Comparative Structural Testing of 'Type C' Radioactive Materials Transportation Packages and Aircraft Flight Data Recorders

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Ottawa, Ontario, Canada
PATRAM 2001
Chicago, September 01-08, 2001

SUMMARY

A major regulatory issue raised during the development of IAEA Regulations for the Safe Transport of Radioactive Material No. ST-1 was the impact test velocity requirement of the newly designated Type C radioactive material transportation package. Several international bodies suggested that the impact test velocity requirement of 90 m/s for the Type C package, intended for air transport of large quantities of radioactive materials, may be less stringent than the aircraft flight data recorders and cockpit voice recorders (FDR) impact test requirements.

The Canadian Nuclear Safety Commission (then called Atomic Energy Control Board), sponsored a research project to investigate this issue with the objective of obtaining a better understanding of the differences between the impact test requirements of a Type C packages and an aircraft flight data recorder.

A 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 internal components of a Type B radioactive material package according to the FDR impact shock test performance specification. The impact shock test specification for flight data recorders requires that an impact shock be applied so that the energy content of the impact shock shall be equivalent to a half-sine wave shock of 6.5 milliseconds and a peak acceleration of 3400 'g'. This acceleration pulse is equivalent to an impact velocity of 138 m/s.

This paper presents and discusses the results of tests done on the flight data recorder using the Type C package impact testing requirements and the results of impact tests done on a Type B package according to the flight data recorder impact shock test specification. Based on the test results, FDR may not survive the Type C test requirements, however, Type C

packages would likely survive the FDR crash survival testing requirements.

INTRODUCTION

At its sixth meeting, SAGSTRAM considered the transport of potentially a high hazard radioactive material by air to be one of the most important regulatory issues identified. The issue centered on the regulatory method of addressing high consequence/low probability accidents in the context of the increasing quantities of plutonium likely to be transported by air for security reasons, and the concern that some member states have adopted or are considering adopting more stringent requirements for the air transport of plutonium than are provided for in the current IAEA regulations.

Further, during the development of IAEA Regulations for the Safe Transport of Radioactive Material No. ST-1, several international bodies suggested that the impact test velocity requirement of 90 m/s for the Type C package may be less stringent than the aircraft flight data recorders (FDR) impact test requirements.

To address these issues and at the recommendation of SAGSTRAM, in 1998, an IAEA - sponsored Co-ordinated Research Project (CRP) was initiated to have a better understanding of accident severity during air transport of radioactive material. The CNSC initiated research project is the Canadian contribution to the IAEA sponsored CRP. This project was undertaken by Bosik Consultants Limited (BCL) under contract for the Atomic Energy Control Board (AECB) of Canada and the tests were conducted at the National Research Council of Canada Flight Impact Simulator Facility in Ottawa.

The primary objective of this project was to better understand:

1. the differences between the Type C packages and the FDR accident condition test requirements;
2. if the test standards for the Type C packages and the FDR can be compared; and,
3. how would a Type C package behave if tested to the FDR impact test requirements.

The project involved:

1. testing of the FDR to a Type C package mechanical test (9 m drop, dynamic crush, penetration and impact at 90 m/s) requirements; and,
2. testing of the internal components of a Type B package (in the absence of a Type C package) to the impact test requirements of a FDR.

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 1. The test requirements for the Type B and Type C package are extracted from the IAEA-1985 regulations [1] and the IAEA-1996 regulations [2] respectively. The operational performance specification for the FDR is defined in the Eurocae specifications [3].

FDRs are required to withstand an impact shock characterized by a half-sine wave shock of 6.5 milliseconds 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 1. A dynamic crush test as required for the radioactive material packages is not required for the FDR.

The 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 independently of the main sequence of tests.

The impact test requirement for a Type B package is to drop the package from a height of 9 m onto an unyielding surface in an orientation to suffer the maximum damage. Type B packages are also required to be tested for the penetration test, static crush test, thermal test and water immersion (pressure) test as summarized in Table 1. Dynamic crush test is only required for the packages that has a mass less than 500 kg, and an overall density no greater than 1000 kg/m^3.

The specimen shall be 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, penetration and crush) shall be such that, on completion of the mechanical test, the specimen shall have suffered such damage as will lead to the maximum damage in the thermal test that follows.

The impact test requirement for a Type C package is a 9 m drop test similar to 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 penetration test, the Type C packages having a mass less than 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 sixty minutes and 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 sixty minutes. 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 FDR and radioactive packages is in the 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 sequence of crash survival tests, the recorder should be capable to preserve and replay the data recorded in the memory module.

For radioactive material packages (such as for Type B or Type C), 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.

Table 1: 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 an 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 minutes	5 times the mass of package for 24 hours	5 times the mass of package for 24 hours
Dynamic crush	n/a	*500 kg mass drop from 9 m height	500 kg mass drop from 9 m height
Thermal test	High temp.: 1100 ^{0}C for 60 minutes Low temp.: 260 ^{0}C for 10 hours	800 ^{0}C for 30 minutes	800 ^{0}C for 60 minutes
Deep sea pressure	6,096 m (60 MPa) for 30 days	15 m (150 kPa) for 8 hours	200 m (2 MPa) for 60 minutes
Sea water/fluids immersion	Various corrosion resistance per EUROCAE ED-55 and ED-56A	n/a	n/a

* Applies for packages having a mass of less than 500 kg.

