UCID-21697

DRAFT CRITERIA FOR PACKAGE DROP AND AIRCRAFT CRASH TESTS

— An Interim Report —

Carl E. Walter, James H. VanSant, and C. K. Chou

Prepared for
U.S. Nuclear Regulatory Commission

LAWRENCE
LIVERMORE
NATIONAL
LABORATORY

DISCLAIMER

This work was supported by the United States Nuclear Regulatory Commission under a Memorandum of Understanding with the United States Department of Energy.

UCID-21697

DRAFT CRITERIA FOR PACKAGE DROP AND AIRCRAFT CRASH TESTS

— An Interim Report —

Date Published: June 28, 1989

Prepared by
Carl E. Walter, James H. VanSant, and C. K. Chou

Lawrence Livermore National Laboratory
7000 East Avenue
Livermore, CA 94550

Prepared for
Division of Safeguards and Transportation
Office of Nuclear Material Safety and Safeguards
U.S. Nuclear Regulatory Commission
Washington, DC 20555
NRC FIN No. L1056

ABSTRACT

Section 5062 of Public Law 100-203 imposes requirements on plutonium air transport (PAT) packages to be used to ship plutonium from one foreign nation to another through U.S. airspace. The law requires the Nuclear Regulatory Commission (NRC) to certify the safety of a PAT package design to Congress. This document presents the draft criteria for the package drop test and aircraft crash test of a candidate PAT package design as required by the law for certification by testing. In the package drop test, the criteria are designed to test the ability of the PAT test package to survive a fall from a cargo aircraft at cruise altitude onto an earth surface. The criteria for the aircraft crash test are based on the impact conditions in an actual worst-case aircraft accident considered to be the PSA Flight 1771 crash in December 1987. The impact conditions in the PSA accident have been closely studied and are used as the basis for the aircraft crash test criteria. The package drop and aircraft crash tests would be required to be conducted to the extent practicable and are designed to test the package to the severe conditions required by the law.

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

ACKNOWLEDGMENTS

The information embodied in these criteria has been developed by staff members of the LLNL Nuclear Systems Safety Program with the cooperation of other Laboratory resources. In particular, we acknowledge the specific contributions of:

Stephen Blair
David Carpenter
J. C. Chen
C. K. Chou
Mark Eli
Charles Herget
Garry Holman
Richard Mensing
Martin Schwartz
James VanSant
Carl Walter
Monika Witte

The principal authors have benefited from direction provided by C. K. Chou and consultations with Larry Fischer.

The following staff members of the Nuclear Regulatory Commission have guided this work:

Robert Burnett, Director, Division of Safeguards and Transportation
Charles MacDonald, Chief, Transportation Branch
John Cook, Section Leader, Transportation Branch
John Jankovich, Technical Monitor

This document was prepared for publication by Wallace Clements as technical editor; Lisa Hensel and Ellen Sturmer provided publication services.

GLOSSARY

Aerodynamic drag enhancers—Structures attached to the exterior of a PAT package to increase drag and thus reduce its free-fall velocity.

Altitude—Vertical distance to a point in airspace from mean sea level.

Applicant—The person making application to the Nuclear Regulatory Commission for certification of a specific model of a PAT package under Section 5062 of Public Law 100-203.

BAe—British Aerospace (the "e" is added to distinguish it from British Airways).

Cargo aircraft—An aircraft that is used to transport cargo and is not engaged in transporting passengers.

CFR—Code of Federal Regulations.

Containment vessel—The vessel designed to meet the requirements of 10 CFR 71 and NUREG-0360 for plutonium containment during transport.

Drop altitude—The altitude at which the PAT test package is released and its free fall begins.

Elevation—Vertical distance of ground surface above mean sea level.

FAA—Federal Aviation Administration.

Impact angle—The angle between the longitudinal axis of the fuselage of the test aircraft and the representative impact plane. By definition, this angle is restricted to values less than 90°.

Maximum cruising altitude—The maximum altitude at which an aircraft can fly efficiently for sustained periods.

NASA—National Aeronautics and Space Administration.

NRC—Nuclear Regulatory Commission.

NUREG-0360—An NRC staff document entitled: "Qualification Criteria to Certify a Package for Air Transport of Plutonium."

Orientation—Orientation of an object (e.g., an aircraft) with respect to the spatial Cartesian coordinate system (x, y, z axes).

Package—The protective packaging together with its radioactive contents as assembled for transport.

Packaging—The assembly of components necessary to ensure compliance with the packaging requirements of 10 CFR 71 and NUREG-0360. It may consist of two or more (nested) containment vessels, absorbent materials, spacing structures, thermal insulation, radiation shielding, devices for dissipating heat from radioactive decay of the plutonium and increasing aerodynamic drag, and impact limiters. The tie-down system and auxiliary equipment may be designated as part of the packaging.

PAT—Plutonium air transport.

PAT package—The package for air transport of plutonium, including the plutonium itself, the inner and outer containment vessels, and all packaging components whose function relates to safety, protection, or aerodynamic drag enhancement.

PAT test package (or simply **test package**)—The PAT package (containing simulated plutonium) used to perform the tests specified in this document.

PSA—Pacific Southwest Airlines.

PST—Pacific standard time.

Reliability—The probability that a test can be conducted in accordance with the test plan and meet all criteria within stated tolerances.

Representative impact plane—The representative impact plane is the plane that best fits the irregularities of the actual surface in the vicinity of an aircraft crash impact point. This plane extends for a radius of at least the wingspan of the aircraft, from the point where the longitudinal axis of the fuselage strikes the earth's surface. The representative impact plane is determined by minimizing the variance of surface elevations from the plane measured on a square grid at 3-m intervals.

RPV—Remotely piloted vehicle. An aircraft which can be operated without human presence aboard. RPVs can take off, fly preprogrammed patterns or real-time commanded maneuvers, and land by radio command from a ground or airborne station. Control may be fully automatic, automatic with manual override, or remotely manual.

RQD—Rock quality designation, a measure (%) of the spacing of preexisting fractures in rock core samples. (See Appendix 2.)

SARP—Safety analysis report for packaging. A document prepared by the applicant which provides the technical evaluation and review of the design, testing, operational procedures, maintenance procedures, and quality assurance program followed in packaging plutonium for air transport. The purpose of the SARP is to demonstrate compliance with NRC safety standards, 10 CFR 71, and all other applicable requirements.

S-number—Relative value of the softness (hardness) or penetrability of soil or rock determined by experimental measurement. The depth penetrated by a defined projectile fired at a measured velocity into soil or rock is used in an empirical correlation to determine the *S*-number. Values of less than 2 are generally found for rock structures; values of 2 to 4 for dry, cemented sand structures. (See Appendix 2.)

True airspeed—Aircraft speed relative to the air.

10 CFR 71—Title 10, Code of Federal Regulations, Part 71: "Packaging and Transportation of Radioactive Material."

1. INTRODUCTION

The purpose of this document is to define the criteria for the package drop test and aircraft crash test specified in Section 5062 of Public Law 100-203 (Ref. 1, reproduced in Appendix 1 of this document). The law pertains to the certification of package designs by the Nuclear Regulatory Commission for the transportation of plutonium by aircraft through United States airspace from a foreign country to a foreign country.

In 1975 Congress enacted Public Law 94-79 (Ref. 2), which establishes general requirements and rules for both domestic and import/export shipments of plutonium by air. Public Law 94-79 provides, in part, as follows:

> **The Nuclear Regulatory Commission shall not license any shipments by air transport of plutonium in any form, whether exports, imports or domestic shipments:** ***Provided, however,*** **That any plutonium in any form contained in a medical device designed for individual human application is not subject to this restriction. This restriction shall be in force until the Nuclear Regulatory Commission has certified to the Joint Committee on Atomic Energy of the Congress that a safe container has been developed and tested which will not rupture under crash and blast-testing equivalent to the crash and explosion of a high-flying aircraft.**

Before the enactment of Public Law 94-79, the NRC and the Department of Transportation had developed standards for the integrity of packages used to ship plutonium and other radioactive materials, as given in 10 CFR 71 of NRC Regulations (Ref. 3) and 49 CFR 100-199 of Department of Transportation Regulations (Ref. 4). These standards for plutonium shipping packages are based on three main considerations: (1) protection of the public from external radiation, (2) assurance that any release of the contents of a package during either normal or accident conditions of transport will not exceed a specified limit, and (3) assurance subcriticality will be maintained.

In response to Public Law 94-79, the NRC established a certification program for packages used in air shipment of plutonium. The program consisted of three elements: (1) evaluation of the conditions that could be produced in severe aircraft accidents, (2) development of qualification criteria prescribing appropriate performance and acceptance standards for packages used to transport plutonium by air, and (3) establishment of a series of physical tests and engineering studies of plutonium packages to demonstrate their ability to meet the qualification criteria. The certification program and the qualification criteria are described in NUREG-0360 (Ref. 5).

Plutonium air transport (PAT) packages subject to the Public Law 100-203 requirements set forth in this document must also comply with the Public Law 94-79 design requirements. The criteria contained in this document constitute additional confirmatory effort as required by Public Law 100-203.

1.1 Public Law 100-203

Public Law 100-203 enacted by Congress on December 22, 1987, contains Section 5062, entitled "Transportation of Plutonium by Aircraft Through United States Airspace." Several provisions of Section 5062 are particularly relevant with respect to implementing the law. Section 5062 provides, in part, as follows:

> **(a) In General—Notwithstanding any other provision of law, no form of plutonium may be transported by aircraft through the airspace of the United States from a foreign nation to a foreign nation unless the Nuclear Regulatory Commission has certified to Congress that the container in which such plutonium is transported is safe, as determined in accordance with subsection (b)...**

Subsection 5062(b) contains the following paragraph on testing:

> **(2) TESTING.—In order to make a determination with respect to a container under paragraph [5062(b)] (1), the Nuclear Regulatory Commission shall—**
>
> **(A) require an actual drop test from maximum cruising altitude of a full-scale sample of such container loaded with test materials; and**
>
> **(B) require an actual crash test of a cargo aircraft fully loaded with full-scale samples of such container loaded with test material unless the Commission determines, after consultation with an independent scientific review panel, that the stresses on the container produced by other tests used in developing the container exceed the stresses which would occur during a worst-case plutonium air shipment accident.**

Subsection 5062(d) provides as follows:

> **(d) Design of Testing Procedures—The tests required by subsection (b) shall be designed by the Nuclear Regulatory Commission to replicate actual worst case transportation conditions to the maximum extent practicable. In designing such tests, the Commission shall provide for public notice of the proposed test procedures, provide a reasonable opportunity for public comment on such procedures, and consider such comments, if any.**

1.2 Worst-Case Aircraft Accident

Section 5062, above, requires that a "worst-case" aircraft accident be considered to the maximum extent practicable. The NRC has specified (Ref. 6) that the conditions associated with the crash of PSA Flight 1771 on December 7, 1987, are sufficiently representative of a worst-case aircraft accident to be suitable for use as the basis for conducting an aircraft crash test under Public Law 100-203. This accident was used for developing test criteria such as the aircraft's impact velocity and orientation for the required crash test, as well as the geotechnical properties of the ground surface and near-surface at the test impact area.

1.2.1 Accident Conditions

A BAe 146-200 aircraft was used on PSA Flight 1771. On December 7, 1987, Flight 1771 departed from Los Angeles at 15:30 PST with a scheduled arrival in San Francisco at 16:43 PST. At 16:13:03 PST the Oakland Air Route Traffic Control Center recorded radio messages from the crew indicating that a gun had been fired on board and that an emergency was being declared by means of their transponder code. The last radar return was recorded at 16:14:36 PST, 512 m northeast of the impact location. The altitudes corresponding to the last two radar returns were not recorded.

The BAe 146-200 aircraft apparently remained intact until it crashed, nose first, on a hillside of the Santa Rita Range in San Luis Obispo County. There were no survivors, and only minor ground fires resulted from the approximately 3200 kg (1000 gallons) of fuel estimated to be on board at the time of the crash. A dense black smoke cloud was observed at the time of the crash, indicating that some of the fuel apparently burned in the air above the impact point. The aircraft and its contents fragmented into many small pieces, mostly dispersed south of the impact point within a radius of about 100 m (see Fig. 1-1). The most distant aircraft piece was found 260 m from the impact point, and some paper debris was found as far away as 2 km.

The crash produced an irregularly shaped depression about 3.5 m deep by 6 m wide by 12 m long. These dimensions are estimated from eyewitness reports, photographs, and geophysical surveys. The volume of soil displaced is estimated to have been about 74 m^3, with a corresponding mass of some 175 Mg (195 tons).

Available radar-tracking data and data from the aircraft flight data recorder have been studied in considerable detail to establish the impact angle and velocity of the aircraft. The flight data recorder is considered to provide the best estimates of impact conditions. Data from the flight recorder and additional information are summarized in Table 1-1.

1.2.2 Aircraft Description

The BAe 146-200 is a high-wing, four-engine, jet-powered aircraft used in short-range (2000-km) intercity flights. It carries 83 to 112 passengers and normally a crew of four. The series 200, shown in Fig. 1-2, has an overall length of 28.6 m and a wing span of 26.3 m. Fuselage diameter is 3.6 m. Maximum takeoff weight is 42,200 kg. At the time of the PSA 1771 crash, the estimated total weight was 29,300 kg. The design cruise Mach number at 6.7 km (22,000 ft) altitude is 0.7. The corresponding true airspeed is 218 m/s (425 kt).

Table 1-1. Summary of approximate impact conditions for the worst-case aircraft accident.

