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TECHNICAL FEASIBILITY OF A PAT AIRCRAFT CRASH TEST

December 13, 1989

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Prepared for
U.S. Nuclear Regulatory Commission

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ABSTRACT

This report reviews the technical feasibility of crashing an aircraft containing plutonium air transport (PAT) test packages 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, and a Boeing 707 aircraft, equipped with a remote guidance system and having appropriate structural modifications, is the example test aircraft. The results of this review indicate that the test criteria for the aircraft crash test specified in Ref. 1 are technically feasible and that the test can be successfully accomplished. Preparation for the test will require the development of a guidance system and the completion of all structural modifications that are needed to successfully fly the aircraft during the conditions preceding the crash. Access to existing data on the structural and flight characteristics of the test aircraft is necessary to complete these tasks.

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1. INTRODUCTION

The criteria for a crash test of an aircraft loaded with plutonium air transport (PAT) test packages are presented in Ref. 1. This crash test must be performed to demonstrate that the PAT packages of a design submitted to the Nuclear Regulatory Commission for certification would survive a severe crash of the cargo aircraft designated to carry them. In order to determine if the test conditions are indeed reasonably achievable, the technical feasibility of conducting such a test according to the specified criteria must be assessed. That is the purpose of this report.

The methodology used for the assessment is to identify the principal tasks, suggest a method by which each could be accomplished, and define any related difficulties. This process leads to a conclusion about the overall technical feasibility of the test. However, if the test plans and design details are developed further, different methods for accomplishing the tasks may be discovered.

1.1 Background

Section 5062 of Public Law 100-203 defines specific tests required for PAT packages designed for transporting plutonium from one foreign nation to another through U.S. airspace. One of these tests, which is the subject of this report, is a crash test of the cargo aircraft designated to carry the PAT packages. The U.S. Nuclear Regulatory Commission (NRC) funded the Nuclear Systems Safety Program of Lawrence Livermore National Laboratory to define the test criteria for this test, which are documented in Ref. 1.

Studies pursued in obtaining information used to develop the test criteria include surveys of candidate test aircraft, aircraft guidance systems, and available test ranges as well as structural-dynamics analyses of PAT packages and aircraft during a crash. The surveys included visits to airframe manufacturers, an aircraft modification facility, manufacturers of aircraft guidance systems, and national test ranges. Much of this information is used in selecting example methods for performing an aircraft crash test.

1.2 Test Criteria

Subsection (b)(2)(B) of section 5062 of Public Law 100-203 states that the Nuclear Regulatory Commission shall "require an actual crash test of a cargo aircraft fully loaded with full-scale samples of such [PAT] container loaded with test material...." Subsection (d) reads in part: "The tests...shall be designed by the Nuclear Regulatory Commission to replicate actual worst case transportation conditions to the maximum extent practicable...." Subsection (b)(3) requires that the NRC may not certify the subject PAT package if it ruptured or released its contents during the crash test.

The worst-case transportation conditions designated by the NRC occurred in the accidental crash of PSA flight 1771 on Dec. 7, 1987, near Paso Robles, California. The aircraft crash test criteria developed in Ref. 1 are based on this accident. The required flight conditions of the crash test aircraft before impact are designed to approximately replicate those occurring in this PSA accident. The required surface conditions at the impact point of the crash test aircraft are also designed to approximately replicate those at the PSA accident site; they are derived from geotechnical property measurements of the soil at the accident site. Generally, the surface hardness must be no less than that of the intensely weathered and fractured shale and sandstone at the PSA crash site. Reference 1 gives additional criteria for the crash test. The most significant are as follows:

- The crash test aircraft may be of a different design than the designated cargo aircraft, if approved by the NRC.
- A reduction in the number of PAT test packages carried in the crash test aircraft is allowed, if approved by the NRC.
- A remote guidance system is required for the test aircraft.
- An allowable plutonium leakage rate is defined for the PAT test packages. It is based on national and international standards, and corresponds to a plutonium leakage that is regarded as acceptable.

2. FEASIBILITY ASSESSMENT

The principal technical requirements for successfully completing a PAT package crash test are reviewed. The conclusion of the assessment is that 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.

2.1 Test Site

The crash impact area must have acceptable geotechnical properties and be located where adequate safety can be assured, accessibility is acceptable (for soil testing and recovery), and sufficient services are available to support the test. To determine if an acceptable test site will be available, several national test range installations were visited. Information received indicates 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.

Table 1. Summary of technical feasibility review of aircraft crash test.