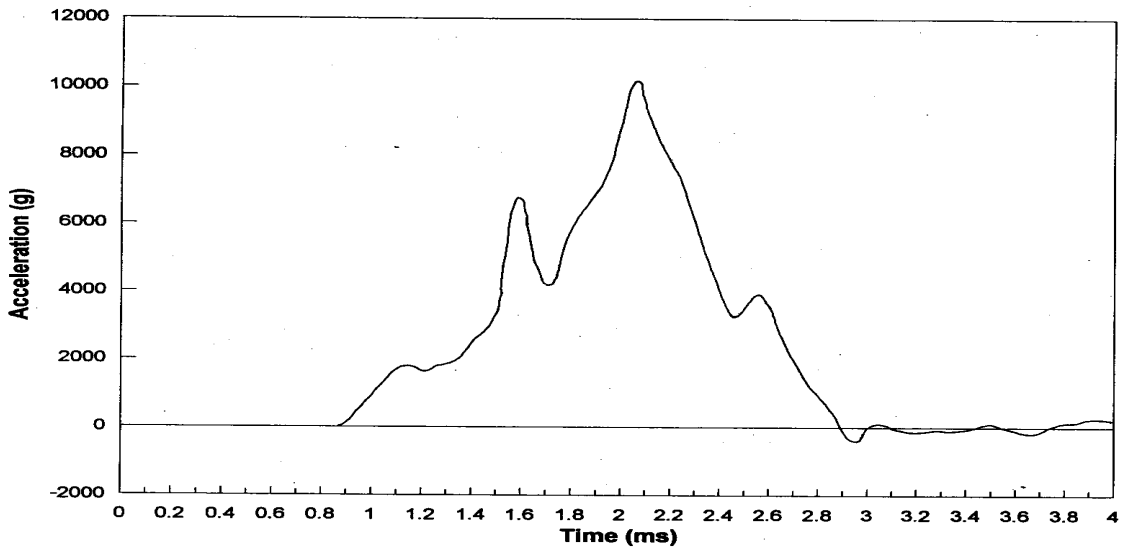
TESTS CONDUCTED ON FLIGHT DATA RECORDERS (FDR)

Tests were conducted on two separate specimens of FDR 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 penetration test. The mass of the specimen tested is approximately 20 lb and is as illustrated in figure 2.

First specimen: 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 forces recorded was approximately 1.362 million N (300,000 pounds). The total duration of the test was 2.2 ms as compared to the specified duration of 6.5 ms for FDR. Based on the total projectile weight of 13.18 kg,



the acceleration as a function of time was determined and is shown in Figure 1. The peak acceleration acting on the FDR is determined as 10,344 'g' which is approximately three times greater than the 3,400 'g' specified for the FDR.
The post-test inspection results shows that there was considerable damage to the specimen. The metal encased memory module had been breached and some of the insulation had become removed, however, the memory chips were found intact and attached to the board.

Figure 1 - Acceleration versus Time for FDR impacted against steel plate at 93 m/s

Second specimen: Subjected to other Mechanical tests

The second specimen was subjected to a 9 m drop test, dynamic crush and a penetration test. 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 penetration test punctured the memory module and got embedded in the specimen. Since the memory module container was breached, the memory module would not have survived any subsequent thermal tests. The pre and post test FDRs are illustrated in figures 2 and 3 respectively.

Figure 2 - Flight Data Recorder (Pre-test)

