Testing Type A Packagings

Prepared By the

Packaging Management Council (PMC)

With support from the

Energy Facilities Contractor Group's

Waste Management/

Packaging & Transportation Working Group

September 2020

Principal Authors, Working Group Members (WG), and Reviewers of this Document

Principle Authors

Erich Opperman (WG), Tetra Tech, CES HEI, Oak Ridge, TN

Reviewers

David J Allen, Consolidated Nuclear Security, LLC (CNS), Y-12 National Security Complex, Oak Ridge, TN
Chris Carthel, Consolidated Nuclear Security, LLC (CNS), Pantex Plant, Amarillo, TX
Anthony Donner, Nuclear Waste Partnership, LLC (NWP), Waste Isolation Pilot Plant (WIPP), Carlsbad, NM
Steven Fellows (WG), Los Alamos National Laboratory (LANL), Los Alamos, NM
Mark Hawk, PMC Member, Knoxville, TN
Stephen McGaughey, CH2M HILL Plateau Remediation Company (CHPRC), Hanford Site, Richland, WA
Sylvia McGhee, Tetra Tech CES HEI, Oak Ridge, TN
Larry Stuhl, Battelle, Pacific Northwest National Laboratory (PNNL), Richland, WA

Acknowledgements
The following three individuals are acknowledged for their leadership in the early years of Department of Energy Type A package testing:

Don Edling, Mound Laboratories, Miamisburg OH, *DOE Evaluation Document for DOT 7A Type A Packaging*, March 1987 (Mound Red Book)

Donna (Kelly) Lindstrom and John Obrien, Richland WA, *Test and Evaluation Document for US DOT Specification 7A Type A Packaging*, DOE/RL-96-57 (Volumes 1 & 2), April 1996 (Hanford Blue Book)

Copyright Approvals

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACRONYMS

10 CFR	Title 10 of the Code of Federal Regulations
49 CFR	Title 49 of the Code of Federal Regulations
ANSI	American National Standards Institute
CG	Center of Gravity
cm	Centimeter
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
HMR	Hazardous Materials Regulations (49 CFR § 171–180)
IAEA	International Atomic Energy Agency
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
in.	Inch
kg	Kilogram
lb.	Pound
LOI	Letter of Interpretation
m	Meter
NCT	Normal Conditions of Transport
QA	Quality Assurance
QC	Quality Control
RAM	Radioactive Material
SF	Safety Features
U.S.	United States
UV	Ultraviolet

1.0 INTRODUCTION

This document furnishes guidance and methods for conducting Type A radioactive material packaging tests and demonstrating compliance with the United States (U.S.) Department of Transportation (DOT) packaging-requirements for Type A packagings. The primary emphasis is on the following Title 49 of the Code of Federal Regulations (49 CFR) requirements:

- § 173.410 General design requirements.
- § 173.412 Additional design requirements for Type A packages.
- § 173.461 Demonstration of compliance with tests.
- § 173.462 Preparation of specimens for testing.
- § 173.465 Type A packaging tests.
- § 173.466 Additional tests for Type A packagings designed for liquids and gases.
- § 178.350 Specification 7A; general packaging, Type A.

These sections of the regulations identify the (1) performance requirements, (2) design and testing requirements, and (3) associated methods for demonstrating Type A packaging compliance.

1.1 Purpose

The purpose of this document is to provide guidance for the people that plan, carry out, and document Type A package physical testing. This guidance document is based on the premise that Type A package testing requires knowledgeable personnel with an understanding of regulatory packaging design and testing requirements. The requirements in 49 CFR § 178.350 "Specification 7A; general packaging, Type A" are intended to simulate events that can be encountered during normal conditions of transport (NCT), including rough handling and minor mishaps (loading/unloading operations). Type A packagings are intended to perform their containment and shielding functions under NCT. To facilitate a graded approach to package testing, an evaluation of the packaging design should be carried out to identify the components that are considered important to package performance, i.e., the safety features (SF). These SFs are parts or components of the packaging that are critical to safe transport and operations. The failure or malfunction of an SF could result directly in unacceptable package performance such as loss of containment with release of radioactive material, loss of shielding, or inability to remove content decay heat.

1.2 Scope

The scope of this report includes:

- Roles and responsibilities of people involved with package testing.
- The regulatory methods that can be used to demonstrate package performance under the NCT specified in 49 CFR § 173.412, § 173.465, and § 173.466.
- Guidance for carrying out the physical packaging tests including pre-test considerations.
- Post-test package acceptance criteria used to determine if the test package meets the performance requirements under NCT.
- Documentation of testing and examples of the documents that should be maintained by a shipper.
- Closure instructions, user requirements, and quality control (QC) considerations for packaging construction and use.
- An appendix consisting of an example of a template for a Type A Test Report.