ITEM	REMARKS
TEST SITE	
Geotechnical properties	Required properties expected to exist at the example test range. Geotechnical measurements of target area needed.
Safety	All requirements achievable at the example test range.
Accessibility	Acceptable at several candidate test ranges.
Weather	Acceptable at several candidate test ranges.
Environmental impact	Will not be an issue at several candidate test ranges.
Services	All required services available at several candidate test ranges.
TEST AIRCRAFT SELECTION	
Cargo aircraft performance	Analytical tools exist; expert support available; aircraft performance characteristics and structural design details needed.
Test aircraft performance	Analytical tools exist; expert support available; aircraft performance characteristics and structural design details needed. Flight system or structural modifications may be needed if performance during the test is different from the cargo aircraft.
Aircraft equivalence	Need to develop computer models for comparison studies; cargo and test aircraft design details needed. Analytical tools and support available.
PAT TEST PACKAGES	
Modifications	Not needed.
Surrogate plutonium	Acceptable materials available; selection must be made.
REMOTE AIRCRAFT GUIDANCE	
Methodology	Simulation and prototype systems must be developed and demonstrated; this is the major task of the test program.
Availability	Several organizations have expertise to develop a system; may be able to modify an existing autopilot system.
EMERGENCY FLIGHT TERMINATION	
Methodology	Must chose a method agreeable to test range management.
Availability	Several methods have previously been demonstrated.
POSTCRASH ACTIVITIES	
Recovery of test packages	Conventional equipment can be used.
Package tests	Leakage testing applied to PAT-1 package can be used.
Cleanup and rehabilitation	Services available. Conventional equipment can be used.
RELIABILITY ANALYSIS	Needed for assured success.

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 in 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 an aircraft-crash test site. The test area must be uninhabited and large enough to insure complete safety during the testing program. In addition, it must have controlled access to prevent unauthorized personnel from entering 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. Even though the test aircraft is expected to crash very close to the intended impact point, a large buffer zone is needed for safety. Likewise, a large control area will be needed when practice flights are made to test the aircraft and its remote guidance system. The example range substantially exceeds these space requirements. Moreover, it is surrounded by additional test range areas that could effectively enlarge the available safety area for the test.

The crash 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 crash test can be performed without a safety incident.

2.1.3 Accessibility

The test area must be traversable by vehicles so that geotechnical property measurements can be made and test equipment installed before the test, and so that the PAT test packages and the crashed aircraft can be readily recovered after the crash. Also, the target area must be reasonably close to an aircraft runway that can be used for practice takeoffs and landings and, if necessary, for emergency landings.

The example test range is a region of moderately rough terrain that can be easily entered with four-wheel-drive vehicles. A temporary road could be easily made to the target area from nearby paved roads, if needed.

2.1.4 Services

Various equipment, facilities, and services will be needed to perform the crash test:

- Road-construction and fire-extinguishing equipment.
- Conventional and standby electric power sources.
- Equipment for measuring geotechnical properties of soil.
- Ground security control.
- Facilities for housing ground control and instrumentation equipment.
- Atmospheric measurements.
- Radar and photographic equipment to track the aircraft during its final crash descent.
- Equipment to recover the test packages after the crash.
- Facilities to perform verification and acceptance tests (e.g., package leak tests and instrumentation tests).

All of these items are available at the example range except for the geotechnical and road equipment, which can be obtained from nearby contractors.

2.1.5 Weather

The crash test should be conducted where the normal weather provides many extended 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 crash test program.

2.1.6 Environmental Impact

All activities of the crash test 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 crash test would come under this umbrella as well as being under the scrutiny of the range management.

2.2 Test Aircraft Selection

If the designated cargo aircraft is a wide-body jet (e.g., B-747, L-1011, or DC-10), an alternative test aircraft is more practical. Cost and availability are the primary reasons for choosing a substitution. A flyable B-747 is expected to cost more than $40 million, whereas a flyable B-707 can probably be obtained for less than $1.5 million. Used wide-body jets are much in demand by commercial airlines for use in passenger and freight service, whereas many used narrow-body jets—e.g., B-707s, B-720s, DC-8s, Convair 880s and 990s—are for sale with few buyers. However, approval to use a substitute aircraft must be obtained from the NRC. A requisite for this approval is that the NRC be provided convincing information showing that the crash environment for the test packages will be at least as severe in the substitute aircraft as it would be in the designated cargo aircraft.