Flight	PSA 1771
Date	December 7, 1987
Aircraft type	BAe 146-200
Flight altitude (initial)	6.7 km (22,000 ft)
Elevation of crash site	403 m (1322 ft)
Surface inclination:	
Maximum slope	24°
In vertical plane containing trajectory*	16°
Surface hardness*	Intensely weathered and fractured shale and sandstone
Aircraft status at impact:	
Velocity*	282 m/s (925 ft/s)
Mach number	0.83
Surface impact angles (see Fig. 1-3b)*:	
Fuselage	52° (sum of pitch and surface inclination angles)
Trajectory	60° (sum of trajectory and surface inclination angles)
Direction (heading)	210° true
Pitch angle	36° down
Trajectory angle	44° down
Mass	29,300 kg

* Important parameters for crash test.

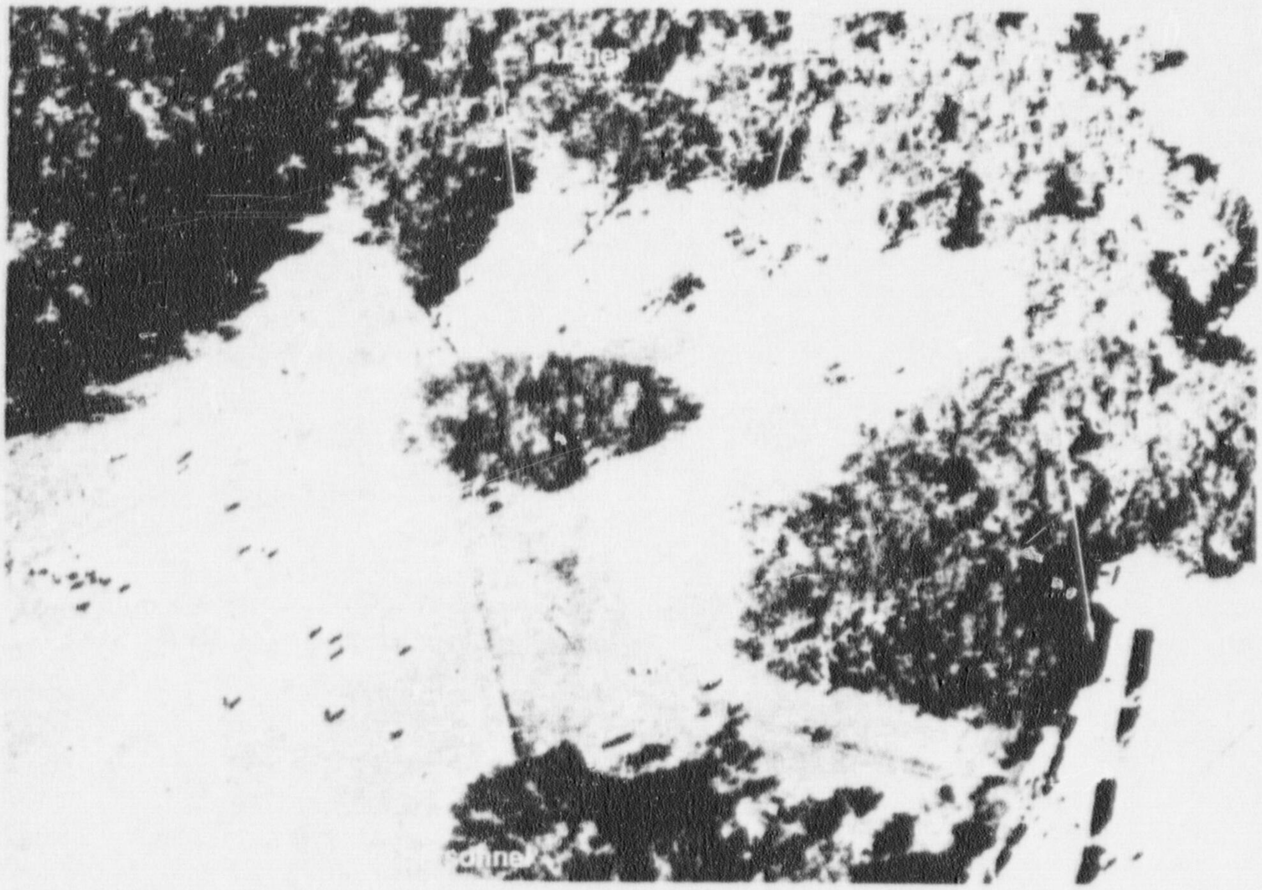

Fig. 1-1. Photo of PSA flight 1771 crash site.

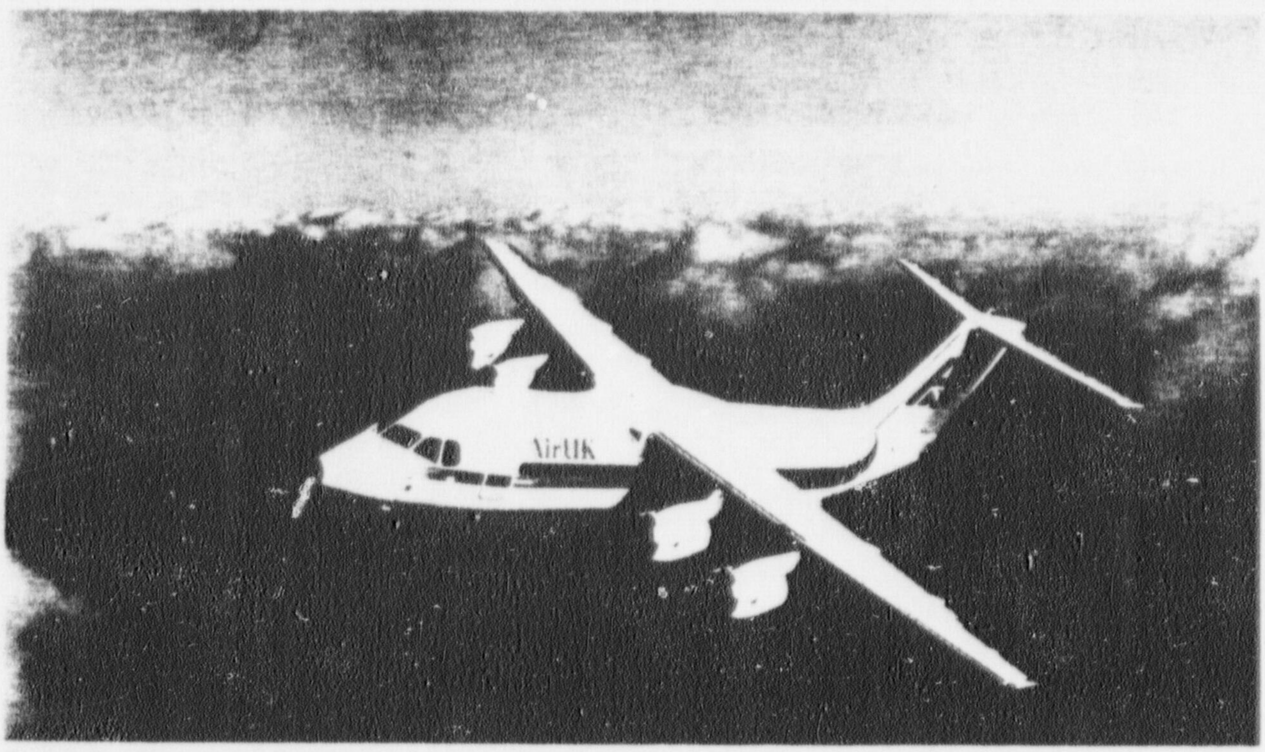

Fig. 1-2. BAe 146-200 aircraft.

1.2.3 Surface Properties at Crash Site

Properties of the surface and near-surface earth materials at the crash site have been determined by geotechnical measurements and penetration tests. These property data are summarized in Table 1-2. In-situ measurements and laboratory tests on core samples taken from five drill holes have been studied to characterize the crash site hardness. Locations of the drill holes are shown in the topographic sketch in Fig. 1-3(a), which also shows a vertical projection of the final portion of the aircraft's trajectory. Figure 1-3(b) shows a side view of the aircraft's final trajectory (in vertical plane containing the trajectory).

The depth of topsoil at the crash site is less than 0.3 m. Beneath the topsoil is a layer of intensely weathered and fractured rock consisting of a sequence of interbedded clay-shales and fine-grained sandstones. This layer varies in thickness between 4.5 and 9 m.

Table 1-2. Geotechnical measurements at the PSA 1771 crash site.

	Best Estimate or Average	Coefficient of Variation*
Penetrability constant (S-number):		
Intensely weathered rock	2.5 ± 0.5	
Soil	3.4 ± 0.3	
Rock quality designation (RQD):		
Intensely weathered rock	15	0.9
Unconfined compressive strength (MPa):		
Weathered rock	27.0	0.4
Unweathered rock	119.0	0.2
Weathered and unweathered rock	73.0	0.6
Unconsolidated undrained strength (MPa):		
Soil	0.76 ± 0.35	
Seismic wave properties (upper 5 m):		
Shear wave velocity (m/s)	610	0.3
Compression wave velocity (m/s)	1320	0.3
Bulk density (kg/m^3):		
Rock	2370	0.1
Soil	2090	0.1
Water content, soil (%)	16.2	0.3
Porosity (%):		
Rock	8.0	
Soil	32.0	0.2

* The coefficient of variation is provided for those parameters where sufficient data are available.

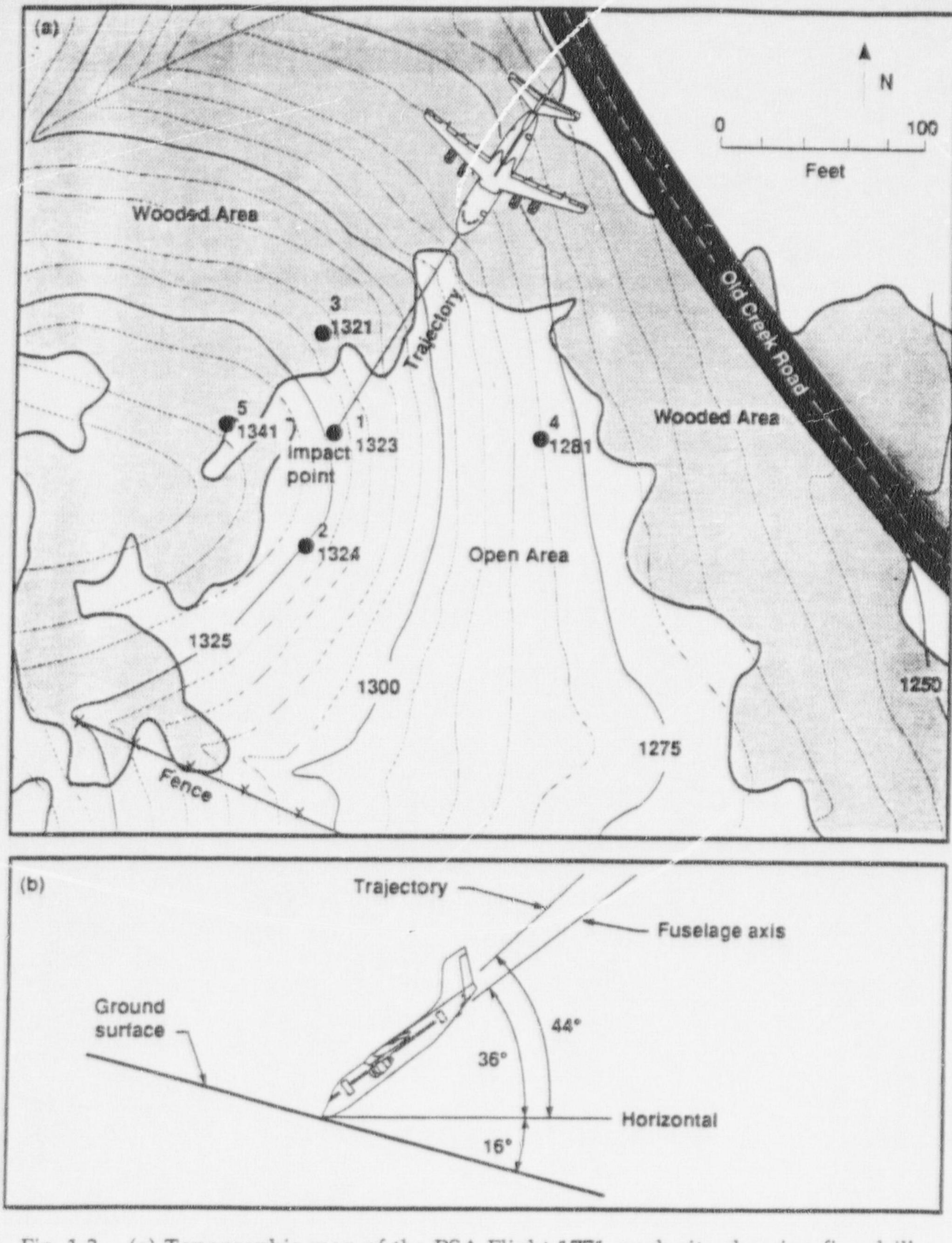

Fig. 1-3. (a) Topographic map of the PSA Flight 1771 crash site showing five drill hole locations and elevations (in feet). (b) Side view of final trajectory, showing pertinent angles.

A more complete description of the geology and geotechnical properties at the crash site is presented in Appendix 2, together with a discussion of penetrability and rock quality designation.

1.3 Examples

Examples illustrating possible approaches to meeting the test criteria for the package drop and aircraft crash tests are provided in some cases in Sections 2 and 3. The examples are provided for selected test criteria in order to illustrate methods that the applicant may consider for meeting the test criteria to the maximum extent practicable. The applicant is free to propose other methods to meet the test criteria. Regardless of the methods used, they must be shown to satisfy the test criteria in the documentation submitted to the NRC per Sections 2.5 and 3.5.

Note: Examples may be deleted in future revisions of this report.

