UCRL-ID-104553
PATC-IR 89-08

TECHNICAL FEASIBILITY OF A PAT PACKAGE DROP TEST

December 28, 1989

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Prepared for
U.S. Nuclear Regulatory Commission

DISCLAIMER

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

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ABSTRACT

This report reviews the technical feasibility of drop-testing a plutonium air transport (PAT) package to satisfy a requirement of Public Law 100-203. All principal tasks that must be done to complete the test program are identified, and methods for accomplishing the tasks are suggested. At least one of several candidate test ranges is an acceptable test site, a C-130 aircraft is the example drop-test aircraft, and tracking radar and cinetheodolite cameras are the example equipment for tracking the test package during free fall and measuring its trajectory parameters. The results of this review indicate that the test criteria for a PAT package drop test specified in Ref. 1, are technically feasible and that the test can be successfully accomplished.

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1. INTRODUCTION

The criteria for drop-testing a plutonium air transport (PAT) test package from an aircraft are specified in Ref. 1. The present report assesses the technical feasibility of satisfying those criteria by describing an example methodology by which the drop test can be accomplished. The assessments are based on supporting analyses and available equipment, technology, and test ranges that would be suitable for conducting the test.

1.1 Background

Section 5062 of Public Law 100-203 defines specific tests required for certifying packages designed for transporting plutonium in aircraft from one foreign country to another through U.S. airspace. One of these tests, which is the subject of this report, is an air drop of a PAT test package from the maximum cruising altitude of the cargo aircraft in which the PAT package will be carried. The U.S. Nuclear Regulatory Commission (NRC) funded the Nuclear Systems Safety Program of Lawrence Livermore National Laboratory to define the criteria for this test, which are documented in Ref. 1.

The criteria in Ref. 1 are based on extensive background information developed specifically for this purpose. Studies pursued in obtaining the information included performing ballistic analyses of candidate packages, making surveys of candidate test ranges, identifying aircraft that would be suitable for dropping the test package, and selecting appropriate test instrumentation and equipment. Much of this information was obtained during visits to U.S. military test ranges. The information is used here to develop an example test methodology from which a corresponding technical feasibility assessment is made. The example methodology is intended solely for this purpose. If test plans and design details are further developed, other methods for accomplishing the test may be discovered and preferred.

1.2 Test Criteria

Public Law 100-203 specifies that one of the certification requirements for a PAT package design is to drop-test a full-scale PAT test package from the maximum cruising altitude of the cargo aircraft designated to carry the package. The primary acceptance criterion specified by the law for this test is that the plutonium container dropped in the test shall not rupture or release any of its contents.

Reference 1 further defines and interprets the test requirements specified in Public Law 100-203. For example, Ref. 1 allows the test package to be dropped from a lower altitude than the law's "maximum cruising altitude". This would be allowed if the resulting ground impact velocity is not less than the sea level impact velocity when dropped from the maximum cruising altitude. Also defined in Ref. 1 are the maximum amount of plutonium that can be released from the dropped test package and still qualify as nonrelease, which is an A_2 quantity per week (see Ref. 2 for definition of an A_2 quantity), and the minimum ground hardness in the impact area, which is equivalent to severely weathered, and fractured shale and sandstone.

2. FEASIBILITY ASSESSMENT

The principal technical requirements for successfully completing a PAT package drop test are reviewed. The conclusion of the assessment is the criteria specified in Ref. 1 are technically feasible. Table 1 summarizes the items that were addressed and corresponding assessments that lead to this conclusion. Details are given in the following.

Table 1. Summary of technical feasibility review of PAT package drop test.

ITEM	REMARKS
1. Geotechnical properties	Required properties expected to exist at several candidate test ranges; measurements of selected target area are needed.
2. Safety	All requirements achievable at several candidate test ranges.
3. Accessibility	Acceptable at several candidate test ranges.
4. Weather	Suitable at several candidate test ranges.
5. Environmental impact	Will not be an issue at several candidate test ranges.
6. Services	Required services available at several candidate test ranges.
7. Test package modifications	Not needed.
8. Surrogate plutonium	Acceptable materials available; selection must be made.
9. Test package ballistics	Computer code available; ballistic properties of package are needed.
10. Drop altitude	Can be lower than maximum cruising altitude of cargo aircraft.
11. Test aircraft	C-130, B-52 or helicopter, aircraft would be acceptable, depending on drop altitude.
12. Aircraft modifications	Not needed; instrumentation, data recorders, and package release device will probably be needed.
13. Package drop	Can be done with C-130, B-52 or helicopter aircraft, using drag parachute and timed release device. Impact accuracy is acceptable.
14. Drop measurements	Cinetheodolite cameras with tracking radar can be used.
15. Package recovery	Test instrumentation can be used to locate; conventional equipment can be used to recover the package.
16. Package testing	Leakage testing applied to PAT-1 package can be used.
17. Rehabilitation of impact area	Conventional equipment can be used.
18. Reliability	Expected to be high; analysis needed to assure success.