This feasibility study is based on the assumption that the designated cargo aircraft will be a wide-body jet and that approval for a substitute narrow-body jet will be obtained. To describe a process for justifying and selecting a substitute test aircraft, the Boeing 747 is assumed to be the designated cargo aircraft and the Boeing 707 the selected substitute test aircraft. The assumptions are made only for the purpose of assessing feasibility.

The B-707 would cost much less than a B-747, and its design is similar. The two aircraft have approximately the same fuselage density (aircraft weight divided by fuselage section area), and they both have four turbojet engines. A three-engine aircraft may not be an acceptable substitute for the B-747 because the third engine is in the tail section and could create unrepresentative high stresses on the test packages during the crash.

Based on the following methodology, it is technically feasible to use a substitute test aircraft.

2.2.1 Cargo Aircraft Performance

The first step in the test-aircraft selection process could be to determine if the designated cargo aircraft can indeed be maneuvered to achieve, without any failures, the required flight parameters at impact (i.e., at least 282-m/s impact velocity, at least 60° between the aircraft axis and the impact surface, and within the other limits specified in Ref. 1). If the cargo aircraft cannot achieve these parameters (e.g., because of aerodynamic or structural limitations), then there would be justification to apply to the NRC for a variance, in accordance with the allowances specified in Ref. 1. However, an alternative approach is to acquire a test aircraft that can achieve the specified requirements.

Several questions must be resolved to determine the cargo aircraft's performance capability. First, can it be maneuvered to the impact conditions? Commercial aircraft are designed to be aerodynamically stable, which makes them difficult to fly in a steep high-speed dive. For example, if the aircraft should be put into a dive by initiating a nose-down pitch attitude without significant roll, it would tend to nose up out of the dive as its speed increased and its altitude decreased. The result could be insufficient impact velocity or angle to meet the test criteria. However, a maneuver that may yield the desired impact conditions is a spiral dive in which the roll is terminated near ground level. (This may have been the flight path of PSA Flight 1771 before it crashed, and military fighter aircraft use a similar maneuver to achieve high speed dives.) In any event, an achievable flight maneuver that will yield the required impact conditions must be determined. If the designated cargo aircraft cannot be flown to these conditions, then the maneuver that yields impact conditions closest to the required ones must be determined. Methods to accomplish this task may include review of flight test data from identical aircraft and use of a flight-simulation computer code containing flight-characteristics data for the cargo aircraft. Review of available flight test data is not expected to resolve the question by itself, because commercial aircraft are usually not tested at the extreme conditions described. Therefore, computer simulations must be performed. Several flight-simulation computer codes are currently used by aircraft manufacturers and national aeronautics laboratories. But these codes require input that includes appropriate flight-characteristics data, which must be obtained from the aircraft manufacturer. This information is usually proprietary to the manufacturer, and a means to acquire it must be determined.

The second question that must be addressed relates to the aerodynamic stability of the designated cargo aircraft. That is, during a flight to the required impact conditions, would any aerodynamic instabilities, such as flutter or flow separation, induce a reduction in flight control to the extent that the required impact conditions could not be achieved? Or, would these instabilities mechanically excite any part of the aircraft structure to the extent that a failure would occur? Commercial aircraft must be certified by the Federal Aviation Administration (FAA) to assure that these phenomena will not occur if the aircraft is flown only within an accepted flight envelope (e.g., equivalent airspeed, altitude, and Mach number envelope). But the flight conditions that will be required for the crash test will likely be outside this envelope. There are three methods that can be used to answer this aerodynamic stability question:

- Aircraft flight tests.
- Wind-tunnel tests with models.
- Computer model analyses.

The most expedient method is probably computer analyses, even though flight-characteristics data and structural design details for the cargo aircraft will be needed. There are organizations (federal and commercial) that are currently active in this technical area and have the appropriate analytical tools and expertise to perform the analyses. As in the solution to the first question, if aerodynamic instabilities prevent the aircraft from achieving the required impact conditions, then flight conditions must be defined which result in impact conditions as close as practicable to those required.

Another question to resolve relates to the stable aerodynamic and dynamic forces on the aircraft. Given the required flight path, conditions, and maneuvers leading to impact, can the aircraft withstand the resultant aerodynamic and acceleration forces? This question can be answered by performing analyses with appropriate structural-analysis computer codes that are currently available. However, the aircraft's aerodynamic characteristics and structural design data will be needed—again, data that is usually proprietary to the manufacturer. There are organizations which have the requisite tools and experience and could be engaged to answer the question and determine the aircraft's flight limitations.

