total number	6	2	5	40	26	21	20
Probability (%)	11.3	3.8	9.4	75.5	49.1	39.6	37.7

Aviation fuel is also of greatest relevance with respect to the thermal impact to a package due to the high temperature occurring during hydrocarbon fires. Figure 10 gives a cumulative probability distribution of the reported values for fuel load at impact. In 60% of all accidents, the available fuel mass at impact is below 10 t; only in 10% of the cases did more than 40 t of fuel contribute to the impact fire.

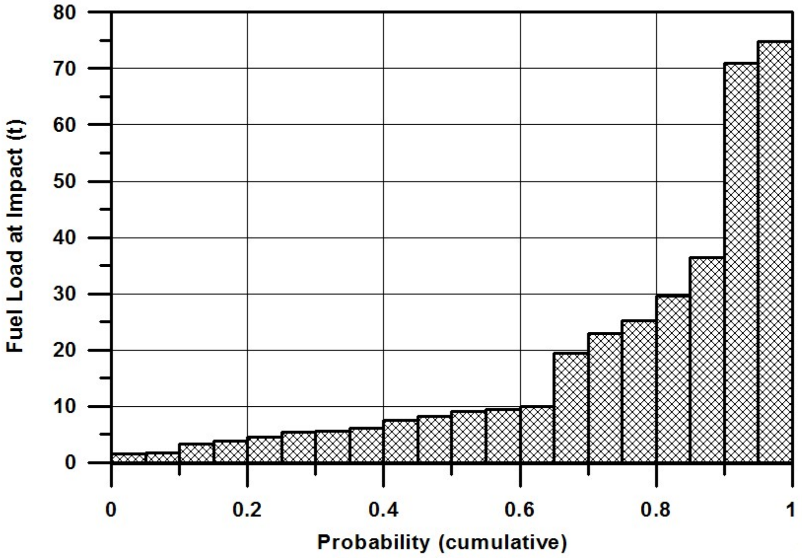

FIG. 10. Cumulative probability of reported aviation fuel load at impact (20 accidents).

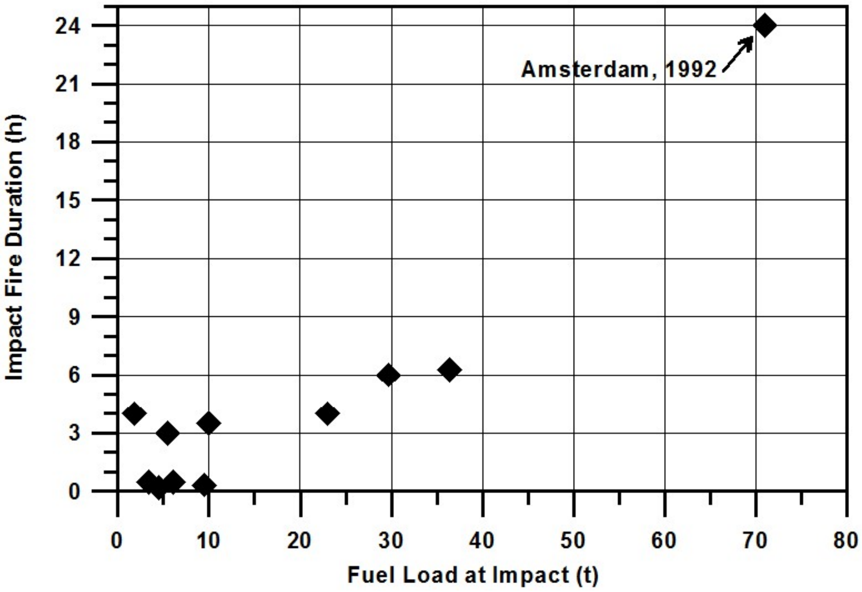

FIG. 11. Impact fire duration versus aviation fuel load at impact. Only accidents with both values reported are included (11 accidents).

Figure 11 shows the correlation between impact fire duration and fuel load at impact. Note that in all of the following figures the given fire duration is always the duration of the fire until it is extinguished. The data point with 24 h fire duration again is the 1992 Boeing 747 crash in Amsterdam, which had very special circumstances. Due to other factors interfering with the fire duration, a potential positive correlation between impact fire duration and fuel load at impact was noticeable for high rather than for low fuel loads.

For the interpretation of these findings, it should be kept in mind that the duration of the kerosene fire itself must have been much shorter in all cases with a reported fire duration of half an hour or more (see Section 6.1). Nevertheless, the extent of an intense short time hydrocarbon fire influences the ignition and burning of other combustible materials from the aircraft itself and from the surrounding (trees, buildings, etc.).

Figure 12 presents a similar diagram for the dependency between impact fire duration and the normal impact velocity. As already found in the analysis in Ref. [8], there is a limitation of the fire duration for high impact velocities. The same phenomenon was found in this database, except for two special accidents with an impact velocity above 100 m/s. In both accidents, there was a secondary fire affecting the fire's duration (a building fire in Amsterdam in 1992, and a forest fire in Thailand in 1991 (see Appendix VII)).

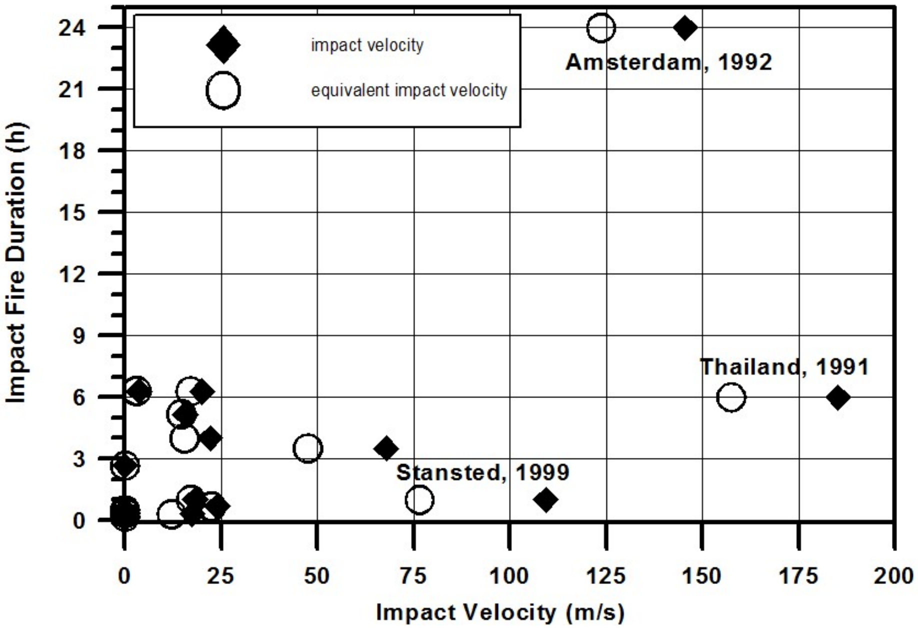

FIG. 12. Impact fire duration versus (normal) impact velocity and adjusted (normal) impact velocity (based on 90th percentile surface type correction). Only accidents with both values available are included (15 accidents).

The remaining accidents with relatively high impact velocity support the assumption of decreasing fire duration with rising impact velocity. The accident with the highest impact velocity among is the crash of a Korean Airlines Boeing 747 cargo aircraft near Stansted (United Kingdom) in 1999, resulting in a huge fireball and only a few small fires in the totally fragmented wreckage (see Appendix VII for more details).

Other information of interest obtained from the questionnaire is the ground fire area (initial and final) and the distance which the fire moved from the location of impact. Figure 13 gives the relationship between impact fire duration and fire area. As expected, a long duration fire is often connected with a large fire area (secondary fire), whereas a short duration fire is concentrated in small areas (aircraft fire). One exception is the accident in Amsterdam in 1992, where rather small initial (50 m²) and final (240 m²) ground fire areas were reported. In this case, there is a high concentration of combustible material in the apartment building. The reported ground fire area does not take into account that the fire spread also took place in vertical direction inside the remaining multi-story apartment building parts.

In all accidents with at least a 4 h fire duration after impact (12 cases), two-thirds took place in areas with houses (2 cases) or trees and tall vegetation (6 cases). Hence, the long fire duration is mainly due to secondary fires, which also increase in size and move in most cases. The average of reported (secondary) fire movement from the impact location is 200 m (range: 0–600 m).

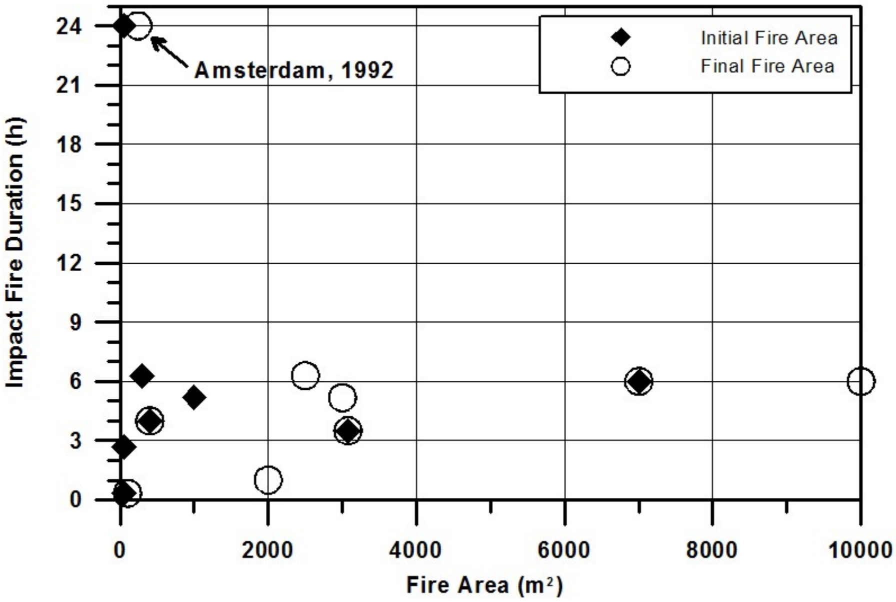

FIG. 13. Impact fire duration versus initial and final ground fires. Only accidents with both values available are included (eight cases with initial area, nine cases with final area).

Hence, it is unlikely that a package will be involved in the fire scenario for the entire duration of the fire. Furthermore, the soil underneath and surrounding objects, such as debris and other packages, will reduce the package surface exposed to the fire. For a package that is not fully engulfed or is situated at a distance from the fire, the thermal impact strongly decreases (see Appendix VI on equivalence of fire scenarios).

6.3.SUMMARY AND CONCLUSIONS

Compared with impact velocity figures, information on fire severity (intensity and duration) is sparse and inaccurate. There is no automatic recording of fire information except for cases of inflight fires. In addition, investigation of the fire scenario is of secondary interest in accident investigation if fire impact is not the major cause for fatalities and injuries. Accordingly, only a subset of the 53 accident data set with indication of fire contains detailed fire information. The number of available cases for fire analysis further decreases when investigating correlations between different parameters related to fire severity (fuel load, fire duration, fire area, combustible material involved).

There is also no information available on fire temperature. Even the information on fire duration is not a direct indicator of the potential duration of package exposure to the fire in terms of full engulfment. Therefore, this statistical analysis of fire information from the 53-accident database can only give a rough estimate of major trends and dependencies. Further interpretation was needed to obtain conclusions with respect to equivalence to the IAEA Type C fire test requirements.

Most of the accidents in the database involve fires, mostly post-impact fires or accidents which end up in a post-impact fire. The median of reported total fire duration of all fire accidents is 3 h (Fig. 8). It could be further inferred from Fig. 8 that when taking all 53 accidents into account, the median value would be less than 1 h. For the adjusted fire duration (including known or estimated factors between fire extinguishment and fire containment), the respective median values are 1.2 h for the fire cases and up to 20 min for all accidents (Fig. 9). The 90th percentile of the cumulative probability distribution is approximately 6 h with or without adjustment and for 46 of the 53 accidents. The percentage of all accidents with an adjusted fire duration of at least 1 h is approximately 45%. These results are only valid for the 53 accident subset of the total number of 336 accidents with destruction of the aircraft (hull loss) during the period 1990–2000. Section 8 shows that accident sequences belonging to this subset are not distributed in the subset in the same way as in the full 336 accident dataset. The subset contains a higher fraction of accident sequences with two or three events compared with the 336 accident database. Accordingly, the frequency of accidents with fire in the 53 accident subset likely overestimates the occurrence of fire in the original set of 336 accidents.

In most accidents with long fire duration (>1 h), there is a strong indication that secondary fires were involved. In these cases, the fire area grows and moves, implying a low probability of long duration fixed location fire. Hence, there is only a low probability of engulfing a package in the fire for the total fire duration. Furthermore, there are mitigating factors, such as surrounding debris, which result in a reduction of the package exposure area compared with the engulfing IAEA test fire.

For high speed impact accidents there appears to be a trend of a decrease in total fire duration if no further combustible material (buildings, vegetation) is available. These accidents typically result in rather large debris areas which reduce the probability of combustible material agglomeration. This is especially true with respect to kerosene pool fires, which will not occur after high speed impact due to kerosene dispersal and fireball formation.

The temperature of 800°C is a reasonable estimate for average fire temperatures in aircraft accident fires if no kerosene is involved. From numerical thermal analysis of a package engulfed in a typical large kerosene pool fire (1100°C, see Appendix VI) an approximate equivalent fire duration of 20 min can be derived, leading to a thermal impact equivalent to 800°C with 1 h duration. Assuming an appropriate pool sinking rate of 5 mm/min for a large open kerosene pool fire, a fire of 20 min duration would require an initial pool level of 10 cm, which is unlikely to persist for the whole spill area without artificial containment. An impact crater could limit the pool area. However, only small amounts of the aviation fuel will remain in a crater, since cratering only occurs in accidents with high impact velocities. Hence, a kerosene pool fire does not seem to be of concern either for high speed or low speed impacts with respect to Type C package performance. Nevertheless, a large amount of fuel at aircraft impact can increase the extent and duration of secondary fires, as some accidents have shown.

The above findings give further support to the conclusion that most accidents even with a reported fire duration above 1 h do not imply a higher thermal impact with respect to a package in comparison with the IAEA fire test duration of 60 min for Type C packages. Furthermore, the combination of high speed impact and long duration fire is improbable. However, in the rather unlikely event of an aircraft impact in areas with additional agglomerated combustible material (e.g. buildings), a more severe fire scenario cannot be excluded. Due to the nature of the information available on aircraft accident fire scenarios, a more detailed statistical analysis with respect to the IAEA Type C fire test requirements is not possible.

7. WATER IMMERSION ACCIDENT

7.1.INTRODUCTION

Of the 64 aircraft accidents recorded from the data collection involving 66 aircraft, eight accidents resulted in impacts with water. The distribution of these water accidents is given below:

- Open water: 4;
- Sheltered water: 1;
- Shoreline: 2;
- Other: 1.

Six of these accidents provided the depth of the water, which ranged from 2 to 2150 m. Two accidents did not provide water depth information. Half of the accidents occurred in water with a depth of 100 m and greater; while half occurred in water with depths of 5 m and less.

Information concerning the amount of time taken between the accident and the recovery of the FDR was provided for five of these accidents. The FDR recovery time interval ranged from immediate to 10 d. The time interval between the accident and recovery of major debris, including cargo, was provided for two accidents. This major debris/cargo recovery time ranged from 13 to 117 d.

Water immersion during an accident imposes stress on a package because of increased pressure and corrosion/deterioration of the packaging seals. Water immersion environments can occur during both sea and air transport modes.

Factors related to the magnitude of water immersion loads include immersion depth and duration. Immersion times can be bounded by the time to recover the FDR and the recovery of significant amounts of the aircraft wreckage.

The immersion depth can be divided into three categories:

- Deep water >200 m, which includes the oceans;
- Shallow water ≥15 m and ≤200 m which applies to the ocean shelf, lakes, etc.;
- Very shallow water <15 m.

This complies with the testing performance specifications, which are as follows:

- Under 15 m of water for 8 h;
- Under 200 m of water for 1 h.

7.2.EVALUATION OF IMMERSION DATA FROM THE DATA SET

Evaluation of the entire data set of 336 accidents shows that 19 of these resulted in immersion (two accidents gave no indication of the type of impact surface). This gives a ratio of 5.6% for accidents resulting in immersion. Out of these 19, the applications of the coarse filter (see Section 4.1) gave the following distribution (Table 4).

TABLE 4. ACCIDENT DISTRIBUTION

Possible high impact accidents	4
Low impact accidents	10
Undetermined	5

Further examination of the questionnaires showed that only 4 of 53 replied concerning immersion, all instances of which occurred over the open sea. One accident occurred near the Dominican Republic. This accident was a high equivalent impact velocity accident (250 m/s) and most of the debris was found at a depth of 2195 m. The second accident, also a high equivalent impact velocity accident (144 m/s), occurred near Egypt where the water depth was 100 m. The third, also a high equivalent impact velocity accident (105 m/s), occurred over the Atlantic Ocean at an unknown depth. The last accident occurred over the Black Sea, a low equivalent impact velocity accident, for which the depth of water at which most of the debris found was about 500 m.

7.3.CLASSIFICATION OF IMMERSION ACCIDENTS

Taking into account the test specifications for the Type C package, it is necessary to consider an accident scenario involving immersion in water. An accident can involve either a low (≤90 m/s) or high (>90 m/s) equivalent impact velocity where immersion could occur. The immersion can occur in either very shallow water, (<15 m), which covers shallow lakes, rivers, marsh, etc., shallow water (≥15 m and <200 m), covering the continental shelf, lakes, etc., or deep water (≥200 m), which includes the oceans and deep lakes (Table 5).

TABLE 5. ACCIDENT CLASSIFICATION

Immersion type	Immersion depth
Very shallow water	<15 m
Shallow water	≥15 m and <200 m
Deep water	≥200 m

Applying this accident classification table directly to the accidents involving immersion from the data set presented in Section 7.2 is not possible since some data are undetermined. Adding undetermined equivalent impact velocity and undetermined depth to the table above and applying the data from the data set gives the following result (Tables 6 and 7).

TABLE 6. DATA DISTRIBUTION AMONG ACCIDENT CLASSIFICATIONS

Immersion type	Number of accidents		
	Equivalent impact velocity ≤90 m/s	Equivalent impact velocity >90 m/s	Equivalent impact velocity undetermined
Very shallow water[a]	4	0	0
Shallow water	5	1	1
Deep water	1	2	1
Undetermined	1	0	3

[a] All accidents involving immersion in very shallow water are those in ditches or swamps.

TABLE 7. DATA DISTRIBUTION AMONG ACCIDENT CLASSIFICATIONS AS A PERCENTAGE OF THE TOTAL POPULATION

Immersion type	Percentage of accidents			
	Equivalent impact velocity ≤90 m/s	Equivalent impact velocity >90 m/s	Equivalent impact velocity undetermined	Total
Very shallow water[a]	21.0	0	0	21.0
Shallow water	26.3	5.3	5.3	36.9
Deep water	5.3	10.5	5.3	21.1
Undetermined	5.3	0	15.7	21.0
Total	57.9	15.8	26.3	100.0

[a] All accidents involving immersion in very shallow water are those in ditches or swamps.

7.4.CONSEQUENCES OF DIFFERENT SCENARIOS

The paragraphs in the following Sections 7.4.1 to 7.4.3 are taken from IAEA-TECDOC-1231, Severity, Probability and Risk of Accidents during Maritime Transport of Radioactive Material [9].

7.4.1. Studies by CRIEPI

The Central Research Institute of the Electric Power Industry (CRIEPI), in Japan, estimated the consequences of the release of radioactivity from spent fuel, high level waste and PuO_2 arising from the loss of a transport package in the deep ocean and in shallow seas off the north-east coast of Japan. Submergence of the cask to a depth of 2500 m was assumed after loss in the deep ocean. Loss in shallow coastal waters was assumed to result in cask submergence to a depth of 200 m. Radioactive release into the deep ocean was conservatively modelled assuming that the release rate was controlled solely by the leaching of radionuclides from the bulk material matrix, with no credit given for the retardation of release by fuel rods, canisters, and/or the radioactive material package. For release after package submergence into shallow waters, any retarding effect of fuel cladding or canisters was ignored. Instead, leaching of radionuclides was assumed to cause the water in the package to become saturated with each radionuclide in the radioactive material carried in the package. The release of radionuclide saturated water from the cask was controlled by buoyancy driven flow through the gap in the failed O-ring seal of the package.

Once released into the ocean, the concentration of radionuclides was estimated using a multi-compartment flow model [10] for deep ocean release and ocean current data [11] for near shore release. The maximum calculated surface concentration of radionuclides was then used as input to a marine food pathway model [12], [13] which in turn provided doses for individuals whose diet was set by a Japanese market basket formulated by the Nuclear Safety Commission of Japan and who ate only maximally contaminated marine foods that became contaminated due to the hypothetical loss of the package into the ocean. Table 8 presents the maximally exposed individual doses estimated by these calculations.

TABLE 8. CRIEPI ESTIMATES OF MAXIMALLY EXPOSED INDIVIDUAL DOSE RESULTING FROM A LOSS OF A PACKAGE CONTAINING RADIOACTIVE MATERIAL INTO THE OCEAN [14]

Nuclear material	Quantity	Accident location	Submergence	Maximal[a] exposed individual dose (mSv a^{-1})
Spent fuel – Normal burnup	1 cask (7 PWR assemblies)	Near shore	200 m	4.1×10^{-4}
Spent fuel – High burnup	1 cask (12 PWR assemblies)	Near shore	200 m	2.3×10^{-3}
High level waste	1 cask (28 canisters)	Near shore At sea	200 m 2500 m	4.1×10^{-4} 4.7×10^{-9}
PuO_2 powder	1 cask (14.5 kg)	Near shore	200 m	1.4×10^{-5}

[a] ‘Maximal’ means that all seafood eaten is assumed to be contaminated.

7.4.1. ISPN–CEPN study

ISPN-CEPN used the POSEIDON code [15], [16] to estimate the maximally exposed individual doses that might result if 1 kg of PuO_2 powder containing about 4×10^{14} Bq of Pu nuclides and ^{241}Am was released into the western English Channel during a shipping accident. The compartment model implemented in the POSEIDON code models flows between well mixed compartments and within each compartment adsorption and scavenging of radionuclides by sediments, sediment resuspension, dissolution of absorbed radionuclides, and entry of radionuclides into marine food chains from the uptake of contaminated water and sediments by marine plants and organisms. Consumption of contaminated marine foods as specified by a market basket for reference population groups then allows doses to be calculated for individuals in the groups who eat seafood caught only from specified ocean regions (ocean compartments). Table 9 presents the results of these POSEIDON calculations.

TABLE 9. CONSEQUENCES OF THE LOSS OF 1 kg OF PuO_2 INTO THE WESTERN ENGLISH CHANNEL [14]

Exposed population		Consumed seafood (kg/y)	POSEIDON Compartments fished	First year maximal[a] individual dose (mSv/y)
Reference group	Size			
Average European	10^7	13.1	All compartments	5×10^{-5}
Average Frenchman	10^7	17.4	All compartments	2×10^{-4}
French fisherman	10^2	25.0	Western English Channel	9×10^{-4}
IAEA Reference Man	10	219.5	Western English Channel	8×10^{-3}

[a] ‘Maximal’ means that all seafood eaten is assumed to be contaminated. Market basket values reflect critical groups in all areas of the world according to current known dietary habits.

7.4.2. Sandia study

Sandia National Laboratories used the MARINRAD code [17] to estimate the ingestion doses that might result from the loss into the ocean of a TN-12 spent fuel cask while traversing the Grand Banks fishing region. The MARINRAD code models transport of radionuclides between ocean compartments by: ocean currents; deposition of radionuclides onto compartment sediments; uptake of radionuclides from these sediments and/or ingestion of suspended radionuclides by seaweed; plankton; crustaceans; molluscs; larval fish; bioaccumulation of radioactivity due to predation in marine food chains; and radiological exposures caused by ingestion of marine foods and desalinized seawater, inhalation of sea spray, swimming in contaminated seawater and exposure to contaminated sediments.

The calculation assumed that the ship collision caused the TN-12 cask to be lost in the sea and that the entire cask inventory was released into ocean waters over time periods ranging from 3 to 300 years. The results of the calculation indicate that radiological exposure is largely determined by the ingestion pathway and is largest for individuals who consume seafood taken exclusively from the Top Labrador compartment of the 19 compartment ocean model, the compartment that includes the Grand Banks. Near term yearly individual doses for individuals who consumed seafood harvested exclusively from this compartment increase as the radionuclide release time decreases. When release takes place over three years, yearly individual doses reach a maximum value of about 18 mSv per year five years after the sinking of the radioactive material transport ship and then fall to 10 mSv per year at 100 years after the sinking. When release takes place over 300 years, average yearly individual doses throughout the first 100 years are about 0.4 mSv/a.

7.5.CONCLUSIONS

The result of the evaluation of the data set shows that accidents involving immersion are not very common. Only 5.6% of the 336 accidents resulted in immersion.

Looking further into the details of the accidents involving immersion reveals that in 16% of the cases it was not possible to determine either equivalent impact velocity or immersion depth. In

21% of the cases it was not possible to determine immersion depth and in 26% of the cases it was not possible to determine the equivalent impact velocity.

The large amount of undetermined data shows that the uncertainty of the results in this evaluation is high. Nevertheless, analysing the data, it is possible to estimate the outcome.

Considering the cases where the equivalent impact velocity and immersion depth are possible to estimate — in 26% of the cases it was not possible to determine the equivalent impact velocity — calculations yield the following:

- In 16% of the accidents involving immersion the equivalent impact velocity is over 90 m/s. In these accidents the immersion depth was less than 200 m in one-third of the cases and more than 200 m in two-third of the cases;
- The fraction of accidents involving immersion where the equivalent impact velocity is less than or equal to 90 m/s is 58%. Out of these, only 10% resulted in an immersion depth of more than 200 m. One of these accidents occurred over the Black Sea in which the depth of immersion of major debris was 500 m.

For the accidents occurring over shallow water, where the equivalent impact velocity was low, the package will likely be recovered without any increased dose to the public. In the case of the high equivalent impact velocity accident, the package may be damaged at impact. The consequence of this is described in Section 7.4.2.

For accidents resulting in an immersion depth of over 200 m, it may not be possible to recover the package. For the accidents resulting in an immersion depth in excess of 200 m, where it is possible to define the equivalent impact velocity, it is clear that both high and low equivalent impact velocities occur. The consequences of a scenario where a package is lost at great depth are described in Sections 7.4.1 and 7.4.3.

In conclusion, it is not likely that the consequences of high or low equivalent impact velocity accidents at different immersion depths will result in any significantly increased individual doses.