2.1 Test Site Selection

The drop test area must have acceptable geotechnical properties and be in a location that will provide adequate safety, be sufficiently accessible (for soil testing and package recovery), and be near enough to needed services. To determine if an acceptable test site will be available, several military test range installations were visited. Information received indicated that at least one of them will be able to meet the site selection criteria. This is the example test range for this feasibility assessment. The example range is not stated so that a future selection process will not be jeopardized.

2.1.1 Geotechnical Properties of Impact Area

Preliminary geotechnical properties survey has been made at several candidate test ranges. At least one of the candidate ranges has properties that are approximately equivalent to the criteria specified in Ref. 1. Therefore, suitable surface conditions can probably be found at a test range. To confirm acceptability of a selected target area, several standard geotechnical measurements must be made to define the geotechnical properties.

2.1.2 Safety

Providing for safety is of paramount consideration in selecting the drop test site. The drop area must be uninhabited and large enough to insure complete safety during the test. In addition, the test area must have controlled access to prevent anyone from entering it during the test.

These requirements can be satisfied at several candidate ranges. They have test areas that are uninhabited and remote from populated areas, and all entry points can be controlled. A drop area approximately 2 km in diameter is needed to insure safety. The example range can provide a test area that is several times the minimum required safety radius. In addition, the range management enforces established safety requirements.

The drop test program will include an approved safety plan. This plan must satisfy all the safety requirements imposed by the range management and the NRC. With the approved safety plan, high confidence is assured that the drop test can be performed without a safety incident.

2.1.3 Accessibility

The drop area must be traversable by vehicles so that geotechnical measurements can be made and test equipment installed before the drop, and so that the test package can be readily recovered after the drop. Also, the drop area must be reasonably close to the airfield used by the drop aircraft.

The example test area is in a region of moderately rough terrain that can be easily entered with four-wheel-drive vehicles. A temporary road could be easily made from nearby paved roads to the drop area if needed. Also, the example test range is located near a suitable airfield. Therefore, the example test area has adequate accessibility.

2.1.4 Services Available

Various types of equipment, facilities, and services will be needed to perform the drop test:

1. Equipment to recover the test package after it is dropped.
2. Radar and photo tracking equipment to follow the package during the drop.
3. Atmospheric measurements.
4. Soil measurements.
5. Ground security control.
6. Facilities for pre- and post-drop testing (e.g., package leakage tests).

All of these services are available from either the candidate ranges or nearby contractors.

2.1.5 Weather

The drop test should be conducted where the normal weather provides many periods of good visibility, no precipitation, and little wind. The weather conditions at the example range have been reviewed and found to be suitable for a drop test.

2.1.6 Environmental Impact

All of the drop test activities must conform to the National Environmental Policy Act requirements. However, the nature of these activities is such that it can be readily shown that they will not affect the quality of the environment, they will not be environmentally controversial, nor will they evoke any litigation. Therefore, any assessment of environmental impact will most likely result in a finding of no significant impact. Also, the example range has in place with overseeing agencies the requisite environmental impact reports addressing all test activities at the range. The package drop test would be covered under this umbrella as well as being under the scrutiny of the range management.

2.2 Test Package

The following discussion describes how a PAT test package can be feasibly provided for a successful test.

2.2.1 Modifications

Items may be added to the test package, such as instrumentation or components for releasing the package from the drop aircraft, as long as they do not alter the ballistic or structural characteristics of the test package. However, such items can be avoided; a conceptual design has been developed for release equipment that does not require any modification of the test package. Furthermore, there should be no need to install instrumentation on the test package. The package's free-fall ballistic trajectory and velocity can be tracked with cinetheodolite cameras and radar from release to ground impact. High speed photography during impact can also be achieved. The only additions to the test package that would be needed are non-intrusive painted photographic targets and radar reflectors. The example test range services can provide the camera and radar equipment.