2.2.2 Test Aircraft Performance

Selection of a test aircraft should be dependent on the outcome of the cargo aircraft evaluation studies described in Section 2.2.1. Once the crash flight parameters are defined and accepted by the NRC, then similar evaluation studies must be performed for the candidate test aircraft.

A flight maneuver and path that will yield the required crash parameters must be found in the same manner as with the cargo aircraft. The organization that did this study for the cargo aircraft would be the best candidate to do the corresponding study for the test aircraft. The same tools can be used for both studies. Only the specific aircraft performance characteristics would be different. However, should the results of the study indicate that the chosen test aircraft cannot be flown to the required crash conditions, then either a different test aircraft must be substituted (i.e., one that will be able to achieve the required conditions), or aircraft modifications must be determined which would allow the required conditions to be achieved. The most feasible approach is not self-evident and would require further study.

The aerodynamic stability of the selected test aircraft must also be studied. The same organization and tools used for studying the aerodynamic stability of the cargo aircraft could be employed for this study. If this study shows a limitation on the ability of the test aircraft to achieve its required performance, then appropriate additional studies should follow, as in the flight path study.

The ability of the selected test aircraft to endure the aerodynamic and acceleration forces sustained during the required test flight maneuvers must be determined. This should also be an adjunct effort to the cargo aircraft studies. However, should modification of the test aircraft's structure become necessary, for whatever reason, this task must be assigned to an organization that has the experience and ability to develop the redesign details, make the corresponding modifications, and perform any ground or flight tests that may be required by the FAA for recertification. Several commercial facilities have this ability.

2.2.3 Aircraft Equivalence

A condition for approval to perform the crash test with a different aircraft than the specified cargo aircraft is dependent on being able to produce at least as severe a crash environment for the test package in the substitute aircraft as would occur in the cargo aircraft if it were crash-tested. For example, if a B-707 aircraft is substituted for a B-747, the B-707 is smaller and hence may not accommodate the intended cargo load. Therefore, a crash environment comparison must be made and appropriate adjustments made to the test aircraft to achieve an equivalent or more severe crash environment.

Equivalence can be determined but studing the various package interactions that would occur during a crash. Example interactions are:

- Between packages.
- Between packages and the aircraft.
- Between packages and objects that become missiles in the crash.
- Between packages and the ground.

The study of the first interaction above would determine how the number and configuration of packages in the aircraft affect stress levels in the packages. For example, the interaction between adjacent packages located side by side in the aircraft fuselage is probably insignificant, whereas the interaction between packages aligned one behind the other is probably very significant. Thus, the problem would be to determine the minimum number of aligned packages that would result in an equivalent maximum stress to at least one package.

The second interaction above is between the packages and the aircraft structure and components. The third is between the packages and missiles created during a crash, such as structural beams or accessories, that might strike the packages. The fourth is between the packages and the ground after they have penetrated the aircraft fuselage. In all such interactions, an equivalence must be established for at least the package sustaining the highest forces and stresses.

Also, any cumulative damage must be accounted for. Should the total damage to the package in the test aircraft crash be less than would occur in a crash of the cargo aircraft, then appropriate additions or modifications to the test aircraft must be made to satisfy the equivalence requirement. Examples of items that would probably not be equivalent without modifications are the cargo decks and auxiliary power units in the tail sections. These items are larger and heavier in the B-747 than in the B-707. Required additions or modifications would be determined by analysis and design studies.

A method for evaluating the crash environment is to develop analytical models of the various package interactions. These models can be computerized to estimate relative stresses and forces in the packages. Absolute values are not needed because the objective is to establish equivalent package environments in the two aircraft. The models can be developed using design drawings of the aircraft and from information obtained by personal inspections of the applicable aircraft. Appropriate structural-dynamics computer codes, that are currently available, can be used to perform the stress calculations.

2.3 PAT Test Packages

One or more full-scale PAT test packages will be required for the crash test. The actual number of test packages to be carried in the test aircraft depends on the outcome of the equivalence studies described in Section 2.2.3. The following discussion describes how test packages can be feasibly provided for a successful test.

2.3.1 Modifications

Any modifications to the test packages necessary to successfully perform the crash test may be applied only as approved by the NRC under the condition that the modifications will not change the packaging response. Modifications should be avoided if possible. For example, package tie-downs and support structures can be either identical in the test and cargo aircraft or different if the response to the packaging will not be affected. Also, instruments such as accelerometers or strain gauges that should be placed on the packages can be attached without modifying them or affecting their stress levels.