8. ACCIDENT SEQUENCES

Aircraft accident environments normally involve several stresses imposed on packaging in a sequential manner. To gain an understanding of these accident sequences, ICAO ADREP data for aircraft accidents that involve the destruction of the aircraft from 1990 to 2000 were reviewed and evaluated. The data provided the following six events associated with aircraft accidents:

- Ground impact;
- Impact in flight/collision;
- Post-impact fire;
- No post-impact fire;
- Explosion;
- Immersion.

For ease of discussion, the impact in flight/collision event has been designated 'Inflight Impact', the post-impact fire event has been designated 'Ground Fire', the no post-impact fire event has been designated 'Inflight Fire' and the explosion event has been designated 'Inflight Explosion'.

ICAO ADREP data categorize aircraft accidents into accidents involving a single event, two events in sequence, three events in sequence; and four or more events in sequence. As 338 aircraft were included in the accident data, the total number of accidents is taken as 338 in this section. Of the 338 accidents which were reviewed, 49.4% involved single events, 46.5% involved two event sequences, 3.8% involved three event sequences, and 0.3% involved four event sequences. These results are shown in Fig. 14.

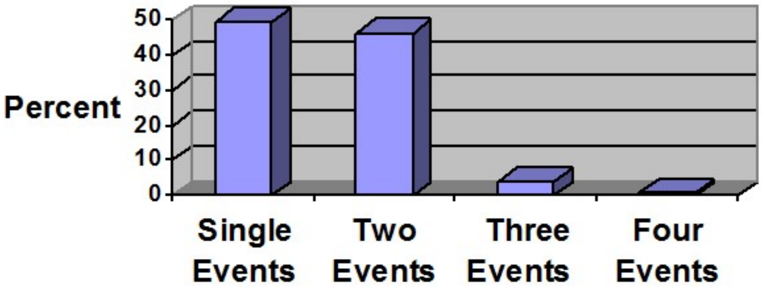

FIG. 14. Order of the accident sequence.

8.1.SINGLE EVENT ACCIDENTS

Out of the 336 accidents reviewed, 167 were single event aircraft accidents comprising 49.4% of the accidents. There were seven types of single events that resulted in the aircraft being declared destroyed. Five of these event types are the result of an aircraft accident. Of the other two event types, one resulted from the aircraft being over-stressed and the other from the aircraft being removed from service due to mercury contamination.

Of the five single event accident types, 94.6% involved ground impact, with the remainder involving inflight explosions (2.4%), inflight fires (1.2%), ground fires (1.2%), and immersion (0.6%). The proportion of each accident type for the single event accident is shown in Fig. 15.

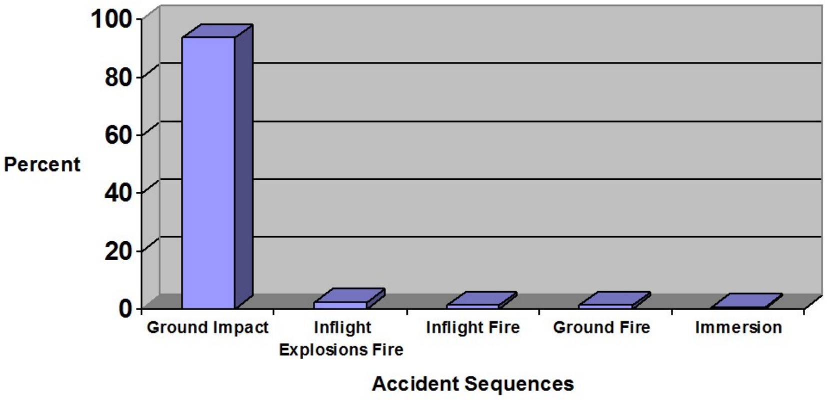

FIG. 15. Single event accidents.

8.2.TWO EVENT ACCIDENT

Out of the 338 accidents reviewed, 157 were two event accident sequences, comprising 46.5% of the accidents. There were seven combinations of two event accident sequences. The Ground Impact/Ground Fire accident sequence makes up most of the two event accident sequences, representing a fraction of 73.9%. The percentages of the different accident sequences during two event accidents are shown in Table 10 and in Fig. 16.

TABLE 10. TWO ACCIDENT EVENT SEQUENCES

Accident Sequence	Percentage
Ground impact followed by a ground fire	73.9%
Ground impact followed by immersion	10.8%
Inflight explosion followed by a ground impact	6.4%
Inflight fire followed by a ground impact	3.8%
In-flight impact followed by a ground impact	2.6%
In-flight fire followed by a ground fire	1.9%
In-flight fire followed by immersion	0.6%

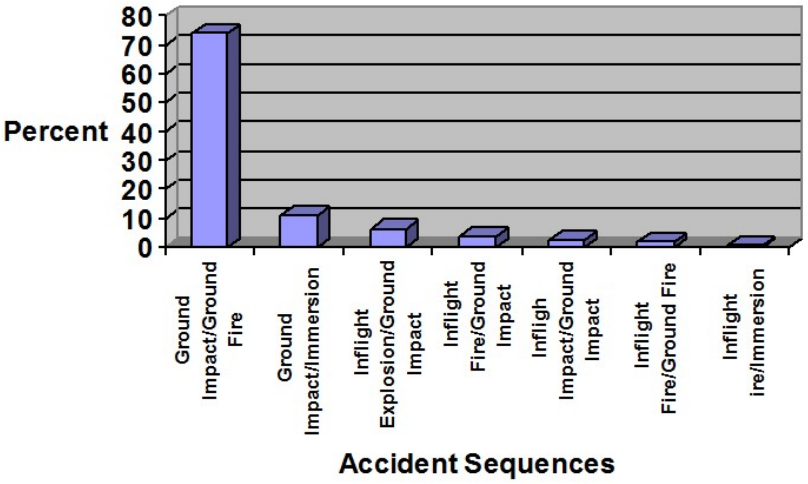

FIG. 16. Two event accident sequences.

8.3.THREE EVENT ACCIDENT SEQUENCES

Out of the 338 accidents, 13 were three event accident sequences, making up a small proportion of the accidents reviewed, representing only 3.8%. The percentages of the different accident sequences during three event accident are shown in Table 11 and in Fig. 17.

TABLE 11. THREE ACCIDENT EVENT SEQUENCES

Accident Sequence	Percentage
Inflight fire/ground impact/ground fire	30.7%
Inflight impact/ground impact/ground fire	15.4%
Inflight explosion/ground impact/ground fire	15.4%
Inflight explosion/ground impact/immersion	15.4%
Ground impact/ground fire/immersion	15.4%
Inflight fire/ground impact/immersion	7.7%

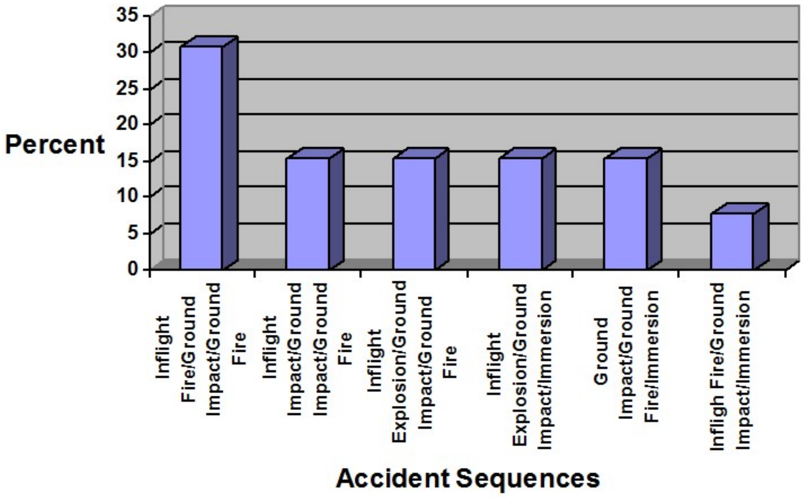

FIG. 17. Three event accident sequences.

8.4.FOUR EVENT ACCIDENT SEQUENCES

There was only one four event accident sequence in the data reviewed. This sequence represents only 0.3% of the data involved:

- Inflight fire/ground impact/ground fire/immersion.

8.5.COMPARISON OF DATABASES

To judge whether the 53 accident subset of the initial 336 database is equivalent with respect to probability of accident types, the sequence of events in both databases are compared. Table 12 compares the percentage of the number of events in both databases. There is a noticeable shift of probabilities to multiple event accidents in the 53 accident subset compared to the initial database. When taking Figs 15–17 into account, it is obvious that the 53 accident subset is likely to contain a higher percentage of fire events than the original database. Furthermore, the probability distribution of two event accident sequences (Table 13) is similar for accident sequences including a fire event. This indicates that the fire analysis in Section 6 is conservative.

The difference between the databases with regard to single event accidents may affect the interpretation of impact velocity analysis in Section 5. However, as already stated in Section 5.4, this difference is mainly due to a lower number of landing accidents within the 53 accident database, which are not relevant for high energy impact accidents.

TABLE 12. PROBABILITY OF THE NUMBER OF EVENTS IN THE INITIAL AND FINAL ACCIDENT DATABASES

No. of events	336 accident database	53 accident database
One event	49.4%	32.1%
Two events	46.5%	54.7%
Three events	3.8%	11.3%
Four events	0.3%	1.9%

TABLE 13. PROBABILITY OF TWO EVENT ACCIDENT SEQUENCE IN THE INITIAL AND FINAL ACCIDENT DATABASES

Sequence of events in two events accidents	336 accident database	53 accident database
Ground impact/ground fire	73.9%	79.3%
Ground impact/immersion	10.8%	10.3%
Inflight explosion/ground impact	6.4%	0.0%
Inflight fire/ground impact	3.8%	6.9%
Inflight impact/ground impact	2.6%	0.0%
Inflight fire/ground fire	1.9%	3.4%
Inflight fire/immersion	0.6%	0.0%

9. AIRCRAFT ACCIDENT RATES

9.1.GENERAL

The establishment of reliable information on aircraft accident rates covering worldwide operations has traditionally been hindered by incomplete and unreliable reporting of both accidents and operational statistics. However, since the late 1980s, the United Kingdom based organization Airclaims has been collaborating with Western aircraft manufacturers to collect data on all operational statistics and accidents involving Western built turbine powered aircraft over 5700 kg mass. The analysis which follows is based on Airclaims data, supplied for this purpose by the UK Civil Aviation Authority. For the purposes of this CRP, the IAEA was interested in accident rates for the period 1990–2000 inclusive. The only aircraft types for which comprehensive and reliable operational and accident statistics, by aircraft type, are available in this period are turbofan/turbojet powered aircraft made by Western manufacturers, and so the analysis which follows is confined to this aircraft class. Accident rate analysis carried out for other purposes has indicated that accident rates appear to vary according to geographical region, type of operation, and aircraft size (with smaller aircraft appearing to suffer higher accident rates than larger aircraft). Accordingly, the analysis gives accident rates for both cargo and non-cargo operations separately by geographical region, as well as the worldwide frequencies.

9.2.DATA SOURCE: AIR CLAIMS

- The data cover fatal accidents involving destroyed aircraft for all Western built jets in the period 1990–2000, inclusive;
- For each State and aircraft type, the data gives total hours, total flights for both cargo and passenger (i.e. non-cargo) operations;
- Also given is a count of fatal accidents in each category of operation, together with a classification of the damage to the aircraft (total loss, partial loss, etc.);
- The data do not make a distinction between variants of the same aircraft type;
- The aircraft types of interest are those with a maximum certificated mass of 27 000 kg or more. However, some variants of the Fokker F28, of which significant numbers exist, have maximum mass just below 27 000 kg and the format of the data does not make it possible to distinguish between F28 variants. So the mass cut-off for this analysis was set at 25 000 kg to ensure that all F28s were included.

9.3.RESULTS

The results are summarized in Table 14, which gives the number of total loss fatal accidents per million flights for Western built jet aircraft with maximum mass above 25 000 kg for the period 1990–2000 inclusive. Because of previously observed variations in accident frequencies between different geographical regions and for different types of operations, the results are presented below by geographical region for both cargo and non-cargo operations.

TABLE 14. NUMBER OF TOTAL LOSS FATAL ACCIDENTS INVOLVING WESTERN BUILT JET AIRCRAFT WITH MAXIMUM MASS >25 000 kg FOR THE PERIOD 1990–2000

Airclaims area (see definitions in Appendix 9.1)	Number of accidents per million flights		
	Cargo operations	Non-cargo operations	All operations
Africa	9.12	2.80	3.26
Europe non-JAA[a]	20.88	1.99	2.28
South & Central America	3.47	1.43	1.53
Asia	7.81	1.22	1.42
China	0.00	1.14	1.13
USA	0.91	0.19	0.24
JAA*	0.00	0.23	0.23
North America & Caribbean	0.00	0.22	0.21
Australasia	0.00	0.00	0.00
Worldwide	**1.93**	**0.57**	**0.64**

[a] Joint Aviation Authorities (European).

However, aircraft accidents occur in an unpredictable manner and, as such, these accident rates could be influenced by statistical variation. In view of this, a confidence limit analysis was carried out assuming that the accident statistics conform to a Poisson probability distribution (this is a conventional assumption for the statistical analysis of 'rare' events). The results of this confidence analysis can be summarized as follows.

The worldwide accident rate (all operations) for the period 1990–2000 involving turbofan/turbojet powered aircraft built by Western manufacturers and with a mass exceeding 25 000 kg for total loss fatal accidents is 0.64 per million flights. Similarly, the total loss accident rate is approximately 0.8 per million flights.

However, USA (passenger operations) and JAA (passenger operations) have an accident rate which is significantly better (at the 95% confidence level) than the worldwide average for all operations.

The following areas have accident rates which are significantly worse (at the 95% confidence level) than the worldwide average for all operations:

- Asia (passenger and cargo operations);
- Africa (passenger and cargo operations);
- China (passenger operations);
- Europe, non-JAA (passenger operations);
- South and Central America (passenger operations);
- Worldwide cargo operations.

The accident rate for passenger operations by US and JAA operators is 0.2 per million flights.

However, the following areas have accident rates which are significantly worse (at the 95% confidence level) than 0.2 per million flights:

- South and Central America (passenger and cargo operations);
- Asia (passenger and cargo operations);
- Africa (passenger and cargo operations);
- China (passenger operations);
- Europe non-JAA (passenger and cargo operations);
- USA (cargo operations);
- Worldwide cargo operations

9.4.UPDATED ACCIDENT RATE INFORMATION

Figures 18 and 19 provide data on aircraft accident numbers from 1995 to 2004. This information was compiled in 2005 and may not be complete for 2004. The data presented originate from ICAO and are based on information reported by States to ICAO as well as by industry sources.

ICAO does not provide statistics based on hull losses or number of aircraft destroyed. Instead, it uses the number of accidents involving fatal injuries to persons as a measure. In doing so, it was recognized that not all such accidents would necessarily involve the destruction of aircraft. Examples of such accidents would be fatal injuries incurred in the evacuation of an aircraft, persons falling off stairs and collision of aircraft with persons during ground movements.

Figure 18 provides the number of fatal accidents in commercial operations involving aircraft over 27 000 kg. Figure 19 shows the data for aircraft of a maximum certificated takeoff weight of 2250–27 000 kg. ICAO does not collect any data on accidents involving aircraft with a mass less than 2250 kg.

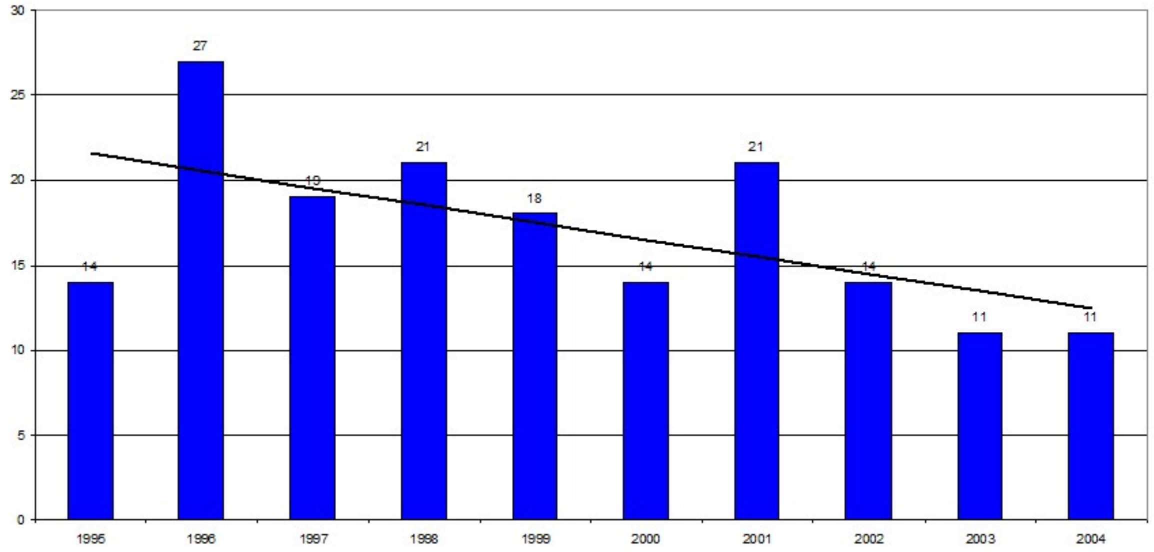

FIG. 18. Number of fatal accidents during commercial operation of fixed wing aircraft over 27 000 kg.

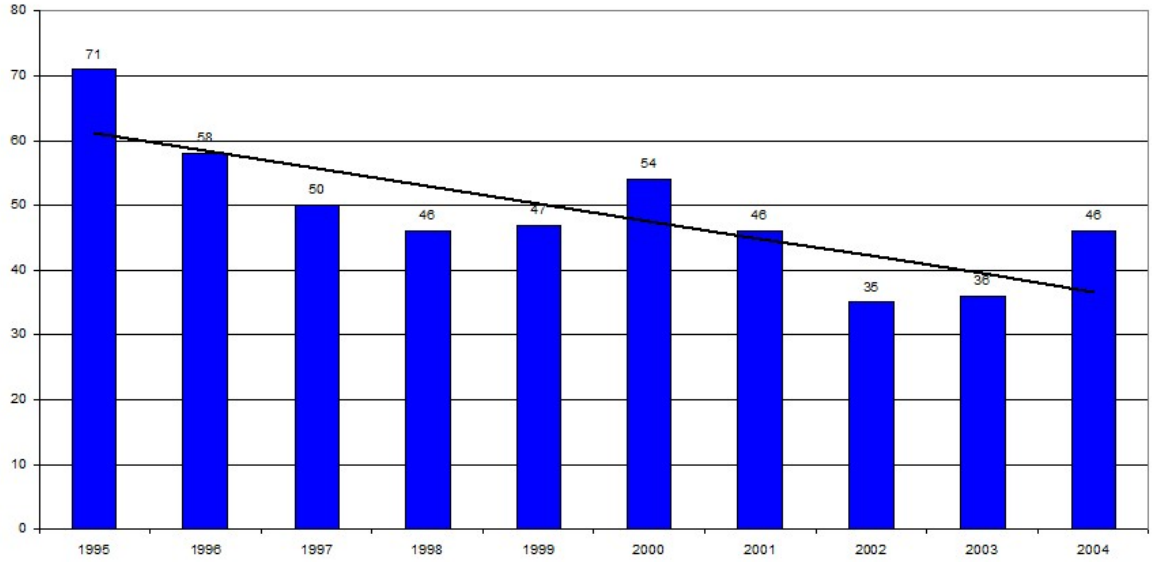

FIG. 19. Number of fatal accidents during commercial operations: fixed wing aircraft, 2250–27 000 kg.

As stated in Section 9.1, the number of accidents involving small aircraft is larger than the figure for larger aircraft.

Figure 20 provides information on the number of departures for the years 1995 to 2004. A significant increase in the number of operations from 1995 to 2004 can be observed.

Figure 21 provides the worldwide rate of fatal aircraft accidents for fixed wing aircraft in scheduled commercial operations. Due to the reduction in the number of accidents over the ten year period and the increase in the number of operations, the rate of fatal accidents dropped from about 1.7 per million departures in 1995 to about 0.4 per million departures in 2004.

Figure 22 shows the number of fatal accidents in cargo operations and the number of fatal accidents in passenger operations. It indicates that the number of fatal accidents in passenger operations dropped over the period, while the number of fatal accidents in cargo operations remained almost the same, surpassing in 2004 for the first time, the number of fatal accidents in passenger operations.

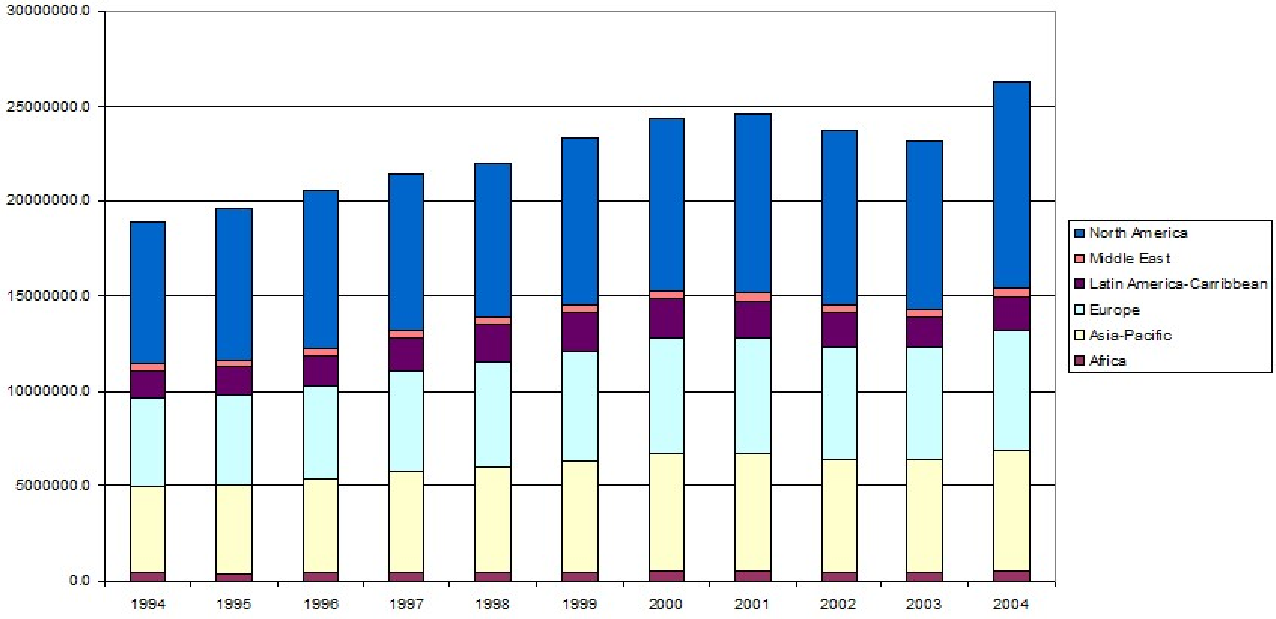

FIG. 20. Number of departures during scheduled operations.

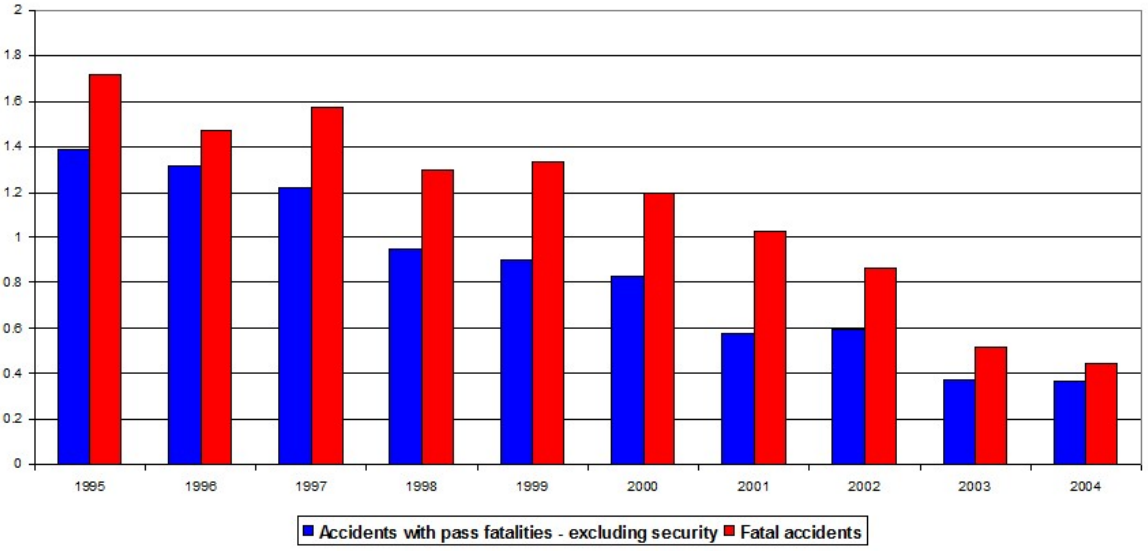

FIG. 21. Number of fatal accidents per 1 000 000 departures during scheduled operations.

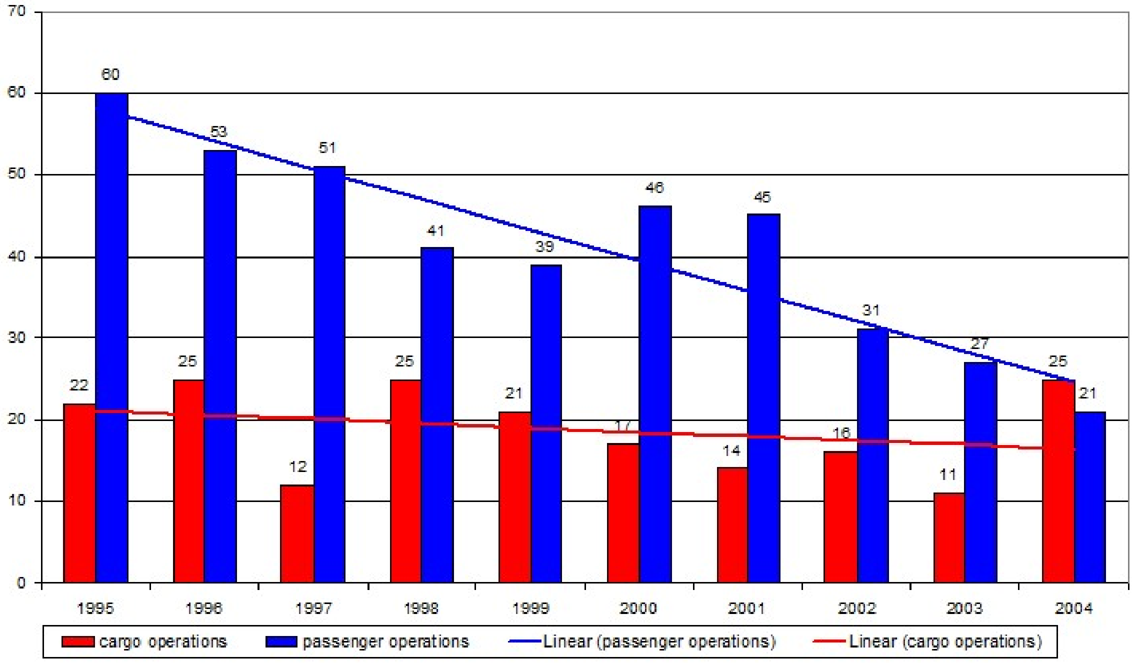

FIG. 22. Number of fatal accidents in passenger operations and in cargo operations for fixed wing aircraft, 1995–2004.