2.2.2 Surrogate Plutonium

For safety, a surrogate material will be used in place of plutonium in the test package. The surrogate material must be nontoxic and match the physical properties of the plutonium as much as practical, so that mechanical stresses in the test package during impact will not be less than they would be if plutonium were used. Several surrogate materials can be formulated from a tailored mixture of nontoxic pure metal, metal oxide, or metal carbide powders (e.g., iron, copper, or tungsten) having the same average density and particle size distribution as the plutonium oxide powder the PAT package is designed to carry.

2.3 Ballistic Analysis

A detailed ballistic analysis of the test package is required to determine its expected trajectory and velocity during its free fall from release to ground impact. Results of this analysis will be used to determine the required altitude and location of the package at release so that it will impact the designated target area at the required velocity.

A computer code has been developed specifically for ballistic analyses (Ref. 5). It can also be used to perform the ballistic analyses required to develop a test plan. In addition, it can be used a few minutes before the package is dropped, with the most recent atmospheric data included, to determine the optimum location for release of the package from the drop aircraft. In addition to atmospheric data, the code requires data on ballistic characteristics of the package, such as aerodynamic drag, profile dimensions, and mass.

Ballistic analyses of an example PAT package have been performed and results indicate that dropping the example package from an aircraft is feasible.

2.4 Drop Altitude Determination

In accordance with the test criteria stated in Ref. 1, a package release altitude that is lower than the maximum cruising altitude of the cargo aircraft is possible. This can occur because atmospheric density increases with decreasing altitude, and the package velocity during free fall can reach a maximum and then continuously decrease until impact, provided the package is released at a high enough altitude. An example cargo aircraft is a Boeing 747, which has a maximum cruising altitude of approximately 13.7 km (45,000 ft). An example package would weigh between 2.5 and 3.0 Mg and its volume would be between 2.7 and 3.2 m^3. The phenomenon of decelerating free-fall velocity noted above would probably occur for this example package released at this cruising altitude. A preliminary estimate of a minimum release altitude for the example test package without aerodynamic drag enhancers is approximately 7.3 km (24,000 ft). Dropping the example test package from this altitude is feasible.

2.5 Drop-Test Aircraft Selection

The test will require an aircraft that can be used to successfully drop the test package from a selected altitude. Aircraft available to the test area should be reviewed to determine which type is the most appropriate for the drop test. An aircraft that will satisfy the test requirements for the example package stated above is a C-130 military cargo aircraft. It is a high-wing, four-engine, turboprop aircraft with a rear cargo door that can be remotely operated during flight. It is typically used by the U.S. military to air-drop combat troops and equipment. These aircraft are operating from several Air Force Bases accessible to the candidate test ranges.

2.5.1 Aircraft Requirements

The drop test aircraft must be able to airlift a 3 to 4 Mg load (test package, drop pallet, parachute pack, release skid, data recorders, etc.) to the selected altitude and drop the load as required. The aircraft must be able to follow a specified heading and release the test package at a specified location in airspace. The C-130 aircraft satisfies these requirements for drop altitudes up to about 8 km. For higher altitudes, a B-52 aircraft is recommended. For altitudes up to about 5 km , a helicopter aircraft can be used. The navigation equipment in these aircraft can be used synchronously with radar tracking equipment to guide them to a specified drop point. Thus, these aircraft should be feasible for dropping the test package.

2.5.2 Aircraft Modifications

No modifications to the aircraft should be needed to perform the drop test. However, some special equipment will probably have to be installed in the aircraft.

Specifically, a structure will be needed to support the test package assembly and to provide for its release from the aircraft. A conceptual design that has been proposed for this structure in a C-130 aircraft (Ref. 6) supports the test package assembly on an incline so that when the assembly is released the package will slide naturally out the rear of the aircraft. A remotely controlled mechanism will be required to release the assembly on command.

Other additions to the aircraft that will probably be needed include data recorders for the aircraft flight parameters, such as heading, altitude, speed, package release, etc. There are several options for recording these data, and none of them poses any serious technical difficulties. Thus, aircraft modifications can be limited to installed equipment that are either commercially available or feasible to design and fabricate.

2.6 Required Drop-Test Tasks

Several major tasks are involved in performing the drop test:

1. The test package must be released for free fall in a manner that gives a high probability of hitting the selected impact area.
2. The test package's velocity and trajectory must be measured throughout its free fall to ground impact.
3. After impact, the test package must be located and recovered.
4. The recovered package must be tested to determine if it meets the leakage criteria.
5. The impact area must be rehabilitated.

Accomplishment of these tasks is feasible according to the following descriptions.