2. PACKAGE DROP TEST

2.1 Introduction

Subsection 5062(b)(2)(A) of Public Law 100-203 requires that a PAT test package be dropped from the maximum cruising altitude of the cargo aircraft proposed for transport of plutonium. This section describes the criteria for the package drop test and supporting information that the applicant must submit to the NRC.

2.2 Responsibilities

2.2.1 Nuclear Regulatory Commission

The NRC will review and approve the test plan and all other documentation required by Section 2.5, determine whether the drop test has been conducted properly, and review the test results. NRC will use these results, together with all other results and information required for certification, to determine whether the PAT package design can be certified to the Congress as safe.

2.2.2 Applicant

The applicant for certification of a proposed PAT package design shall have completed all the NRC prerequisites for certification, including the SARP. The applicant is responsible for providing the test package, transport aircraft definition, test equipment, test facilities, test range, and all other necessary resources to be used in the drop test. The prerequisites are those actions that must be completed before the package drop test can be performed. These include the requirements defined by Public Law 94-79 and Code of Federal Regulations 10 CFR 71 and 49 CFR 100-199. The applicant's PAT package design must satisfy the qualification criteria of NUREG-0360 and a SARP must be prepared and submitted to the NRC for approval before the package drop test will be conducted.

2.3 Test Criteria

2.3.1 PAT Test Package

The test package shall be a full-scale replica of the proposed package for air transport of plutonium. It shall be equivalent to the package proposed to NRC for approval, except that it will contain simulated contents (see Section 2.3.2). If drag enhancers are included in the PAT package design, they must also be included on the test package for the drop test and on the test packages used in the prerequisite tests performed in accordance with NUREG-0360.

For purposes of the test, other items may be added to the test package, such as instrumentation or components for releasing the package from the aircraft, as long as they do not alter the ballistic or structural characteristics of the test package such that the ground impact velocity or resulting mechanical stresses on the package would be reduced.

2.3.2 Simulated Contents

A surrogate material shall be used in place of plutonium, one which simulates plutonium's nontoxic properties to the maximum extent practicable. The applicant shall specify the surrogate material and all its pertinent properties (Section 2.5.1.3).

2.3.3 Cargo Aircraft

The applicant shall specify the cargo aircraft that will be used for transport. The maximum cruising altitude of the cargo aircraft during transport and the basis for its determination shall also be specified (Section 2.5.1.1).

2.3.4 Drop Altitude

The applicant shall specify the altitude at which the free fall will begin and the ground impact elevation. If the specified release altitude is not the maximum cruising altitude, the applicant shall submit sufficient information to demonstrate that the ground impact velocity of the package will not be less than it would be if its free fall began at the maximum cruising altitude and its ground impact elevation were at sea level. The applicant is required to perform a ballistic analysis of the test package's free fall to determine impact velocity and trajectory (see Section 2.5.1.4).

Example: The cargo aircraft's maximum cruising altitude is 13 km (43,000 ft). The initial free-fall altitude specified for the test package is 7 km (23,000 ft), and the elevation of the ground impact area is 1 km (3,300 ft). These selections are justified by the results of a free-fall ballistic analysis, in conjunction with measured drag coefficients for the specified package, which indicate its impact velocity under these conditions will be at least as great as its impact velocity would be if dropped from 13 km (43,000 ft) to a ground impact elevation of sea level. This occurs because the falling package reaches its greatest velocity at a relatively high altitude and then is slowed down by the increasing air density it encounters with decreasing altitude. (See Fig. 2-1.)

2.3.5 Test Package Orientation

After the test package is transported to the maximum cruising altitude, or equivalent drop altitude (see Fig. 2-1), it may be released in a way which may result in rotation or spin, however, no artificial spin which provides gyroscopic stability to the test package shall be permitted. The package shall be allowed to fall freely and seek its natural orientation affected only by its design, initial altitude, and atmospheric conditions. Its orientation at impact shall be uncontrolled.

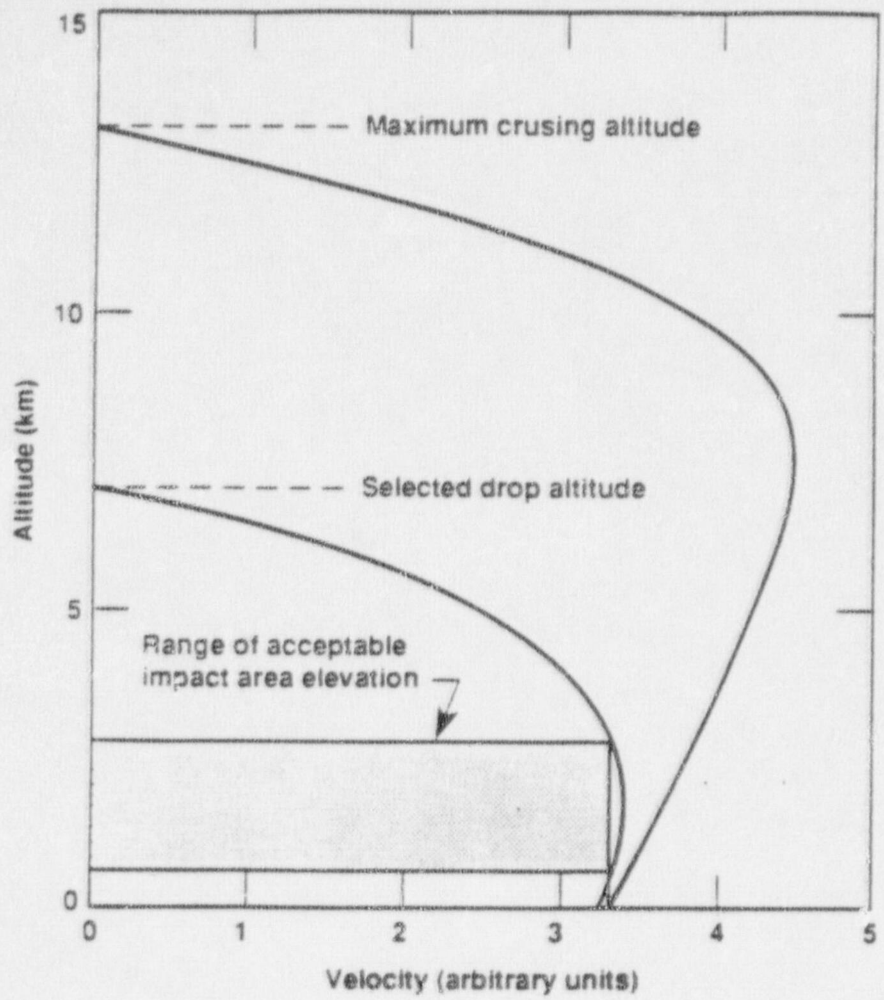

Fig. 2-1. Free-fall velocity as a function of altitude for similar objects released at two altitudes.

2.3.6 Horizontal Velocity

The test package is allowed but not required to have a horizontal velocity when its free fall begins. (Note that this allows for dropping the package from a level-flying airplane or a hovering vehicle such as a helicopter.)

2.3.7 Measurements

Instrumentation and data acquisition shall be provided by the applicant to determine at least the test package's altitude, velocity, and orientation at the beginning of its free fall and on impact with the ground. Measurement of elapsed time for the free fall is also required. These measurements shall be made with sufficient accuracy to allow comparison with results of the ballistic calculations (Section 2.5.1.4).

Example: The test package will be tracked with a system of accurately timed and positioned cinetheodolite cameras in order to (1) measure position, rate of change of position, and orientation of the test package throughout its free fall, and (2) define a precise impact location for the test package to facilitate recovery. Three views of the test package, approximately 120° apart, will be provided from ground stations. This method of instrumentation is nonintrusive, and only suitable markings are required on the package.

2.3.8 Test Range

2.3.8.1 Selection

The package drop test shall be conducted at a test range approved by the NRC. The applicant shall specify the selected test range and define the basis for selection (Section 2.5.1.5).

2.3.8.2 Impact Area Elevation

The test package may impact the ground at any elevation at or above sea level. The applicant shall specify the ground impact elevation for the free-fall drop test and the expected impact velocity.

Example: The specified impact elevation is 700 m (2300 ft). Based on an analysis performed for Section 2.3.4, the package's impact velocity at 700 m is greater than its impact velocity at sea level. (This occurs because the package, in falling, reaches its greatest velocity at a relatively high altitude and then is slowed down by the increasing air density it encounters at lower altitudes; see Fig. 2-1.)

2.3.8.3 Impact Area Size

The impact area specified for the drop test shall be large enough to give a high probability that the test package will fall within it, in order to ensure the safety of the public and of test personnel.

Example: The designated impact area is 5 km in diameter. This size is determined from a ballistic analysis of the package's free fall (Section 2.5.1.4), a safety evaluation (Section 2.5.1.6), and a reliability analysis (Section 2.5.1.8).

2.3.8.4 Impact Area Geotechnical Characteristics

The earth structure below the ground surface at the designated impact area may consist of topsoil, weathered rock, and underlying competent rock. The thickness of the topsoil shall be 0.3 m or less. The geologic materials in the subsurface at the impact area, to a minimum depth of 5 m, should be equivalent to or harder than the intensely weathered and fractured shale and sandstone of the PSA 1771 crash site (see Appendix 2). Examples of geologic materials harder or softer than those at the PSA crash site are shown in Table 2-1.

Table 2-1. Examples of geologic materials harder or softer than those at the PSA 1771 crash site.

Geologic Material	Qualitative Hardness
Gabbro	
Basalt	
Granite	
Welded tuff	
Conglomerate	
Cemented sandstone	
Caliche-cemented claystone	
Unweathered shale and sandstone	Harder ↑
Intensely weathered and fractured shale and sandstone	Site material has moderate hardness.
Volcanic ash	↓ Softer
Decomposed granite	
Stiff clay	
Sand	
Bay mud	
Peat	

The applicant shall investigate the geotechnical properties of the ground surface and subsurface at the test site. The investigation may include the following in-situ and laboratory measurements/tests as needed to characterize the impact area:

- Field exploratory drilling and soil/rock sampling.
- Geophysical measurements to obtain representative shear wave and compression wave velocities.
- In-situ dynamic penetration tests.
- Basic soil/rock properties including shear modulus, Poisson's ratio, bulk modulus, pressure/volume characteristic, and porosity.
- Density and unconfined compressive strength.

The applicant shall report the method used in determining the geotechnical properties and the results obtained.

Example: The applicant selects a designated impact area which is basically formed with interbedded shale and sandstone. The geotechnical investigations at the site include one exploratory drill hole at the designated impact point to a depth of 20 m. In addition, four other drill holes are drilled around this point at a distance of 100 m to the same 20-m depth to establish the site's geostructural profile. A gas-gun penetration test is performed adjacent to each of the drill hole locations. Geophysical measurements of shear and compressional velocities are performed along two cross sections through the center of the designated impact point. Analyses of the resulting in-situ geotechnical data, together with analyses of the results of laboratory tests of core samples, support the conclusion that the designated impact area meets the criterion of equivalent hardness. The applicant uses a composite of these measurements to indicate that the test site meets the test criteria.

2.3.9 Number of Drop Tests

Only one drop test is required, provided all test criteria are satisfied. Should any criterion not be satisfied during a drop test, the applicant may request the NRC to review the test conditions and results and determine whether a retest is required. Should a retest be required, a new test package may be used.

2.4 Acceptance Criteria

2.4.1 Acceptance

Acceptance is specified by Public Law 100-203, Section 5062, which states that the container shall not rupture or release its contents during testing. The packaging shall restrict accumulated loss of its plutonium contents to not more than an A_2 quantity in a period of one week. An A_2 quantity of plutonium is defined in Table A-1 of Ref. 3. For the package drop test, only the inner or outer container is required to meet the release limit. Any amount of deformation is permissible, provided that the release limit is satisfied. (See NUREG-0360 for an example procedure to determine an A_2 quantity.)

2.4.2 Post-Test Inspection and Evaluation

As part of the test plan in Section 2.5, tests and inspections shall be designated and subsequently performed by the applicant to determine how well the test package survived the drop. Release and leakage tests may be used to determine that the content release limits have been satisfied. The release or leakage tests must be interpreted in terms of the corresponding release of actual plutonium that would result from such damage to the package (Section 2.5.1.3). Reference 8 may be used as a guide for release or leakage tests to be performed. Corresponding quantities of released plutonium shall be less than specified in Section 2.4.1.

2.4.3 NRC Test Monitoring

The NRC will have the option to appoint delegates to witness the package drop test and related test range activities, in order to verify conformance to the test criteria and the accepted test plan.

2.5 Submissions Required

2.5.1 Pretest Information

Before performing the drop test for certification of the PAT package, the applicant shall submit to the NRC, for review and approval, all information defined in Sections 2.5.1.1 through 2.5.1.8.

2.5.1.1 Cargo Aircraft Definition

The applicant shall specify the cargo aircraft to be used in transporting the PAT packages, its maximum cruising altitude during transport of the packages, and the basis for determining the maximum cruising altitude.

2.5.1.2 Test Plan

The applicant shall prepare a range-specific drop test plan that defines in detail all aspects of preparing and performing the test. The plan shall contain at least the following information:

1. Test range description—Identify the selected test range, including its location, owners, management organization, size, elevation, etc.

2. Compliance with policies and procedures—Define applicable policies and procedures that will be required by the test range management and describe how they will be satisfied.

3. Support equipment, services, and facilities—Define equipment, services, and facilities that will be required. Define the sources of these required support items and how they will be provided.

4. Pretest preparations—Define all site activities that must be completed before the drop test can be performed and how these activities will be accomplished: e.g., impact surface preparations, impact area security, test package assembly, instrument installation, activation, and checkout, etc.