9.5.CONCLUSION

Based on the information at hand, it would appear that there has been some improvement with respect to the safety of operations. However, the improvements are mostly seen in passenger operations, while it appears that neither an improvement nor any deterioration in the safety of cargo operations could be demonstrated. This indicates that the conclusions drawn in other parts of this report, which are based on the frequency of accidents, remain valid.

10. ESTIMATION OF RISK FOR THE AIR TRANSPORT OF PACKAGES WITH LARGE QUANTITIES OF RADIOACTIVE MATERIAL

10.1. INTRODUCTION

The IAEA Transport Regulations, i.e. TS-R-1 (2005 Edition) **Error! Reference source not found.**, provide for the air transport of large quantities of radioactive material:

- In a Type B package provided that the activity of the contents does not exceed the limits prescribed in the regulations,
- In a Type C package.

The CRP participants analysed data on aircraft accidents, focusing on large commercial aircraft with a weight >27 000 kg, and by selecting accidents that resulted in complete destruction of the aircraft or in fatalities, or in destroyed aircraft + fatalities. From this analysis, the probabilities/frequencies of aircraft accidents with a significant challenge to the integrity of Type C packages can be estimated. A complete risk estimate would also assess potential radiological consequences that could result in the case that radioactive material is released from an affected package to the environment, or in the case that the accident leads to a substantial reduction of the shielding performance of the package and to enhanced direct radiation dose rates near the damaged package. The following discussion will concentrate mainly on probabilities/frequencies of accident impacts.

There are several ways to express or to normalize this risk and to try to put it into perspective with other risks:

- On a per package basis,
- On the basis of the current transport practice or that foreseeable for the near future.

10.1.1. Risk per package basis

Assume that a Type C package with high activity inventory is transported by aircraft from location A to location B. What is the probability per flight that the aircraft has an accident? What fraction of such accidents can be expected to be of a severity to sufficiently damage the package so that it loses part of its containment function and/or a significant dose rate increase results near the package?

10.1.2. Risk per annual transport volume basis

How many Type C packages are transported by aircraft per year? A rough estimate of this number allows one to evaluate the probability of an aircraft accident happening involving such a package with a large quantity of radioactive material. By considering the various types of aircraft accidents and their potential severity to the package (e.g. impact severity, fire severity), one can roughly estimate the frequency of aircraft accidents which could have radiological consequences.

10.2. ESTIMATE OF ACCIDENT PROBABILITIES

Figure 23 attempts to draw simplified conclusions from the databases of 336 aircraft accidents. It shows a crude and approximate event tree constructed from the accident data file and from data on aircraft accident rates. To systematize and simplify data processing, accidents were classified according to event sequence from single events, e.g. ground impact only, fire only to very rare event sequences of up to four events, specifically inflight fire/ground impact/ground fire/immersion. By reference to the accident reports, a simplified and approximate classification of ground impact severity was derived and accidents were categorized as being low impact, high impact, or unknown severity of impact (because of a lack of sufficient data in the accident files).

During the time period assessed by the CRP (1994–2004), the aircraft traffic (number of starts) increased by roughly 25%, while the absolute number of fatal aircraft accidents reduced (Fig. 21). In effect, during the time period assessed by the CRP, the accident rate with the aircraft destroyed for scheduled flights was about 8×10^{-7} per flight (see Section 9.3).

According to the accident statistics for the time period 1990–2000, about 50% of all such accidents resulted in a ground impact with no additional fire that could be of concern to a package on board. Of these accidents, approximately 80% were classified as low speed accidents and 20% as high speed accidents. This ratio was also assumed for aircraft accidents with ‘unknown’ impact severity. About 34% of all the accidents were two event accidents with ground impact followed by fire. Again here 80% of these accidents were attributed to low speed and 20% to high speed impact. The remaining 16% of aircraft accidents with the aircraft destroyed are represented in Figure 23 as ‘others’ and comprise all other single to multiple event sequences.

By multiplying the overall aircraft accident rate with the aircraft destroyed of 8×10^{-7} per flight by the conditional probabilities given in the simplified event tree, the respective probabilities of the final branches can be calculated and are given in Fig. 23; for example, a high speed ground impact involving no fire of any importance has a probability of 8×10^{-8}.

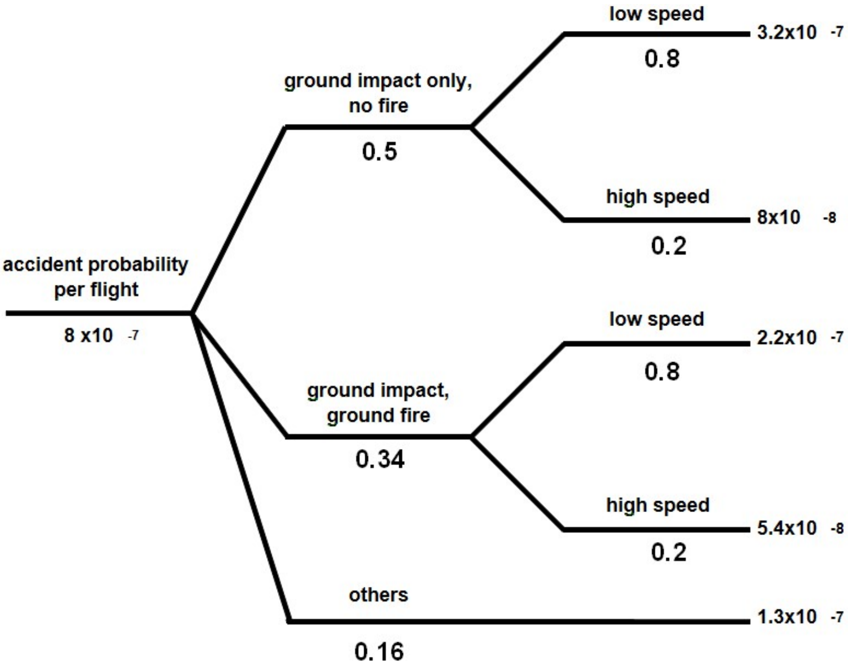

FIG. 23. Simplified event tree of aircraft accidents (>27.000 kg mass, destroyed).

10.2.1. Accident probability per package basis

Assuming that a package is transported by aircraft (mass >27 000 kg), in our case a Type C package with a large quantity of radioactive material, the probability that the package is involved in an aircraft accident (i.e. aircraft destroyed) is 8×10^{-7}. In most cases, the ground impact will be of 'low speed', the probability being about $3.2\times10^{-7} + 2.2\times10^{-7} = 5.4\times10^{-7}$. The probability of a high speed ground impact is approximately 1.3×10^{-7} ($8\times10^{-8} + 5.4\times10^{-8}$) and that of a high speed impact accident followed by fire of 5.4×10^{-8}. Using the above quoted accident rate of 1.3×10^{-7} accidents with high speed ground impact as an approximate measure, one can conclude that for a given package when transported by aircraft the probability of being subjected to a high speed impact aircraft accident is about 1 in 8 million per flight.

10.2.2. Accident probability per annual transport volume basis

The participants in the CRP were not aware of any Type C packages that were being transported by air on a regular basis. Type B packages are allowed to carry up to $3000A_1$ or $100\,000A_2$, whichever is lower, when in special form and $3000A_2$ otherwise. By defining 'larger quantities' of radioactive material contained in a Type B package as activity exceeding one-tenth of the above limits for Type B packages, one can estimate that not more than 1000 such packages were being transported by air annually as observed in 2005.

Referring to Fig. 23 and comparing the upper limit of 1000 such packages per year transported by large aircraft, with the overall rate of large aircraft destroyed being 8×10^{-7} per flight and assuming one such package per flight, if any, leads to this conclusion: On average, one would expect that an aircraft accident in which a package as defined above is on board has an annual frequency of 8×10^{-4}. In other words, such an accident with destroyed aircraft would be expected to happen somewhere in the world on average every 1250 years. This makes it evident that such an event is very rare for the current annual transport volume, which is not expected to increase much in the near future. If one were to consider a more realistic figure of 100 Type C packages per year, transported by air, one would expect that an aircraft accident in which a package, as defined above, is on board has an annual frequency of 8×10^{-5}. In other words, such an accident with destroyed aircraft would be expected to happen somewhere in the world on average every 12 500 years.

11. DISCUSSION AND CONCLUSIONS

11.1. COMPARISON BETWEEN FDR AND TYPE C PACKAGE REQUIREMENTS

The purpose of this CRP was to gather data on aircraft accident frequency and severities and to analyse them to validate Type C package test requirements.

The study shows that the test requirements and acceptance criteria for FDRs and Type C packages are different, and no direct comparison of the impact test criteria can be made. The acceptance criterion for a radioactive material package is a very low level of leakage of the contents, whereas FDRs must allow retrieval of the data contained on the recording media.

of greater Based on the test results, FDRs may not survive Type C test requirements. However, a Type C package would likely survive the FDR crash survival testing requirements. It should be noted that Type C packages differ significantly in size, mass, and stiffness and the test may not be applicable to other design. The details of comparative study of Type C package and Flight Data Recorder test requirements can be found in Appendix I.

11.2. IMPACT VELOCITY REQUIREMENT FOR A TYPE C PACKAGE

Two approaches were considered to determine the probability of the equivalent impact velocity in an accident that may exceed 90 m/s:

(1) The first approach considers only the events for which data were extracted from completed questionnaires. The mean and 90th percentile probabilities were calculated for this approach;
(2) The second approach considers all of the events, assuming that there is no correlation between the energy of impact of an event and the fact that the relating questionnaire has been filled out or not. The approach leads to the following conclusions:
    a. The most probable value of an impact exceeding 90 m/s is close to 11%;
    b. A probability of an impact exceeding 90 m/s by about 10% to 14% cannot be rejected with a good confidence level;
    c. A probability of an impact exceeding 90 m/s by less than 8% or more than 18% can be rejected with a good confidence level.

First, using the raw data on impact velocities from the 53 accidents, it was determined that the P(>90 m/s) = ~19%. Then, when considering the complete set of raw data (339), the P(>90 m/s) is between 8% and 18%, with the most probable value being 8%. Then, when adjusting the data for impact angle and surface hardness, the P(>90 m/s) is between 2% and 9%.

Assumptions

The analysis for determining the impact load was based on certain assumptions as noted below:

- The data analysed in detail for impact analysis is a small sample from a large number of accidents. There is considerable uncertainty in the calculation of the probability estimate of the accident severity occurring with a desired velocity;
- The data provided in aviation accident reports are not easily convertible to the Type C packaging requirement, which is impact normal to the plane onto an unyielding target. Consequently, the information analysed to determine the impact velocity is sometimes based on the best judgment and limited available information;

- The analysis has been simplified by ignoring non-linear effects that certain aircraft parameters may have in calculating the impact velocities;
- The calculated equivalent velocity factors are based on a limited number of package stiffness and surface stiffness combination data. In particular, the package stiffness for various packaging designs can vary considerably. The velocity ratios in the table are therefore not necessarily conservative;
- The analysis does not consider that the packaging may have seen puncture or crush loading prior to impact. The analysis therefore ignores any impact that these loading may have on the equivalent velocity factors;
- An important conservative assumption made in the analysis is that even though during an aircraft accident some impact energy is absorbed by the aircraft structure, it was not taken into account;
- The impact analyses are very conservative because only accidents where the aircraft was completely destroyed were considered. Furthermore, the data were subjected to a coarse filter so that only high velocity aircraft accidents were considered. All accidents with an impact speed below 60 m/s were discarded (unless they involved fire or immersion);
- The impact analyses are also conservative because when the angle of impact was not known, no correction was made. This resulted in an overstatement of the equivalent impact velocity.

11.3. REQUIREMENTS FOR THERMAL ENVIRONMENT

Compared with impact velocity figures, the information on fire severity (intensity and duration) was sparse and inaccurate. There is no automatic recording of fire information except for cases of inflight fire. In addition, investigation of the fire scenario is of secondary interest in accident investigation when fire is not the major cause for fatalities and injuries. There is no information on fire temperature available. Accordingly, only a subset of the 53 accident data set with indication of fire contains detailed fire information. The number of available cases for fire analysis further decreases when investigating correlations between different parameters related to fire severity (fuel load, fire duration, fire area, combustible material) involved.

Based on the available information, it was estimated that the median time of fire duration would be less than 1 h. For the adjusted fire duration, the respective median values are 1.2 h for the fire cases and about 20 min for all accidents. The percentage of all accidents involving fire with adjusted fire duration of at least 1 h is approximately 45%.

The information on fire duration that is available is not a direct indicator of the potential duration of package exposure to the fire in terms of full engulfment. Since this is a condition seldom seen in a real fire, the assumption of a fully engulfed package is very conservative. Therefore, this statistical analysis of fire information from the 53 accident database can only give a rough estimate of major trends and dependencies.

Further interpretation was needed to obtain conclusions with respect to equivalence to the IAEA Type C fire test requirements. Given that an aircraft accident fire is unlikely to be fully engulfing, a reported fire of duration of longer than 1 h does not imply a higher heat input than the IAEA Type C regulatory fire test. Furthermore, the combination of high speed impact and long duration fire is improbable. However, in the rather unlikely event of an aircraft impact in areas with additional agglomerated combustible material (e.g. buildings) a more severe fire scenario cannot be excluded.

11.4. REQUIREMENTS OF THE WATER IMMERSION ENVIRONMENT

Only 5.6% of the 338 accidents resulted in water immersion. It is estimated that in 16% of the accidents involving immersion, the equivalent impact velocity is over 90 m/s. In these accidents the immersion depth was less than 200 m in one-third of the cases and more than 200 m in two-thirds of the cases. The fraction of accidents involving immersion where the equivalent impact velocity is less than or equal to 90 m/s are 58%. It may be recalled that in 26% of the cases it was not possible to determine the equivalent impact velocity. Out of these only 10% resulted in an immersion depth of more than 200 m. One of these accidents occurred over the Black Sea where the depth of immersion of major debris was 500 m. For accidents resulting in an immersion depth over 200 m, it may not be possible to recover the package. Therefore, the consequences of the release of the radionuclides were investigated. It was concluded that the release would not result in any significant individual dose.

11.5. ACCIDENT SEQUENCES

The following six air accident events were defined:

- Ground impact;
- In-flight impact;
- Ground fire;
- In-flight fire;
- In-flight explosion;
- Water immersion.

Of the 338 accidents reviewed, 49.4% involved single events, 46.5% involve two event sequences, 3.8% involve three event sequences, and 0.3% involves four event sequences. The probability of a two event accidents sequence from two databases is estimated in Table 15.

TABLE 15. PROBABILITY OF TWO EVENT ACCIDENTS

Sequence of events in two event accidents	336 accident database	53 accident database
Ground impact/ground fire	73.9%	79.3%
Ground impact/immersion	10.8%	10.3%
Inflight explosion/ground impact	6.4%	0.0%
Inflight fire/ground impact	3.8%	6.9%
Inflight impact/ground impact	2.6%	0.0%
Inflight fire/ground fire	1.9%	3.4%
Inflight fire/immersion	0.6%	0.0%

11.6. AIRCRAFT ACCIDENT RATES

Accident rate analysis carried out for other purposes has indicated that accident rates appear to vary according to geographical region, type of operation and aircraft size (with smaller aircraft appearing to suffer higher accident rates than larger aircraft). Accordingly, the analysis reported gives accident rates for both cargo and non-cargo operations separately by geographical region, as well as the worldwide frequencies.

11.7. ESTIMATION OF THE RISK OF TRANSPORTING LARGE QUANTITIES OF RADIOACTIVE MATERIAL BY AIR

The risk in transporting large quantities of radioactive material was estimated. On a per package basis, the probability that the package is involved in an aircraft accident in which the aircraft is destroyed is ~8×10^{-7} per flight. The probability of a high speed ground impact is approximately 1.3×10^{-7} per flight and that of a high speed impact accident followed by fire is 5.4×10^{-8} per flight. Using the above quoted accident rate of 1.3×10^{-7} per flight, the probability that a package will be subjected to a severe impact aircraft accident is about 1 in 8 million per flight.

On a per annual transport volume basis, assuming an upper limit of 1000 packages that contain large quantities of radioactive material per year transported by aircraft with the overall aircraft accident rate of aircraft destroyed of 8×10^{-7} per flight and assuming one such package per flight, leads to a frequency of about 8×10^{-4} per year. In other words, such an accident with destroyed aircraft would be expected to happen somewhere in the world on average every 1250 years. This makes it evident that such an event is very rare for the current volume of annual transports, which is not expected to increase much in the near future

11.8. CONCLUSIONS

This study provided an understanding of the technical basis of the regulatory tests. The accident frequency of transport by air is very low. In addition, the probability of an accident exceeding the severity of the regulatory tests is low. Further, there is a low probability of a Type C package being on board. If an accident involving a package is more severe than the regulatory tests, it may not necessarily result in a significant, or any, release of the contents of the package.

Based on the information at hand, it would appear that there has been some improvement with respect to the safety of operations. However, the improvements are mostly noted in passenger operations, while it appears that neither improvement nor any deterioration in the safety of cargo operation could be demonstrated.

Notwithstanding the limitations listed above, it appears that the IAEA regulatory standards for Type C packages in the IAEA Regulations for the Safe Transport of Radioactive Material, SSR-6 (Rev. 1) (2018 Edition) are adequate [1].

APPENDIX I. COMPARATIVE STUDY OF TYPE C PACKAGE AND FLIGHT DATA RECORDER TEST REQUIRMENTS

I.1. INTRODUCTION

The project, detailed in Ref. [4], studying the Type C package test requirements and flight data recorder (FDR) test requirements involved:

- Testing of the FDR to Type C package mechanical test (9 m drop, dynamic crush, puncture-tearing and impact at 90 m/s) requirements;
- Testing of the internal components of a Type B package (in the absence of a Type C package) to the impact test requirements of an FDR.

I.2. COMPARISON OF APPLICABLE TEST REQUIREMENTS AND ACCEPTANCE CRITERIA

The comparison of the main test requirements for the FDR, Type B package and Type C package are summarized in Table 16. The test requirements for the Type B and Type C package are extracted from the 1985 IAEA Transport Regulations [18] and the 1996 IAEA Transport Regulations [2], respectively. The operational performance specification for the FDR is defined in the European specifications [19].

TABLE 16. COMPARISON OF TEST SPECIFICATIONS FOR FDRs AND TYPE B AND TYPE C PACKAGES

Test element	FDR	Type B	Type C
Impact shock	Half-sine wave shock of 6.5 ms duration and a peak of 3400*g*	9 m drop on unyielding surface	1.9 m drop on unyielding surface 2.90 m/s impact test on an unyielding surface
Penetration resistance	227 kg probe drop from 3 m height	1 m drop onto a bar	250 kg probe drop from 3 m height
Static crush	5000 lb (22.25 kN) for 5 min	Five times the mass of package for 24 h	Five times the mass of package for 24 h
Dynamic crush	n/a	500 kg mass drop* from 9 m height	500 kg mass drop from 9 m height
Thermal test	High temperature: Heat flux of 50 000 BTU/(ft^2·h) (157 625 W/m^2), nominal flame temperature of 1100^{0}C for 60 min Low temperature: 260^{0}C for 10 h	800^{0}C for 30 min	800^{0}C for 60 min
Deep sea pressure	6096 m (60 MPa) for 30 d	15 m (150 kPa) for 8 h	200 m (2 MPa) for 60 min
Sea water/fluids immersion	Various corrosion resistance per EUROCAE ED-55 and ED-56A	n/a	n/a

* Applies for packages having a mass not greater than 500 kg instead of the ‘impact shock’ test.

FDRs are required to withstand an impact shock characterized by a half-sine wave shock of 6.5 ms duration and a peak acceleration of 33 342 m/s^2 (3400*g*). This acceleration pulse is equivalent to an impact velocity of 138 m/s and a displacement of 0.448 m. The total area under the acceleration–time curve is 14.069 *g*-s.

FDRs also undergo the static crush, penetration resistance, thermal (low and high temperature fire tests), deep sea pressure and fluids immersion tests (corrosion tests), as indicated in Table 16. A dynamic crush test as required for radioactive material packages is not required for FDRs.

FDRs are required to withstand each of the following three test sequences independently:

(1) Impact shock, penetration resistance, static crush, high temperature fire and immersion;
(2) Impact shock, penetration resistance, static crush, low temperature fire and immersion;
(3) Impact shock, penetration resistance, static crush, deep sea pressure and immersion.

The corrosion test may be performed on a separate recorder independent of the main sequence of tests.

The impact test requirement for a Type B package involves dropping the package from a height of 9 m onto an unyielding surface in such an orientation as to suffer the maximum damage. Type B packages are also required to be tested for the puncture-tearing test, static crush test, thermal test and water immersion (pressure) test, as summarized in Table 16. The dynamic crush test is only required for packages that have a mass not greater than 500 kg, and an overall density no greater than 1000 kg/m^3.

The specimen is subjected to the cumulative effects of the mechanical tests and thermal test. The order in which the specimen is subjected to the mechanical tests (drop, puncture-tearing and crush) is such that, on completion of the mechanical test, the specimen will have suffered damage that will result in the maximum damage during the thermal test that follows.

The impact test requirement for a Type C package is a 9 m drop test similar to that for Type B packages. In addition, Type C packages are subjected to an impact on an unyielding target at a velocity of not less than 90 m/s at such an orientation as to suffer maximum damage. For the puncture-tearing test, the Type C packages having a mass <250 kg are subjected to a 250 kg probe falling from a height of 3 m. For the thermal test, the package is exposed for 60 min, while for water immersion tests, the package is immersed under a head of 200 m (equivalent to 2 MPa external gauge pressure) for a period of 60 min. The test sequence for Type C packages is similar to Type B packages, except that separate specimens are allowed to be used for the 90 m/s velocity impact test.

The primary difference between testing specifications for FDRs and radioactive packages is in survivability and usage following testing. The purpose of an FDR is to record aircraft parameters and other flight information prior to an accident so that the information may be used to assist in determining the possible cause of the accident. Therefore, the primary crash survival requirement for the FDR is that following the sequence of crash survival tests, the recorder should be capable of preserving and replaying the data recorded in the memory module.

For Type C packages, the primary objectives of the package are to retain sufficient shielding of the radiation at the surface of the package and restrict any leakage of the radioactive contents to very stringent regulatory quantities. In general, this requires that there be less physical damage to the radioactive packaging following testing.

I.3. TESTS CONDUCTED ON FLIGHT DATA RECORDERS

Tests were conducted on two separate sample types of FDRs to Type C package requirements. The first specimen was subjected to the Type C requirement of impacting onto an unyielding target at a velocity of 90 m/s. The second specimen was subjected to the 9 m drop test, dynamic crush and a puncture-tearing test. The mass of the specimen tested is approximately 9 kg and is as illustrated in the following pages.

I.4. FIRST SAMPLE TYPE: SUBJECTED TO IMPACT TEST AT 90 M/S

The first specimen was fired from a cannon impacting onto an unyielding target. The projectile velocity recorded was 93 m/s and the peak force recorded was approximately 1.4×10^6 N. The total duration of the test was 2.2 ms as compared with the specified duration of 6.5 ms for the FDR. Based on the total projectile weight of 13.18 kg, the acceleration as a function of time was determined and is shown in Fig. 24. The peak acceleration acting on the FDR was determined to be 10 344*g*, which is approximately three times greater than the 3400*g* specified for the FDR.

The post-test inspection results showed that there was considerable damage to the specimen. The metal encased memory module had been breached and some of the insulation had been removed. However, the memory chips were found to be intact and attached to the board.

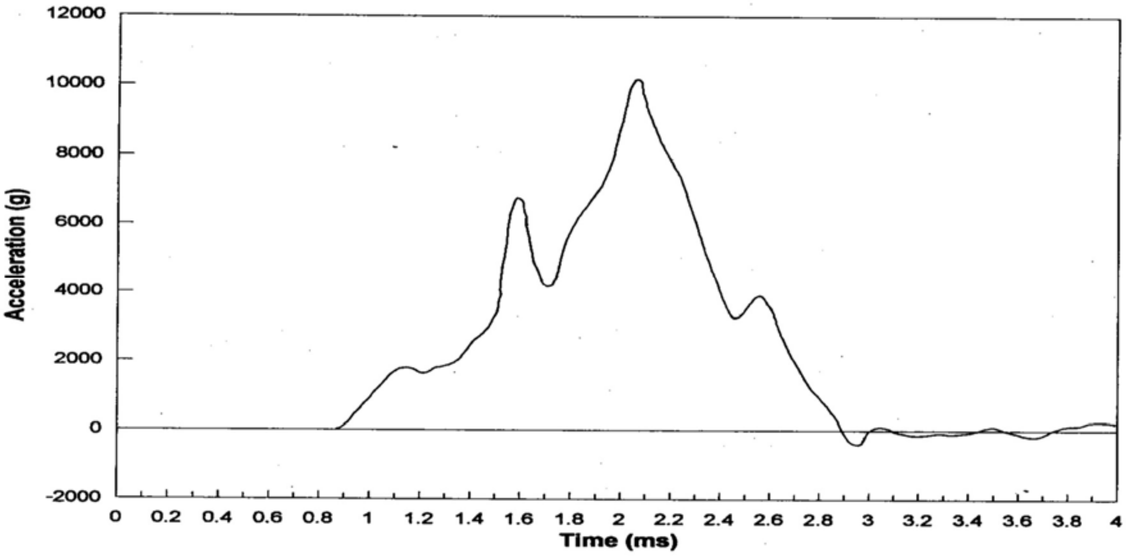

FIG.24. Acceleration versus time for an FDR impacted against a steel plate at 93 m/s. Reproduced courtesy of Institute of Nuclear Materials Management [4].

I.5. SECOND SPECIMEN: SUBJECTED TO OTHER MECHANICAL TESTS

The second specimen was subjected to 9 m drop, dynamic crush and puncture-tearing tests. There were only minor deformations observed to the outer container after the 9 m drop test. However, after the dynamic crush test the external container and the internal memory module container were fractured and severely deformed. The probe for the puncture-tearing test punctured the memory module and became embedded in the specimen. Since the memory module container was breached, it would not have survived any subsequent thermal tests. The pre- and post-test FDRs are illustrated in Figs 25 and 26, respectively.