2.0 DEFINITIONS

Aspect ratio of a package is the ratio of the length of the package over its width. For example, a 40’ long freight container that is 8’ wide would have an aspect ratio of 40:8.

Containment system means the assembly of components of the packaging intended to retain the Class 7 (radioactive) material during transport (49 CFR § 173.403).

Compliance summary is a listing of the regulations in the 49 CFR § 178.350 packaging specification followed by a discussion of how each regulation is complied with. The format for a compliance summary typically includes a list of the specific regulation paragraphs or subparagraphs in one column, an explanation of how the regulations are complied with in a second column, and a discussion of shipper considerations in a third column.

Design means the description of a special form Class 7 (radioactive) material, a package, packaging, or LSA-III that enables those items to be fully identified. The description may include specifications, engineering drawings, reports showing compliance with regulatory requirements, and other relevant documentation (49 CFR § 173.403).

Design team is a group of stakeholders having a role in the development and testing of a package design. The team may include the *shipper/offeror*, package *designer* (including *testing organization*), and *fabricator*. Note: Design team members are shown in italics in this report.

Hold point refers to putting a hold on fabrication activities until an inspection is made. Hold points are particularly important when work cannot be inspected at a later date due to being inaccessible.

Normal conditions of transport (NCT) is a scenario or term, used in both the DOT and International Atomic Energy Agency (IAEA) regulations in which the package is subjected to conditions of rough handling and minor mishaps or incidents during transportation. Type A packages are required to demonstrate that they can withstand normal conditions of transport by meeting the performance and test requirements of 49 CFR § 173.412, § 173.465, and § 173.466.

Packaging model is a reduced scale representation of the packaging design.

Package means the packaging together with its radioactive contents as presented for transport (49 CFR § 173.403).

Packaging means, for Class 7 (radioactive) materials, the assembly of components necessary to ensure compliance with the DOT packaging requirements. It may consist of one or more receptacles, absorbent materials, spacing structures, thermal insulation, radiation shielding, and service equipment for filling, emptying, venting and pressure relief, and devices for cooling or absorbing mechanical shocks. The conveyance, tie-down system, and auxiliary equipment may sometimes be designated as part of the packaging (49 CFR § 173.403).

Packaging Manufacturer means the person certifying that the package meets all requirements of 49 CFR § 178.350, which included 40 CFR subpart B, 49 CFR § 173.403, § 173.410, § 173.412, § 173.415, § 173.465, § 178.2, and § 178.3.

Performance requirements are the containment and shielding criteria of 49 CFR § 173.412(j) and somewhat indirectly, the heat transfer considerations of 49 CFR § 173.442 and § 173.474(b). The former requires the package to prevent loss or dispersal of radioactive contents, or a significant increase in radiation levels at external surfaces. The latter two requirements are to determine effectiveness of heat transfer characteristics of the package, if applicable (e.g., for high alpha emitting special form radioactive material**,** when subject to NCT).

Prototype packaging is a full-scale packaging fabricated in accordance with a version or concept of the new packaging design.

Radioactive contents means a Class 7 (radioactive) material, together with any contaminated or activated solids, liquids, and gases within the packaging (49 CFR § 173.403).

Safety features (SFs) are specific packaging components appearing on the latest list of packaging parts (e.g., on drawings) that have been evaluated and whose failure or malfunction could result in a condition such as loss of containment with subsequent radioactive material release, loss of shielding, or a significant reduction in heat transfer capability. The packaging *designer* should perform the evaluation of each packaging component as early in the design process as practical (49 CFR § 173.465(c)).

Surrogate contents are used as non-radioactive substitute contents in package testing to simulate the actual radioactive contents that will be shipped.

Tests for purposes of this document, include but are not limited to the (1) acceleration and vibration capability requirement in the general design requirements of 49 CFR § 173.410(f), (2) reduction of ambient pressure requirement in the Type A package design requirements of 49 CFR § 173.412(f), and (3) Type A packaging tests in 49 CFR § 173.465 and § 173.466.

Test package is the packaging and surrogate contents that are used for testing.

Type A package means a packaging that, together with its radioactive contents limited to A_1 or A_2 as appropriate, meets the requirements of 49 CFR § 173.410 and §173.412 and is designed to retain the integrity of containment and shielding required by Part 173 under normal conditions of transport as demonstrated by the tests set forth in 49 CFR § 173.465 or §173.466. A Type A package does not require Competent Authority approval (49 CFR § 173.403).[1]

[1] Note that although a Type A package does not require Competent Authority approval as defined in 49 CFR § 105.5, Type AF designs require approval by the U.S. Nuclear Regulatory Commission in accordance with Title 10 of the Code of Federal Regulations (10 CFR) part 71 (Ref. 49 CFR § 173.471).

Ullage means the volume of free space that is available above the surface of the liquid.