5. Test procedures—Describe in detail the step-by-step events and procedures that test personnel will follow when the drop test is performed. The procedures shall address at least the period beginning with preparing and

installing the test package on the aircraft and ending with completion of the acceptance tests and refurbishment of the impact area.

6. Instrumentation and data acquisition and reduction—Describe all measurements that will be made during the drop test and the sensing instruments that will be used to make the measurements. Describe the data acquisition equipment and the data reduction methods that will be used. Also, define the resolution and accuracy of the measurements and uncertainty values of the reduced data.

7. Test package transport to drop point—Describe the type of aircraft that will be used for the drop test, who will provide (own) and fly it, and how it will transport the test package to the drop altitude: i.e., how the test package is carried by the aircraft and how it will be released. Describe the aircraft's flight path and its expected altitude and velocity when the test package is released. Describe in detail the process by which the test package will be freed from the aircraft and any devices used in transporting the test package. In addition, describe effects on the aircraft of releasing the test package.

8. Test package release—Define the expected velocity, trajectory, orientation, and altitude of the test package when it is released. Specify the release point required for the test package to fall within the impact area. Describe how the aircraft will be maneuvered to the required position and speed for the release so that the test package's trajectory will intercept the designated impact area. Describe how current atmospheric conditions will be incorporated in the final selection of the release point.

9. Acceptance testing—Describe in detail the process for testing the test package after the drop test to determine whether the inner or outer container has ruptured in accordance with Section 2.4. Define the measurements that will be made, and the accuracy and sensitivity of the instruments.

10. Test package recovery—Describe how the dropped test package will be located and how it will be retrieved. Present the results of analyses that predict penetration depth of the test package in the designated impact area. The recovery plan shall take into account the possibility that the test package may not fall within the impact area and also that it may come to rest out of sight below the soil surface.

11. Weather data—Describe any limitations that weather conditions may impose on test program activities. Define seasonal periods during which these weather conditions can be expected and how they are accounted for in the test plan. Describe weather data that will be needed for the drop test, the intended use of the data, and what the source of the data will be.

12. Test site refurbishments—Define after-test refurbishments required for the test site. Describe how these refurbishments will be accomplished and the acceptance criteria they must meet.

13. Environmental impact mitigation—Define possible environmental concerns that could develop from the drop test activities and how they will be mitigated.

14. Schedule—Provide a time schedule of drop test events, showing major milestones including the following:

    - Pretest analyses completed.
    - Test range selected.
    - Test package delivered.
    - Test aircraft selected.
    - Pretest submissions to NRC completed.
    - Test range operations begun.
    - Test range management approvals obtained.
    - Systems pretest checkout completed.
    - Drop test performed.
    - Acceptance tests performed.
    - Impact area refurbishment completed.
    - Final departure from test range.
    - Reports due to NRC.

15. Test personnel organization—Provide an organization chart of personnel who will have key responsibilities during the drop test program. List test personnel by technical discipline and their assigned responsibilities. Show who is the responsible test director, and give the relationships and responsibilities of the test director to the test range management and any other participating agencies.

16. Safety—Incorporate the results of the safety evaluation required in Section 2.5.1.6. Describe how the operating plans and procedures will be implemented to assure safety during all phases of the drop test.

17. Emergency plan—Develop a potential list of hazards and a plan to be implemented in the event of an accident or emergency condition. Describe how the plan would be implemented should an emergency occur.

2.5.1.3 Test Package Design

The applicant shall submit engineering drawings with accompanying text describing the design details of the test package, including instrumentation, simulated plutonium, and special items to be included during the drop test. The test package shall be essentially identical to the PAT package and to the test package used in the certification tests required by NUREG-0360. Any differences shall be noted and their significance discussed.

The surrogate material used to simulate the plutonium shall be specified. All pertinent properties of the surrogate material shall be given. The relationship between acceptance test measurements and release of actual plutonium shall be given. (Note that the safety evaluation required in Section 2.5.1.6 must include evaluation of surrogate material release.)

2.5.1.4 Test Package Ballistics

The applicant shall present the results of ballistic analyses of the test package in free fall to determine the expected trajectory and impact velocity. The method of analysis shall be described and the source of all data used in the analysis shall be given. The methods and results of confirmatory calculations performed to verify that the results are valid shall also be given. The analyses shall include at least the following effects:

- Aerodynamic design and weight of the package.
- Altitude-dependent air properties.
- Altitude-dependent wind.
- Release altitude.
- Release velocity.
- Package orientation.
- Impact elevation.

The applicant shall specify the altitude, speed, orientation, and direction of travel of the test package at release and predict its free-fall trajectory and its velocity at impact. If the test package is released at an altitude lower than the maximum cruising altitude, the applicant shall also describe and justify in detail why its impact velocity will not be less than that of a package released from the maximum cruising altitude (see Sections 2.3.4 and 2.3.8.2).

2.5.1.5 *Test Range Selection*

The applicant shall specify the test range selected for the drop test and justify its selection, addressing at least the following topics:

- Geotechnical properties at the impact area.
- Accessibility of the impact area.
- Availability of required services and utilities.
- Required modifications.
- Prior environmental impact studies.
- Safety.

The method used to select candidate ranges having suitable near-surface geotechnical properties shall be described. The measured properties, the methods used in determining those properties, and the results obtained shall be given, as well as a description of how the designated impact area meets the criteria for near-surface geotechnical properties (Section 2.3.8.4).

2.5.1.6 *Safety Evaluation*

The applicant shall evaluate the safety of all equipment, materials, and operations related to the drop test. All hazards and safety measures shall be described. Operating plans and procedures shall be designed to ensure safety of the public and the test personnel and compliance with all applicable safety procedures and regulations. The applicant shall provide a complete description of the safety evaluation. This evaluation shall be in addition to the safety plan required in the test plan (Section 2.5.1.2).

2.5.1.7 *Liability Assignments*

The applicant shall define applicable legal liabilities for all test-related activities and identify the parties that will assume these liabilities.

2.5.1.8 *Reliability Analysis*

The applicant shall perform a reliability analysis of the drop test to show that there is a high probability of achieving all specified parameters in a single test the first time it is performed without compromising safety. Elements of the test that influence the reliability of measurements and probability of achieving the expected impact velocity and trajectory shall be included in the analysis. Reliability, accuracy, and uncertainty values available from manufacturers of test equipment shall be used where obtainable. If not obtainable, these values shall be specified by the applicant and the basis for selecting them shall be explained. The analyses performed to demonstrate a high reliability that the actual drop test will conform with the approved drop test parameters shall include consideration of:

- Failure modes and effects—Relationships between components, subassemblies, and subsystem failure modes and resultant system function are defined. Relative failure criticality values are assigned to each mode and appropriate design or operation changes are made.

- Fault trees—The sequence of events which could lead to a top-level undesirable event or major hazard is traced. The probability of the top level event occurring is determined using the probabilities of individual chained events.

- Redundancy—Calculations are made to determine the improvement in system reliability that can be provided by redundancy of various components or subsystems. The results are used to guide test system design.

- Historical failures—Past performance data of identical and similar equipment and system designs are collected to derive expected reliability values. This information is used to select equipment most suited for the test.

- Environmental factors—The effect of local environmental conditions on performance of all systems is evaluated and appropriate test plan changes are incorporated.

- Human factors—The impact of people interacting with the test equipment and subsystems is evaluated to determine their influence on the overall system reliability. Where appropriate, the demand on human interaction is reduced to improve system reliability.

2.5.2 Interim Reports

Beginning with the initial operations at the test range, the applicant shall report periodically to the NRC on the status and progress of all test range activities on a timely basis. The reporting schedule shall be defined in the test plan (see Section 2.5.1.2).

2.5.3 Final Report

On completion of the drop test program, the applicant shall prepare a detailed report describing all phases and activities of the test program, including methods, results, and conclusions.

2.5.4 Preparation of Submissions

Documents and applications submitted to the NRC shall be prepared in accordance with the instructions given in Ref. 9.

2.6 Variances

Should the applicant determine that fulfillment of any criterion or combination of criteria specified in this section is not achievable, a request for variance may be submitted to the NRC. Section 5062, paragraph (d), of Public Law 100-203 applies to deviations from exact achievement of the worst-case accident conditions. The applicant must define the requested variances and corresponding criteria and give justification for the variances. The applicant must also demonstrate that the variances will not degrade the objectives of the package drop test. The NRC will determine if the requested variances are acceptable.

3. AIRCRAFT CRASH TEST

3.1 Introduction

Subsection 5062(b)(2)(B) of Public Law 100-203 requires that the specified cargo aircraft be crash-tested while fully loaded with PAT test packages. The aircraft crash test may be waived if an independent scientific panel reviews the PAT package developmental tests and determines that such tests would subject the PAT package to stresses that exceed those that would occur in a worst-case aircraft accident. The purpose of this section is to identify the specific criteria that an applicant must satisfy if the aircraft crash test option is exercised.

The aircraft to be crashed will be loaded with PAT test packages of the type which successfully met the drop test criteria of Section 2. The aircraft impact conditions will be designed to replicate those of the worst-case accident as defined in Section 1.2.1.

Few crash tests of transport aircraft have been conducted. The FAA/NASA Controlled Impact Demonstration Test provides a point of reference for the aircraft crash test discussed here. The FAA/NASA test is summarized in Appendix 4.

3.2 Responsibilities

3.2.1 Nuclear Regulatory Commission

The NRC will review and approve the test plan and all other documentation required by Section 3.5, monitor the crash test, and review and assess the test results. NRC will determine on the basis of the surrogate content used whether any of the test packages were damaged sufficiently in the crash test to result in unacceptable release of plutonium. NRC will use these results together with the previously approved results of other tests including the package drop test to determine whether the PAT package design can be certified to Congress as safe for use in air transport of plutonium.

3.2.2 Applicant

The applicant for certification of a proposed PAT package design shall have successfully completed the drop test according to the criteria specified in Section 2. The applicant is responsible for providing all test hardware; packages, aircraft, equipment, facilities, range, and all other necessary resources to be used in the aircraft crash test.

3.3 Test Criteria

3.3.1 Test Aircraft

The test aircraft shall be of the same type as the cargo aircraft that the applicant specifies for transporting plutonium (see Section 2.3.3). A test aircraft of a different type may be used if the applicant submits convincing analyses and conclusions that the substitute aircraft will not cause the crash environment to be less severe for the PAT test packages than if the specified cargo aircraft were used. The impact conditions are specified in Sections 3.3.6 and 3.3.8.

Example 1: The cargo aircraft specified by the applicant is the new Boeing 747-400 Combi. These aircraft are only now beginning to be delivered by the manufacturer; they are not yet on the used aircraft market. Therefore the proposed test aircraft is a Boeing 747-100, a type which is available on the used market. The applicant determines that structural differences between the 747-100 test aircraft and the 747-400 Combi have a negligible effect in the postulated crash environment.

Example 2: The cargo aircraft specified by the applicant is the new Boeing 747-400 Combi. Instead of using this aircraft in the crash test, the applicant proposes to use a Boeing 707 aircraft. The supporting analyses that justify this choice include:

- Estimates of maximum forces, stresses, and damage to PAT packages resulting from a crash of the 747-400 Combi cargo aircraft during the required crash conditions (see Sections 3.3.6 and 3.3.8).

- Analyses to determine a combination of (1) loading arrangement for PAT packages in a Boeing 707 and (2) crash conditions for the loaded aircraft which would produce at least as severe forces, stresses, and damage to the PAT packages as estimated for the cargo aircraft.

- A computer flight simulation of the Boeing 707 aircraft showing that it can be remotely flown to achieve the conditions required in Section 3.3.6.

3.3.2 Remote Aircraft Guidance

The test aircraft shall be equipped as an RPV to enable its flight to be controlled remotely for repeated (practice) takeoffs and landings, flight maneuvers, and the final dive to the designated impact area (see Section 3.3.8). The RPV guidance system shall include a radio-commanded manual override feature to permit all aircraft flight functions to be remotely operated in a manual mode. The system shall be capable of performing the number of flights required for checkout and finally the crash test.

3.3.3 Emergency Flight-Termination System

The test aircraft shall be provided with an emergency flight-termination system that will ensure a safe operation in the event of an RPV system malfunction. This flight termination system must be approved by the test range management. In choosing the system, at least two means of flight termination shall be considered, analyzed, and compared. The governing attribute for selection of the proposed system shall be the safety of test personnel and the public.

3.3.4 Loading Arrangement

The test aircraft shall be loaded with as many PAT test packages as required to produce at lease as severe crash conditions as those potentially present in the cargo aircraft. The method of securing the packages to the aircraft shall be identical to the arrangement to be used when transporting plutonium. The interior of the aircraft shall be equipped as closely as practicable to that of the cargo aircraft, except for equipment needed for remote control operation and test instrumentation. If a different interior arrangement is necessary, the applicant shall present convincing evidence that the proposed arrangement will not cause the crash environment to be less severe.

Example 1: The test aircraft is the same type and model as the cargo aircraft that will be used to transport the PAT packages. The number of test packages in the test aircraft will be the same as the number of PAT packages that are planned to be in the cargo aircraft. The cargo arrangement of the test packages will be identical to the cargo arrangement for transporting the PAT packages.

Example 2: The loading arrangement in the cargo aircraft will be eight cylindrical packages, their cylindrical axes parallel to the aircraft fuselage axis, four in line on each side of the cargo deck and evenly spaced. Results of analyses and studies indicate that for the specified impact conditions (see Section 3.3.6) there is negligible lateral interaction between packages. Therefore a test aircraft loading arrangement is four packages in line in the center of the fuselage. Consequently, a Boeing 707 is a suitable aircraft to perform the test. Spacing and tie-down configurations in the test aircraft will be similar to those in the cargo aircraft.