2.6.1 Test Package Drop

To achieve the best impact accuracy in the target area, it is desirable to reduce the horizontal velocity of the test package as much as practicable. The ground speed of the test aircraft can be reduced by flying into the wind and with the wing flaps partly extended to reduce the airspeed. This results in a release of the package assembly from the test aircraft at a minimum ground velocity.

After the test package assembly is released from the aircraft, its horizontal velocity can be further reduced before the package is released for free fall. A proposed method to accomplish this is with a parachute. The test package would be fastened to a pallet with straps that include explosive cutters. The pallet would also have a parachute pack attached. This assembly would be dropped from an aircraft, and the parachute would be deployed with a static drag line. A timing device connected to the explosive cutters would also be started when the pallet is dropped. After a set time, which would allow the assembly to slow down to a low velocity, the cutters would be actuated and the test package would fall free. This concept is described further in Ref. 6.

Also given in Ref. 6 is a probabilistic analysis of the accuracy achieved by dropping an example test package according to the above method. Typically, if a C-130 aircraft drops the package assembly at 7.3 km (24,000 ft), the probability of the package impacting within 1 km of a target is 99%. This accuracy could be improved by dropping the package assembly from a lower altitude; the minimum release altitude that provides the required impact velocity w · depend on the ballistic characteristics of the test package. Target accuracy can be further improved by performing practice drops before the drop test to provide calibration data. It is clear that target accuracies compatible with available radar and camera tracking systems' capability can be achieved.

2.6.2 Drop Measurements

Velocity and trajectory measurements of the test package during its free fall can be made with available tracking cinetheodolite camera and radar systems. By using measurements from three or more cameras and radar tracking beams, time-dependent values of velocity and spatial position can be determined. A primary value that will be needed is the ground impact velocity of the package. This can be accurately determined by extrapolation of the curve through values of measured velocities and altitudes to ground elevation. The tracking cameras have a framing rate of 30 frames per second at 0.001 second exposure per frame and a range of 15 km. The expected accuracy of the velocity measurements is within approximately 2 m/s.

As discussed in Section 2.5.2, other measurements should be made in the drop aircraft to correlate aircraft flight parameters with the package assembly drop. There are several available methods to accomplish this. For example, the existing flight data recorder could be used, or an additional data recorder could be installed.

2.6.3 Test Package Recovery

Locating the impact point is not expected to be difficult, although, depending on its design, the test package could penetrate the ground deep enough to be buried from view. The tracking radar can be used to determine the impact point within 30 m, and a visible crater should be created by the package impact. Once the impact point is located, conventional digging equipment, such as a backhoe machine and hand tools, can be used to extract the package from the ground. Such equipment is commonly available and can be transported to the impact area.

2.6.4 Test Package Leakage Testing

After recovery of the test package, evaluation tests must be performed to determine if the containment vessel (which for the drop test contains surrogate plutonium) satisfies the allowed leakage criterion specified in Ref. 1. That is, it must not release more than the equivalent of an A_2 quantity of plutonium per week (For a typical mixture of plutonium oxide powder, an A_2 quantity is approximately 2.5 mg). There are several possible methods for performing leakage tests that are prescribed by national and international standards organizations (Refs. 3 and 4). A recommended test method is one used on the PAT-1, a PAT package approved by the NRC for transport of plutonium oxide powder (Ref. 7). In this test a mass spectrometer is used to measure gas leakage rates from the containment vessel pressurized with helium. An equivalence between helium leakage and plutonium oxide release is theoretically determined. The vessel can also be accepted as leak tight if the helium leakage is less than 10^{-8} n.m /s (10^{-7} atm-cm^3/s). This method has been successfully. demonstrated with conventional vacuum equipment; thus, it is also feasible for a drop test package.

2.6.5 Rehabilitation of Impact Area

After completion of the drop test, the impact area must be rehabilitated to conditions established by the test range management. The equipment needed for this task is that typically used for commercial earth moving and construction.

2.7 Reliability Analysis

A reliability analysis of the PAT package drop test is prescribed in Ref. 1 to assure a high probability of successful completion of the test. Such an analysis helps to identify any components of a test plan or participating equipment that might pose an unacceptable level of reliability. If the analysis shows any questionable areas, appropriate corrective action can be taken before plans for the test are finalized. A reliability analysis will insure a successful test; it should be made during the design phase of the drop-test program.

3. CONCLUSIONS

In this feasibility review of the principal components of a PAT package drop test, there are no technical barriers to performing the test in an orderly and successful manner. An overall assessment points to the conclusion that conducting a drop test in accordance with the criteria specified in Ref. 1 is technically feasible.

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