3.0 ROLES AND RESPONSIBILITIES ASSOCIATED WITH TESTING

This section defines typical roles and responsibilities of personnel that have a vested interest in providing technical input to package testing. It is recognized that the roles can be defined in many ways and carried out by single persons, a vendor, or teams. Successful testing requires a comprehensive and/or functional understanding of the packaging design to ensure that the specific tests challenge the features important to safety. The people designing and analyzing the packaging often have those insights (e.g., the *designer*). Roles and responsibilities are further defined in ANSI N14.7-2013, *Guidance for Packaging Type A Quantities of Radioactive Materials* (Ref. 1), and briefly described in this section.

Testing is often carried out to support the package design process. The design process generally involves three organizations (referred to as the *design team* in this report): the (1) *shipper/offeror*, (2) *designer*, and (3) *fabricator*. These organizations work under their applicable quality programs. The *shipper/offeror* provides information on what is being shipped, facility limitations, quantities, schedule, etc., referred to as the “Design Input.” The *designer* takes the design input and develops the details of the packaging. This can include drawings, calculations, evaluations, and test plans. These documents should be sufficient to allow the performance of all necessary analysis and testing. The *designer* also ensures that necessary coordination occurs between the *shipper/offeror* and the *fabricator* and carries out design, analysis, and testing to produce the design. When the design is completed, the *shipper/offeror's* organization will review for accuracy and accept (i.e., approve) the design and associated documentation. The *fabricator* builds the hardware per drawings and specifications.

Figure 3.1 is an example of how the various organizations could work together. As noted above, a single person, shipper, or small knowledgeable team may carry out all of the roles shown in Figure 3.1.

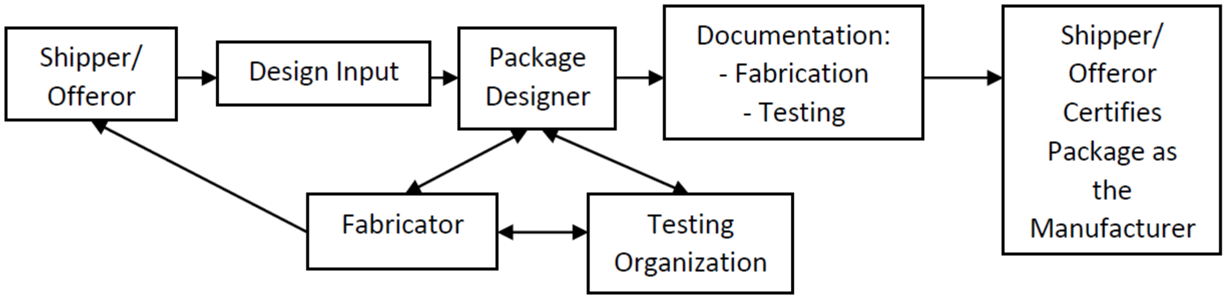

Figure 3.1 Design Process

3.1 Shipper/Offeror

The *shipper/offeror* is responsible for the radioactive material to be shipped. As such, the *shipper/offeror* provides details of the radioactive content such as identification of radionuclides and activity, the physical form (solid, liquid, and gas) and characteristics of the radioactive material, shielding requirements, content size and shape, desired amount (density, weight, and/or volume) to be shipped, the facilities where the packaging will be loaded and unloaded (if relevant), special operational considerations (e.g., temperature limits), and schedule. This information makes up the design input. Further details of content characterization and design input considerations are found in (Ref. 2 & 3).

3.2 Package Designer

Based on the design input from the *shipper/offeror*, the role of the *designer* is to establish the hardware configuration of the new packaging. This involves interpreting the design input requirements and conferring with the necessary stakeholders (e.g., shipping and receiving facilities, testing facilities, analysts, operations personnel) to resolve questions so the design process can move forward. The *designer* typically develops a plan that includes the design approach, design reviews if needed, definition of SF, the optimum drop orientation for the drop test, the number of drops to be performed, and determination of the methods that will be used for test compliance. This plan gives the *shipper/offeror* the scope and steps that will be carried out during the design process.

3.2.1 Testing Organization

The *designer* may choose to perform tests of the proposed design using either a prototype or a scaled model of the design. The test packages are to be prepared in accordance with 49 CFR § 173.461(b) and § 173.462, and the tests are to be performed in accordance with § 173.465 or § 173.466. Testing includes loading the prototype packaging with surrogate contents that physically represent the actual radioactive contents that will be shipped, closing the package, performing the prescribed tests, and documenting the results of each test. Measurements, photographs, and videos of testing should be carried out.