3.3.5 Fuel Loading

The test aircraft shall have only sufficient fuel to complete the test mission with an adequate reserve as specified by the FAA or the test range, whichever is greater.

3.3.6 Impact Conditions

The test aircraft shall be flown in such a manner that its final trajectory (at impact) has the parameter values specified below. Figure 3-1 illustrates the relationships between the trajectory parameters.

3.3.6.1 *Representative Impact Plane*

The representative impact plane is the plane that best fits the irregularities of the actual surface in the vicinity of an aircraft crash impact point. This plane extends for a radius of at least the wingspan of the aircraft, from the point where the longitudinal axis of the fuselage strikes the earth's surface. The representative impact plane is determined by minimizing the variance of surface elevations from the plane measured on a square grid at 3-m intervals. The representative impact plane shall determine the *x-y* plane of a Cartesian coordinate system centered at the planned impact point, through which the *z*-axis also passes. The *x*-axis is the normal projection of the aircraft's final trajectory (at impact) on the representative impact plane. In this coordinate system the *y*-axis accounts for aircraft yaw and lateral velocity. Trajectory parameters shall be referred to the coordinate system as shown in Fig. 3-1, both in planning the test and reporting the test results.

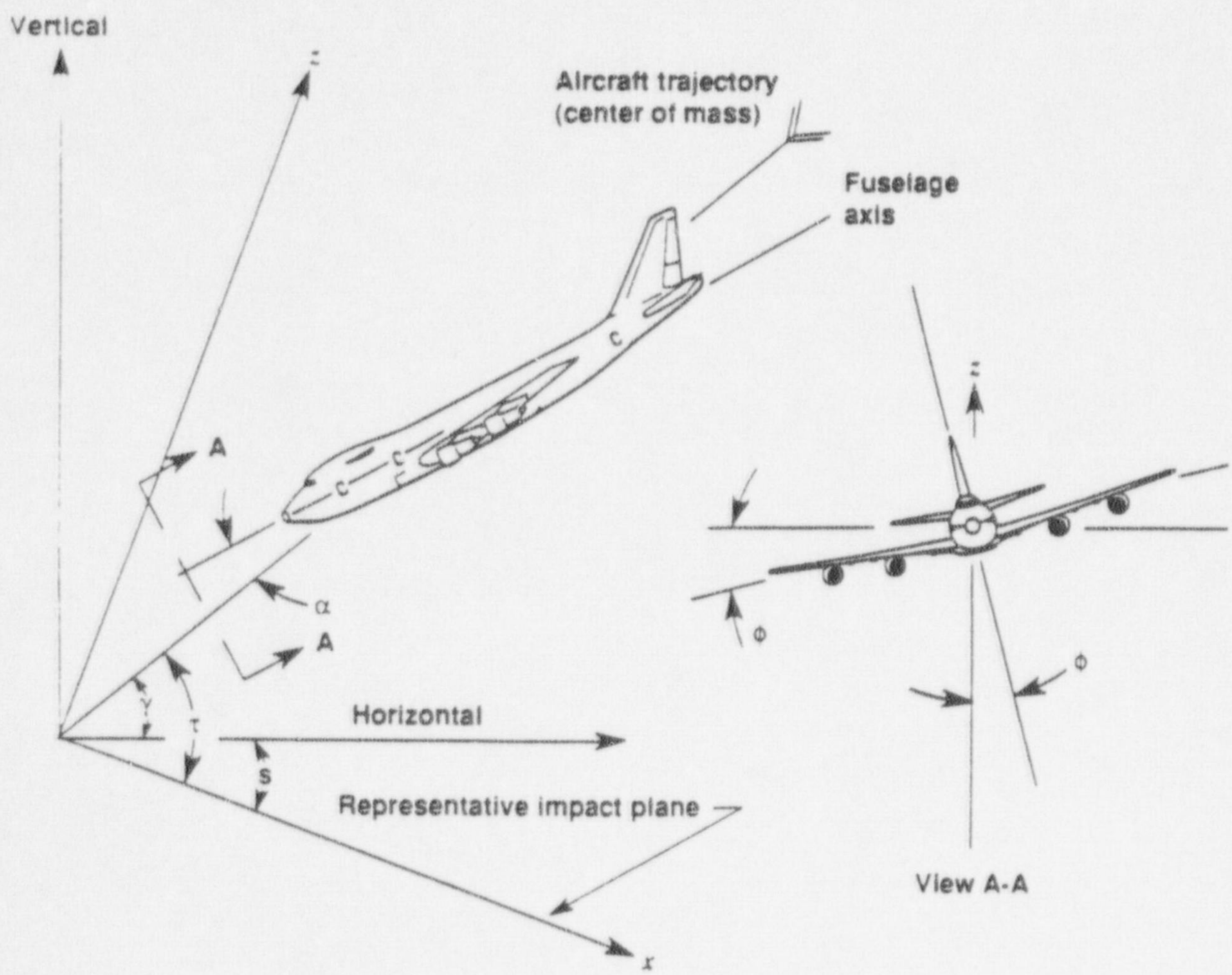

Fig. 3-1. Trajectory criteria at impact for the aircraft crash test. See text for parameter definitions and values.

3.3.6.2 *Impact Angle*

The angle τ between the aircraft trajectory (center of mass) and the representative impact plane at nose-down impact of the aircraft shall be a minimum of 60°. The angle α between the longitudinal axis of the fuselage and the aircraft trajectory shall be 10° or less as measured in the plane containing those axes.

3.3.6.3 *Roll Angle*

The roll angle ϕ at impact shall be less than 10° with respect to the representative impact plane.

3.3.6.4 *Impact Velocity*

The impact velocity of the test aircraft shall be at least 282 m/s (925 ft/s). Impact velocity is defined as the velocity of the aircraft along its trajectory (center of mass). The velocity component in the y-direction shall be less than 5% of the impact velocity.

If a substitute aircraft is used in place of the specified cargo aircraft, the applicant shall determine if a higher impact velocity is needed to produce at least as severe a crash environment for the PAT test packages as would occur in a crash of the specified cargo aircraft. If a higher impact velocity is needed, the applicant shall specify its value and support its selection with appropriate analyses and conclusions according to Section 3.3.1.

3.3.7 Measurements

Instrumentation and data acquisition shall be provided by the applicant to determine, at a minimum, the aircraft's altitude, velocity, and orientation from initiation of the dive to the moment of impact. These measurements shall be redundant and made with sufficient accuracy to verify that the crash test criteria are satisfied and to allow comparisons to aerodynamic analyses (Section 3.5.1.3).

Example: The test aircraft will be conspicuously marked (painted) to facilitate quantitative analysis of cinetheodolite pictures for determining aircraft pitch, roll, yaw, altitude, and velocity parameters. Pictures will be taken from three different locations to allow precise position definition. The cinetheodolites will provide photographic coverage of the test from commencement of the dive maneuver throughout the dive at a framing rate greater than 5 frames/s. The cinetheodolites will provide a higher framing rate (e.g., >20 frames/s) to permit position resolution within 15 m during the final 10 s before impact. Magnification and clarity of resultant photographs will be sufficient to make position and velocity measurements with less than 5% error when analyzed together with cinetheodolite azimuth and elevation readings. Other required measurements will be made with instrumentation on board the test aircraft and transmitted by telemetry to ground receivers.

3.3.8 Test Range

3.3.8.1 Selection

The aircraft crash test shall be conducted at a test range approved by the NRC. The applicant shall specify the selected test range and define the basis for its selection (Section 3.5.1.7).

3.3.8.2 Impact Area Elevation

The test aircraft may impact the ground at any elevation at or above sea level. The elevation of the designated impact area shall be specified by the applicant.

3.3.8.3 Impact Area Size

The applicant shall specify the designated impact area size having the geotechnical properties specified in Section 3.3.8.4. A larger safety area surrounding the impact area shall also be specified to ensure safety of test personnel and of the public in conformance with test range policy.

Example: The designated impact area is 1 km in diameter, large enough to ensure that the aircraft will crash within this area. The specified safety area is 20 km in diameter, which is part of the test range and is cleared of all personnel during test periods.

3.3.8.4 Impact Area Geotechnical Properties

The criteria given in Section 2.3.8.4 apply. In addition, the designated impact area shall be relatively smooth.

Example: The smoothness of the impact area is characterized by maximum departures of 1 m from the representative impact plane per 100 m in any direction.

3.3.9 Number of Crash Tests

Only one crash test is required, provided all crash acceptance criteria are satisfied. Should any criterion not be satisfied during the aircraft crash test, the NRC will review the test conditions and results and determine what further activities will be required of the applicant.

3.4 Acceptance Criteria

3.4.1 Acceptance

Section 2.4.1 applies to the aircraft crash test as well. The release limit must be satisfied by each test package present in the aircraft crash test.

3.4.2 Post-Test Inspection and Evaluation

Section 2.4.2 applies.

3.4.3 NRC Test Monitoring

The NRC will have the option to appoint delegates to witness the aircraft crash test and related test range activities, in order to verify conformance to the test criteria and the accepted test plan.

3.5 Submissions Required

3.5.1 Pretest Information

Before performing an aircraft crash test for certification of the test package, the applicant shall submit to the NRC, for review and approval, all information defined in Sections 3.5.1.1 through 3.5.1.10 following.

3.5.1.1 Test Plan

The applicant shall prepare a range-specific aircraft crash test plan that defines in detail all aspects of preparing and performing the test. The plan shall contain at least the following information:

1. Test range description—Define the selected test range, including its location, owners, management organization, size, elevation, etc.

2. Compliance with policies and procedures—Define applicable policies and procedures that will be required by the test range management and describe how they will be satisfied.

3. Support equipment, services, and facilities—Define equipment, services, and facilities that will be required: e.g., electrical power, water, communications, buildings, roads, transportation, moving equipment, operating and service personnel, etc. Define the sources of these required support items and how they will be acquired.

4. Pretest preparations—Define all site activities that must be completed before the crash test can be performed and how these activities will be accomplished:

e.g., impact surface preparations, impact area security, aircraft loading, start-up and checkout, RPV guidance system activation and checkout, practice flights, instrument installation, activation, and checkout, etc.

5. Test procedures—Describe in detail the step-by-step events and procedures that test personnel will follow when the crash test is performed. The procedures shall address at least the period beginning with assembly and installation of the test packages in the test aircraft and ending with completion of the acceptance test and refurbishment of the impact area.

6. Instrumentation and data acquisition and reduction—Describe all measurements that will be made during the crash test and the sensing instruments that will be used to make the measurements. Describe the data acquisition equipment and the data reduction methods that will be used. Also, define resolution and accuracy of the measurements and uncertainty values of the reduced data.

7. Test aircraft—Define the aircraft that will be used in the crash test. Describe services, modifications, and added equipment that will be required for the aircraft and how they will be installed and implemented. Present the analyses and results that indicate the aerodynamic and structural capability of the test aircraft to achieve the required impact conditions.

8. Aircraft flight plan—Define in detail the aircraft flight plan beginning with initial roll-out to the crash. Define up to what point in the flight plan the test flight can be aborted and the aircraft returned safely. Include alternate plans that can be implemented if necessary.

9. Impact conditions—Specify the test aircraft's impact velocity and orientation. Describe how these impact conditions will be achieved: i.e., what type of guidance system will be used in this terminal flight phase, how it will be monitored and controlled, how the aircraft velocity and orientation will be controlled, etc.

10. Aircraft guidance system—Describe the type of aircraft guidance system (e.g., remote, automatic, manual, etc.) that will be used to control the test aircraft during all phases of practice and test flights. Describe the systems to be installed in the aircraft and on the ground, and where the ground system will be located. Describe the method and procedures for operating the systems.

11. Flight training—Describe in detail the types and number of flight training sessions, ground and air, that will be implemented to develop a high level of confidence in being able to control the aircraft as required. Describe in detail each training phase and how it will be conducted. Define the flight personnel qualification standards established by the test range management.

12. Aircraft recertification—Define all steps necessary to recertify the test aircraft if required by the FAA or any other regulatory agency that may be involved.

13. Test packages—Describe the cargo configuration of test packages that will be used in the test aircraft. Describe the method of loading them into the aircraft and the method of tie-down.

14. Reliability—Discuss the reliability analysis performed for the aircraft crash test and the steps taken to ensure high reliability.

15. Test package recovery—Describe how the test packages will be located after the crash and how they will be retrieved. The recovery plan shall take into account the possibility that the test packages may not come to rest at the final impact site and also that they may be out of sight below the ground surface. This implies that a locater device may be needed for each test package.

16. Acceptance testing—Describe in detail the process for testing the test packages after the crash test in accordance with Section 2.4.2 to determine whether the inner and outer containers have ruptured. Define the measurements that will be made, the instruments used to make them, and the expected accuracies and sensitivities.

17. Weather data—Describe any limitations that weather conditions may impose on test program activities. Define seasonal periods during which these weather conditions can be expected and how they are accounted for in the test plan. Describe weather data that will be needed for the aircraft crash test.

18. After-test refurbishments—Define any after-test refurbishments required for the test site. Describe how they will be accomplished and the acceptance criteria they must meet.

19. Environmental impact mitigation—Define possible environmental concerns that could develop from the aircraft crash test activities and how they will be mitigated.

20. Schedule—Provide a time schedule of crash test events from commencement of operations at the test range to final departure from the range. Include all major milestones, such as the following:

    - Range occupied.
    - Aircraft received.
    - Aircraft guidance system installed.
    - Aircraft recertification completed.
    - Flight training completed.

- Crash site preparation completed.
- Test range safety evaluation completed.
- Test packages delivered and loaded.
- Crash test completed.
- Acceptance testing completed.
- Refurbishment completed.
- Range departure.
- Reports due to NRC.