FIG. 25. Flight data recorder (pre-test). Reproduced courtesy of Institute of Nuclear Materials Management [4]

FIG. 26. View of probe embedded in FDR. Reproduced courtesy of Institute of Nuclear Materials Management [4]

I.6. TEST CONDUCTED ON THE INTERNAL COMPONENTS OF A TYPE B PACKAGE

In the absence of a Type C package, tests were performed on a Type B package F-112/F-256 provided courtesy of MDS Nordion, Kanata, Canada. Because of the size limitations of the testing equipment, the outer drum and the wood inserts were removed and only the inner components were subjected to the test. The mass of the specimen tested was 21.25 kg and is illustrated in Fig. 28.

The specimen was fired from a cannon impacting onto a column designed to provide the 3400*g* reaction. The projectile velocity and the forces on the column as a function of time were recorded. Based on this data and the total projectile weight of 34.5 kg, the acceleration as a function of time was determined and is shown in Fig. 27. The impact speed recorded was 131 m/s and the maximum deceleration exerted on the specimen was 3100*g*, which is lower than the 3400*g* peak loading specified for an FDR. However, the duration of the impact shock was approximately 9 ms as compared with the specified FDR impact shock duration of 6.5 ms. By summing the area under the curve in Fig. 27, the acceleration-time is calculated as 13.6 *g*-s, which is 97% of 14.069 *g*-s as specified for FDRs.

The post-test inspection results show (Fig. 28) that there were only minor deformations on the outer container and no visible damage to the inner package insert. The leakproof inserts passed the leak test requirements.

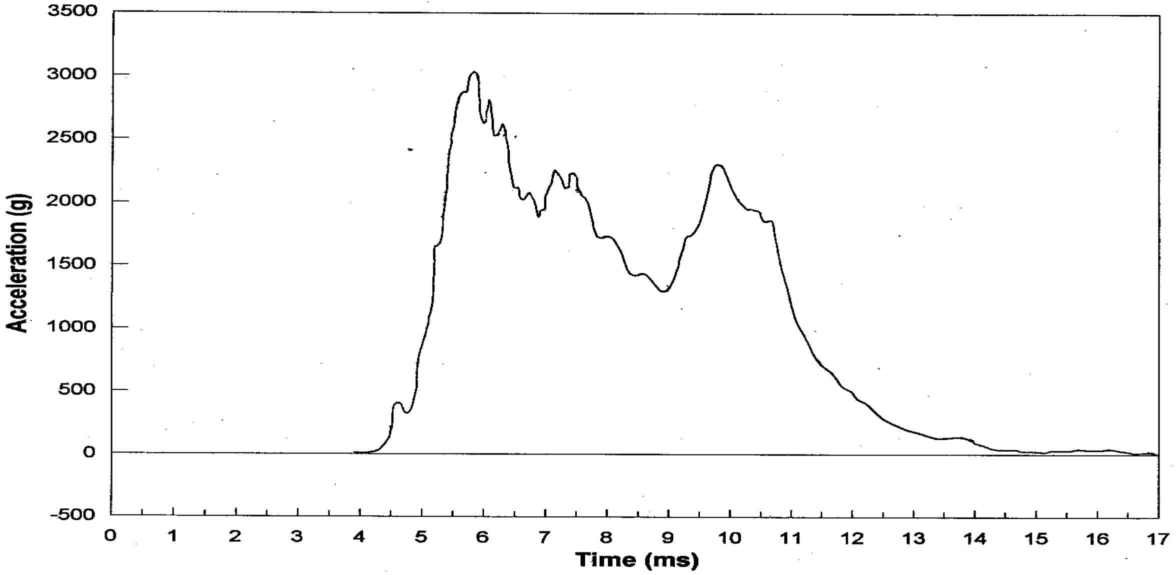

FIG. 27. Acceleration force loading on a Type B package during FDR impact test specification. Reproduced courtesy of Institute of Nuclear Materials Management [4]

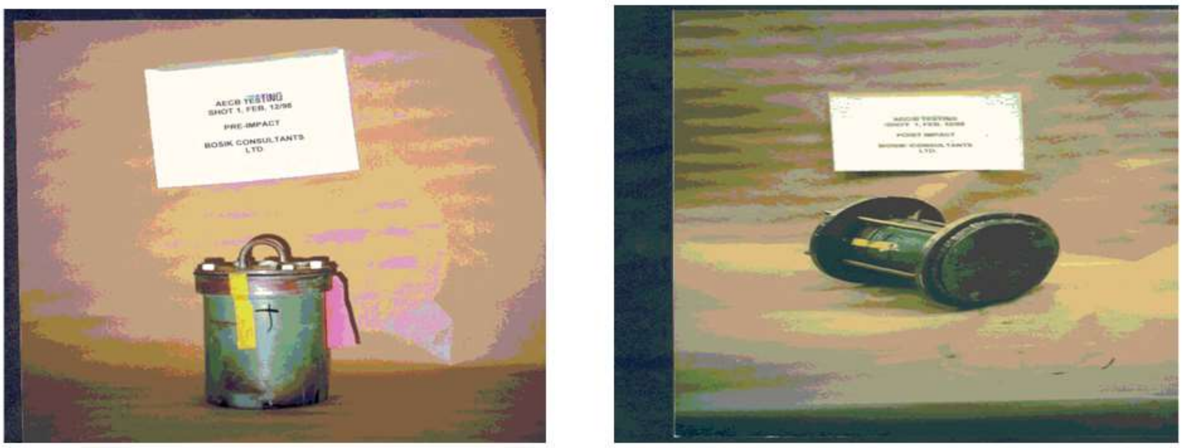

FIG. 28. Type B package MDS Nordion model F-112/F-256 pre-test (left) and post-test (right).Reproduced courtesy of Institute of Nuclear Materials Management [4]

I.7. RESULTS

FDRs have a higher impact test velocity requirement as compared with the Type C package requirements. However, in this test programme, when subjected to the Type C impact test requirements, the FDR was severely damaged to the extent that it was unlikely that the recorded data could have been retrieved. On the other hand, the Type B package tested without the outer drum and wood inserts survived the FDR impact test specification requirements with minor deformation only.

For the tests carried out in this project, the peak forces acting on the FDR when impacting the rigid plate at the Type C impact of 90 m/s were found to be approximately three times greater than that required for the FDR specification.

For impacts onto the essentially rigid target, all of the kinetic energy of the package is absorbed by deformation of the package. For impacts onto real yielding targets the kinetic energy is absorbed by deformation to the target as well as by deformation of the package. The severity of damage is therefore seen to be greater when the specimen is subjected to the Type C impact test requirements.

I.8. CONCLUSION

The study shows that the test requirements and acceptance criteria for FDRs and Type C packages are different and no direct comparison of the impact test criteria can be made. The acceptance criterion for a radioactive material package is a very low level of leakage of the contents, whereas FDRs must allow retrieval of the data contained on the recording media.

The target hardness has a major influence on the survivability of the test specimen. The impact velocity for the performance specification of FDRs is higher than that for Type C packages. However, the FDR specification does not require all the impact energy to be absorbed by the FDR. Because of the Type C impact of 90 m/s onto an unyielding target, the peak acceleration seen by the FDR is determined as being about three times more than that required for the FDR specification. The level of damage is therefore seen to be greater when the specimen is subjected to Type C requirements.

Based on the test results, FDRs may not survive the Type C test requirements. However, the Type C package would likely survive the FDR crash survival testing requirements.

It should be noted that the radioactive material packages (Type B and Type C) differ significantly in size, mass and stiffness and the test may not be applicable to other designs. The locations of FDRs and the radioactive material package in the aircraft are also significantly different, which will have an impact on the forces that FDRs and Type C packages will be subjected to.

APPENDIX II. INFORMATION SOUGHT IN THE QUESTIONNAIRE ON AIR ACCIDENTS

To gather information about the parameters of air accidents, in particular the angle and speed of impact, the duration of any fire and duration of immersion in water, the Accident Investigation Units of all ICAO Member States in which severe aircraft accidents occurred were requested to complete detailed questionnaires. The questionnaires and corresponding guidance for completing the questionnaires are reproduced in this appendix as follows:

- Section II.1. AIRCRAFT IMPACT QUESTIONNAIRE
- Section II.2. GENERAL GUIDANCE FOR COMPLETING THE IAEA AIRCRAFT ACCIDENT QUESTIONNAIRE
- Section II.3. AIRCRAFT ACCIDENT FIRE AND WATER IMMERSION INFORMATION
- Section II.4. GENERAL GUIDANCE FOR COMPLETING THE IAEA AIRCRAFT ACCIDENT FIRE AND WATER IMMERSION QUESTIONNAIRE

II.1. AIRCRAFT IMPACT QUESTIONNAIRE

1ST TIER CATEGORY (EXCEL WORKBOOK)	2ND TIER CATEGORY (EXCEL WORKSHEET)	3RD TIER CATEGORY (EXCEL WORKSHEET COLUMN HEADING)	4TH TIER CATEGORY (ANSWERS TO 3RD TIER CATEGORY)
IDENTIFICATION WORKBOOK			
	Accident Identification		
	Accident Date		
	Accident Time		
		Local Time	
		Local Time Zone	
		Universal Time (UTC)?	
		Universal Date (UTC)?	
	Aircraft Information		
		Company/Organization Operating Aircraft (Flight No.)	
		Aircraft Type Category	
		Aircraft Manufacturer	
		Aircraft Model/Series	
		Aircraft Registration	
		Aircraft Construction No./Serial No.	

-
  - Aircraft Maximum Certificated Gross Weight (kilograms)
  - Flight Type
  - Aircraft Construction No./Serial No.
  - Aircraft Maximum Certificated Gross Weight (kilograms)
  - Flight Type
    - Scheduled Passenger
    - Nonscheduled Passenger
    - Scheduled Freight
    - Nonscheduled Freight
    - Scheduled Mixed Passenger/Freight
    - Nonscheduled Mixed Passenger/Freight
    - Positioning
    - Training
    - Other
  - Flight Data Recorder (FDR) Recovered (Yes/No/Unknown)
  - No. of Recorder Parameters
  - Time of Flight Data Recorder Stop
  - Last Recorded FDR Speed
  - Quick Access Recorder (Yes/No/Unknown)
- Accident Location
  - Location Name
  - State/Province
  - Country
  - Latitude

- Longitude

IMPACT PARAMETER WORKBOOK

- Aircraft Impact Parameters
  - Rate of Descent (meters/second)
  - Flight Path Angle (degrees)
  - Aircraft Impact Speed (meters/second)
  - Type of Aircraft Impact Speed
    - Indicated
    - Calibrated
    - True
  - Ground Speed (meters/second)
  - Impact Angle w/ respect to Surface
    - Value (degrees)
    - Low (0-30 degrees), if value unavailable
    - Medium (30-60 degrees), if value unavailable
    - High (60-90 degrees), if value unavailable
  - Impact Pitch Angle from Horizontal
    - Value (degrees)
    - Low (0-30 degrees), if value unavailable
    - Medium (30-60 degrees), if value unavailable
    - High (60-90 degrees), if value unavailable
  - Impact Roll Angle from Horizontal
    - Value (degrees)
    - Low (0-30 degrees), if value unavailable

		Medium (30-60 degrees), if value unavailable
		High (60-90 degrees), if value unavailable
	Impact Roll Angle from Horizontal	
		Value (degrees)
		Low (0-30 degrees), if value unavailable
		Medium (30-60 degrees), if value unavailable
		High (60-90 degrees), if value unavailable
	Impact Yaw Angle	
		Value (degrees)
		Low (0-30 degrees), if value unavailable
		Medium (30-60 degrees), if value unavailable
		High (60-90 degrees), if value unavailable
	Impact Flight Path Angle	
		Value (degrees)
		Low (0-30 degrees), if value unavailable
		Medium (30-60 degrees), if value unavailable
		High (60-90 degrees), if value unavailable
Impact Location Parameters		
	Impact Location Surface Description	
		Mountainous
		Hilly
		Rolling
		Level/Flat
		Water
		Other

	Unknown
Impact Location Surface Slope Angle	
	Value (degrees)
	Low (0-30 degrees), if value unavailable
	Medium (30-60 degrees), if value unavailable
	High (60-90 degrees), if value unavailable
Impact Location Surface Condition	
	Wooded/Tree Covered
	Grass
	Crops/Cultivated Field
	Sand
	Swamp
	Snow/Ice
	Pavement
	Rock
	Open Water
	Sheltered Water
	Built-up Area/Houses
	Tall Vegetation
	Other
	Unknown
Impact Location Elevation (meters)	
Impact Location Crater? (Yes/No/Unknown)	
Main Crater Area (square metres)	
Main Crater Depth (meters)	
Additional Crater(s) Area (square metres)	

  - Additional Crater(s) Depth (meters)
- Impact Debris Field
  - Aircraft Breakup Before Impact
    - None
    - Minor
    - Substantial
    - Complete
    - Unknown
  - Aircraft Breakup at Impact
    - None
    - Minor
    - Substantial
    - Complete
    - Unknown
  - 1st Major Debris Dimensions (meters)
  - Additional Major Debris Dimensions (meters)
- Fire Parameters
  - Ground Operations Fire (Yes/No/Unknown)
  - In-Flight Fire (Yes/No/Unknown)
  - Impact Fire (Yes/No/Unknown)
  - Aircraft Fuel Load @ Impact (kilograms)
  - Time of Fire Initiation
  - Initial Ground Fire Area Involvement
  - Final Ground Fire Area Involvement
  - Time of Fire Emergency Response
  - Time of Fire Containment

  - Time of Fire Extinguishment
  - Type of Fuel Involved in Fire
    - Aircraft Fuel
    - Other Aircraft Fluids
    - Oven Contents
    - Waste Receptacle Contents
    - Cargo
    - Wheel/Tires
    - Other
    - Unknown
  - Distance Fire Moved from Aircraft
- Ground Feature Horizontal Impact Collision Parameters
  - Ground Feature Description
  - Horizontal Impact Speed (meters/second)
  - Skid Distance from Initial Ground Contact (meters)
- Water Immersion Parameters
  - Water Depth of Major Debris (meters)
  - Time of Flight Data Recorder Recovery
  - Time of Major Component/Cargo Recovery

FLIGHT HISTORY WORKBOOK

- Cargo Aboard Aircraft
  - Cargo General Description
  - Weight of Cargo Carried (kilograms)

  - Dangerous Goods Carried (Yes/No/Unknown)
- Last Departure Airport
  - Name
  - Scheduled Departure Time
  - Actual Departure Time
  - Departure Time Zone
  - Accident Distance to Departure Airport (kilometres)
  - Accident Direction to Departure Airport
- Taxi to Takeoff
  - Time of Pushback
  - Fuel Load @ Pushback (kilograms)
  - Regulated Take Off Weight @ Pushback (kilograms)
  - Zero-Fuel Take Off Weight (kilograms)
- Takeoff Roll
  - Time of Takeoff Roll Start
  - Fuel Load @ Takeoff Roll Start (kilograms)
- Aircraft Flight
  - Under Primary Radar Monitoring (Yes/No/Unknown)
  - Under Secondary Radar Monitoring (Yes/No/Unknown)
  - Duration of Flight (Time Airborne)
- 1st Major Event in Accident Sequence
  - Description

        - Time
        - Flight Phase
        - Aircraft Altitude (meters)
        - Aircraft Speed (meters/second)
        - Aircraft Track
    - Other Major Event(s) in Accident Sequence
        - Description
        - Time
        - Flight Phase
        - Aircraft Altitude (meters)
        - Aircraft Speed (meters/second)
        - Aircraft Track

- **WEATHER CONDITIONS WORKBOOK**
    - Weather @ Nearest Weather Station
        - Weather Station Name
        - Weather Report Time
        - Outside Air Temperature (degrees C)
        - Wind Direction
        - Wind Speed (meters/second)
        - Maximum Wind Gust Speed (meters/second)
        - Altimeter Setting (millibars)
        - Density Altitude (millibars)
        - Barometric Pressure (millibars)
        - General Weather Description
        - Windshear/Microburst (Yes/No/Unknown)

	Windshear/Microburst Doppler Data Available (Yes/No/Unknown)
	Distance to Accident Location (kilometres)
	Direction to Accident Location
Weather @ Accident Location	
	Outside Air Temperature (degrees C)
	Wind Direction
	Wind Speed (meters/second)
	Maximum Wind Gust Speed (meters/second)
	Altimeter Setting (millibars)
	Density Altitude (millibars)
	Barometric Pressure (millibars)
	General Weather Description
	Windshear/Microburst (Yes/No/Unknown)
	Windshear/Microburst Doppler Data Available (Yes/No/Unknown)

II.2. GENERAL GUIDANCE FOR COMPLETING THE IAEA AIRCRAFT ACCIDENT QUESTIONNAIRE

The following guidance material for completing the impact information questionnaire was distributed with the questionnaire by ICAO.

The International Atomic Energy Agency (IAEA) is collecting and analysing aircraft accident data to study issues related to aircraft accident forces and develop a better understanding of aircraft accident frequencies and severity. The results are expected to be used in the regulatory review and revision process to evaluate the level of protection provided by Type C packaging requirements given in IAEA Safety Series ST-1, “Regulations for the Safe Transport of Radioactive Materials”.

Data is being collected on aircraft accidents involving non-military aircraft with a maximum gross certificated takeoff mass greater than 27 000 kilogram (ICAO Category 4 and 5) which result in the destruction or major damage (an insurance write-off) of the airframe. Of primary interest are data concerning high energy accidents involving commercial aircraft with impacts at velocities greater than 75 metres/second. Aircraft accident data concerning fires, water immersion, and the accident sequence are also of interest.

The attached questionnaire is designed to collect data on aircraft accident severities. The questionnaire is divided into two parts, formatted into columns consistent with information categories that will be used to assemble an Excel database. The first part of the questionnaire, consisting of Sections 1 to 5, is designed to collect data that are directly applicable to the derivation of the parameters of interest. However, since these data may not be readily available for some accidents, the second part of the questionnaire, consisting of Sections A to F, is designed to collect additional data that can be used in the evaluation.

If information requested in each numbered Sections is complete (i.e. Section 1), information in the next numbered Section (i.e., Section 2) should be provided, if applicable. However, if information in a specific applicable numbered Section is not available, additional information is requested in Sections A to F, as indicated on the questionnaire following each numbered Section. For example, if information in Section 1 is not available, additional information on accident identification is requested in Sections A, E, and F. This additional information will be evaluated to derive the parameters requested in the associated numbered Section, if possible.

When filling out the questionnaire, attention should be given to providing the unit of measure for the parameter requested [i.e., velocity in metres per second (m/s)]. Additionally, if data on the range of a parameter (i.e. velocity estimate of 85–95 m/s) is given in the records, this range should be given on the questionnaire along with the most likely value for that parameter, if available. For initial questions that are answered no, all parameters which follow as a subcategory should be marked “not applicable”. For initial questions that are answered unknown, all parameters which follow it as a subcategory should be marked “not available”. For a parameter that stand by itself, and the information is not available for the accident, the entree should be marked “not available”. Parameters left blank leave the impression that the recorder missed these parameters. Negative answers acknowledge that an attempt was made to fill in the parameter.

The primary source of information for filling in the questionnaire is the official accident investigation report of the State investigating the accident. However, other applicable information including official accident investigation files with related raw data sheets, investigator interview sheets, etc., may provide a valuable source of data for the parameters of interest.

The following discussion provides specific guidance on each section and parameter requested in the questionnaire. The user should refer to this specific guidance to obtain a more detailed description of the information requested.

SPECIFIC GUIDANCE

Section 1. ACCIDENT IDENTIFICATION

The parameters specified in this section are used to identify a specific aircraft accident and to assure that the accident under consideration is the same accident considered elsewhere. Most of the parameters specified are provided on the questionnaire but should be verified to confirm that the correct accident is being considered.

Accident Identification. The ICAO ADREP accident identifier.

Accident Date (year/month/day). This date should be the day of the accident at its location (local date). There may be a variation in accident days within a day or two depending on the source of information and the reference point. If Greenwich Mean Time (or Universal Coordinated Time) is used as the accident time (see below), then the accident date must be consistent with the time.

Aircraft Information

Aircraft Manufacturer. The company that assembled the aircraft airframe. If the aircraft is built under license by another company or in another country, use the other company or country. If necessary for clarification, provide the parent company in parentheses.

Aircraft Model/Series. The specific aircraft model or series according to the aircraft manufacturer nomenclature. Aircraft that are built under license in another country are not considered a different aircraft type, but are often designated differently from the aircraft assembled by the parent company. Use the manufacturer aircraft designation for the aircraft and if necessary for clarification, provide the parent company designation in parentheses.

Aircraft Registration. The registration of the aircraft at the time of the accident. This information is critical in assuring the correct aircraft information is matched with the correct accident. Most of the registrations of the aircraft involved in the accidents will have already been identified from available resources.

Flight Type. The classification of the various flights that an aircraft can undertake. This information is useful for classifying aircraft accidents by flight type. The classification of flights are given below:

- Passenger (P)
- Freight (F)
- Mixed (M) - Passenger/Freight (as flown by Combi type aircraft where cargo is carried within the main cabin along with passengers).
- Other (O) - includes maintenance flights, test flights, demonstration flights
- Unknown (U)

Scheduled (S) or Non-Scheduled (NS) Was the flight scheduled or non-scheduled?

Section 2. AIRCRAFT IMPACT PARAMETERS

The parameter of interest is the aircraft impact velocity. More precisely, the aircraft speed with respect to the ground, at the moment of impact in the direction normal to the impact surface. If this information is not provided, then it will be developed from other parameters which may be present.

Rate of Descent (supply units). The vertical speed of the aircraft at the moment of impact. The reported value and its units should be provided. Rate of Descent used to be the first derivative of the altitude output from the Central Air Data Computer (CADC) referenced to the local air mass. This created problems in vertical microbursts. Newer aircraft with Inertial Reference Systems (IRS) integrate the vertical acceleration so Rate of Descent is purely vertical speed relative to the ground. Units are usually reported as feet per minute.

Aircraft Ground Speed at Impact (supply units). The speed of the aircraft at impact with respect to the ground. The reported value and its units should be provided. Units are usually reported as feet per minute.

Impact Angle with Respect to Impact Surface (degrees). The angle of aircraft flight direction with respect to the impact surface. The aircraft flight direction is not necessarily the same as the orientation of the aircraft. Also, the impact surface is not necessarily horizontal. These two aspects complicate this parameter. Keep in mind that what is desired is the aircraft velocity normal to the impact surface. This information is used to adjust the impact velocity if it is not defined in the normal direction. If the value is unavailable, the following responses may be used for this parameter.

- Value: A value for this parameter is most desirable. However, this information may not be provided, in which case it may have to be derived from the accident narrative;
- Low (0–30°): If the aircraft was approaching the crash location at a 'shallow' angle or low angle as in an airport or runway approach;
- Medium (30–60 °): If the aircraft was approaching the crash location at a medium angle or a semi-controlled dive;
- High (60–90 °): If the aircraft was approaching the crash location at a high angle or a uncontrolled dive.

Section 3. IMPACT LOCATION PARAMETERS

The parameter of interest is the surface type from which the surface hardness of the impact location will be determined. This information will almost certainly not be provided and thus, must derived by the accident narrative.

Surface Type at Impact Location: This is the specific description of the actual accident location. The path taken by an aircraft that is in distress condition can cover a large area. Care must be taken to define where the "impact" of the aircraft begins and ends. A commonly used definition is the impact location begins at the point where the aircraft makes continuous contact with the ground and ends where all motion of the main aircraft "body" ends. This is an intentional imprecise definition because of the uncertainty of the events which may occur during the course of the accident. Judgment must be exercised when defining the aircraft impact location to capture the important event(s) which may affect the loading on the aircraft cargo. Even with the impact location defined, several different types of surfaces may be encountered by the aircraft. If one surface condition cannot be specified, check all those that apply. If it is possible to define the sequence in which the surfaces encountered, this sequence should be recorded. In other cases, where several different types of surfaces are encountered several times during the accident sequence, it may be possible to assign a percentage to the surfaces encountered. The following descriptors will be used to classify the specific accident surface condition:

- Grass;
- Crops/Cultivated Field;
- Sand;
- Swamp;
- Snow/Ice;
- Pavement (use for runways and highways);
- Rock;

- Open Water;
- Sheltered Water;
- Built-up Area/Houses (use for towns, cities, buildings surrounding airports);
- Tall Vegetation;
- Other;
- Unknown.

Section 4. IN-FLIGHT FIRE PARAMETERS

The parameter of interest is the total fire duration time from initiation to final extinguishment. This parameter is of interest because of the relationship of the fire to the thermal heat load as applied to aircraft cargo. Care should be exercised in determining this parameter because of inconsistencies in fire recording times. It is probably best to enter the total fire duration time, if stated, and then record the other given fire related times. This will allow consistency checks to be made of the total fire duration with the accident sequence. Any time scale may be used to develop the fire sequence history as long as the reference point used throughout the sequence development is consistent. In other words, use the same “zero” time.

Duration of Fire (minutes): The duration of the fire from the time of its initiation during the flight to the time that the fire is considered extinguished, according to the fire emergency response.

Combustible Material Involved in the Fire. Type of fuel involved in fire. This parameter may be used to develop a fire temperature distribution if sufficient information is found to justify such development. If multiple types of fuel are involved in the fire, use the fuel type that is predominant. The following descriptors will be used to classify the types of fuel involved in the fire:

- Aircraft Fuel;
- Aircraft Fluids (hydraulic fluid);
- Cargo - describe the type of cargo involved in the fire (luggage, chemicals, etc);
- Wheel(s)/Tyre(s);
- Other — describe the type of fuel involved in the fire;
- Unknown.

Section 5. SURFACE FIRE PARAMETERS

The parameter of interest is the total fire duration time from initiation to final extinguishment. This parameter is of interest because of the relationship of the fire to the thermal heat load as applied to aircraft cargo. Care should be exercised in determining this parameter because of inconsistencies in fire recording times. It is probably best to enter the total fire duration time, if stated, and then record the other given fire related times. This will allow consistency checks to be made of the total fire duration with the accident sequence. Any time scale may be used to develop the fire sequence history as long as the reference point used throughout the sequence development is consistent. In other words, use the same “zero” time.

Duration of Fire (minutes): The duration of the fire from the time of its initiation during the ground accident or following ground impact to the time that the fire is considered extinguished, according to the fire emergency response.

Combustible Material Involved in the Fire: Type of fuel involved in fire. This parameter may be used to develop a fire temperature distribution if sufficient information is found to justify such development. If multiple types of fuel are involved in the fire, use the fuel type that is predominant. The following descriptors will be used to classify the types of fuel involved in the fire:

- Aircraft Fuel;
- Aircraft Fluids (hydraulic fluid);
- Cargo - describe the type of cargo involved in the fire (luggage, chemicals, etc);
- Wheel(s)/Tyre(s);
- Other — describe the type of fuel involved in the fire;
- Unknown.