2.3.2 Surrogate Plutonium

For safety, a surrogate material will be used in the test packages in place of plutonium. The surrogate material must be nontoxic and match the physical properties of the plutonium as closely as practicable, so that mechanical stresses in the test package during the crash 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, tungsten) having the same average density and particle size distribution as the plutonium oxide powder the PAT package is designed to carry.

2.4 Remote Aircraft Guidance

The test aircraft will be equipped with an autopilot, which to be acceptable for the crash test must provide a means of remotely piloting the aircraft during all phases of flight, including repeated takeoffs, landings, circuits, maneuvers, and the final crash dive. Remote guidance can be provided in one of three ways: by a preprogrammed automatic-guidance system, by a terminal homing system, or by a ground-based pilot through a radio-commanded manual override feature. The control system must provide sufficient control authority to achieve the required impact conditions. As there can be only one crash test per aircraft, the guidance system must be very reliable so that there will be high confidence in achieving a successful crash test. The following methodology describes how this can be feasibly achieved.

2.4.1 Methodology

When an aircraft has been selected and found acceptable by the methodology described in Sections 2.2.2 and 2.2.3, then an autopilot—one that is acceptable for the crash test—may have to be adapted to the aircraft. This would be the case if a B-707 were chosen as the test aircraft, for example, because a B-707 autopilot that can meet the flight requirements specified in Ref. 1, does not presently exist. Therefore, an autopilot that will satisfy the operating requirements must be developed or procured. An existing autopilot system designed for an aircraft similar to the B-707 (e.g., a KC-135 autopilot system) could possibly be modified to be suitable for the B-707; if so, this would considerably reduce the development time and effort.

The response characteristics of the aircraft's flight controls will be needed to program the guidance system. These characteristics can be provided in part by the aircraft manufacturer. However, the crash-test flight conditions are expected to be outside the normal operating envelope of the aircraft. Therefore, additional data on the flight characteristics must be developed. One source is from computer simulations of the flight control system using extrapolated aerodynamic data. Any modifications made to the aircraft or variations in its loading configuration can be incorporated into the computer code, but these simulations will probably not be able to generate all the required characteristics. Further data may have to be obtained from test flights. Characteristics unique to individual aircraft of a given design can be obtained this way.

A developmental program will probably be needed to produce an acceptable autopilot. After a working system is installed in the aircraft, test flights will be needed to eventually derive a final design that will satisfy all requirements.

2.4.2 Availability

Organizations that have the capability and experience to develop the required flight-control systems have been contacted. They have extensive experience in modifying full-scale aircraft to operate as drones (i.e., remotely controlled, with no crew aboard), and they have expressed an interest in developing a system for the crash test. Also, suitable computer codes for simulating aircraft control systems can be obtained from several sources.

2.5 Emergency Flight-Termination System

The test aircraft must be provided with an emergency flight-termination system that will insure safety in the event of a nonrecoverable malfunction. At least two means of flight termination must be considered, analyzed, and compared. In fact, some test ranges may require a backup termination system. Assuring the safety of test personnel, the public, and property will be the governing attribute for selecting a system. The selected method must be approved by the safety review staff of the test range. The technical feasibility of receiving approval is assured by the following methodology.

2.5.1 Methodology

There are several previously employed methods for emergency termination of the flight of drone aircraft:

- Cut off a wing with explosive charges.
- Shut off fuel to the engines.
- Use the controls to crash-dive the aircraft.
- Use air-to-air missiles to destroy the aircraft.
- Destroy the aircraft with explosive charges.

Wing-cutting with explosives is an example primary method for flight termination. To insure high reliability, redundant charges can be installed and ignition can be invoked by multichannel ground-to-air communications. Cutting off one wing in flight brings down the aircraft quickly with minimum falling debris. However, air-to-air missiles can be used as a backup.

Before a termination system is installed on the test aircraft, it must be fully demonstrated for reliability. The communication system can be ground-tested first and then flight-tested. In separate ground tests the explosive firing system charge would be tested, and the cutting ability of the explosive would be demonstrated. Full-scale wing samples can be obtained from scrapped aircraft. Explosives would not be installed on the test aircraft until unmanned flights were begun.

2.5.2 Availability

Emergency flight-termination systems are in use by all U.S. military flight-test ranges. Existing technology can be applied in designing a suitable system that will meet the crash-test requirements. It may be necessary to integrate the control and communication system with the ground control and communication subsystems of the aircraft guidance system. The design and fabrication of an acceptable system should be relatively straightforward.