21. Test personnel—Provide an organization chart of personnel who will have key responsibilities during the aircraft test program. List test personnel, technical discipline, and assigned responsibilities. Show who is the responsible test director and give the relationships and responsibilities of the test director to the test range management and any other participating agencies.

22. Safety and security—Incorporate the results of the safety evaluation required in Section 3.5.1.8. Describe how the operating plans and procedures will be implemented to assure safety during all phases of the crash test.

23. Emergency plan—Develop a plan that can be implemented in the event of an accident or emergency condition. Describe how the plan would be implemented should an emergency occur.

3.5.1.2 Test Package Design

The applicant shall submit engineering drawings with accompanying text describing the design details of the test package and instrumentation or special items to be included during the crash test. Drawings of the PAT package design to be certified by the NRC shall also be included. The test package must be essentially identical to the PAT package and to the test package used in the drop test and in the certification tests required by NUREG-0360. Any differences shall be noted and their significance discussed.

The surrogate material used to simulate the plutonium that will ultimately be transported in the certified PAT package shall be specified. All pertinent properties of the surrogate material shall be given. The relationship between acceptance test measurements and release of actual plutonium shall be given. (Note that the safety evaluation required in Section 3.5.1.8 must include evaluation of surrogate material release.)

3.5.1.3 *Cargo Aircraft and Cargo Arrangement Specifications*

The applicant shall specify the cargo aircraft to be used in transporting the PAT packages and its maximum cruising altitude as defined in Section 2.3.3. The transport configuration and loading arrangement of the PAT packages in the cargo aircraft shall also be specified.

3.5.1.4 *Test Aircraft Definition*

The applicant shall specify the aircraft type that will be used in the crash test. The applicant shall submit detailed results and descriptions of flight simulation analyses that are specific to the test aircraft and confirm that the test aircraft will provide impact conditions which are identical to or more severe than specified in Sections 3.3.6 and 3.3.8.4 These analyses shall be based on known aerodynamic and structural characteristics of the test aircraft and the characteristics of the remote aircraft guidance system.

If the test aircraft is not the same type as the cargo aircraft, the applicant shall submit detailed descriptions and results of additional analyses supporting the acceptability of the selected test aircraft. These additional analyses shall address at least the following points:

- Estimates of the maximum relative forces, stresses, and damage to PAT packages resulting from a crash of a fully loaded cargo aircraft under crash conditions specified in Sections 3.3.6 and 3.3.8.4. Influencing factors that must be considered in these analyses include:
  - — Interaction between packages.
  - — Interaction between packages, tie-down components, cargo containers, and aircraft structure.
  - — Effect on the packages of various materials in the aircraft: e.g., fuel, plastics, compressed air, missiles, etc.
  - — Change of soil properties due to impact of the aircraft.
  - — Interaction between packages and soil.

- Analyses that determine the test aircraft crash velocity and orientation and the cargo configuration of PAT test packages required to produce relative forces, stresses, and damage to the test packages at least as severe as those determined in the crash estimates above. Influencing factors that must be considered in these analyses include:
  - — The number of test packages required in the test aircraft.
  - — Cargo arrangement of test packages in the test aircraft
  - — Tie-down method and cargo deck structure.

— Soil compaction by the test aircraft and its effect on the packages.

— Other factors that may affect the packages during the crash.

3.5.1.5 Remote Aircraft-Guidance System

The applicant shall describe in detail the control system, or systems, that will be used to control the test aircraft during all phases of flight, including takeoffs, landings, flight maneuvers, and the final dive to impact. Describe at least the following aspects:

- The type of flight control systems to be used.
- The operation of these systems and the interaction of flight control personnel with them.
- The systems on board the aircraft and the ground-based systems.
- Operation of the systems when the flight is controlled by a pilot on board the aircraft, by a pilot at a remote location, and by auto pilot.
- Integration of the flight control systems with the flight characteristics of the selected test aircraft.
- Computer simulation and testing of the flight control systems.
- Ground and flight testing.

3.5.1.6 Emergency Flight-Termination System

Describe in detail the emergency flight-termination system (Section 3.3.3) that will be installed and how it will be controlled. Describe the analyses and testing performed to validate the ability of the flight termination system to perform its function, and the process required to obtain range management approval for its use.

3.5.1.7 Test Range Selection

The applicant shall specify the test range selected for the aircraft crash test and the basis for its selection, addressing at least the following topics:

- Geotechnical properties at the impact area.
- Accessibility of the impact area.
- Availability of required utilities and services.
- Required modifications.
- Prior environmental impact studies.
- Safety.

The method used to select candidate ranges having suitable near-surface geotechnical properties shall be described. The measured properties, the methods used in determining those properties, and the results obtained shall be given, as well as a description of how the specified impact area meets the criteria for near-surface geotechnical properties (Section 3.3.8.4).

3.5.1.8 Safety Evaluation

The applicant shall evaluate the safety of all equipment, materials, and operations related to the crash test. All hazards and safety measures shall be described. Operating plans and procedures shall be designed to ensure safety of the public and the test personnel and compliance with all applicable safety procedures and regulations. The applicant shall provide a complete description of the safety evaluation. This evaluation shall be in addition to the safety plan required in the Test Plan (Section 3.5.1.1).

3.5.1.9 Liability Assignments

The applicant shall define applicable legal liabilities for all activities and identify the parties that will assume these liabilities.

3.5.1.10 Reliability Analysis

The applicant shall perform a reliability analysis of the aircraft crash test to show that there is a high probability of achieving success with a single test the first time it is performed without compromising safety. Elements of the test that influence the reliability of measurements and probability of achieving the expected impact velocity and trajectory shall be included in the analysis. Reliability, accuracy, and uncertainty values available from manufacturers of test equipment shall be used where obtainable. If not obtainable, these values shall be specified by the applicant, and the basis for selecting them shall be explained. The analyses performed to demonstrate a high reliability that the actual aircraft crash test will conform with the approved crash test parameters shall include consideration of:

- Failure modes and effects—Relationships between components, subassemblies, and subsystem failure modes and resultant system function are defined. Relative failure criticality values are assigned to each mode and appropriate design or operation changes are made.

- Fault trees—The sequence of events which could lead to a top-level undesirable event or major hazard is traced. The probability of the top level event occurring is determined using the probabilities of individual chained events.

- Redundancy—Calculations are made to determine the improvement in system reliability that can be provided by redundancy of various components or subsystems. The results are used to guide test system design.

- Historical failures—Past performance data of identical and similar equipment and system designs are collected to derive expected reliability values. This information is used to select equipment most suited for the test.

- Environmental factors—The effect of local environmental conditions on performance of all systems is evaluated and appropriate design or operation changes are incorporated.

- Human factors—The impact of people interacting with the test equipment and subsystems is evaluated to determine their influence on the overall system reliability. Where appropriate, the demand on human interaction is reduced to improve system reliability.

The reliability analyses should include considerations such as:

- Number of cinetheodolite cameras.
- Redundant telemetry for flight control and data transmission.
- Redundant homing beacons to the designated impact point.
- Standby diesel-generator power source.
- Climate-controlled enclosures for all electronic equipment.
- Standby pilot.
- Installation of structural reinforcement on high-stress members of the test aircraft.

3.5.2 Interim Reports

Beginning with the initial operations at the test range, the applicant shall report periodically to the NRC on the status and progress of all test range activities on a timely basis. The reporting schedule shall be defined in the test plan (see Section 3.5.1.1).

3.5.3 Final Report

On completion of the aircraft crash test program, the applicant shall prepare a report describing all phases and activities of the test program, including methods, results, and conclusions.

3.5.4 Preparation of Submissions

Documents and applications submitted to the NRC shall be prepared in accordance with the instructions given in Ref. 9.

3.6 Variances

Should the applicant determine that fulfillment of any criterion or combination of criteria specified in this section is not achievable, a request for variance may be submitted to the NRC. Section 5062, paragraph (d), of Public Law 100-203 applies to deviations from exact achievement of the worst-case accident conditions. The applicant must define the requested variances and corresponding criteria and give justification for the variances. The applicant must also demonstrate that the variances will not degrade the objectives of the aircraft crash test. The NRC will determine if the requested variances are acceptable.

4. REFERENCES

1. United States Public Law 100-203, Title V—Energy and Environment Programs, Subtitle A—Nuclear Waste Amendments, Part F—Miscellaneous, Section 5062, December 22, 1987.

2. United States Public Law 94-79, Section 201 (89 Stat. 413, 42 USC 5841 note), August 9, 1975.

3. Nuclear Regulatory Commission, Packaging and Transportation of Radioactive Material, Title 10 Code of Federal Regulations, Part 71 (10 CFR 71).

4. Department of Transportation, Hazardous Materials Regulations, Title 49 Code of Federal Regulations, Parts 100-199 (49 CFR 100-199).

5. Nuclear Regulatory Commission, Qualification Criteria to Certify a Package for Air Transport of Plutonium, NUREG-0360, January 1978.

6. Nuclear Regulatory Commission, Selection of a Worst Actual Aircraft Accident for Murkowski Amendment Implementation (Public Law 100-203), NRC Memo SECY-88-344, December 15, 1988.

7. International Atomic Energy Agency, Regulations for the Safe Transport of Radioactive Materials, IAEA Safety Series 6, 1973 Revised Edition. (Available from UNIPUB Inc., P.O. Box 433, New York, N.Y. 10016.)

8. American National Standard for Radioactive Materials—Leakage Tests on Packages for Shipment, ANSI N14.5-1987, American National Standards Institute, Inc., 1430 Broadway, New York, N.Y. 10018.

9. Nuclear Regulatory Commission, Technical Writing Style Guide, NUREG-0650, November 1979.

APPENDIX 1
REPRINT OF SECTION 5062 OF PUBLIC LAW 100-203

SEC. 5062. TRANSPORTATION OF PLUTONIUM BY AIRCRAFT THROUGH UNITED STATES AIR SPACE. 42 USC 5841 note.

(a) IN GENERAL.—Notwithstanding any other provision of law, no form of plutonium may be transported by aircraft through the air space of the United States from a foreign nation to a foreign nation unless the Nuclear Regulatory Commission has certified to Congress that the container in which such plutonium is transported is safe, as determined in accordance with subsection (b), the second undesignated paragraph under section 201 of Public Law 94-79 (89 Stat. 413; 42 U.S.C. 5841 note), and all other applicable laws.

(b) RESPONSIBILITIES OF THE NUCLEAR REGULATORY COMMISSION.—

(1) DETERMINATION OF SAFETY.—The Nuclear Regulatory Commission shall determine whether the container referred to in subsection (a) is safe for use in the transportation of plutonium by aircraft and transmit to Congress a certification for the purposes of such subsection in the case of each container determined to be safe.

(2) TESTING.—In order to make a determination with respect to a container under paragraph (1), the Nuclear Regulatory Commission shall—

(A) require an actual drop test from maximum cruising altitude of a full-scale sample of such container loaded with test materials; and

(B) require an actual crash test of a cargo aircraft fully [77] loaded with full-scale samples of such container loaded with test material unless the Commission determines, after consultation with an independent scientific review panel, that the stresses on the container produced by other tests used in developing the container exceed the stresses which would occur during a worst case plutonium air shipment accident.

(3) LIMITATION.—The Nuclear Regulatory Commission may not certify under this section that a container is safe for use in the transportation of plutonium by aircraft if the container ruptured or released its contents during testing conducted in accordance with paragraph (2).

(4) EVALUATION.—The Nuclear Regulatory Commission shall evaluate the container certification required by title II of the Energy Reorganization Act of 1974 (42 U.S.C. 5841 et seq.) and subsection (a) in accordance with the National Environmental Policy Act of 1969 (83 Stat. 852; 42 U.S.C. 4321 et seq.) and all other applicable law.

(c) CONTENT OF CERTIFICATION.—A certification referred to in subsection (a) with respect to a container shall include—

(1) the determination of the Nuclear Regulatory Commission as to the safety of such container;

(2) a statement that the requirements of subsection (b)(2) were satisfied in the testing of such container; and

(3) a statement that the container did not rupture or release its contents into the environment during testing.

(d) DESIGN OF TESTING PROCEDURES.—The tests required by subsection (b) shall be designed by the Nuclear Regulatory Commission to replicate actual worst case transportation conditions to the maximum extent practicable. In designing such tests, the Commission shall provide for public notice of the proposed test procedures, provide a reasonable opportunity for public comment on such procedures, and consider such comments, if any.

(e) TESTING RESULTS: REPORTS AND PUBLIC DISCLOSURE.—The Nuclear Regulatory Commission shall transmit to Congress a report on the results of each test conducted under this section and shall make such results available to the public.

[77] Copy read "full".

APPENDIX 1 (CONTINUED)
REPRINT OF SECTION 5062 OF PUBLIC LAW 100-203

President of U.S.

(f) ALTERNATIVE ROUTES AND MEANS OF TRANSPORTATION.—With respect to any shipments of plutonium from a foreign nation to a foreign nation which are subject to United States consent rights contained in an Agreement for Peaceful Nuclear Cooperation, the President is authorized to make every effort to pursue and conclude arrangements for alternative routes and means of transportation, including sea shipment. All such arrangements shall be subject to stringent physical security conditions, and other conditions designed to protect the public health and safety, and provisions of this section, and all other applicable laws.

(g) INAPPLICABILITY TO MEDICAL DEVICES.—Subsections (a) through (e) shall not apply with respect to plutonium in any form contained in a medical device designed for individual human application.

(h) INAPPLICABILITY TO MILITARY USES.—Subsections (a) through (e) shall not apply to plutonium in the form of nuclear weapons nor to other shipments of plutonium determined by the Department of Energy to be directly connected with the United States national security or defense programs.