Section A. ADDITIONAL ACCIDENT IDENTIFICATION INFORMATION

The parameters specified in this section provide additional information used to identify a specific aircraft accident and to assure that the accident under consideration is the same accident considered elsewhere. This additional information supplement the information provided in Section 1.

Accident Time. This parameter is the local time of the accident at its location. There may be variation in the accident time depending on the source of information and the reference point. If local time is used for the accident time, then the local time zone information is also desirable. With local time and time zone specified, the accident time can be related to Universal Time (Greenwich Mean Time). It is important to remember that the local time zone may change depending on the time of the year, i.e. daylight savings time. Even within a country or a State, the local time zone may not be the same throughout. If the local time zone is not provided with the local time, that is not a critical issue, simply desirable, but identification of the time as local or Universal is critical. Again, the accident time and accident date must be consistent, whatever reference point is used.

Aircraft Information

Company/Organization Operating Aircraft (Flight No.): The company or organization that was actually operating the aircraft at the time of the accident. This may not be as straightforward as it first appears. Aircraft are leased by companies to fulfil specific assignments, sometimes on a flight-by-flight basis. An aircraft that is owned by one company, leased to another company, who subleases the aircraft to another company on a one-time specific flight basis and uses a flight crew from still another company can confuse this seemingly straightforward matter. In cases like this, use your best judgment as to who would actually be operating the aircraft when the accident occurred. Providing the flight number for this accident flight is another desirable parameter but is not critical for accident identification. Most of the accidents that will be included in the development of this accident database will have already been identified from available resources.

Aircraft Type Category: Examples of aircraft type category are turbojet, turboprop, 4-engine pistonprop, 2/3-engine pistonprop, helicopter. This information is useful for classifying aircraft accidents by type category. Occasionally, special studies are done by type category which could provide useful information in filling in some parameters.

Aircraft Construction Number/Serial Number: This information refers to the aircraft construction number (sometimes referred to as the contract number) and the serial number or the order of the aircraft that it left the assembly line. Boeing and Douglas and a few other aircraft manufacturers use aircraft construction numbers and serial numbers. Most other aircraft manufacturers use only the serial number or line number. This information is critical in assuring the correct aircraft information is matched with the correct accident. Most of the construction number/serial number of the aircraft involved in the accidents will have already been identified from available resources.

Aircraft Maximum Certificated Gross Weight (kilograms): The maximum weight that the aircraft has been certified by regulatory body (usually the U.S. Federal Aviation Administration) for normal operations. Sometimes this is referred to as the Maximum Gross Takeoff Weight (MGTW) which is the maximum weight that an aircraft has been certified to begin its takeoff roll. The weight of the aircraft when it leaves its parking spot or jetway is heavier than the MTGW by the weight of the fuel it takes to go from its parking spot or jetway to the beginning of its takeoff roll. This value should be expressed in kilograms. If it is expressed in other units, it should be converted to kilograms, but its reported value and its units should be provided in parentheses.

Flight Data Recorder. Was the aircraft equipped with a flight data recorder (FDR) and was the FDR recovered? The responses to this question:

- Equipped / recovered;
- Equipped / not recovered;
- Not equipped.

No. of Flight Data Recorder Parameters: Number of parameters recorded by the flight data recorder. A listing of the flight data recorder parameters is useful but not necessary for our purposes.

Time of Flight Data Recorder Stop: Time when the flight data recorder stopped recording. A reference point must be provided with this information. A useful reference point for many accidents is the time that the aircraft impacts with the surface.

Last Recorded FDR Speed (metres/second): The last speed recorded by the flight data recorder. The speed recorded by the flight data recorder is usually the indicated airspeed. If this information (type of airspeed) can be obtained from the accident report, it should be recorded.

Accident Location

The following parameters should be provided to specify the accident location. Fill in as many parameters as possible.

Location Name. Name of the closest village, town, city, prominent landmark, mountain peak, high ground, lake, stream, river, etc., that is listed for the accident. If necessary, and if the information is available, give the distance and approximate direction from that location, i.e. 5 kilometres northwest of such-and-such mountain peak or village. It is sometimes desirable to provide the distance and approximately direction from a location that is more prominent that what is listed for the accident location, i.e. capital city of the country or a major nearby city or a well known landmark.

State/Province: Name of the state, province, prefecture, county, whatever political subdivision that is listed for the accident location, if provided.

Country: Name of the country that is listed for the accident location. If the accident happened over the ocean, then the nearest point of land, even if that country which "owns" that point of land did not undertake the accident investigation.

Latitude (degrees / minutes): The latitude of the accident location to as much precision as available. North or South latitude must be specified. One degree of latitude is approximately 60 miles so every minute of precision specified is approximately one mile closer to the actual accident location.

Longitude (degrees / minutes): The longitude of the accident location to as much precision as available. East or West longitude must be specified. One degree of longitude (depending, of course, on the corresponding latitude) is approximately 60 miles so every minute of precision specified is approximately one mile closer to the actual location.

Section B. ADDITIONAL IMPACT PARAMETER INFORMATION

The additional parameters specified in this section are aircraft accident conditions that will be used to develop the accident parameters of interest provided in Section 2.

Impact Flight Path Angle (degrees): The angle of the aircraft flight path with respect to the local horizontal surface. This parameter is useful to determining the Rate of Descent and the aircraft impact velocity normal to the surface if these values are not available. Note also that this parameter differs from the Impact Angle with Respect to the Surface by the angle of the impact surface. If the impact surface is horizontal, then these two values are equal.

Aircraft Impact Speed (metres/second): Generally, the information provided for the aircraft at the moment of impact is the aircraft airspeed. What is desired for this parameter is the speed of the aircraft along the actual flight path in relation to the ground at the moment of impact. This is probably not going to be available. Thus, the aircraft impact speed (assuming it is reported as an aircraft airspeed) must be converted to an equivalent aircraft ground speed. This value should be recorded in metres/second. If it is reported in other units, it should be converted to metres/second, but the reported value and its units should be provided in parentheses.

Type of Aircraft Impact Speed: The speed of the aircraft at the moment of impact must also be specified by the type of aircraft speed recorded. The following are the types of airspeed definitions that are in use.

- Indicated Airspeed (IAS): The aircraft airspeed as measured by the pitot-static system, corrected for instrument, calibration, or lag error, but subject to ambient pressure and static pressure measurement errors;
- Calibrated Airspeed (CAS): The aircraft airspeed as measured by the pitot-static system, calibrated to allow for compressibility according to the International Standard Atmosphere (ISA) at Sea Level. The speed indication reading given by a perfect system in which there are no errors in the measurement of ambient pressure and static pressure and no instrument reading, calibration or lag errors (see Engineering Sciences Data Unit 86031 paragraph 5.2 for necessary equation for calculating the airspeed from pressure measurements). Calibrated Airspeed can also mean the Indicated Airspeed corrected for instrument error and position error which would make it equivalent to Rectified Airspeed;
- True Airspeed (TAS): The Equivalent Airspeed corrected for the difference between ambient air density and the calibration air density.

Aircraft Pitch, Roll and Yaw Impact Angles. These angles are used to orient the aircraft at the moment of impact. This information is desirable for orienting the packages within the aircraft for maximum impact loading. Again, as for Impact Angle with Respect to Impact Surface, a value for each of these parameters is desired. However, if this information is not provided, it may be derived from the accident narrative. In such cases, look for key words which may provide a clue for the aircraft orientation at the moment of impact, i.e. high angle of attack (high pitch angle), aircraft rolled sideways (high roll angle), aircraft hit sideways (high yaw angle). If the value is not given in the data, the following responses may be used for these parameter:

- Low (0 –30°): If the aircraft was approaching the crash location at a "shallow" angle or low angle as in an airport or runway approach;
- Medium (30–60°): If the aircraft was approaching the crash location at a medium angle or a semi-controlled dive;
- High (60–90°): If the aircraft was approaching the crash location at a high angle or a uncontrolled dive.

Section C. ADDITIONAL IMPACT LOCATION PARAMETER INFORMATION

These parameters that will be used to develop the information provided in Section 3 concerning surface type and slope angle from which the surface hardness of the impact location will be determined. This information will almost certainly not be provided and thus, must derived by the accident narrative.

Impact Location Surface Description: A general description of the impact location surface. The following descriptors are used to classify the accident surfaces:

- Mountainous;
- Hilly;
- Rolling;
- Level/Flat;
- Water;
- Other;
- Unknown.

Impact Location Surface Slope Angle: The slope angle of the impact location from the horizontal. A value for this parameter is the most desirable but is not usually available, in which case it must be derived from the accident narrative. The following parameters value can be used:

- Low (0–30°): Gently rolling terrain and hilly country are usually low angle slopes
- Medium (30–60°) : Mountainous terrain are usually medium angle slopes
- High (60–90°): Sheer cliffs are high angle slopes

Impact Location Elevation (metres). This is the elevation of the impact location. This information may be important in determining the final aircraft impact speed if this information is not directly available from the accident report. The value for this parameter should be recorded in metres. If this parameter is reported in other units, it should be converted to metres but its reported value and its units provided in parentheses.

Impact Location Crater? (Yes/No/Unknown): Was a crater created at the impact location? Yes, no or unknown answer only.

Main Crater Area (square metres): This is the area of the main crater in the impact location. If the previous parameter is marked no or unknown, this parameter should be 'Not Applicable" for no and "Not Available" for unknown. It may not be possible to easily identify the main crater, especially if the aircraft broke up in flight. In these cases, it is probably best to use the largest crater form, unless there is information in the accident narrative that this particular crater is not the "main" crater. This parameter should be recorded in square metres. If this parameter is reported in other units, it should be converted to square metres but its reported value and its units provided in parentheses.

Main Crater Depth (meters): This is the depth of the main crater identified in the impact location. If the Impact Location Crater parameter was marked no or unknown, this should be marked "Not Applicable" for no and "Not Available" for unknown. This parameter should be recorded in metres. If this parameter is reported in other units, it should be converted to metres but its reported value and its units provided in parentheses.

Additional Crater(s) Area (square metres): The area of the other 'important' crater(s) in the impact location. This entry is only for the purpose of characterizing other significant crater(s) in the impact location. An example where this entry may be important is where the aircraft breaks up in flight and several large pieces hit close together. It may not be possible choose one crater as the "main" crater because they are all about the same size. This parameter should be recorded in square metres. If this parameter is reported in other units, it should be converted to square metres but its reported value and its units provided in parentheses.

Additional Crater(s) Depth (metres): These are the depths of the other crater(s) identified in the impact location. This parameter should be recorded in metres. If this parameter is reported in other units, it should be converted to metres but its reported value and its units provided in parentheses.

Impact Debris Field

All the information in this category is used to characterize the breakup of the aircraft during the accident sequence. This information may be important in determining the speed and direction of the aircraft, and the sequence of events during the accident sequence.

Aircraft Breakup Before Impact. This information is used to characterize the breakup of the aircraft before the impact. The following descriptors will be used to classify the in-flight breakup:

- None;
- Minor: small pieces of the aircraft break off, minor portion of a wing or fuselage, or an engine;
- Substantial: major pieces of the aircraft separate, major portion of a wing or fuselage, or several engines;
- Complete;
- Unknown.

Aircraft Breakup at Impact: This information is used to characterize the breakup at the impact location. The following descriptors will be used to classify impact breakup:

- None;

- Minor: small pieces of the aircraft break off, minor portion of a wing or fuselage, or an engine;
- Substantial: major pieces of the aircraft separate, major portion of a wing or fuselage, or several engines;
- Complete;
- Unknown.

First Major Debris Dimensions (metres). The physical characteristic of largest intact piece left of the aircraft. It may be useful to describe the largest part left of the aircraft and its location in relation to the impact crater as well as providing dimensions of the part. This parameter should be recorded in metres. If this parameter is reported in other units, it should be converted to metres but its reported value and its units provided in parentheses.

Additional Major Debris Dimensions (metres): The dimensions of the other “major” debris field(s). This entry is only for the purpose of characterizing other significant debris field(s) in or near the impact location. This may be important in cases of in-flight aircraft breakup where major portions of the aircraft separate from the main or largest part of the aircraft prior to impact. It may be useful to describe the other major parts of the aircraft and its location in relation to the impact crater as well as providing dimension of the parts. This parameter should be recorded in metres. If this parameter is reported in other units, it should be converted to metres but its reported value and its units provided in parentheses.

Ground Features Horizontal Impact Collision Parameters

This category field is used to characterize important parameters that may affect the impact loads if an aircraft skids along the ground following initial contact. If the aircraft does not skid along the ground following initial contact, but instead creates a large crater, then all parameters of this category should be marked “Not Applicable”. If the answer to this category is not known, then all parameters of this category should be marked “Not Available”.

Ground Feature Description: This parameter describes the major object struck by the aircraft as it skids along the ground following initial contact. Small objects such as vehicles, people, animals, small buildings, trees, etc., which do not cause major breakup of the aircraft structure or do not affect the general skid direction of the aircraft, will not impose large impact loads on any cargo carried within the aircraft and should not be included. One consideration is that smaller aircraft will be affected by smaller objects. So a large aircraft may not have to consider a truck or a small water tank whereas a small aircraft would.

Horizontal Impact Speed (metres/second): The horizontal speed of the aircraft when it struck the ground feature described above is the parameter of interest. This parameter should be recorded in metres/second. If this parameter is reported in other units, it should be converted to metres/second, but its reported value and its units provided in parentheses.

Skid Distance from Initial Continuous Ground Contact to Rest (metres): The distance that the aircraft travelled from initial continuous contact with the ground to the final resting or stopping location of the aircraft. This parameter should be recorded in metres. If this parameter is reported in other units, it should be converted to metres, but its reported value and its units provided in parentheses.

Water Immersion Parameters

This category field is used to characterize important parameters for the immersion of aircraft cargo in depths of water. If no large body of water is involved with the accident or no part of the aircraft is lost in the water, then all parameters of this category should be marked "Not Applicable". If the answer to this category is not known, then all parameters of this category should be marked "Not Available".

Water Depth of Major Debris (metres): The depth of the water where the major part of the debris is located. This parameter should be recorded in metres. If this parameter is reported in other units, it should be converted to metres, but its reported value and its units provided in parentheses.

Time of Flight Data Recorder / Cockpit Voice Recorder Recovery: The time and day the flight data recorder was recovered from the water.

Time of Major Component/Cargo Recovery: The time and day the major component/cargo was recovered from the water.

Section D. Additional Fire Parameter Information

The parameters in this section will be used to supplement the information in Sections 4 and 5. The key parameter of interest is the total fire duration time from initiation to final extinguishment. Care should be exercised in determining this parameter because of the inconsistency in the fire recording time. It is probably best to enter the total fire duration time, if stated, and then record the other given fire related times. This will allow consistency checks to be made of the total fire duration with the accident sequence. Any time scale may be used to develop the fire sequence history as long as the reference point used throughout the sequence development is consistent. In other words, use the same "zero" time.

Ground Operation Fire (Yes/No/Unknown): This parameter may be of importance because fires associated with aircraft ground operations may involve greater amounts of combustible material or fuel, i.e. refueling operations. Yes, no or unknown response only.

Aircraft Fuel Load at Impact (kilograms): This parameter is of interest for In-Flight Fire and/or Impact Fire. This parameter should be recorded in kilograms. If this parameter is reported in units other than kilograms, it should be converted to kilograms but its reported value and its units provided in parentheses. If the fuel load is provided in terms of a volume measurement, i.e. liters, gallons, then it will be necessary to provide the assumed density and temperature of the fuel when the conversion to mass is made.

Time of Fire Initiation: The time and day when the fire was initiated either in-flight or at / during a ground impact accident. This parameter is useful in determining the total fire duration.

Initial Ground Fire Area Involvement (square metres): The area covered by the fire at impact or when the fire initially breaks out. This parameter should be recorded in square metres. If this parameter is reported in other units, it should be converted to square metres, but the reported value and its units provided in parentheses.

Final Ground Fire Area Involvement (square metres): The final area covered by the fire. This parameter should be recorded in square metres. If this parameter is reported in other units, it should be converted to square metres, but the reported value and its units provided in parentheses.

Time of Fire Emergency Response: The time and day that the fire emergency response began to take effective action against the fire. If that is unavailable, then the time the fire emergency response arrived at the impact location. In either case, it is important to specify how this time is defined.

Time of Fire Containment: The time and day that the fire was considered contained, according to the fire emergency response.

Time of Fire Extinguishment: The time and day that the fire was considered extinguished, according to the fire emergency response. Some comments describing how this time has been defined may be appropriate with this time, i.e. hot spots only remaining, or small fires allowed to burn out, etc.

Distance Fire Moved from Aircraft (metres). The distance the fire moved from the aircraft during the course of the accident sequence. This information may be useful in determining the total fire duration or for adjusting the fire temperature. This parameter should be recorded in metres. If this parameter is reported in other units, it should be converted to metres, but its reported value and its units provided in parentheses.

Section E. ADDITIONAL FLIGHT HISTORY INFORMATION

The parameters specified for this flight history information will be used to supplement the information provided in Sections 2, 3, 4, and 5, to reconstruct the history of the flight in which the accident occurred. This information may be useful in determining several parameters previously defined if they are not provided, i.e. accident location (time of flight following takeoff from last departure), fire duration (fuel load at impact based on known time of flight and average fuel usage) etc.

Cargo Aboard Aircraft

This information characterizes the cargo carried by the aircraft.

Cargo General Description: This parameter is the general description of the cargo carried by the cargo within the cargo hold (if an aircraft configured to carry passengers) or within the main cabin (if an aircraft configured to carry freight). Passenger luggage carried in the main cabin should not be included. If the aircraft is configured to carry freight and passengers, general passenger luggage within the passenger cabin should not be included, but passenger luggage outside of the passenger cabin should be included.

Weight of Cargo Carried (kilograms): This is the total weight of the cargo carried by the aircraft within the cargo hold (if an aircraft configured to carry passengers) or within the main cabin (if an aircraft configured to carry freight). Passenger luggage carried in the main cabin should not be included. Again, if the aircraft is configured to carry freight and passengers, general passenger luggage within the passenger cabin should not be included, but passenger luggage outside of the passenger cabin should be included. This parameter should be recorded in kilograms. If this parameter is reported in other units, it should be converted to kilograms, but its reported value and its units provided in parentheses.

Dangerous Goods Carried (Yes/No/Unknown): Were dangerous goods as defined by ICAO carried as cargo in the flight? Yes, no or unknown response only.

Dangerous Goods Involved in Accident (Yes/No/Unknown): Were dangerous goods as defined by ICAO involved in the accident either as initiator or as an accident intensifier? Yes, no or unknown response only.

Airport Information

This information characterizes the last departure by the aircraft immediately prior to the accident.

Name: Name of the last departure airport by the aircraft. The ICAO four character designator or the IATA three character designator for the airport would be useful in confirming the identity of the last departure airport but is not essential.

Actual Departure Time: The actual time of departure by the aircraft.

Departure Time Zone: The local time zone associated with the scheduled and actual departure times. This information is essential in reconstructing the aircraft flight history.

Accident Distance to Airport Runway (give reference point, kilometres): The distance from the accident to the runway. If the accident occurs in the takeoff flight phase (takeoff roll, initial climb), then the distance to the departure runway should be given and the departure airport specified. If the accident occurs in the landing approach/landing flight phases (airport approach, runway approach or final approach, landing roll), then the distance to the arrival runway should be given and the arrival airport specified. If the accident occurs in the climb to cruise, in-flight or cruise or initial descent flight phases, then either the departure runway or arrival runway may be used as long as the airport is identified as such. When specifying the distance, a reference point should be given, such as runway midpoint or aerodrome reference point. This information may be useful in defining the accident location and characterizing the impact location if this information is not provided by the accident report. This parameter should be recorded in kilometres. If this parameter is reported in other units, it should be converted to kilometres, but its reported value and its units provided in parentheses.

Accident Direction to Airport Runway: The direction from the accident to the airport. As with the previous entry, the departure runway should be used if the accident occurs close to departure, the arrival runway should be used if the accident occurs close to arrival. In-between, use the departure or arrival runway, whichever is closer. Be sure to identify whichever is used as the departure or arrival airport. General descriptors of the direction are usually adequate for our purposes, i.e. North, Northwest, West-Northwest. However, if more precise descriptors are provided, it is essential to specify the reference point for the descriptor, i.e. 45 ° from magnetic north, or 45 ° from true north. A problem with these descriptors is the variation of the magnetic north (or south) from true north (or south) at various locations around the globe.

Taxi to Takeoff

This information characterizes the parameters during the taxi to takeoff phase.

Fuel Load at Pushback (kilograms): The estimated fuel load aboard the aircraft when it leaves its parking spot. This parameter should be recorded in kilograms. If this parameter is reported in units other than kilograms, it should be converted to kilograms but its reported value and its units provided in parentheses. If the fuel load is provided in terms of a volume measurement, i.e. liters, gallons, then it will be necessary to provide the assumed density and temperature of the fuel when the conversion to mass is made.

Actual Take Off Weight at Pushback (kilograms): The weight of the aircraft when it leaves its parking spot. This weight is usually the certificated Maximum Take Off Weight (MTOW) plus the fuel needed to taxi from its parking spot until the aircraft begins its takeoff roll. This parameter should be recorded in kilograms. If this parameter is reported in other units, then it should be converted to kilograms, but its reported value and its units provided in parentheses.

Zero-Fuel Take Off Weight (kilograms): The Maximum Takeoff Weight (MTOW) minus the total usable-fuel weight. This is usually the limiting case for wing bending moment because the wings are empty and the fuselage if full. Always accurately calculated and given to the pilot-in-command before departure.

Takeoff Roll

This information characterizes the parameters during the actual takeoff roll, that is from the moment the aircraft releases it brakes on the runway and begins its takeoff roll, or rolls onto the runway, until the wheels leave the ground for good.

Time of Takeoff Roll Start: The time that aircraft begins its takeoff roll.

Fuel Load at Takeoff Roll Start (kilograms): The estimated fuel load aboard the aircraft when it begins its takeoff roll. This parameter should be recorded in kilograms. If this parameter is reported in units other than kilograms, it should be converted to kilograms but its reported value and its units provided in parentheses. If the fuel load is provided in terms of a volume measurement, i.e. liters, gallons, then it will be necessary to provide the assumed density and temperature of the fuel when the conversion to mass is made.

Aircraft Flight

This information characterizes the parameters after takeoff until the initial impact with the ground.

Primary Radar Monitoring (description): Description of the aircraft track recorded by the primary radar under control of the departure or landing airport.

Secondary Radar Monitoring (description): Description of the aircraft track recorded by the secondary radar under the control of departure or landing airport.

Duration of Flight (Time Airborne): Estimated flight time of the aircraft from the moment the aircraft began its takeoff roll until the aircraft makes initial continuous contact with the ground.

Ground Speed from Radar Monitoring (metres/second): The ground speed of the aircraft as recorded by either primary or secondary radar monitoring at the time of impact.

Section F. WEATHER CONDITIONS

The parameters specified for the weather conditions will be used to supplement Sections 1, 2, and 3, to derive impact parameters, if this information is not given in the accident report, or to verify the consistency and accuracy of the parameters if such information is given. Weather conditions can have a large effect on the aircraft flight conditions prior to impact, especially in its contribution to aircraft impact speed by windshear or microburst. Unfortunately, weather conditions at the accident location when the accident occurred is often not recorded. What is often available is the weather report at a nearby weather station. The weather report at the accident location at the time of the accident is the preferred information. If that is unavailable, then the weather report at the nearest weather station should be used.

Weather at Nearest Weather Station

This information characterizes the weather conditions at the nearest weather station.

Weather Station Name: Official reporting name of weather station and any identifying code designator.

Weather Report Time: Time of weather report and associated time zone.

Outside Air Temperature (degrees C): Outside air temperature as reported in degrees Celsius, if available. If outside temperature is reported in degrees Fahrenheit, then in convert to degrees Celsius but provide Fahrenheit measurement in parentheses.

Wind Direction (bearing): General description of the wind direction in relation to true north is generally adequate, i.e. North, Northwest, West-Northwest. If a compass heading is provided for wind direction, it is essential to specify the reference point for the heading, i.e. 45° from magnetic north, or 45° from true north. A problem with these descriptors is the variation of the magnetic north (or south) from true north (or south) at various locations around the globe. Wind Direction is critical in determining ground speed.

Wind Speed (metres/second): Average wind speed reported by the station in metres/second. If the average wind speed is reported in other units, convert to metres/second but provide the reported measurement and its units in parentheses.

Maximum Wind Gust Speed (metres/second): The instantaneous maximum wind speed reported by the station in metres/second. If the maximum wind speed is reported in other units, convert to metres/second but provide the report measurement and its units in parentheses.

Altimeter Setting (hectopascals): The standard atmospheric air pressure to which the aircraft altimeter is referenced at time of the accident. This value should be recorded in hectopascals. If the altimeter setting is reported in other units, convert to hectopascals but provide the report measurement and its units in parentheses. [One hectopascal = 1013.25 millibars (mb) = 1 hectopieze = 14.6959 lbs/in^2 = 101.325 kN/m^2 = 761.484 mm Hg at 16.6 °C and mean sea level (MSL)]

Density Altitude (hectopascals): The pressure altitude at the weather station corrected for non-International Standard Atmosphere (ISA) conditions. The ISA is 1013.25 mb or hectoPa or 1.01325 bars or hectopieze or 14.6959 lbs/in^2 or 101.325 kN/m^2 or 761.848 mm Hg or 29.994 inches Hg at 16.6 °C at MSL. This value should be recorded in hectopascals but provide the report measurement and its units in parentheses. Note that the Density Altitude is the altitude in ISA at which the air density is the same as it is in the conditions being considered. Density Altitude is often quoted in feet or metres according to the application. The ISA definition also depends on an assumed variation of temperature with altitude as well as assumed sea level pressure and temperature. Thus, at a particular physical altitude, the pressure altitude may vary with changes in the weather so that the air density at a given pressure altitude may differ from that in the ISA model at that pressure altitude.

Barometric Pressure (hectopascals): The local atmospheric pressure at the weather station. This value should be recorded in hectopascals. If the altimeter setting is reported in other units, convert to hectopascals but provide the report measurement and its units in parentheses. [One hectopascal = 1013.25 millibars (mb) = 1 hectopieze = 14.6959 lbs/in^2 = 101.325 kN/m^2 = 761.484 mm Hg at 16.6 °C and MSL]

General Weather Description: The general description of the weather, i.e. rain, snow, fog, clear, cloudy, etc.

Wind shear/Microburst (yes/no/unknown): Was there the presence of a wind shear and/or microburst near the weather station? Yes, no, or unknown response only.

Wind shear/Microburst Doppler Data Available (yes/no/unknown): Is doppler radar data from a microburst/wind shear detection system available? Yes, no, or unknown response only.