Figure 3 - View of probe embedded in FDR

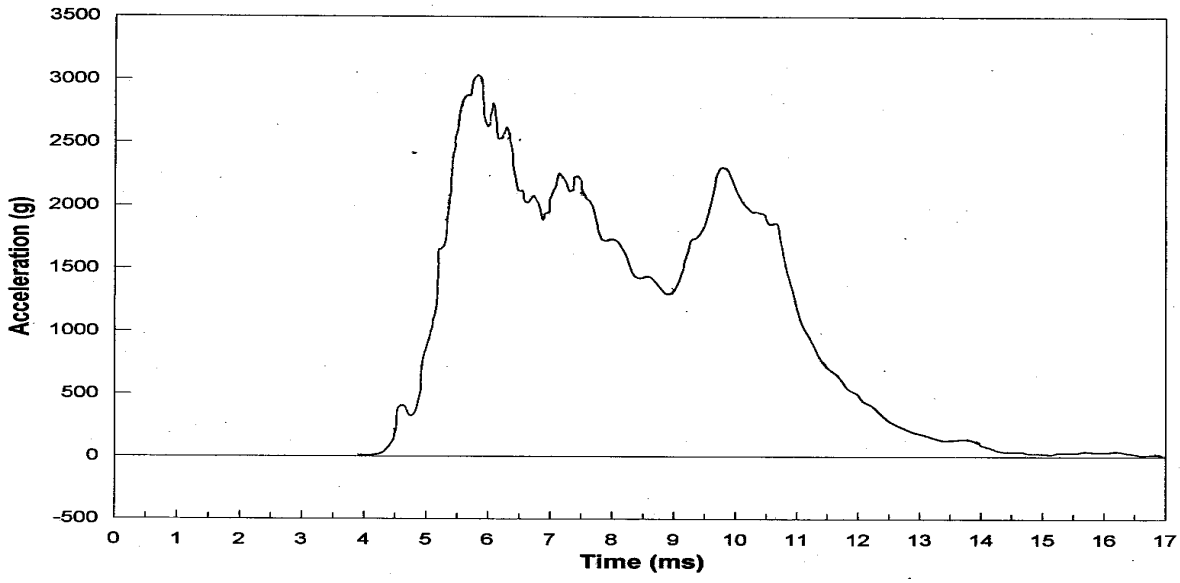
TEST CONDUCTED ON THE INTERNAL COMPONENTS OF A TYPE B PACKAGE

In the absence of a Type C package, tests were performed on a Type B package F-112/F-256 provided by the 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 is 21.25 kg and is as illustrated in figure 5.

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 Figure 4. 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 to the specified FDR impact shock duration of 6.5 ms. By summing the area under the curve of figure 4, the acceleration-time is calculated as 13.6 g-s, which is 97% of 14.069 g-s as specified for FDR.



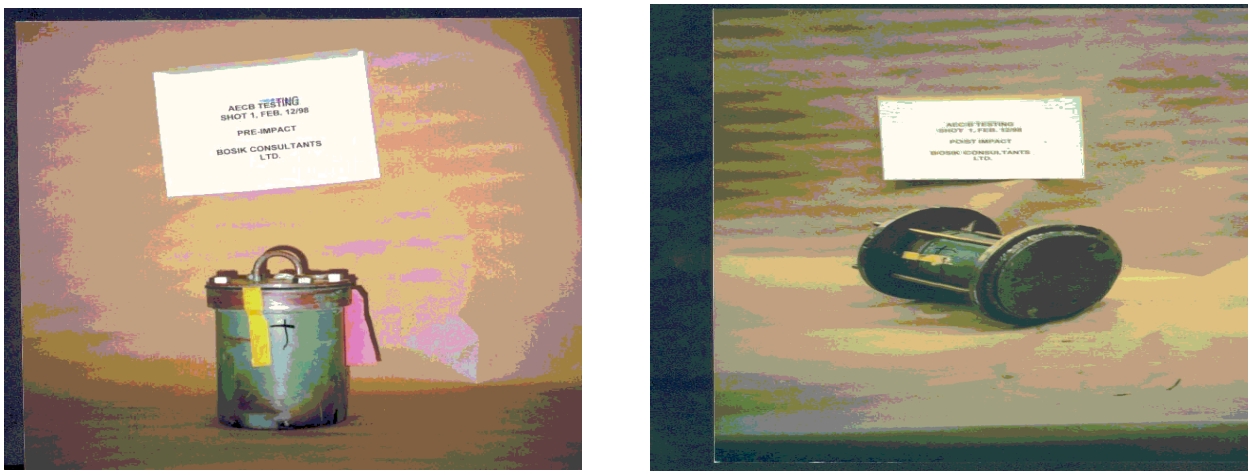


Figure 4 - Acceleration Force loading on a Type B package during FDR impact test specification

The post-test inspection results shows (figure 5) that there were only minor deformations observed to the outer container and that there was no visible damage to the inner package insert. The leak proof inserts passed the leak test requirements.

Figure 5 - Type B package MDS Nordion model F-112/F-256 (pre-test and post-test)

DISCUSSION OF RESULTS

FDRs have a higher impact test velocity requirement as compared to the Type C package requirements. However in this test program, when subjected to the Type C impact test requirements, the FDR was severely damaged to the extent that it is unlikely that the recorded data could have been retrieved. On the other hand, the Type B package tested 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.

A comparison of level of severity caused by impacts onto an unyielding target to real yielding targets is being investigated by the IAEA sponsored CRP [5] and is also discussed in reference 6. The report [6] concludes that for a wide range of packages and targets there is a substantial increase in impact velocity required to produce damage that is equivalent to the damage from the regulatory impact onto an unyielding target.

CONCLUSION

The study shows that the test requirements and acceptance criteria for FDR and Type C package are different and no direct comparison of the impact test criteria can be made. The acceptance criteria for a radioactive material package is a very low level of leakage of the contents whereas FDR 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 seen by the FDR is determined as 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 the Type C requirements.

Based on the test results, FDR may not survive the Type C test requirements, however, 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 units design.

The IAEA sponsored Co-ordinated Research Programme (CRP) [5], that has a broader scope, is assigned the task to collect and analyze the data related to aircraft accident frequency and severity including due to impact loading, during air transport of radioactive materials.

REFERENCES

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