(i) INAPPLICABILITY TO PREVIOUSLY CERTIFIED CONTAINERS.—This section shall not apply to any containers for the shipment of plutonium previously certified as safe by the Nuclear Regulatory Commission under Public Law 94-79 (89 Stat. 413; 42 U.S.C. 5841 note).

(j) PAYMENT OF COSTS.—All costs incurred by the Nuclear Regulatory Commission associated with the testing program required by this section, and administrative costs related thereto, shall be reimbursed to the Nuclear Regulatory Commission by any foreign country receiving plutonium shipped through United States airspace in containers specified by the Commission.

APPENDIX 2
THE PSA 1771 CRASH SITE CHARACTERISTICS AND GEOTECHNICAL PROPERTIES

PSA Crash Site Description

The geotechnical criteria for the designated impact area for the package drop and aircraft crash tests (see Sections 2.2.7.4 and 3.2.7.4) are based on data from extensive in-situ testing performed at the PSA 1771 crash site. The crash site is located near the top of an east-facing hillside at an approximate elevation of 403 m (1322 ft) above mean sea level (see Fig. 1-3). The crash site slopes steeply; slope gradients vary from about 20 to 40 percent in the vicinity of the impact point near the edge of a wooded area. According to the landowners, the aircraft destroyed about a half-dozen oak trees during impact. However, most of the area involved was grass-covered.

Site Geology

The impact site is covered with about 0.15 to 0.6 m of dark brown, root-bearing clayey silt colluvial soil that contains variable amounts of sand and weathered rock fragments. The colluvial soil is generally loose and shows evidence of downslope creep.

Beneath the colluvial soil cover at the crash site is a sequence of interbedded clay shales and fine-grained sandstones mapped by Hall (Ref. A2-1) as the late Mesozoic Toro Formation. Lenses of very hard, calcareous siltstone and sandstone occur locally within these rocks. Beds within the shale-sandstone sequence are typically 6 to 75 mm thick. In the vicinity of the crash site the beds strike northwest and dip 50°-70° toward the southwest.

The impact point is approximately 90 m (295 ft) southwest of a branch of the Nacimiento Fault System, a major geologic feature of the Central California Coastal ranges (Ref. A2-2). The Nacimiento Fault System was an important tectonic feature during the late Mesozoic and early Cenozoic eras of earth history (50-150 million years ago) but has not been active in geologically recent times (Ref. A2-3). However, as a result of past tectonic activity, the beds of the Toro Formation at the crash site have been intensely fractured and sheared. Rock Quality Designation (RQD) values even for lightly weathered to unweathered rocks beneath the crash site average less than 30, "poor" rock in a geotechnical sense.

In addition to this intense deformation, near-surface portions of the bedrock sequence have been further weakened by intense weathering and in-place decomposition. These processes have reduced the upper 4.5 to 9 m of the shale-sandstone sequence to materials in which the bedrock structure is generally visible but which have the geotechnical properties of hard soil or very weak rock.

Geotechnical Properties

Investigation of the earth structure of the PSA 1771 crash site included aerial and land surveys, field exploratory drilling and soil/rock sampling, field geotechnical measurements, in-situ dynamic penetrating tests, and laboratory tests on soil/rock samples. The best estimates or average values and the coefficient of variation for each, listed in Table A2-1, are based on the results of these investigations and data for similar geological material. The penetrability constants are calculated from Eq. (1) below, in which the penetration depths were measured from the dynamic penetrating tests. RQD values were determined by a modified core-logging procedure during the exploratory drilling at the site. Unconfined compressive strengths were obtained from laboratory tests on the intact core samples. Shear and compression wave velocities were determined by the seismic downhole survey made at the site. The density and porosity of soil/rock samples were obtained from laboratory tests.

Penetrability (S-number)

The penetrability (*S*-number) is an empirical constant based on soil properties averaged over the penetration distance of a special instrumented projectile (penetrator). The *S*-number reflects the hardness of the geological materials under the dynamic loading of a penetrator. The penetrability constant was first introduced by Young in 1967 (Ref. A2-4) as a measure of earth penetration. Using an experimental data base, Young developed empirical equations to calculate the penetration depth in natural earth materials and to estimate the average and peak axial deceleration of the penetrator (Ref. A2-5). In 1972, the depth prediction capability was refined to predict penetration in layered systems by earth penetrators of various configurations (Ref. A2-6).

Equation (1) has been used to predict penetration depth in a uniform layer of rock or soil (excluding frozen soil) for projectile impact velocities in excess of 200 ft/s.

$$Z = 0.0031\, SN(W/A)^{1/2}\,(V - 100). \qquad (1)$$

where

Z	=	penetration distance (ft),
S	=	soil or rock penetrability constant,
N	=	nose performance coefficient
W	=	projectile weight (lb),
A	=	projectile cross-sectional area (in^2),
V	=	impact velocity (ft/s).

Table A2-1. Geotechnical measurements at the PSA 1771 crash site.

	Best Estimate or Average	Coefficient of Variation*
Penetrability constant (S-number):		
Intensely weathered rock	2.5 ± 0.5	
Soil	3.4 ± 0.3	
Rock quality designation (RQD):		
Intensely weathered rock	15	0.9
Unconfined compressive strength (MPa):		
Weathered rock	27.0	0.4
Unweathered rock	119.0	0.2
Weathered and unweathered rock	73.0	0.6
Unconsolidated undrained strength (MPa):		
Soil	0.76 ± 0.35	
Seismic wave properties (upper 5 m):		
Shear wave velocity (m/s)	610	0.3
Compression wave velocity (m/s)	1320	0.3
Bulk density (kg/m^3):		
Rock	2370	0.1
Soil	2090	0.1
Water content, soil (%)	16.2	0.3
Porosity (%):		
Rock	8.0	
Soil	32.0	0.2

* The coefficient of variation is provided for those parameters where sufficient data are available.

Conversely, if the penetration depth and velocity are measured for a penetrator of known geometry and mass, the S-number can be determined. By rearranging Eq. (1), we obtain Eq. (2),

$$S = \left[\frac{8562}{N\left(\frac{W_M}{A_M}\right)^{1/2}}\right]\left[\frac{Z_M}{(V_M - 30.5)}\right], \qquad (2)$$

where the parameters are as defined above but with their values in SI units. The subscript M is used in Eq. (2) to distinguish those parameters having SI values.

It should be noted that in cases where the penetrator has a tapered or flared body (as is the normal case) the cross-sectional area A is calculated using the average body diameter.

The nose performance coefficient of an earth penetrator is normalized relative to that of a standard penetrator which has a tangent ogive nose with a caliber-radius-head (CRH) value of 6.0 and whose nose performance coefficient, N, is taken as 1.0. Nose performance coefficients vary from 0.56 for a flat nose to 1.34 for a conical nose with length-to-diameter ratio of 3.

The S-number determined from Eq. (2) is an average for the soil over the entire penetration path. This average S-number is adequate for relatively homogeneous soils. However, it is necessary to use different S-numbers for the discrete layers of a layered soil system. Table A2-2 (from Ref. A2-5) lists several test sites with brief soil descriptions and corresponding S-numbers.

Table A2-2. Rock/soil description and corresponding S-numbers. (Modified table from Ref. A2-5.)

Test Site	Soil Description	Depth, m	S-number
Tonopah Test Range and Nevada Test Site, NV	Rock, highly welded, fine-grained agglomerate	0 - 3	1.1
Grants, NM	Sandstone, tres hermanos	0 - 9*	1.3
Northrup Strip WSMR, NM	Gypsite, selenite, hard, moist very homogeneous	0 - 6*	2.5
Main Dry Lake, Tonopah, NV	Sand, silty, very dense, dry, well cemented	2.5 - 7.5	2.5
Eielson AFB, AK	Silt, clayey, frozen (permafrost)	0 - 9*	3.8
Gulkana Glacier, AK	Ice glacier	0 - 6*	4.1
Tonopah test range, NV	Sand, silty, clayey, dense (desert alluvium)	0 - 30*	4.4
Main Dry Lake, Tonopah, NV	Clayey silt, silty clay, dense, hard, dry	0 - 2.5	5.2
Main Dry Lake, Tonopah, NV	Sand, silty, clayey, dense, dry to damp	7.5 - 25*	5.2
Salt target, WSMR, NM	Clay, silty, very stiff, tan with traces of sand, highly montmorillonitic	0.5 - 2.5*	6.5
Eglin AFB, FL	Sand, loose to medium, moist	0 - 21*	7.0
Bryan AFB, TX	Clay, moist, stiff	0 - 4.5*	10.5
Skaggs Island, CA	Clay, silty, wet (bay mud)	0 - 15*	40
Salt target, WSMR, NM	Clay, silty, soft, wet, brown	0 - 0.5	40
Great Salt Lake, Desert, UT	Clay, soft, wet, gray, varved, medium to high plasticity	0 - 4.5*	50

* At least the indicated depth.

The empirical equations for predicting depth of penetration by a penetrator were updated in 1988 (Ref. A2-7). The basic equations have not changed, even though the experimental data base has increased significantly since 1967. The data base indicates that Eq. (1) can be used for both soil and rock. Newer data indicate that Eq. (1) must be modified for lightweight penetrators. For penetration in soils (penetrator weight below 60 lb), the right-hand side of Eq. (1) must be multiplied by a correction factor $K_s = 0.2\ W^{0.4}$, while for penetration in rock (penetrator weight below 400 lb), the correction factor $K_r = 0.166\ W^{0.3}$ is used.

Typical *S*-numbers for soil and rock are given in Table A2-3. It is noted that the *S*-number for soils ranges from 2 for dense cemented sand to 9 for moderately dense sand. The *S*-number for rock ranges from 0.5 for "hard" rock with some cracks and fissures to 5.0 for soil-like, severely weathered rock.

Table A2-3. Ranges of *S*-numbers for various soil/rock materials. (From Ref. A2-7, modified.)

0.5 - 1.4	Hard rock with crack spacing of 0.2 to 1.2 m (the *S*-number varies inversely with crack spacing). This is the effect of cracks and fissures, independent of the weathering effects.
1 - 2.5	Weathered rock, but still "rock". To some extent, weathering will result in lowering the unconfined strength and increasing the bulk porosity. Weathering may also drastically increase the size of the cracks or fissures, resulting in hard blocks of rock, with several centimeters of a soil-like material between blocks. Weathering may be very superficial, but typically may extend over 10 m below the rock surface. Bedrock at depth may or may not be weathered, depending on when the soil cover was laid down relative to when the weathering occurred.
2.5 - 5	Technically weathered rock, but having the appearance and feel of soil. It can usually be dug with a shovel and has a porosity similar to that of soil.
2 - 4	Dense, dry, cemented sand (such as the hard layers in the dry lake playas at the Tonopah Test Range). Dry caliche. Massive gypsite and selenite deposits (White Sands Missile Range, WSMR).
4 - 6	Sandy gravel, no cementation.
6 - 9	Moderately dense to loose sand (>80% sand), no cementation, water content not important.

Rock Quality Designation (RQD)

Natural rock formations often contain joints and fractures, so that the unconfined compressive strength of intact core specimens may fail to characterize the rock as a whole. The RQD has been used as an index for the degree of fracturing of the in-situ rock at a given site (Ref. A2-8). The RQD value is determined by a modified core-logging procedure: The lengths of all solid pieces of core at least 10 cm long are added up, and this length is called the modified core recovery. The modified core recovery, when divided by the total length of the core run and multiplied by 100, is the value of RQD in percent.

References

A2-1. C. A. Hall, Geologic Map of Cambria Region, San Luis Obispo County, CA, U.S.G.S. Misc. field studies, Map MF-599, 1974.

A2-2. California Division of Mines and Geology (CDMG), Geologic Map of California, San Luis Obispo Sheet, CDMG, Sacramento, CA, 1978.

A2-3. E. W. Hart, private communication, CDMG, May, 1989.

A2-4. C. W. Young, The Development of Empirical Equations for Predicting Depth of an Earth-Penetrating Projectile, Sandia National Laboratories, Albuquerque, NM, SC-DR-67-60, May 1967.

A2-5. C. W. Young, Depth Prediction for Earth-Penetrating Projectiles, Journal of Soil Mechanics and Foundations Division, Proc. Am. Civil Engineers, p. 803, May 1969.

A2-6. C. W. Young, Empirical Equations for Predicting Penetration Performance in Layered Earth Material for Complex Penetrator Configurations, Sandia National Laboratories, Albuquerque, NM, SC-DR-72-0523, December, 1972.

A2-7. C. W. Young, Equations for Predicting Earth Penetration by Projectiles: An Update, Sandia National Laboratories Report SAND88-0013, Advanced Projects Division II, Sandia National Laboratories, Albuquerque, NM, July 1988.

A2-8. D. V. Deere, Technical Description of Rock Cores for Engineering Purposes, Rock Mechanics and Engineering Geology, Journal of International Society of Rock Mechanics (Springer-Verlag, Vienna), Vol. 1, p. 16, 1963.

APPENDIX 3
CURRENTLY CERTIFIED PAT PACKAGES

The first PAT package approved by the NRC for air transport of plutonium was the PAT-1, certified in 1978 (Ref. A3-1). This package (see Fig. A3-1) consists of three basic parts: (1) the stainless steel product can, designated PC-1, contained within a containment vessel, (2) the stainless steel outer containment vessel, designated TB-1, and (3) a protective overpack assembly designated AQ-1. TB-1 serves as the containment vessel for the purpose of meeting the requirements of 10 CFR 71 (Ref. A3-2) and the NRC Qualification Criteria (Ref. A3-3). PC-1 serves as a separate inner container as required by 10 CFR 71.42.