Weather Station Distance to Accident Location (kilometres): The distance from the accident to the reporting weather station. Often, the nearest reporting weather station may be an airport, but not necessarily the same airport that the aircraft was departing or approaching when the accident occurred. This distance should be recorded in kilometres but if it is reported in other units, it should be converted to kilometres but the reported distance and its units should be provided in parentheses.

Accident Direction to Weather Station (bearing): The direction from the accident to the reporting weather station. General descriptors of the direction are usually adequate for our purposes, i.e. North, Northwest, West-Northwest. However, if more precise descriptors are provided, it is essential to specify the reference point for the descriptor, i.e. 45° from magnetic north, or 45° from true north. A problem with these descriptors is the variation of the magnetic north (or south) from true north (or south) at various locations around the globe.

Weather at Accident Location

This information characterizes the weather conditions at the accident location. If the only weather information is at the nearest reporting weather station, then all entries should be marked "Not Available".

Outside Air Temperature at Accident (degrees C): Outside air temperature as reported in degrees Celsius, if available. If outside temperature is reported in degrees Fahrenheit, then in convert to degrees Celsius but provide Fahrenheit measurement in parentheses. It should also be recorded as to how this temperature was obtained.

Wind Direction at Accident (bearing): General description of the wind direction in relation to true north is generally adequate, i.e. North, Northwest, West-Northwest. If a compass heading is provided for wind direction, it is essential to specify the reference point for the heading, i.e. 45° from magnetic north, or 45° from true north. A problem with these descriptors is the variation of the magnetic north (or south) from true north (or south) at various locations around the globe. Wind Direction is critical in determining ground speed.

Wind Speed at Accident (metres/second): Average wind speed reported by the station in metres/second. If the average wind speed is reported in other units, convert to metres/second but provide the reported measurement and its units in parentheses.

Maximum Wind Gust Speed at Accident (metres/second): The instantaneous maximum wind speed reported by the station in metres/second. If the maximum wind speed is reported in other units, convert to metres/second but provide the report measurement and its units in parentheses.

Altimeter setting at accident (hectopascals): The standard atmospheric air pressure to which the aircraft altimeter is referenced at time of the accident. This value should be recorded in hectopascals. If the altimeter setting is reported in other units, convert to hectopascals but provide the report measurement and its units in parentheses.

[One hectopascal = 1013.25 millibars (mb) = 1 hectopieze = 14.6959 lbs/in^2 = 101.325 kN/m^2 = 761.484 mm Hg at 16.6 ºC and MSL]

Density Altitude at Accident (hectopascals): The pressure altitude at the weather station corrected for non- International Standard Atmosphere (ISA) conditions. The ISA is 1013.25 mb or hectoPa or 1.01325 bars or hectopieze or 14.6959 lbs/in^2 or 101.325 kN/m^2 or 761.848 mm Hg or 29.994 inches Hg at 16.6 ºC, at mean sea level (MSL). This value should be recorded in hectopascals but provide the report measurement and its units in parentheses. Note that the Density Altitude is the altitude in ISA at which the air density is the same as it is in the conditions being considered. Density Altitude is often quoted in feet or metres according to the application. The ISA definition also depends on an assumed variation of temperature with altitude as well as assumed sea level pressure and temperature. Thus, at a particular physical altitude, the pressure altitude may vary with changes in the weather so that the air density at a given pressure altitude may differ from that in the ISA model at that pressure altitude.

Barometric Pressure at Accident (hectopascals): The local atmospheric pressure at the weather station. This value should be recorded in hectopascals. If the altimeter setting is reported in other units, convert to hectopascals but provide the report measurement and its units in parentheses. [One hectopascal = 1013.25 millibars (mb) = 1 hectopieze = 14.6959 lbs/in^2 = 101.325 kN/m^2 = 761.484 mm Hg at 16.6 ºC and MSL]

General Weather Description at Accident: The general description of the weather, i.e. rain, snow, fog, clear, cloudy, etc.

Windshear/Microburst at Accident (yes/no/unknown): Was there the presence of a windshear and/or microburst near the weather station? Yes, no, or unknown response only.

Windshear/Microburst Doppler Data Available at Accident (yes/no/unknown): Is doppler radar data from a microburst/windshear detection system available? Yes, no, or unknown response only.

II.3. AIRCRAFT ACCIDENT FIRE AND WATER IMMERSION INFORMATION

Aircraft Accident Fire and Water Immersion Information												
Accident Identification		**Accident Fire Parameters**										
Accident Identifier	Accident Date (dd/mm/yy)	Ground Operation Fire (Y/N/Unk)	In-Flight Fire (Y/N/Unk)	Impact Fire (Y/N/Unk)	Aircraft Fuel Load at Fire Initiation (kg)	Time of Fire Initiation	Initial Fire Area (m^2)	Final Fire Area (m^2)	Time Fire Contained	Time Fire Extinguished	Combustible Material Involved in Fire	Distance Fire Moved from Impact Location (m)
Accident Identification		**Accident Water Immersion Parameters**										
Accident Identifier	Accident Date (dd/mm/yy)	Water Depth of Major Debris (m)	Time of Flight Data Recorder Recovery	Time of Cockpit Voice Recorder Recovery	Time of Major Component / Cargo Recovery		Comments					

II.4. GENERAL GUIDANCE FOR COMPLETING THE IAEA AIRCRAFT ACCIDENT FIRE AND WATER IMMERSION QUESTIONNAIRE

The International Atomic Energy Agency (IAEA) is collecting and analysing aircraft accident data to study issues related to aircraft accident forces and develop a better understanding of aircraft accident frequencies and severity. The results are expected to be used in the regulatory review and revision process to evaluate the level of protection provided by Type C packaging requirements given in IAEA Safety Series ST-1, "Regulations for the Safe Transport of Radioactive Materials".

Data is being collected on aircraft accidents involving non-military aircraft with a maximum gross certificated takeoff weight greater than 27 000 kilogram (ICAO Category 4 and 5) which result in the destruction or major damage (an insurance write-off) of the airframe. Of interest are data concerning aircraft accidents involving fire either occurring in-flight; at or following an impact; or during ground operations. Additionally, data involving aircraft accidents that result in the immersion of the aircraft, either in-whole or in-part, in water are also of interest.

The attached questionnaire is designed to collect aircraft accident severity data involving fire and water immersion parameters. The questionnaire consists of two tables with the requested information identified by column headings. The first table requests information on fire accident parameters while the second table concentrates on accident water immersion parameters. Also provided on the accident water immersion parameter table is a column for comments. This column can be used to record additional information or insights concerning either the fire or water immersion data provided for the specified accident.

When filling out the questionnaire, attention should be given to providing the unit of measure for the parameter requested (i.e., fire area in square metres). Additionally, if data on the range of a parameter (i.e. fire area estimate of 80–110 m^2) is given in the records, this range should be given on the questionnaire along with the most likely value for that parameter, if available. On the accident fire parameter table, if the specified accident did not involve a fire, as indicated by a "No" (N) in the ground operation fire, in-flight fire and the impact fire columns, the entrees for remaining parameters should be "not applicable". Similarly, on the accident water immersion parameter table, if the accident did not involve water immersion of the aircraft, in-whole or in-part, the entrees for remaining parameters should be "not applicable". Parameters left blank leave the impression that the recorder missed these parameters. Negative answers acknowledge that an attempt was made to fill in the parameter.

The primary source of information for filling in the questionnaire is the official accident investigation report of the State investigating the accident. However, other applicable information including official accident investigation files with related raw data sheets, investigator interview sheets, etc., may provide a valuable source of data for the parameters of interest.

The following discussion provides specific guidance on each parameter requested in both the accident fire parameter and accident water immersion parameter tables. The user should refer to this specific guidance to obtain a more detailed description of the information requested.

SPECIFIC GUIDANCE

Accident Fire Parameter Table

The parameter of interest is the total fire duration time from initiation to final extinguishment. This parameter is of interest because of the relationship of the fire to the thermal heat load as applied to aircraft cargo. Care should be exercised when determining the parameters that make up this time because of inconsistencies in separate fire recording times. Any time scale may be used to develop the fire sequence history as long as the reference point used throughout the sequence development is consistent. In other words, use the same “zero” time.

Accident Identification: The ICAO ADREP accident identifier.

Accident Date (year/month/day): This date should be the day of the accident at its location (local date). There may be a variation in accident days within a day or two depending on the source of information and the reference point. If Greenwich Mean Time (or Universal Coordinated Time) is used as the accident time (see below), then the accident date must be consistent with the time.

Ground Operation Fire (Yes/No/Unknown): This parameter records whether a fire occurred during ground operation and is exclusive of in-flight and impact fires. Entrees should be “yes”, “no” or “unknown”. If the response is “yes”, then entrees for the In-Flight Fire and Impact Fire columns should be “no”. Ground operation fires are importance because fires associated with aircraft ground operations may involve greater amounts of combustible material or fuel (i.e. refuelling operations).

In-Flight Fire (Yes/No/Unknown): This parameter records whether a fire occurred during the flight. Entrees should be “yes”, “no” or “unknown”. In-flight fires are is importance because these fires may involve longer cargo exposure times when coupled with impact fires.

Impact Fire (Yes/No/Unknown): This parameter records whether a fire occurred during an aircraft accident impact. Entrees should be “yes”, “no” or “unknown”. This parameter is used along with the in-flight fire parameter to estimate the total fire duration.

Aircraft Fuel Load at Fire Initiation (kilograms): This parameter should be recorded in kilograms. If this parameter is reported in units other than kilograms, it should be converted to kilograms but its reported value and its units provided in parentheses. If the fuel load is provided in terms of a volume measurement, i.e. litres, gallons, then it will be necessary to provide the assumed density and temperature of the fuel when the conversion to mass is made.

Time of Fire Initiation: The time and day when the fire was initiated either in-flight, at or following ground impact accident, or during ground operations. This parameter is useful in determining the total fire duration.

Initial Fire Area (square metres): The area covered by the fire at impact or when the fire initially breaks out. This parameter should be recorded in square metres. If this parameter is reported in other units, it should be converted to square metres, but the reported value and its units provided in parentheses.

Final Fire Area (square metres): The final area covered by the fire. This parameter should be recorded in square metres. If this parameter is reported in other units, it should be converted to square metres, but the reported value and its units provided in parentheses.

Time of Fire Containment: The time and day that the fire was considered contained, according to the fire emergency response.

Time of Fire Extinguishment: The time and day that the fire was considered extinguished, according to the fire emergency response. Some comments describing how this time has been defined may be appropriate with this time, i.e. hot spots only remaining, or small fires allowed to burn out, etc.

Combustible Material Involved in the Fire: Type of fuel involved in fire. This parameter may be used to develop a fire temperature distribution if sufficient information is found to justify such development. If multiple types of fuel are involved in the fire, use the fuel type that is predominant. The following descriptors will be used to classify the types of fuel involved in the fire:

- Aircraft Fuel;
- Aircraft Fluids (hydraulic fluid);
- Cargo — describe the type of cargo involved in the fire (luggage, chemicals, etc.);
- Wheel(s)/Tyre(s);
- Other — describe the type of fuel involved in the fire;
- Unknown.

Distance Fire Moved from Aircraft (metres): The distance the fire moved from the aircraft during the course of the accident sequence. This information may be useful in determining the total fire duration or for adjusting the fire temperature. This parameter should be recorded in metres. If this parameter is reported in other units, it should be converted to metres, but its reported value and its units provided in parentheses.

Accident Water Immersion Parameter Table

This table is used to characterize parameters for the immersion of aircraft cargo in depths of water. If no large body of water is involved with the accident or no part of the aircraft is lost in the water, then all parameters of this category should be marked “Not Applicable”. If the answer to this category is not known, then all parameters of this category should be marked “Not Available”.

Accident Identification: The ICAO ADREP accident identifier.

Accident Date (year/month/day): This date should be the day of the accident at its location (local date). There may be a variation in accident days within a day or two depending on the source of information and the reference point. If Greenwich Mean Time (or Universal Coordinated Time) is used as the accident time (see below), then the accident date must be consistent with the time.

Water Depth of Major Debris (meters): The depth of the water where the major part of the debris is located. This parameter should be recorded in metres. If this parameter is reported in other units, it should be converted to metres, but its reported value and its units provided in parentheses.

Time of Flight Data Recorder: The time and day the flight data recorder was recovered from the water.

Time of Cockpit Voice Recorder Recovery: The time and day the flight data recorder was recovered from the water.

Time of Major Component/Cargo Recovery: The time and day the major component/cargo was recovered from the water.

APPENDIX III. STATES WHICH RESPONDED TO THE QUESTIONNAIRE

Afghanistan
Angola
Argentina
Azerbaijan
Bahrain
Bolivia
Brazil
Cambodia
Cameroon
Canada
China
Colombia
Congo
Côte d'Ivoire
Croatia
Czech Republic
Denmark
Djibouti
Dominica
Dominican Republic
Ecuador
Egypt
El Salvador
Eritrea
France
Georgia
Greece
Guatemala
Honduras
India
Indonesia
Iran, Islamic Republic of
Japan
Kenya
Korea, Republic of
Liberia
Libya
Lithuania
Malaysia
Mauritania
Mexico
Morocco
Nepal
Netherlands
Niger
Nigeria
Norway
Pakistan
Panama
Paraguay
Peru
Philippines
Poland
Portugal
Romania
Russian Federation
Saudi Arabia
Spain
Sri Lanka
Switzerland
Taiwan
Thailand
The former Yugoslav Republic of Macedonia
Togo
Turkey
Ukraine
United Arab Emirates
United Kingdom
United States of America
Uruguay
Venezuela

APPENDIX IV. EQUIVALENT IMPACT VELOCITY

To take into consideration the effect of the hardness of the impacted surface, the impact velocity must be adjusted to relate the impact load encountered in a real accident to an equivalent load encountered when impacting on an unyielding surface. This appendix discusses equivalent velocity factors for various surface types seen during aircraft accidents.

IV.1. A SIMPLIFIED MODEL OF PACKAGE IMPACT WITH THE GROUND

Assume:

- A rigid package which is protected by a mass-less packaging material with a linear load deflection relationship;
- That the force resisting penetration of the ground is proportional to the depth of penetration.

Let:

- M be the package mass;
- K_1 be the stiffness of the packaging material;
- δ_1 be the deflection of the packaging material;
- K_2 be the "stiffness" of the ground, assume that $K_2 = \lambda . K_1$;
- δ_2 be the depth of penetration into the ground;
- V be the velocity of impact.

Then, the displacement of the mass after the instant of initial contact with the ground is

$$\delta = \delta_1 + \delta_2 \tag{IV.1}$$

The packaging material and the ground are two linear springs in series with an effective stiffness, K, given by

$$K = \frac{K_1 . K_2}{K_1 + K_2} = K_1 . \left(\frac{\lambda}{1 + \lambda} \right) \tag{IV.2}$$

and the relation between package deformation and mass displacement is

$$\delta_1 = \frac{\lambda}{1 + \lambda} . \delta \tag{IV.3}$$

The mass will come to rest when its initial kinetic energy has been converted into strain energy in the combined spring. That is when

$$\frac{1}{2} . M . V^2 = \frac{1}{2} . K . \delta^2 \tag{IV.4}$$

so the maximum mass displacement is

$$\delta_{\max} = V.\left(\frac{M}{K}\right)^{0.5}$$

(IV.5)

which means that maximum deformation of the packaging is

$$\Delta_{\max} = V.\left(\frac{M}{K}\right)^{0.5}.\frac{\lambda}{1+\lambda} = V.\left(\frac{M}{K_1}\right)^{0.5}.\left(\frac{\lambda}{1+\lambda}\right)^{0.5} \qquad \text{(IV.6)}$$

The force acting on the mass is $K.\delta$ and is a maximum at the point of maximum mass displacement.

So the maximum retardation experienced by the mass, *M*, is

$$A_{\max} = \frac{K.\delta_{\max}}{M} = \frac{K}{M}.V.\left(\frac{M}{K}\right)^{0.5} = V.\left(\frac{K}{M}\right)^{0.5} = V.\left(\frac{K_1}{M}\right)^{0.5}.\left(\frac{\lambda}{1+\lambda}\right)^{0.5} \qquad \text{(IV.7)}$$

Thus, a test at impact velocity V_e on an infinitely hard surface $(\lambda \rightarrow \propto)$ will give the same maximum acceleration and the same maximum package deformation as an impact at velocity *V* on a soft surface provided that

$$V_e = V.\left(\frac{\lambda}{1+\lambda}\right)^{0.5} \qquad \text{(IV.8)}$$

However, this equivalent velocity depends on the ratio of packing stiffness to ground stiffness and is, therefore, dependent on package properties.

IV.2. ADJUSTED IMPACT VELOCITY

The initial evaluation of the data had as its goal to convert the recorded impact ground speed to true impact ground speed, making a correction for pressure altitude and compressibility. The normal component of the true impact ground speed is an appropriate measure for estimating impact forces. To account for the impact angle of the aircraft, an adjusted impact velocity, V_{ai}, is defined as:

— The normal component of the true ground speed, relative to the real impact surface,
— In the absence of data for ground speed and/or impact angle, it is the descent rate adjusted for the orientation of the real impacted surface.

These aircraft parameters are applied to estimate the adjusted impact velocity (V_{ai}) from the aircraft accident data report.

IV.3. IMPACTED SURFACE AND PACKAGE CHARACTERISTICS THAT MAY AFFECT THE IMPACT LOADING

Impact loading seen by the package is dependent on the package stiffness and on the surface hardness of the impacted surface. To take into consideration the effect of the package stiffness and hardness of the impacted surface, an equivalent impact velocity, V_{ei}, is defined. The purpose of defining V_{ei} is to relate an impact load encountered in a real accident to an equivalent load encountered when impacting an unyielding surface as defined in the Transport Regulations. For this analysis, the functional relationship between V_{ei} and V_{ai} is defined as:

$$V_{ei} = k_s\, V_{ai} \tag{IV.9}$$

where k_s is the equivalent velocity factor,
V_{ai} is the actual impact velocity onto a real surface.

Extensive efforts have gone into defining k_s values that are only a function of the energy absorption capability of the impacted surface, independent of the package design.

A simplified mathematical model demonstrating the relationship of the ratio of impacted surface hardness and package stiffness on the equivalent velocity. This model indicates that the impact loading on the package is dependent on the hardness (stiffness) of both the impacted surface and the package and is related through the equation:

$$V_{ei} = V_{ai}\left(\sqrt{\frac{\lambda}{1+\lambda}}\right) \tag{IV.10}$$

where λ is the ratio of stiffness of the impacted surface and stiffness of the package.

To gain an understanding of how k_s (or V_{ei} / V_{ai}) varies with the ratio of package stiffness to ground stiffness, the equation above is plotted and is as shown in Fig. 29.

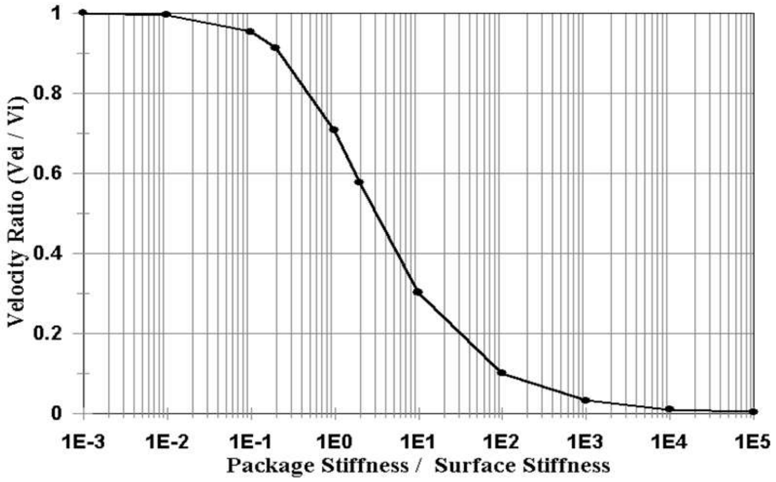

FIG. 29. Velocity ratio (k_s) versus stiffness ratio ($1/\lambda$).

A similar plot can be obtained considering the energy of impact and the relationship between the energy absorption capabilities of the surface and the package.

A review of Fig. 29 shows that for hard impact surfaces relative to the package, the velocity ratio approaches 1, i.e. the equivalent impact velocity approaches the impact velocity for an unyielding surface. In this case, most of the energy of impact goes into deformation of the package. For soft impact surfaces relative to high package stiffness, the soft surface absorbs most of the energy and therefore most of the energy of impact goes into deformation of the surface. The impact velocity onto soft real surfaces therefore approaches only a small proportion of the impact velocity onto the unyielding surface. In the region where the relative stiffness of the surface and the package is similar, the energy of impact is shared between the two impacting objects.

IV.4. EQUIVALENT VELOCITY FACTORS (k_s) FOR VARIOUS SURFACE TYPES FROM THE LITERATURE REVIEW

Table 16 provides the actual impact surface type data seen during the aircraft accidents, and Table 17 provides brief information on the aircraft accidents.

A literature search (Refs [20], [21], [22], [23], [24], [14], [25], [26], [27], [28], [29]) was conducted to gather information on the studies done on relative responses of various packaging impacting on surfaces with differing hardness. The search identified several papers and reports that compared the impact loading on packaging from real and unyielding surfaces. Some of these reports present results using analytical methods, while others present results of experimental programmes. Several types of packages, some prototypical, were evaluated or tested. The review of the data from the literature search suggests that various target surfaces from Table 18 can be put in one of the following general categories:

- Hard surface consisting of concrete, hard rock, soft rock and concrete over soil;
- Mixed surface consisting of asphalt over soil and structures;
- Soft surface consisting of hard soil, soil and soft soil;
- Water.

Table 16 [20], [21], [22], [23], [24], [14], [25], [26], [27], [28], [29] presents the impact velocity ratio data for the four classified impact surfaces. It is recognized that radioactive material packages of various designs and stiffness will be used in air transport. The assignment of the impact surfaces used in the literature to one of the four classified surfaces is therefore made assuming that the equivalent velocity factors are independent of the package stiffness. Further, the value derived by Droste [24] for soft soil is considerably outside the other values reported for soft soil. This value is therefore omitted in deriving equivalent velocity factors.

TABLE 16. AIRCRAFT ACCIDENTS: IMPACT SURFACE TYPE DATA

ICAO ADREP accident identification	Impact angle with respect to surface (degrees, L,M,H)	Aircraft impact speed (m/s)	Impact surface type
95/0389-0	NA	NA	Swamp, tall vegetation, trees
95/0397-0	NA	NA	Wooded/tree covered
90/0525-0	NA	110	Cultivated field
96/0387-0	65	116.3	Rock
96/0029-0	-34.3	90.2	Open water
95/0113-0	Low (0–30°)	164.7	Other
96/0411-0	Low (0–30°)	77.16	Built-up area/ houses
98/0264-0	Low (0–30°)	NA	Grass
99/0377-0	High (60–90°)	231.5	Open water
92/0006-0	Med. (30–60°)	98	Wooded/tree covered
00/0257-0	NA	30-50	Built-up area/houses
00/0378-0	Low (0–30°)	60	Trees, rocks
93/0292-0	High (60–90°)	NA	Open water
93/0413-0	0°	0	Apron/concrete
00/0243-0	NA	73	Built-up area/houses
92/0292-0	Low (0-–30°)	NA	Tall vegetation
93/0156-0	Low (0–30°)	84.5	Grass
91/0367-0	High (60–90°)	113	Rock, tall vegetation
92/0124-0	High, >60°	> 150	Built-up area/houses
96/0339-0	43°	86	Rock
98/0009-0	High (60–90°)	69.5	Grass
92/0251-0	Med. (30–60°)	180.6	Sea ice
92/0151-0	R. Bank 6°	102.8	Wooded/tree covered
94/0001-0	1–5°	141.7	Hills, woods, crops/cultivated field, built-up area/houses

TABLE 16. AIRCRAFT ACCIDENTS: IMPACT SURFACE TYPE DATA (cont.)

ICAO ADREP accident identification	Impact angle with respect to surface (degrees, L,M,H)	Aircraft impact speed (m/s)	Impact surface type
91/0272-0	NA	NA	Sand
97/0174-0	0	NA	Rock
91/0188-0	High (60–90°)	190.7	Tall vegetation
94/0015-0	Low (0–30°)	NA	Tall vegetation, wooded/tree covered
94/0436-0	3°	NA	Wooded/tree covered
99/0472-0	Med. (30–60°)	128.6–154.3	Grass
90/0013-0	Low (<10°)	NA	Wooded/tree covered
90/0158-0	Low (<10°)	74.6	Other (tundra, low bushes, grass)
90/0499-1 (two planes)	0°	NA	Pavement
90/0499-1 (two planes)	0°	51+	Pavement
91/0036-2	0°	60.6	Pavement, grass
91/0049-0	NA	NA	Pavement
91/0052-0	80°	>108	Grass
92/0175-0	NA	154.3	Wooded/tree covered, crops/cultivated field
92/0228-0	Low (0–30°)	66.9	Other (shoreline, mud, grass)
92/0229-0	Low (0–30°)	91.6	Pavement, grass
93/0290-0	Med. (30–60°)	61.7	Grass, tall vegetation
94/0179-0	NA	73.0	Wooded/ tree covered, houses
94/0275-0	NA	128.6	Wooded/ tree covered
94/0344-0	Med. (30–60°)	193	Crops/cultivated field
95/0041-0	NA	64.3	Grass
96/0171-0	NA	>205.8	Swamp
96/0273-0	NA	152–162	Open water

TABLE 16. AIRCRAFT ACCIDENTS: IMPACT SURFACE TYPE DATA (cont.)

ICAO ADREP accident identification	Impact angle with respect to surface (degrees, L,M,H)	Aircraft impact speed (m/s)	Impact surface type
96/0356-0	No Impact	No Impact	No impact, not applicable
96/0519-0	Med. (30–60°)	NA	Pavement, grass
96/0533-0	26°	<20.6	Wooded/tree covered
97/0171-0	NA	72.0	Pavement (runway), grass
97/0110-0	-3°	72.0	Tree covered, tall vegetation
97/0131-0	NA	NA	Pavement, built-up area/houses
99/0126-0	0°	52.5	Pavement, grass

NA: Not Available.