2.6 Test Measurements

The primary measurements that must be made during the crash are the velocity and attitude of the aircraft at impact. These are needed to determine if the test criteria (Ref. 1) have been met. Other desired measurements are aircraft control parameters (e.g., control-surface positions, throttle settings, and engine speed) and high-speed photographs of the aircraft during breakup. Feasible methods to accomplish these measurements are available, as described in the following.

2.6.1 Methodology

Aircraft velocity and attitude at impact can be determined by using three or more cinetheodolite cameras that track the aircraft during the final phase of the crash dive. Velocity can be determined by position-vs-time values from tracking radar synchronized with the cameras. Aircraft attitude can be determined from reference lines on the camera lens and aircraft. These values, as well as the aircraft control parameters, can also be measured with onboard instrumentation connected to air-to-ground telemetry. The survivable flight data recorder carried by all commercial aircraft may serve as a backup source of data.

In addition to the cinetheodolite photography of the aircraft during the final phase of the crash dive, high speed photographs of the aircraft during impact could also be taken with cameras that can run at 10,000 frames per second for one to two seconds. These cameras would have fixed view and focus, and would be triggered at the proper time to view the aircraft at impact.

2.6.2 Availability

Tracking radars with a range of 15 km synchronized with cinetheodolite cameras having a framing rate of 30 frames per second at 0.001-second exposure per frame are available at the example test range. The expected accuracy of the velocity measurements is within approximately 2 m/s.

The fixed high-speed cameras are also standard items that are available from several sources. In preparation for the test, a reliable method to trigger them must be determined.

Telemetering of flight data is an available technology that can be used to transmit measurements from the aircraft to a ground-based recording system.

2.7 Postcrash Activities

After the crash, several tasks must be performed:

- The PAT test packages must be recovered.
- The test packages must be leak tested.
- All debris in the crash area must be removed.
- The crash area must be rehabilitated to return it as nearly to its original condition as practicable.

All of these tasks can be feasibly accomplished by the following methods.

2.7.1 Recovery of Packages

A large crater will probably be created by the aircraft crash. The test packages are expected to be found in or near the crater and possibly buried from view. However, they should not be buried more than one meter, and therefore conventional tools can be used to recover them. Probing rods and digging tools can be used to locate their exact position, and hand tools and a backhoe machine can be used to extract them from the ground. Such equipment are commonly available and can be transported to the impact area.

2.7.2 Leakage Tests

After recovery of the test packages, evaluation tests must be performed to determine if the containment vessels (which contain surrogate plutonium) satisfy the allowed leakage criterion specified in Ref. 1. That is, each vessel must release no more than the equivalent of an A_2 quantity of plutonium per week (for a typical mixture of plutonium oxide powder, and A_2 quantity is approximately 2.5 mg). There are several methods for performing leakage tests that are prescribed by national and international standards organizations (Refs. 2 and 3). 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. 4). 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. A helium leakage less than 10^{-7} atm-cm^3/s, is also accepted as leak tight. This method has been successfully demonstrated with conventional vacuum equipment; thus, it is also feasible for the crash test packages.

2.7.3 Site Cleanup and Rehabilitation

The aircraft is expected to break-up into many relatively small pieces that will be scattered over a large area, as happened in the PSA Flight 1771 crash (Ref. 1). All of the aircraft debris must be recovered and transported to a dumping area. The example range has available services to perform this task, as well as a dumping area where the debris can be discarded or made available to reclaimers. After cleanup, the crash site must be rehabilitated to range requirements. This may entail removing all foreign materials, regrading the site, and replacing vegetation. Conventional construction equipment can be used for this task.

2.8 Reliability Analysis

A reliability analysis of the crash 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 design 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. The reliability analysis will enhance the overall feasibility of the test. It should be made during the design phase of the crash test. Personnel possessing the requisite skills needed to perform the analysis are available.

3. CONCLUSIONS

In this feasibility review of the principal components of an aircraft crash test, there appear to be no technical barriers to performing the test in accordance with the criteria specified in Ref. 1. There are, however, two major technical design issues that will require developmental effort. One is the design of the aircraft guidance system. It will have demanding performance requirements, and an integrated design and testing program will probably be needed to produce an acceptable system. The other issue is determining test aircraft modifications that will insure complete integrity and controllability of the aircraft until impact. In solving these technical challenges, it will be essential to have access to existing structural and flight-performance data for the test aircraft—proprietary information held by the manufacturer of the test aircraft. An overall assessment points to the conclusion that conducting a crash test in accordance with Ref. 1 is technically feasible.

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