The PC-1 product can in the center of the package contains the plutonium to be transported. Its maximum capacity is 2.0 kg of plutonium oxide having a maximum decay heat of 25 W. Surrounding the product can is the sealed TB-1 containment vessel. Outside TB-1 is a heat conductor element that transfers decay heat from the plutonium oxide to the outer redwood assembly, through which it travels to the outside drum of the overpack assembly. Between the TB-1 and the AQ-1 overpack assembly is a thick section of redwood as energy-absorbing material; the redwood is actually in two sections—inner and outer annular sections—which are separated by a cylindrical aluminum load-spreader assembly. The overpack assembly consists of an outer stainless steel drum fully lined with an inner drum of the same material. Approximate outer dimensions of the package are diameter 0.6 m and height 1.1 m, giving an overall volume of about 0.33 m^3. Overall weight of the package is about 225 kg. Average specific gravity is about 0.7.

The second PAT package approved by the NRC for air transport of plutonium was the PAT-2, certified in 1981 (Ref. A3-4). This package (see Fig. A3-2) has somewhat similar construction to the PAT-1 package, but is designed for smaller quantities of plutonium—ranging from a maximum of 3 g of plutonium sulfate tetrahydrate or plutonium nitrate dihydrate to a maximum of 120 g of sintered plutonium oxide. A maximum of 15 g of fissile isotopes Pu-239 and Pu-241 is allowed. Approximate outer dimensions of the package are diameter 0.38 m and height 0.36 m, giving an overall volume of about 0.04 m^3. Overall weight of the PAT-2 package is about 33 kg. Average specific gravity is about 0.8.

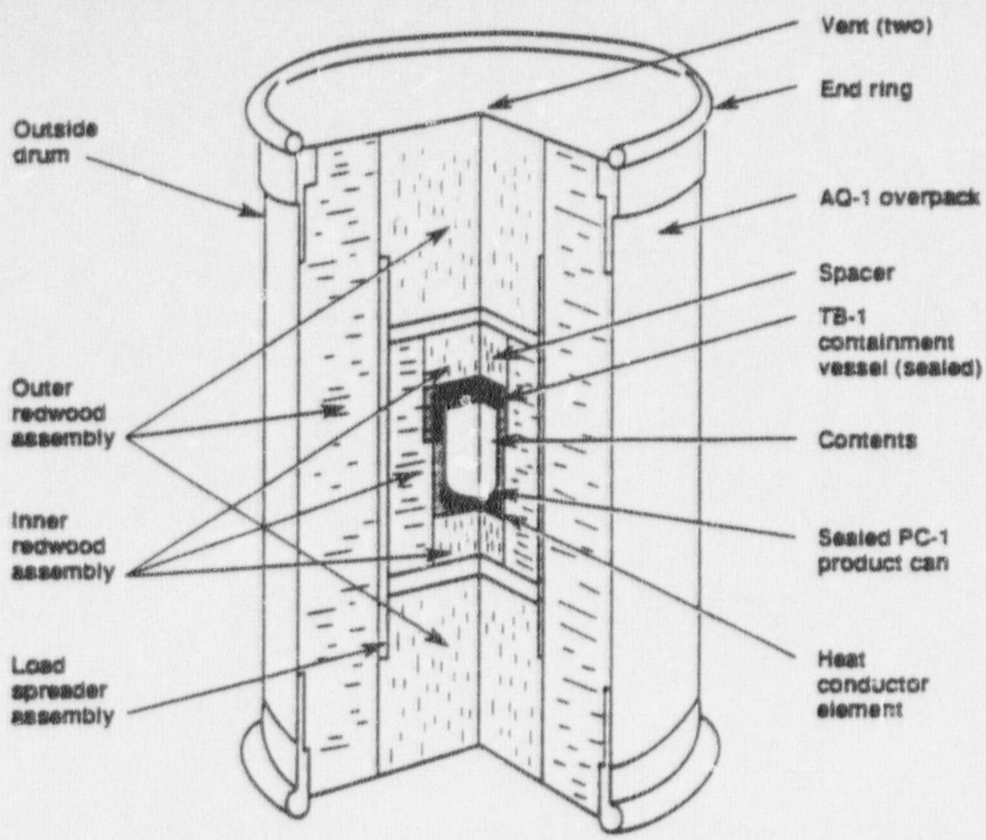

Fig. A3-1. Cutaway view of the first (1978) plutonium air-transportable package (PAT-1) certified by the NRC. Note the specific grain orientation in the redwood.

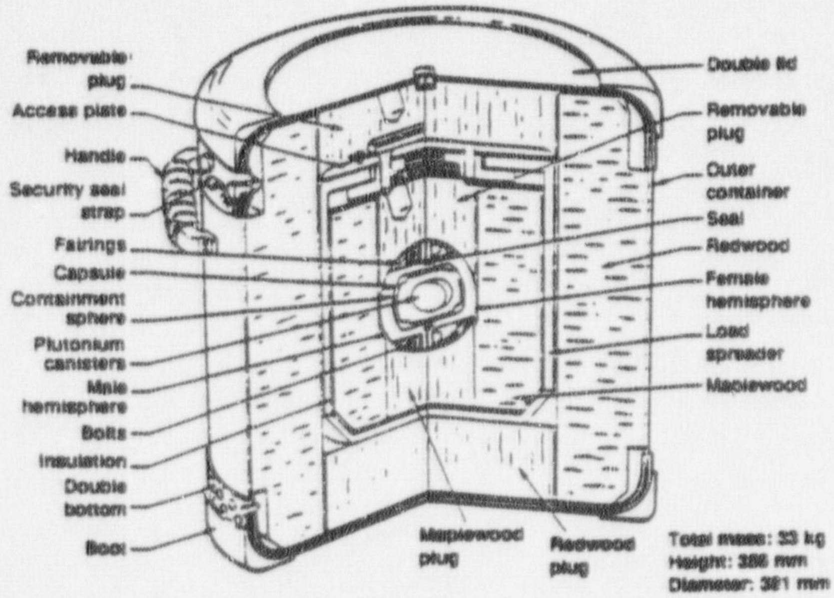

Fig. A3-2. Cutaway view of the second (1981) plutonium air-transportable package (PAT-2) certified by the NRC. Maximum capacity is considerably smaller than for PAT-1, ranging from 3 g of plutonium sulfate tetrahydrate to 120 g of sintered plutonium oxide.

References

A3-1. Nuclear Regulatory Commission, Plutonium Air Transportable Package Model PAT-1: Safety Analysis Report, NUREG-0361, 1978.

A3-2. Nuclear Regulatory Commission, Packaging of Radioactive Material for Transport and Transportation of Radioactive Material Under Certain Conditions, Title 10 Code of Federal Regulations, Part 71 (10 CFR 71).

A3-3. Nuclear Regulatory Commission, Qualification Criteria to Certify a Package for Air Transport of Plutonium, NUREG-0360, January 1978.

A3-4. Sandia National Laboratories, Albuquerque, NM, PAT-2 (Plutonium Air-Transportable Model 2) Safety Analysis Report, SAND81-0001, 1981.

APPENDIX 4
SUMMARY OF THE FAA/NASA CONTROLLED IMPACT DEMONSTRATION TEST

Introduction

In 1984, the Federal Aviation Administration (FAA) and the National Aeronautics and Space Administration (NASA) conducted a controlled impact demonstration (CID) test using a remotely piloted jet transport aircraft. This Appendix contains a brief summary of the test program as described in Refs. A4-1 and A4-2.

The CID test was conducted at Edwards Air Force Base, California (Air Force Flight Test Center), for the acquisition, demonstration, and validation of technology for the improvement of transport aircraft occupant crash survivability. The objectives of the CID program were (1) to demonstrate a reduction of postcrash fire through the use of antimisting fuel, (2) to acquire transport crash structural data, and (3) to demonstrate the effectiveness of existing improved seat-restraint and cabin structural systems.

The aircraft used in the CID test was a four-engine Boeing B-720 jet transport manufactured in the early 1960s. The crash scenario was to be representative of a survivable accident, such as could occur following a missed landing approach or an aborted takeoff. The single initial objective of the test was to demonstrate that, under these conditions, an antimisting compound added to the jet fuel would inhibit fire at impact. Additional test objectives subsequently were introduced which eventually compromised achievement of the initial objective.

Flight Requirements

The airspeed, sink rate, and pitch angle were selected to maintain fuselage integrity during acquisition of longitudinal and vertical acceleration data at impact. Combining all the CID test objectives into one flight resulted in a desired set of impact conditions as shown in Table A4-1.

Table A4-1. Impact flight specifications and measurements for the CID test.

	Specification	Measurement
True airspeed (m/s)	78.5 ± 1.3	77.9
Rate of sink (m/s)	5.2 ± 0.3	5.3
Pitch angle (deg)	1 ± 1	-0.25
Bank angle (deg)	0 ± 2	-12
Heading (deg)	0 ± 2	1.5
Lateral displacement (m)	0 ± 4.6	+6.1 (right)
Longitudinal displacement (m)	0 ± 22.9	-86 (short)

It was further specified that the impact would be with the landing gear in the retracted position, flaps at 30°, and a maximum amount of fuel aboard. With the landing gear retracted, it became necessary to construct "wing-cutter" stanchions in the impact area to provide a mechanism for fuel spill and to impact precisely with respect to these stanchions so as to cut the wings.

Test Aircraft

The Boeing B-720 aircraft is a swept-wing, swept-tail, four-engine, medium-range jet transport. Its empty weight is 44,500 kg, and the structural design gross weight is 92,300 kg. The gross weight at takeoff for the impact flight was 91,000 kg.

Extensive modifications were required to convert the test aircraft from a piloted (crew of three) to a remotely piloted vehicle while retaining the piloted capability of the crew for RPV checkout. Instrumentation was added to support each experiment on the flight and the RPV systems.

Primary flight controls were ailerons, elevator, and rudder. The ailerons and elevator were controlled by aerodynamic tabs and assisted by aerodynamic balance panels. The rudder was hydraulically powered and assisted by aerodynamic balance panels; however, a manually operated aerodynamic tab backup was provided. The outboard ailerons were designed to stay in the faired position with the flaps retracted and then to operate with increasing authority as a function of increasing flap deflection. Upper wing surface spoilers augment roll control with the inboard ailerons and also operate as speed brakes. Double slotted flaps and leading edge flaps provide lift and drag control for slow-speed flight.

Pitch trim was through a variable incidence stabilizer. Roll and yaw trim were operated through aileron and rudder, respectively. The existing PB-20D autopilot was modified and used to operate as the primary RPV flight control. Unused portions of the autopilot were deactivated as a part of the modification for remotely piloted operation to eliminate potential failure points.

Flight Test Procedure

The primary approach in checking out the B-720 RPV systems was piloted flight tests. Both the on-board pilot and copilot could disengage all RPV system functions with a disengage switch on their cockpit control wheels.

Prior to the final unmanned flight, 14 piloted test flights were made with the crew aboard. These flights included 10 remote takeoffs, 13 remote landings, and 69 remote approaches (planned test flight aborts). All remote takeoffs were flown from the Edwards main runway, and remote landings were made on an emergency-recovery lakebed runway. During the remotely controlled portions of these test flights, the crew aboard the airplane kept hands off but were ready to take over should the remote control fail.

Remotely Piloted Vehicle System

The existing autopilot was capable of receiving instrument landing system (ILS) radio signal command inputs to the elevator and aileron channels. Replacing the ILS radio signal command paths with uplinked elevator and aileron command signals provided the basic RPV capability. Rudder pedal commands were added to the basic parallel yaw damper. The autopilot retained its orientation-hold feedback paths so that only uplink commands from the ground were required; that is, no feedback paths from the aircraft were required to be closed on the ground. Both proportional and discrete commands had to be implemented from the ground station. Primary pitch, roll, and yaw commands, as well as the throttle and brakes, were proportional, while flaps, engine fuel shutoff, landing gear up-down, nosewheel steering left-right, and emergency brakes were discrete commands. The ground system was primarily dual-channel for increased reliability; however, some less critical elements were single-channel. The airborne system was simplex or single-channel.

Emergency Flight-Termination System

An independent emergency flight-termination system was installed aboard the B-720 aircraft to ensure that it would not pose a threat to populated areas in the event of any RPV guidance system failure. This system was designed to be isolated, as much as possible, from the on-board B-720 flight control systems. Activation of the emergency flight-termination system resulted in the following actions on board the aircraft:

- Engine 1, 3, and 4 fuel valves were commanded to the off position immediately. To retain aircraft electric and hydraulic power, the number 2 engine was programmed to shut down 25 s later.
- Emergency pneumatic brakes were activated.
- Landing gear was lowered.
- Throttles were moved to the idle position.
- Stabilizer was commanded to the maximum leading edge up (nose down) position.
- Rudder was commanded to full nose right.

The flight-termination command was irreversible, once issued. It was demonstrated during ground tests, but was not active during piloted flights.

Test Results

The final CID test flight was made on December 1, 1984. Complete results of the test are given in Ref. A4-1.

The aircraft came down with the left wing low, 86 m short of the desired impact point. The number one engine struck the ground and forced the aircraft into a 35-40° left yaw angle. Only the right wing at the inboard engine engaged a wing cutter, and the aircraft fuel immediately erupted in flames.

The final RPV flight proved to be a more demanding task for the remote pilot than the earlier practice RPV landings. Not all of the impact parameters were achieved. The actual impact conditions compared to the design goals are summarized in Table A4-1.

References

A4-1. T. W. Horton and R. W. Kempel, "Flight Test Experience and Controlled Impact of a Remotely Piloted Jet Transport Aircraft," NASA Technical Memorandum 4084, 1988.

A4-2. W. Westfield, FAA Technical Center, Atlantic City, NJ, personal communication, February 1989.

Technical Information Department · Lawrence Livermore National Laboratory
University of California · Livermore, California 94551