TABLE 17. INFORMATION ON AIRCRAFT ACCIDENTS FOR DATA SET (1990–2000)

ICAO ADREP accident identification	Airline flight number	Universal date (dd.mm.yy)	Crash altitude (ft msl)	Aircraft type	IAEA surface designator	Notes
95/0389-0	Cameroon AL 3701	03.12.95	?	Boeing 737-2K9 Adv.	water	Entered steep dive on 2nd approach 6 km short of runway, crashed in mangrove swamp, fire duration type not given
95/0397-0	American 965	21.12.95	8900	Boeing 757-223	mixed surfaces	Crashed in wooded/tree covered mountain
90/0525-0	Aeroflot Russian Intl 7266	17.11.90	?	Tupolev Tu-154M/Tu-164	soft surface	In-flight fire, attempting landing at Prague, crashed in cultivated field
96/0387-0	Danish Air Force	03.08.96	?	Grumman 1159 Gulfstream III	hard surface	Flew into high ground, mountainous rocky terrain
96/0029-0	Birgenair/Alas Nacionales 301	05.02.96	7132	Boeing 757-225	water	Aircraft descended 2368 ft in last 8 seconds of flight, crashed in water
95/0113-0	American Jet	03.05.98	?	Grumman 1159 Gulfstream II	mixed surface	Listed as 320? Knots, crashed in mountain
96/0411-0	Million Air 406	22.10.96	?	Boeing 707-323C	mixed surface	Fell back to ground, crashed in level/flat built-up area/houses
98/0264-0	Cubana 389	29.08.98	?	Tupolev Tu-154M/Tu-164	soft surface	Fell back to ground after lift-off, hit buildings on level/flat grass ground
99/0377-0	Egypt Air 990	31.10.99	33 000	Boeing 767-366 ER	water	Rate of descent listed as 24 000 ft/min (121.95 m/s), last recorded FDR speed 458 knots, crashed in water

TABLE 17. INFORMATION ON AIRCRAFT ACCIDENTS (1990–2000) (cont.)

ICAO ADREP accident identification	Airline flight number	Universal date (dd.mm.yy)	Crash altitude (ft msl)	Aircraft type	IAEA surface designator	Notes
92/0006-0	Air Inter 5148	20.01.92	2620	Airbus A.320-111	mixed surface	Hit high ground on approach, crashed in wooded/tree covered mountainous terrain
00/0257-0	Air France 4590	25.07.00	?	Aerospatiale/BAC Concorde 101	mixed surface	Listed as 30–50 m/s, in-flight, engine fail/fire, attempted landing at Le Bourget airport, hit hotel, crashed in level/flat built-up area/houses
00/0378-0	Securite Civile/T&G Aviation	06.09.00	?	Lockheed C-130A-6-LM Hercules	hard surface	Fire-fighting flight, flew into hill during water drop
93/0292-0	Georgian Civil Aviation 6952	21.09.93		Tupolev Tu-134B-3	water	Crashed in water
93/0413-0	Georgian Civil Aviation	22.09.92		Tupolev Tu-134A/B-1/B-3	hard surface	Crashed on apron/concrete
00/0243-0?	Alliance Air 7412	17.07.00	?	Boeing 737-2A8	mixed surface	Stalled during 360º orbit on approach, crashed in level flight built-up area/houses
92/0292-0	Volga-Dnepr WDA-003	23.07.92		Antonov An-12BP	mixed surface	Crashed in mountains with tall vegetation
93/0156-0	Avioimpex 110	20.11.93	4900	Yakolev Yak-42	soft surface	Flew into mountain 2600 ft above runway, crashed in grass-covered mountainous terrain
91/0367-0	Dupont	04.09.91	4100	Grumman 1159 Gulfstream II	hard surface	Flew into high ground, mountainous rocky terrain with tall vegetation

TABLE 17. INFORMATION ON AIRCRAFT ACCIDENTS (1990–2000) (cont.)

ICAO ADREP accident identification	Airline flight number	Universal date (dd.mm.yy)	Crash altitude (ft msl)	Aircraft type	IAEA surface designator	Notes
92/0124-0	El Al Israel 8162	04.10.92	?	Boeing 747-258F	mixed surface	Listed as greater than 150 m/s, in-flight no. 3 engine separation, returning to airport, hit apartment building, crashed in built-up area/houses
96/0339-0	Vnukovo AL 2801	29.08.96	2975	Tupolev Tu-154M	hard surface	Hit high ground on approach 7.7 nautical miles from runway, crashed in mountainous rocky terrain
98/0009-0	Air Sofia S13	04.02.98	?	Antonov An-12	soft surface	Returning to airport, hit high ground, crashed on level/flat grass terrain
92/0251-0	Central Regions 34104	22.03.92	?	Antonov An-30	mixed surface	Crashed in sea ice
92/0151-0	Central Regions 2808	27.08.92	?	Tupolev 134A	mixed surface	Hit trees 2962 m, short of runway, crashed in level/flat wooded/tree covered terrain
94/0001-0	Vostock-Syeskoy Directory Civil Aviation 130	03.01.94	13 120	Tupolev Tu-154M/Tu-164	mixed surface	In-flight engine fail/fire, crashed in hilly terrain with crops/cultivated fields, built-up area/houses
91/0272-0	Nolisair Intl 2120	11.07.91		Douglas DC-8-61	water	Crashed on level/flat sandy terrain
97/0174-0	Saudi Arabian AL 1861	06.09.97	ground	Boeing 737-268 Adv.	hard surface	Rejected takeoff, overran runway, main gear collapse, level/flat rock terrain

TABLE 17. INFORMATION ON AIRCRAFT ACCIDENTS (1990–2000) (cont.)

ICAO ADREP accident identification	Airline flight number	Universal date (dd.mm.yy)	Crash altitude (ft msl)	Aircraft type	IAEA surface designator	Notes
91/0188-0	Lauda Air 004	26.05.91	24 700	Boeing 767-3Z9 ER	mixed surface	Thrust reverser deployed at 24 700 ft, airframe breakup occurred 29 seconds later, airframe breakup estimated at 2000 m (6560 ft), crashed in mountainous jungle with tall vegetation
94/0015-0	British Airways 4272	25.02.94		Vickers Viscount 813	mixed surface	Crashed in rolling tall vegetation, wooded/tree covered terrain
94/0436-0	Air Algerie 702P	21.12.94	?	Boeing 737-2D6C Adv.	mixed surface	Hit electric tower 1.1 miles from runway, fire duration type not given, crashed in level/flat wooded/tree covered terrain
99/0472-0	Korean AL 8509	22.12.99	2532	Boeing 747-2B5F (SCD)	soft surface	Listed as 250–300 knots (128.6–154.3 m/s), crashed on level/flat grass terrain
90/0013-0	Avianca 052	26.01.90		Boeing 707-321B	mixed surface	Crashed in hilly wooded/tree covered terrain
90/0158-0	Markair 3087	02.06.90	?	Boeing 737-2X6C	soft surface	Controlled fight. into terrain 12 km, short of runway, crashed in level/flat, hilly tundra with low bushes, grass
90/0499-1	Northwest 299	03.12.90	ground	Boeing 727-251-2A	hard surface	Listed as 100+ knots (51+ m/s), ground collision
90/0499-1	Northwest 1482	03.12.90	ground	Douglas DC-9-14	hard surface	Listed as 100+ knots (51+ m/s), ground collision, assigned value of impacting aircraft

TABLE 17. INFORMATION ON AIRCRAFT ACCIDENTS (1990–2000) (cont.)

ICAO ADREP accident identification	Airline flight number	Universal date (dd.mm.yy)	Crash altitude (ft msl)	Aircraft type	IAEA surface designator	Notes
91/0049-0	Ryan Intl 590	17.02.91		Douglas DC-9-15RC	hard surface	Crashed on pavement
91/0052-0	United 585	03.03.91	6704	Boeing 737-291	soft surface	Listed as greater than 210 knots (108 m/s), roll began ca. 1000 ft above ground level, crashed on level/flat grass
92/0175-0	Air Transport Intl (782)	15.02.92	3000	Douglas DC-8-63F	mixed surface	Go-around, 2nd missed approach, crashed on level/flat wooded/tree covered terrain with crops/cultivated field
92/0228-0	US Air 405	22.03.92	?	Fokker F-28-4000	soft surface	Early rotation, fell back to ground, stalled, crashed on level/flat shoreline, mud, grass
92/0229-0	TWA 843	30.07.92	?	Lockheed L-1011 TriStar 1	hard surface	Rejected takeoff, fell back to ground, crashed on pavement, grass
93/0290-0	American AW 808	18.08.93	?	Douglas DC-8-61F	mixed surface	Stalled on approach 1400 ft short of runway during sharp turn, crashed level/flat grass with tall vegetation
94/0179-0	US Air 1016	02.07.94	?	Douglas DC-9-31	mixed surface	Attempted go-around, crashed at 350 feet above ground level, crashed in level/flat? Wooded/tree covered terrain with houses
94/0275-0	US Air 427	08.09.94	3600	Boeing 737-3B7	mixed surface	In-flight loss of control, crashed in hilly wooded/tree covered terrain

TABLE 17. INFORMATION ON AIRCRAFT ACCIDENTS (1990–2000) (cont.)

ICAO ADREP accident identification	Airline flight number	Universal date (dd.mm.yy)	Crash altitude (ft msl)	Aircraft type	IAEA surface designator	Notes
94/0344-0	American Eagle 4184	31.10.94	8000	Avions de Transport Regional ATR-72-212	soft surface	Altitude where roll oscillations began, crashed in level/flat crops/cultivated field
95/0041-0	Air Transport International ?(782)	16.02.95	?	Douglas DC-8-63F	soft surface	Attempted 3-engine takeoff, early rotation, climbed 100 feet above ground level, fell back to ground, crashed on level/flat grass
96/0171-0	Valujet AL 592	11.05.96	7200	Douglas DC-9-32	water	Listed as greater than 400 kt (205.8 m/s). Attempting return to airport, crashed in swamp
96/0273-0	TWA 800	17.07.96	14 000	Boeing 747-131	water	In-flight explosion at about 13 760 ft Listed as 500–531 ft/s (152–162 m/s), crashed in water
96/0356-0	FedEx 1406	05.09.96	33 000	McDonnell Douglas DC-10-10CF	hard surface	In-flight cargo fire, emergency landing/evacuation on runway
96/0519-0	Alberto Culver USA	30.10.96	?	Grumman G-1159 Gulfstream IV	soft surface	Crashed on level/flat pavement, grass
96/0533-0	ABX Air 827	22.12.96	?	Douglas DC-8-63F	mixed surface	Listed as less than 40 knots (20.6 m/s), in-flight, stall recovery manoeuvre, crashed in mountainous wooded/tree covered terrain impact speed greater 240 kts

TABLE 17. INFORMATION ON AIRCRAFT ACCIDENTS (1990–2000) (cont.)

ICAO ADREP accident identification	Airline flight number	Universal date (dd.mm.yy)	Crash altitude (ft msl)	Aircraft type	IAEA surface designator	Notes
97/0171-0	FedEx 14	31.07.97	ground	McDonnell Douglas MD-11F(AF)	hard surface	Bounced on landing, overturned, crashed on pavement (runway), grass
97/0110-0	Korean 801	05.08.97	650	Boeing 747-3B5	mixed surface	Controlled flight into terrain short of runway, fire fed by fuel from ruptured fuel line, crashed in hilly tree covered terrain with tall vegetation
97/0131-0	Fine Air/Aeromar 101	07.08.97	10	Douglas DC-8-61F (AF)	hard surface	Stalled on climb-out, loss of control, crashed on pavement, built-up area/houses
99/0126-0	American 1420	01.06.99	ground	McDonnell Douglas MD-82	hard surface	Overran wet runway, crashed on pavement, grass

TABLE 18. EQUIVALENT IMPACT VELOCITY FACTORS (k_s) FROM LITERATURE SEARCH FOR VARIOUS SURFACE TYPES

Literature Reference	Equivalent impact velocity factors (k_s)									
	Concrete	Hard Rock	Soft Rock	Concrete Over Soil	Asphalt Over Soil	Structures	Hard Soil	Soil	Soft Soil	Water
Akamatsui [20], [21]										
TN-24 cask				0.44	0.42		0.53		0.36	
Ammerman [22] 90 000 kg cylindrical cask										
with shock absorber							0.52			
without shock absorber							0.06			
Ammerman [23]										
Wire-mesh package	0.95							0.50		
Al-plate package	0.43							0.23		
Droste [24] Wooden shock absorbers									0.84	
Gonzales [14] ½ scale cylindrical cask	0.71-0.76							<0.5		

TABLE 18. EQUIVALENT IMPACT VELOCITY FACTORS (k_s) FROM LITERATURE SEARCH FOR VARIOUS SURFACE TYPES (cont.)

Literature Reference	Equivalent impact velocity factors (k_s)									
	Concrete	Hard Rock	Soft Rock	Concrete Over Soil	Asphalt Over Soil	Structures	Hard Soil	Soil	Soft Soil	Water
Holt [25]										
Magnox										
Lid-corner (9 m)	0.39									
Lid-edge (9 m)	0.63									
Lid-corner (20 m)	<0.54									
Lid-edge (20 m)	<0.61									
McClure [26], [27]										
LLD-1	0.71							0.43		
6M	0.77							0.42		
BE-83									0.12	
20 t cask						<0.36				
Unknown		0.45	0.4				0.33		0.14	0.22
Shirai [28]										
48Y cylinder	1.0			0.73			0.56 0.52	0.56	0.56	0.56
Van Sant [29]										
Prototype plutonium air transport package	0.89		0.78			0.8			0.67	0.54

TABLE 19. LITERATURE REVIEW OF EQUIVALENT VELOCITY FACTORS FOR THE FOUR DEFINED SURFACE CATEGORIES

	Hard surface	Mixed surface	Soft surface	Water
Akamatsui [20], [21]	0.44	0.42	0.53 0.36	
Ammerman [22]			0.52 0.06	
Ammerman [23]	0.95 0.43		0.50 0.23	
Gonzales [14]	0.74 [a]		0.50	
Holt [25]	0.39 0.63 0.54 0.61			
McClure [26]	0.40 0.45 0.71 0.77	0.36	0.14 0.33 0.43 0.42 0.12	0.22
Shirai [28]	1.0 0.73		0.56 0.56 0.56	0.56
Van Sant [29]	0.89	0.8	0.78 0.67	0.54

[a] Average of the two values given.

The data from Table 19 are used to derive normal distributions for each surface type. From these distributions, statistical parameters for the data are derived, as shown in Table 20.

TABLE 20. STATISTICAL PARAMETERS OF EQUIVALENT VELOCITY FACTORS FROM THE LITERATURE REVIEW FOR THE FOUR SURFACE CATEGORIES

	Sample size	Mean	Median	Standard deviation (sigma)	Mean + sigma	90% percentile
Hard surface	15	0.65	0.64	0.20	0.85	0.94
Mixed surface	3	0.53	0.53	0.24	0.77	0.85
Soft surface	17	0.43	0.42	0.20	0.63	0.70
Water	3	0.44	0.45	0.19	0.63	0.67

Using the equivalent velocity factors given in Table 19 and Eqs IV.9 and IV.10 above, the ratios of package stiffness to surface stiffness were calculated for the various impact surfaces. The data are plotted in Fig. 30, along with an indication of the mean and 90% percentile for each surface type.

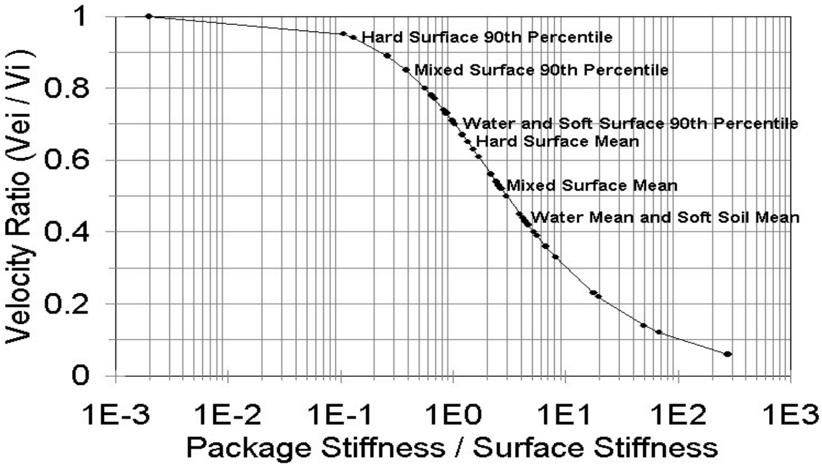

FIG. 30. Derived velocity ratios showing selected statistical parameters.

IV.5. EQUIVALENT VELOCITY FACTORS (k_s) FOR VARIOUS SURFACE TYPES FROM THE ACCIDENT REPORTS

A review of the data collected for impact surface types from the aircraft accident data reports indicates that generally an aircraft crash involves several surface types. However, the data show that impact can be divided into five basic surface types:

(1) Hard surfaces: rock, concrete, pavement and runways;
(2) Vegetation: wooded areas and trees;
(3) Built-up area: structures (houses and commercial buildings), vehicles on the ground and miscellaneous equipment;

(4) Soft surfaces: cultivated soil, grass and mud;
(5) Water: open water, swamps and lakes.

For this evaluation, the characteristic surface type for each crash is taken as the hardest surface involved. For example, if the data for a single crash indicate that the impacted surface involved rock and tall vegetation, the harder surface is used as the characteristic crash surface type. This assumption is conservative in that the package is assumed to impact the hardest surface during accidents where multiple surfaces are involved.

Furthermore, in this study the ‘Vegetation’ and the ‘Built-up Area’ surface types identified by the aircraft crash data are grouped together into the ‘Mixed Surface’ to match the surfaces established above.

The equivalent impact velocity factors (k_s) are given in Table 18 using the statistical parameters defined in Table 20 for the four categorized impact surfaces from the literature review and the accident data reports. These equivalent impact velocities are used to calculate equivalent impact velocities for comparison to an unyielding surface.

TABLE 21. EQUIVALENT VELOCITY FACTORS (k_s) FOR THE CHARACTERISTIC FOUR SURFACE CATEGORIES

Impact surfaces	Surface description	Mean	Mean + sigma	90% percentile
Hard surfaces	Such as rock, concrete, pavement and runways	0.65	0.85	0.94
Mixed surfaces	Such as vehicles on the ground, structures (houses/commercial buildings), miscellaneous equipment and wooded areas and trees	0.53	0.77	0.85
Soft surfaces	Such as soil, cultivated soil, grass and mud	0.43	0.63	0.70
Water	Such as open water, swamp and lakes	0.44	0.63	0.67

IV.6. ALTERNATIVE APPROACH TO ACCOUNT FOR EQUIVALENT IMPACT VELOCITY

An alternative approach to account for equivalent impact velocity is to consider the probability that an aircraft crash will impact a certain type of surface. This can be performed by classifying impact surfaces into the four characteristic surface types given above with their corresponding k_s values of, for example, 0.65, 0.53, 0.44 and 0.43 for the hard, mixed, water and soft surfaces, respectively. For each flight phase, accident data can be evaluated to determine which type of surface the aircraft impacts and a probability can be estimated by dividing the number of crashes into each surface type by the total number of crashes, $P(T_j)$, where j indicates surface type.

These probabilities can then be used to adjust the conditional impact velocity cumulative distribution function for V_i for surface hardness using the logical combination:

$$V_{ei} = V_i \Sigma_j P(T_j) K_{s\,j} \qquad \text{(IV.11)}$$

where

j = surface type, 1 to 4

For example, consider a hypothetical normal impact ground speed of 130 m/s for a landing accident. The percentages of impact surface types are: 30% hard, 39% mixed, 8% water, and 23% soft. The equivalent impact velocity (V_{ei}), using the mean values given in Table 19, is:

$$V_{ei} = 130 \times (0.3\times0.65 + 0.39\times0.53 + 0.08\times0.44 + 0.23\times0.43) = 69.7 \text{ m/s} \qquad \text{(IV.12)}$$

Using the 90th percentile values of Table 21 gives V_{ei} = 107.9 m/s.

APPENDIX V. ANALYSIS OF THE AIRCRAFT ACCIDENT DATA

This appendix evaluates the probability of a high energy impact velocity exceeding 90 m/s (see Section 4.1) using two different approaches:

(1) Considering only the events, for which a questionnaire is available;
(2) Considering all the events, assuming that there is no correlation between the energy of impact of an event and the fact that the related questionnaire has been filled out or not. The validity of this assumption and the possibility of a bias are discussed here.

The database included a total of 336 accidents involving 338 aircraft. However, for the purpose of this appendix, the total number of accidents is taken as 338, i.e. $N_{total} = 338$ accidents. The distribution of the initial classification is shown in Table 22.

TABLE 22. ACCIDENT DISTRIBUTION FOR INITIAL ENERGY CLASSIFICATION

Initial energy classification	No. of accidents
High	$N_H = 42$
Low	$N_L = 196$
Undetermined	$N_U = 100$
Total	338

For ease of comprehension, four sets are defined as follows:

—Ω : the set of all the events;
—Ω_H : the set of the events for which the initial energy classification is ‘high’;
—Ω_L : the set of the events for which the initial energy classification is ‘low’;
—Ω_U : the set of the events for which the initial energy classification is ‘undetermined’.

This first distribution can be completed by taking into account the results of the questionnaires. N = 53 questionnaires have been filled out. The results are given in Table 23 with the correspondence to the initial classification.

TABLE 23. DISTRIBUTION OF HIGH IMPACT ACCIDENTS

Initial energy classification	No. of accidents (Ω)	No. of questionnaires returned (F)	No. of high impact accidents (G)
High	$\Omega_H = 42$	$\nu_H = 12$	$\eta_H = 5$
Low	$\Omega_L = 196$	$\nu_L = 19$	$\eta_L = 0$
Undetermined	$\Omega_U = 100$	$\nu_U = 22$	$\eta_U = 4$
Total	338	$\nu_{total} = 53$	$\eta_{total} = 9$

For ease of comprehension, eight subsets can be defined as follows:

- F: the subset of all the events for which the questionnaire is available (Card F = ν_{total});
- ν_H: the subset of the events of F for which the initial energy classification is ‘high’;
- ν_L: the subset of the events of F for which the initial energy classification is ‘low’;
- ν_U: the subset of the events of F for which the initial energy classification is ‘undetermined’;
- G: the subset of the high impact accidents included in F (Card G = η_{total});
- η_H: the subset of the high impact accidents included in F_H;
- η_L: the subset of the high impact accidents included in F_L;
- η_U: the subset of the high impact accidents included in F_U.

V.1. FIRST APPROACH: CONSIDERING ONLY THE SUBSET OF EVENTS WITH QUESTIONNAIRES (F) (53 EVENTS)

a. Simplistic approach (for large numbers)

The ratio of high impact accidents is:

$$\rho = \eta_{total}/\nu_{total} = 0.17 \qquad \text{(V.1)}$$

The standard deviation is:

$$\sigma = \{[\eta_{total}/\nu_{total}.\ (1-\eta_{total}/\nu_{total})]/\ \nu_{total}\}^{1/2} = 0.052 \qquad \text{(V.2)}$$

As a result, the 90% confidence interval (1.6σ) is:

Probability of high energy impact $\Pi \in [17 - 1.6 \times 5.2\%; 17 + 1.6 \times 5.2\%]$

i.e. $8.5\% \leq \Pi \leq 25.5\%$ with confidence level (CL) = 90%

Therefore, it can be stated with 90% confidence that the probability of a high energy impact (impact velocity >90 m/s) is less than 25.5%.

b. Binomial distribution approach

The binomial distribution gives the discrete probability distribution P_p(n|N) of obtaining exactly n successes out of N Bernoulli trials (where the result of each Bernoulli trial is true (high energy impact) with probability p and false (non-high energy impact) with probability q = 1 – p). The binomial distribution is therefore given by:

$$P\_p(n;N) = p^{n}(1 - p)^{N-n} . N!/(n!(N - n)!) \qquad (V.3)$$

The following probabilities can also be derived.

The probability of obtaining n successes at the maximum = P(≤n) is:

$$P(\leq n) = \sum_{k=0}^{n} P\, p(k; N) \qquad (V.4)$$

The probability of obtaining more than n – 1 success = P(>n) is:

$$P(> n) = \sum_{k=n}^{N} P\, p(k; N) \qquad (V.5)$$

Application to a subset of ν_{total} *= 53 events in which there are* η_{total} *= 9 events with high energy impact*

The aim is to test the confidence on different assumptions on the probability of high energy impact.

As an example, to examine if it is possible that the probability of high energy impact is 10% given 9 high energy impacts out of 53 events, the binomial distribution has to be evaluated with p = 0.1 and N = 53.

Table 24 shows that, if it is assumed that the probability of high energy impact is 10%:

- The probability of obtaining at maximum 9 high energy impacts out of 53 events is 96.5%, i.e. the assumption cannot be rejected;
- The probability of obtaining more than 8 high energy impacts out of 53 events is 7.8%, i.e. the assumption is far from probable (92.2% chance of being false).

As an intermediate conclusion, the binomial distribution allows one to reject the assumption that the probability of high energy impact in the F subset is 10%.

The same calculations can be performed for all the assumptions on the probability of high energy impact. The results are summarized in Table 24.

TABLE 24. VALIDITY OF ASSUMPTION OF PROBABILITY

Π (%)	10	11	12	13	14	15	16	17	18
P(≤9) (%)	96.5	93.9	90.3	85.6	80.0	73.4	66.2	58.6	51
P(>8) (%)	7.8	12.3	18.0	24.6	32.1	40.0	48.0	55.8	63.2

Π (%)	19	20	21	22	23	24	25	26
P(≤ 9) (%)	43.5	36.4	30.0	24.2	19.2	14.9	11.4	8.6
P(>8) (%)	70.0	75.9	81.1	85.4	88.9	91.7	93.9	95.6

From this table, it was calculated that the high energy impact probabilities outside of the range ≤10% and ≥26% can be rejected with a 90% confidence level.

$$11\% \leq \Pi \leq 25\% \text{ with a CL} = 90\%$$

On the other hand, at the 67% confidence level, it can be concluded that the probability of a high energy impact is between 15 and 20%.

$$15\% \leq \Pi \leq 19\% \text{ with a CL} \approx 2/3$$

Limitation of this first approach: No information can be derived from the 338 – 53 = 285 events if there is no questionnaire available. This limitation is addressed in the second approach by considering the subsets of events for which there is no questionnaire.

V.2. SECOND APPROACH: CONSIDERING THE SUBSETS OF EVENTS FOR WHICH THERE IS NO QUESTIONNAIRE (SUBSETS Ω_I–F_I)

This approach assumes that, within the subsets Ω_H, Ω_L, Ω_U, *there is no correlation between the energy of impact of an event and whether or not the related questionnaire has been filled out.* Under this assumption, the probability of high energy impact is the same for F_i and for the whole Ω_i subset, and especially for Ω_i–F_i.

The first step consists in determining the field of the most probable probabilities Π of high energy impact for the events for which the questionnaire is available (subset F_i).

It is also assumed that the so-determined field of the most probable probabilities Π of high energy impact is the same for all the events of Ω_i–F_i.

This assumption provides a field of number of accidents with high energy impact for a given confidence level for the subsets Ω_i–F_i.

The compilation of the results on the subsets Ω_i–F_i and of the results on the events from the questionnaire gives a more accurate evaluation of the probability of high energy impact.

a. *Events initially classified as low energy impact*

$N_L = 196$ events were initially classified as low energy impact (subset Ω_L), $\nu_L = 19$, of which having a questionnaire and $\eta_L = 0$ out of those 19 being high energy impact. The binomial distribution gives the probability of having 0 out of 19 events with high energy impact for different probabilities Π of high energy impact (using the same approach as above). The results are summarized in Table 25.

TABLE 25. VALIDITY OF ASSUMPTION OF PROBABILITY

Π (%)	1	2	3	4	5	6	7	8	9	10	11	12
P(≤0) (%)	82.6	68.1	56.1	46.0	37.7	30.9	25.2	20.5	16.7	13.5	10.9	8.8

From this table, it can be calculated that, regarding the high energy impact probability Π, all the probabilities ≥12% can be rejected with a 90% confidence level.

$$\Pi \leq 11\% \text{ with a CL} = 90\%$$

The most likely probabilities include:

$$\Pi \leq 5\% \text{ with a CL} \approx 2/3$$

The number of events within Ω_L–F_L (= Ω_L–ν_L) is 196 – 19 = 177 events.

Regarding the above calculation, the number of high energy impacts in Ω_L–F_L $_{(196-19)}$ is: $\eta\ (\Omega_L – \nu_L) \leq 0.05 \times 177 = 8.85 \approx 9$, which can be rewritten as follows:

$$\eta\ (\Omega_L – F_L) = 0 + 9\ /–0 \text{ events with a CL} \approx 2/3$$

b. *Events initially classified as high energy impact*

$N_H = 42$ events were initially classified as high energy impact (subset Ω_H), $\nu_H = 12$, of which having a questionnaire and $\eta_H = 5$ out of those 12 being high energy impacts. The binomial distribution gives the probability of having 5 out of 12 events with high energy impacts for different probabilities Π of high energy impact. The results are summarized in Table 26.

TABLE 26. VALIDITY OF ASSUMPTION OF PROBABILITY

Π (%)	20	22	23	25	30	32	35	40	45
P(≤5) (%)	98.0	97.0	96.2	94.6	88.2	84.8	78.7	66.5	52.7

P(>4) (%)	7.3	10.2	11.9	15.8	27.6	33.1	41.7	56.2	69.6

Π (%)	50	51	52	53	55	60	63	64
P(≤5) (%)	38.7	36.0	33.4	30.9	26.1	15.8	11.1	9.7
P(>4) (%)	80.6	82.5	84.2	85.8	88.8	94.2	96.4	97.0

From this table, it can be calculated that, with regard to the high energy impact probability Π, all the probabilities ≤21% and ≥64% can be rejected with a 90% confidence level.

$$22\% \leq \Pi \leq 63\% \text{ with a CL} = 90\%$$

The most likely probabilities include:

$$33\% \leq \Pi \leq 52\% \text{ with a CL} \approx 2/3$$

The number of events within $\Omega_H – F_H$ is 42 – 12 = 30 events.

Regarding the above calculation, the number of high energy impacts within $\Omega_H – F_H$ (42-12) is: $0.33 \times 30 = 10 \leq \eta\ (\Omega_H – F_H) \leq 0.52 \times 30 = 15$, which can be rewritten as follows:

$$\eta\ (\Omega_H – F_H) = 12.5 \pm 2.5 \text{ events with a CL} \approx 2/3$$

c. *Events initially classified as 'undetermined' energy impact*

N_U = 100 events were initially classified as undetermined impacts (subset Ω_U), $\nu_U = 22$, of which having a questionnaire and $\eta_U = 4$ out of those 22 being high energy impacts. The binomial distribution gives the probability of having 4 out of 22 events with high energy impacts for different probabilities Π of high energy impact. The results are summarized in Table 27.

TABLE 27. VALIDITY OF ASSUMPTION OF PROBABILITY

Π (%)	8	9	10	13	14	15	17
P(≤4) (%)	97.2	95.7	93.8	85.2	81.4	77.4	68.5
P(>3) (%)	9.4	13.0	17.2	31.9	37.2	42.5	52.8

Π (%)	20	24	25	30	33	34
P(≤4) (%)	54.3	36.3	32.3	16.5	10.0	8.6
P(>3) (%)	66.8	81.0	83.7	93.2	96.2	97.0

From this table, it can be calculated that, with regard to the high energy impact probability Π, all the probabilities ≤8% and ≥34% can be rejected with a 90% confidence level.

$$9\% \leq \Pi \leq 33\% \text{ with a CL} = 90\%$$

The most likely probabilities include:

$$14\% \leq \Pi \leq 24\% \text{ with a CL} \approx 2/3$$

The number of events within $\Omega_U - F_U$ is 100 – 22 = 78 events.

Regarding the above calculation, the number of high energy impacts within $\Omega_U - F_U$ (100-22) is: $0.14 \times 78 = 10.9 \approx 11 \leq \eta\ (\Omega_U - F_U) \leq 0.24 \times 78 = 18.7 \approx 19$, which can be rewritten as follows:

$$\eta\ (\Omega_U - F_U) = 15 \pm 4 \text{ events with a CL} \approx 2/3$$

d. *Compilation of the results*

The results for the 'second approach' for estimating the probability of a high impact velocity for subsets of events for which there is no questionnaire are summarized TABLE 28.

TABLE 28. PROBABILITY OF A HIGH ENERGY IMPACT VELOCITY FOR SUBSETS OF EVENTS FOR WHICH THERE IS NO QUESTIONNAIRE

Initial classification	No. of high energy impacts for events with a questionnaire	No. of high energy impacts for other events (CL ≈ 2/3)	Total
Low	0	0 + 9/–0	0 + 9/–0
High	5	12.5 ± 2.5	17.5 ± 2.5
Undetermined	4	15 ± 4	19 ± 4
Total	9		$36.5 + \sigma_1 / - \sigma_2$

Within the confidence level chosen (CL ≈ 2/3), σ_1 and σ_2 can be reasonably evaluated by:

$$\sigma_1^2 = 9^2 + 2.5^2 + 4^2$$

$$\sigma_2^2 = 0^2 + 2.5^2 + 4^2$$

i.e. $\sigma_1 = 10.2$

and

$$\sigma_2 = 4.7$$

In conclusion, the number of high energy impacts can be considered as follows:

$$\eta_{\text{total}} = 36.5^{+10.2}_{-4.7} \text{ with a CL} \approx 2/3$$

This corresponds to the probability of high energy impacts given by:

$$\Pi = 10.8\,\%^{+3.0\,\%}_{-1.4\,\%} \text{ with a CL} \approx 2/3$$

$$\text{i.e., } 9.4\% \leq \Pi \leq 13.8\% \text{ with a CL} \approx 2/3$$

The evaluation for a 90% CL can also be derived, which is close to:

$$\Pi = 11\,\%^{+7\,\%}_{-3\,\%} \textit{ with a 90\% CL}$$

$$\textit{8\%} \leq \Pi \leq \textit{18\% with a 90\% CL}$$

e. Conclusion

The second approach is interesting because:

- One can use all the events, not just the events from the questionnaire.
- It is possible to change significantly the most likely value of the probability of high energy impact by considering a larger sample (more than six times larger).
- The maximum value of the probability of high energy impacts occurs at 17% if one considers only the events with a questionnaire and about 11% if all the events are considered.

The conclusion one can draw is:

- The most likely value of the probability of high energy impacts is close to 11%.
- A probability of high energy impacts of about 10–14% cannot be rejected with a good confidence level.
- The probability of high energy impacts lower than 8% or greater than 18% can be rejected with a good confidence level.

APPENDIX VI. ANALYSIS OF THE THERMAL ENVIRONMENT IN ACCIDENTS

VI.1. EQUIVALENCE OF FIRE SCENARIOS

To compare fires of different temperatures with respect to their effect on a package, the net heat flux to a package needs to be calculated. This approach was used in an earlier study [29], where an equivalent fire duration for fires with temperatures other than 800°C was defined. That definition of equivalent fire duration takes the following parameters into account: fire temperature; fire duration; fire geometry; package geometry; and distance between the fire and the package. Only some information on typical debris areas and fire areas is available in accident reports as well as in the questionnaires returned in this project. Furthermore, the data on the combustible material involved and on the fire duration are of limited value with respect to quantitative analysis (see Section 6). Hence, it is impossible to derive reliable information on equivalent fire duration for the accidents in the database with respect to a fully engulfing fire of 800°C.

Instead, the temperature response of a generic package is given for typical fire temperatures of aircraft fires (800°C) and large kerosene pool fires (1100°C) to provide an estimate for the comparison of both fire types with respect to their thermal impact on packages which are fully engulfed by a fire. Comments on the likelihood of a fully engulfing fire in real accident scenarios are given in Section 6 of this report.

The results of thermal package response are based on simplified one-dimensional, numerical simulations of a steel wall of 30 cm thickness which is insulated at the back. The driving net heat flux is calculated from radiative heat transfer between the fire with temperature T_f and the package surface temperature T_p. The following formula for net radiative heat flux q_{fp} ignores the secondary effect of convective heat transfer as well as differences between emissivities ε and absorption factors of the package and of the fire (σ = Stefan–Boltzmann constant).

$$q_{fp} = \frac{\varepsilon\sigma}{2-\varepsilon}\left(T_f^4 - T_p^4\right) \tag{VI.1}$$

The net radiative heat flux q_{fp} from a 1100°C fire to a cold object is approximately 2.7 times higher than the corresponding value for an 800°C fire. Table 29 gives relative numerical results of maximum temperatures at different depths for a package with a total steel wall thickness of 30 cm depending on the fire scenario compared with the maximum wall temperatures in a test fire environment of 800°C and 60 min duration.

TABLE 29. RATIOS OF THE MAXIMUM TEMPERATURE AT DIFFERENT DEPTHS OF A STEEL WALL FOR DIFFERENT KEROSENE FIRE SCENARIOS TO THAT OF AN 800°C 60 min FIRE

Depth in package wall	1100°C 60 min	1100°C 30 min	1100°C 20 min	1100°C 15 min	1100°C 10 min
9 cm	2.21	1.43	1.08	0.88	0.66
16 cm	2.18	1.25	0.90	0.72	0.53
25 cm	2.00	1.24	0.90	0.72	0.53

Table 29 shows that the increase in maximum wall temperatures due to a rise of the flame temperature to 1100°C is lower than expected from the increase of initial net radiative heat flux to the package. The equivalent fire duration for 1100°C depends on the depth of the material. For a Type C package, a thin package wall is implausible. Hence, an adequate indication on equivalence of fire duration may rather be derived from medium or deep wall locations than surface values. As seen in the table, the equivalent duration of a 1100°C fire compared with an 800°C fire of 60 min duration is slightly above 20 min, which coincides approximately with the radiative heat flux factor of 2.7 [30].

Another major aspect in the comparison of fire environments is the type of package exposed to the fire. The test fire for Type C packages is a fully engulfing fire which implies a package lifted from the ground. This is not the case in real accident scenarios, where packages are probably located between other objects such as other packages or debris. Hence, the average surface area of a package exposed to the fire is obviously lower in an accident compared with the test fire.

In addition, the package may be located outside the major fire area due to a spreading of the aircraft load, especially in high velocity impact accidents or due to a movement of the fire area from the initial location (e.g. secondary fire buildup). In this case the thermal impact to the package is additionally reduced due to the decrease of exposed package surface compared with a full engulfing environment and due to the distance between the fire and the object.

The latter effect can be described in terms of a view factor, which is defined as the relation between the actual radiative heat flux to a unit area of an object exposed to the fire and the unit area radiative heat flux of the flame surface. Packages outside the fire area receive a thermal impact which is far lower than for packages engulfed by the fire.

VI.2. FIRE DURATION DATA COLLECTED

Table 30 shows all 29 accidents of the 53 accident database with the total fire duration information available (inflight fire + ground operation fire + impact fire), starting with the longest total fire duration. Information is provided as returned in the questionnaires with few exceptions (see below). Some comments on the reliability of the data are given in Section 6. The last column indicates whether or not the fire was contained (blank = no information provided; ? = unknown; number = duration in min; X = some information provided but unusable due to missing or questionable duration information). Information indicating fire containment does not include containment time in all cases. Hence, only ten accidents could be used for deriving an adjusted fire duration in order to estimate the severity of aircraft accident fire scenarios to a package (see Section 6). The fire duration data collected is given in Table 30.

TABLE 30. AIRCRAFT ACCIDENT TOTAL FIRE DURATION DATA

ICAO ADREP accident identification	Operator and flight No.	Universal date (UTC) (dd.mm.yy)	Aircraft model and series	Total fire duration (min)	Total fire duration (h)	Fire contain. (min)
95/0389-0	Cameroon AL 3701	03.12.1995	Boeing 737-2K9 Adv.	1440	24.00	
92/0124-0	El Al Israel AL8162	04.10.1992	Boeing 747-258F	1440	24.00	151
97/0110-0	Korean AL 801	05.08.1997	Boeing 747-3B5	378	6.30	?
96/0411-0	Millon Air 406	22.10.1996	Boeing 707-323C	377	6.28	377
90/0525-0	Aeroflot Russian Airlines 7266	17.11.1990	Tupolev Tu-154M/Tu-164	375	6.25	360
92/0292-0	Volga-Dneiper WDA-003	23.07.1992	Antonov An-12BP	360	6.00	
91/0188-0	Lauda Air 004	26.05.1991	Boeing 767-3Z9 ER	360	6.00	360
97/0171-0	FedEx 14	31.07.1997	McDonnell Douglas MD-11F (AF)	330	5.50	?
00/0378-0	Sécurité Civile/T&G Aviation	06.09.2000	Lockheed C-130A-6-LM Hercules	310	5.17	X
94/0275-0	USAir 427	08.09.1994	Boeing 737-3B7	300	5.00	?
93/0156-0	Avioimpex 110	20.11.1993	Yakovlev Yak-42	240	4.00	X
97/0174-0	Saudi Arabian AL 1861	06.09.1997	Boeing 737-268 Adv.	240	4.00	240
96/0356-0	FedEx 1406	05.09.1996	McDonnell Douglas DC-10-10CF	229	3.82	?
98/0009-0	Air Sofia S13	04.02.1998	Antonov An-12BP	210	3.50	46
00/0243-0?	Alliance Air 7412	17.07.2000	Boeing 737-2A8	180	3.00	?
00/0257-0	Air France 4590	25.07.2000	Aerospatiale/BAC Concorde 101	160	2.67	X
93/0293-0	Orbi Georgian AW	22.09.1993	Tupolev Tu-154	60	1.00	60
99/0472-0	Korean AL 8509	22.12.1999	Boeing 747-2B5F (SCD)	60	1.00	
92/0229-0	Trans World AL 843	30.07.1992	Lockheed L-1011-385-1 Tristar	41	0.68	9
97/0131-0	Fine Air/Aeromar 101	07.08.1997	Douglas DC-8-61F (AF)	33	0.55	18
94/0436-0	Air Algerie 702P	21.12.1994	Boeing 737-2D6C Adv.	30	0.50	
91/0036-2	USAir 1493	02.02.1991	Boeing 737-3B7	30	0.50	?
99/0126-0	American 1420	02.06.1999	McDonnell Douglas MD-82	21	0.35	?
98/0264-0	Cubana 389	29.08.1998	Tupolev Tu-154M/Tu-164	20	0.33	20
93/0413-0	Georgian Civil Aviation	22.09.1993	Tupolev Tu-134A/B/B-1/B-3	20	0.33	
92/0228-0	USAir 405	23.03.1992	Fokker F-28-4000	18	0.30	X
94/0179-0	USAir 1016	02.07.1994	Douglas DC-9-31	10.5	0.18	?
90/0499-1	Northwest AL 1482	03.12.1990	Douglas DC-9-14	10	0.17	?
95/0041-0	Air Transport Intn'l (ATI) Ferry flight	17.02.1995	Douglas DC-8-63F	1.5	0.03	X

APPENDIX VII. DESCRIPTION OF SELECTED ACCIDENTS INVOLVING FIRE

This appendix contains additional details about some selected accidents in the database involving fire. Most of these accidents have already been mentioned in brief in the fire environment analysis (Section 6) and will now be presented in more detail for a better understanding of the thermal environment in large aircraft accidents involving the destruction of the aircraft. The brief descriptions are based on ICAO ADREP summaries, on information from the questionnaire, and on additional sources, e.g. official accident investigation reports.

VII.1. AMSTERDAM, 4 OCTOBER 1992, EL AL CARGO, BOEING 747, ICAO ADREP 92/0124-0

Shortly after takeoff from Schiphol Airport, engine No. 3 caught fire and separated from the wing, also ripping engine No. 4 from the wing. Due to further wing damage, the crew experienced steering problems. When preparing for an emergency landing in Schiphol, about 8 min after loss of the two engines, the crew lost control and the airplane dived in a right turn into an 11 floor apartment building which partly collapsed and caught fire. Fragments of the aircraft and most of the cargo were scattered in front and behind the apartment building. A total of 47 people were killed, 43 of them on the ground.

Eyewitnesses reported a large fireball at impact [31]. The fire that followed showed no characteristics of a hydrocarbon fire after 15 min. Fire fighting with water began approximately 10 min after the crash. After 45 min, foam was used to contain and extinguish the fire. The fire in the collapsed part of the apartment building was brought under control about 1 h after impact [32], and the large fire was extinguished after 1.5 h. Note that both values from the fire brigade report are lower than the reported fire containment time of 151 min given in the questionnaire. Smouldering of parts of the cargo, the aircraft and the apartment debris continued for about 24 h.

Based on expert estimates, about 60 t of the 71 t kerosene load at takeoff was on board at impact. According to the soil analysis, only 50 t were consumed in the fireball and in the subsequent ground fire. Estimates of further combustible material involved in the fire are 40 t (aircraft), 50–60 t (cargo) and 50 t (apartment building).

VII.2. THAILAND 26 MAY 1991, LAUDA AIR BOEING 767, ICAO ADREP 91/0188-0

On a flight from Bangkok to Vienna, the aircraft experienced a thrust reverse of the left engine during climb, followed by a loss of control. The aircraft broke up before it crashed into mountainous jungle terrain. Most of the wreckage was found within an area of one square kilometre. None of the 10 crew members and the 213 passengers survived the crash.

The investigation of the debris and eyewitness reports revealed that fire started after inflight breakup due to fuel tank separation or disintegration. The inflight fire affected parts of the wing sections and the fuselage near the wing. No fire fighting activities took place due to the remote location and general inaccessibility of the accident site [33]. Some areas with debris showed no indication of ground fire, whereas others had long fires with ignition of the surrounding forest.

According to the accident report, the recording tape media in the flight data recorder (FDR) from the airplane was melted due to the post-crash fire. It was impossible to extract any information from the recorder. The thermal damage to the tape recording medium was most probably the result of prolonged exposure to temperatures below the 1100°C testing level (due to a secondary fire), but far more than the 30 min test duration [33]. The fire duration in the questionnaire was reported as “>360 min”.

VII.3. GUAM, 6 AUGUST 1997, KOREAN AIR BOEING 747, ICAO ADREP 97/0110-0

On the approach to Guam International Airport, with reduced visibility due to showers, the crew were unaware that the glide slope was unavailable, and ignored indications for a too low approach path. The aircraft crashed into high terrain about three miles from the airport, disintegrating and catching fire. Of the 254 people on board, 228 were killed.

The wreckage path was about 640 m long and 120 m wide (2100 ft × 400 ft). The fuselage broke into five major parts, which were found in one main area, including the major parts of both wings [34]. Crew members aboard another aircraft saw a huge fireball in this area. The wreckage and eyewitness reports indicate that after impact the major parts of the wreckage exhibited an intense fire sustained by fuel, including a burn-through of parts of the fuselage. Also, in the area neighbouring the wreckage, fire damage to trees and foliage was found.

Approximately 52 min after the impact, first rescuers arrived at the crash site and only found small areas of fire. Due to the terrain and a broken oil pipeline struck by the landing gear, the rescuers had difficulty reaching the wreckage with fire-fighting equipment. As most survivors were located away from flames at that time, no fire suppression was used so as to avoid interference with the rescue operations. The last report of small remaining fires was about 6 h after the impact.

VII.4. STANSTED (UK), 22 DECEMBER 1999, KOREAN AIR BOEING 747, ICAO ADREP 99/0472-0

After takeoff from Stansted Airport, the cargo aircraft made a left turn during initial climb and then descended rapidly from approximately 770 m with all engines running close to takeoff power. The impact took place at around a 40° pitch angle attitude with an impact speed in the range of 130–155 m/s (250–300 kt). The AAIB Accident Bulletin [35] reported that the major cause of the accident was malfunction of the Captain’s ADI (Attitude Director Indicator). All four crew members were killed. At impact an explosion with a huge fireball was observed, resulting in a wide spread of small debris parts with the wind. The wreckage trail extended to a distance of approximately 450 m. The impact crater was 43 m long, 13 m wide and 3.5 m deep. The aircraft fuel load at takeoff was approximately 31 t (68 300 lb) and the total cargo weight was 63.7 t (140 452 lb). When the fire fighters arrived at the scene a few minutes after impact, there were only minor small fires in the crash area, indicating that most of the aircraft fuel was spread and burnt in the initial fireball. The total fire duration reported in the questionnaire was 60 min.

DEFINITIONS

The following definitions are used for the purpose of the IAEA Coordinated Research Programme (CRP) on Accident Severity during the Air Transport of Radioactive Material and are provided to clarify the terminology used to collect and analyse aircraft accident severity data.

accident sequence. The sequence or series of events which occur during the course of an accident.

adjusted fire duration. Fire duration time adjusted to fire containment time either from known duration or estimated, based on average factors.

ADREP. Accident Database Report from the International Civil Aviation Organization (ICAO).

aircraft accident. Any event involving an aircraft which results in the destruction of the aircraft (corresponding to Section 0301(D) of the ADREP).

aircraft type. A specific make and model of aircraft, including modifications that do not change its handling or flight characteristics. As used with respect to the certification of aircraft, those aircraft which are similar in design.

airport. An area of land or water that is used or intended to be used for the landing and takeoff of aircraft, and includes its buildings and facilities, if any. Airports include heliports, short takeoff and landing ports, and seaplane bases.

airport approach. The flight phase which consists of the time the aircraft intercepts the initial navigation fix until the aircraft crosses the outer marker.

category 4 aircraft. Aircraft with a maximum certificated takeoff mass greater than 27 000 kg and less than 272 000 kg.

category 5 aircraft: Aircraft with a maximum certificated takeoff mass greater than 272 000 kg.

climb to cruise (CC). The flight phase, which consists of the time after takeoff flight when the aircraft landing gear is retracted and all aircraft flaps are in their normal cruise configuration until the aircraft has reached its initial assigned cruising or en route altitude.

en route (ER) or cruise. The flight phase, which consists of the time when the aircraft has reached its initial assigned cruising or en route altitude until the time the aircraft begins its descent from its final assigned cruising or en route altitude. Minor adjustments in assigned cruising or en route altitude are considered to be part of the en route flight phase.

equivalent fire duration time. The fire duration time adjusted for equivalent heating in a fully engulfing 800°C fire and the difference between the fire extinguishing time and the fire containment time.

equivalent impact velocity. The velocity of impact with an unyielding surface which gives a level of damage equivalent to that expected to occur to a package experiencing the actual impact conditions of the accident being considered, taking into account the normal impact velocity and surface properties.

fire containment time. The time from the beginning of fire until the fire is fully contained or under control.

fire duration time. The time from fire initiation until the fire is extinguished.

flight direction. The course in which the centre of mass of the aircraft is moving.

flight phase. The parts of flight which are distinctly different due to the configuration of the aircraft and/or the conditions under which the flight is taking place. The following flight phases are defined: ground operations; taxi; takeoff (TO); initial climb (IC); climb to cruise (CC); en route (ER) or cruise; initial descent (ID) or descent from cruise; airport approach (AA); runway approach (RA); and landing (L).

ground operations. The flight phase, which consists of any moment that the aircraft is stationary or is not moving under its own power on the ground, i.e. towed between parking positions or on pushback.

ground speed. The speed of the aircraft relative to the ground.

impact angle. The angle between the aircraft flight direction at the moment of impact and the impact plane.

impact plane. The idealized surface which is hit by the aircraft. This surface may not necessarily be horizontal or vertical or even level.

impact velocity. The aircraft ground speed at the moment of impact to the impact plane. A vector quantity, the magnitude of which is speed, and the direction of motion at the moment of impact.

indicated airspeed. The speed of the aircraft as indicated by its instrumentation without compensation for instrument error, altitude, atmospheric temperature or compressibility.

initial climb (IC). The flight phase, which consists of the time the aircraft wheels leave the ground until the aircraft landing gear is retracted and all aircraft flaps are in their normal cruise configuration.

initial contact. The instant of time when the aircraft first comes into contact with the impact plane. The initial contact may not coincide with the moment of impact if the aircraft is skipping along the ground during the accident sequence.

initial descent (ID) or descent from cruise. The flight phase, which consists of the time when the aircraft begins its descent from its final assigned cruising or en route altitude until the aircraft intercepts the initial navigation fix.

landing (L). The flight phase, which consists of the time the aircraft wheels make initial contact with the runway or landing surface until the aircraft leaves the runway or landing surface onto the designated taxiway.

normal impact velocity. The component of the aircraft ground speed at the moment of impact normal to the impact plane.

other flight phase. The flight phase which consists of taxi and ground operations.

moment of impact. The instant of time when the aircraft contacts the impact plane and breaks up or stays in continuous contact with the impact plane.

runway approach (RA). The flight phase, which consists of the time the aircraft crosses the outer marker defined or final approach fix until the aircraft wheels make initial contact with the runway.

speed. A scalar quantity, the magnitude of velocity, or a measure of the rate of motion.

taxi. The flight phase, which before takeoff consists of the beginning of aircraft movement under its own power after pushback until the aircraft reaches its beginning of takeoff roll, and after landing, consists of the aircraft leaving the runway or landing surface onto the designated taxiway until it travels under its own power to its designated parking position.

takeoff (TO). The flight phase which consists of the beginning of the aircraft takeoff roll to the moment the aircraft wheels leave the ground.

thermal test conditions for a Type C package. The thermal test conditions for a Type C package are specified in IAEA Safety Standards Series No. SSR-6 (Rev. 1), para. 736.

true airspeed. The indicated speed of the aircraft corrected for instrument error, altitude, atmospheric temperature and compressibility.

Type C package. Packaging and its radioactive contents certified for aircraft transport in accordance with IAEA Safety Standards Series No. SSR-6 (Rev. 1).

unyielding surface. A flat, horizontal surface of such character that any increase in its resistance to displacement or deformation upon impact by the specimen would not significantly increase damage to the specimen (IAEA Safety Standards Series No. SSR-6 (Rev. 1), para. 717).

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