The *testing organization* should have written procedures and test plans written or reviewed by the *designer* that address (1) the identification of the SFs that will be challenged during the tests, (2) preparation of test packages, (3) performance of tests, (4) disassembly and measurement of test packages, and (5) documentation of results including appropriate methods for recording results of the SF performance under NCT. Test plans should identify specific criteria for determining if a test package passed or failed the tests as per § 173.412(j). Testing documentation should include pictures and videos of the packages before, during, and after the tests to record damage resulting from the tests. Even though pictures/videos are taken, damage to the package is to be documented with dimensional measurements so parameters like radiation level changes at the package surface can be determined. A template for a test report is provided in Appendix A.

3.3 Fabricator

The *fabricator* builds the packaging in accordance with the approved design. The *fabricator* purchases raw materials and components identified in the design documents and develops processes and procedures to carry out construction. The *designer* and *shipper/offeror* may specify certain hold points for hardware inspections, or tests, during fabrication—such as reduction of ambient pressure tests, final containment leak tests, or weld inspections. The *fabricator* should provide a fabrication plan and/or schedule showing the hold points, as required, to ensure good communications.

When issues arise that may require a change in the approved design, the *fabricator* coordinates with the *designer* who confers with the *shipper/offeror* to resolve the issue. If a change to the design is required during fabrication, the *designer* reviews the change(s) and makes appropriate modifications to regulatory compliance documentation and then has the *shipper/offeror* approve the change(s). When the *fabricator* completes the fabrication of the Type A packaging and all associated inspections and quality verification steps (e.g., leak tests, load tests, weld inspections), the fabrication documentation is provided to the *designer* for review and acceptance. The design and quality verification documents should satisfy the applicable regulatory requirements identified in 49 CFR § 173.415(a).

The documentation generated by the *fabricator* should show how the packaging hardware meets the design drawings and specifications. Documentation should include a Certificate of Conformance including the *fabricator's* signature documenting that the finished packaging conforms to the approved design and specifications. Other documents may include inspection plans, schedules, calculations, verifications, and quality documents (e.g., inspection reports, certified material test reports, fastener certifications, leak test results, weld inspection reports).

3.4 Shipper/Offeror Certifying the Package

The *shipper/offeror* of a Type A package is often required to also assume a unique role—that of the "packaging manufacturer." 49 CFR § 178.350(c) defines the packaging manufacturer as the person certifying that the package (i.e., content + packaging) meets all requirements of § 178.350. While being the packaging manufacturer is not a traditional *shipper/offeror* function, the regulatory definition now results in the *shipper/offeror* often (not always) being the only person with sufficient knowledge of content loading details. As the packaging manufacturer, the *shipper/offeror* has the specific knowledge to document how the packaging was loaded with content and how that content was secured to meet the content form, physical characteristic requirements, and radiation level requirements of § 173.412(j)(2) and § 173.441. There are exceptions to this rule; for example, shipments where the same content is loaded into the packaging repeatedly such as packaging designed for radioactive sources (e.g., Co-60 or Cs-137) that have rigid content and dunnage specifications. These fixed designs uniquely define the package internals, which enables calculation of the radiation level considerations for all shipments.

4.0 METHODS TO MEET PERFORMANCE REQUIREMENTS

The package design requirements in 49 CFR § 173.410(f) (vibration), § 173.412(f) (reduced external pressure), and test requirements identified in § 173.465 and § 173.466 (water spray, free drop, stacking, and penetration) that are typically addressed by testing are summarized in Table 4-1. There are a variety of procedures, approaches, or methods (e.g., testing, comparison, evaluation) used for documenting that a package can successfully perform under the design and test requirements. These methods are discussed in this section.

Under NCT, the package is required to "perform" in an acceptable manner. The regulatory performance requirements are defined as the ability of the package to provide containment, shielding, and heat transfer, as applicable, under NCT. Containment prevents loss or dispersal of radioactive contents, shielding attenuates radiation coming from the contents, and effective heat transfer ensures decay heat is removed from the package. The package *designer* has the methods (or options) listed in § 173.461 for determining how to document that the package meets the performance requirements under the NCT. In accordance with § 173.461, the *designer* can (1) perform "tests with prototypes or samples," (2) reference previous satisfactory demonstration of compliance of a similar package, (3) perform tests "with models of appropriate scale," or (4) make "calculations or reasoned evaluation."

Table 4-1. Requirements Addressed by Testing

Title	Regulation	Location in Report
General design requirements.	49 CFR § 173.410(f): Vibration	5.3.1
Additional design requirements for Type A packages.	49 CFR § 173.412(f): Reduction of ambient pressure	5.3.2
Type A packaging tests (solids).	49 CFR § 173.465: (a) the packaging with contents must be capable of withstanding the following tests: (b) Water spray (c) Free drop from 0.3 meters (m) (1 foot [ft.]) to 1.2 m (4 ft.), if packaging contains fissile material, then free drop is preceded by eight 0.3m (1 ft.) drops (d) Stacking (e) Penetration from 1 m (3.3 ft.)	 5.2 5.2.1 5.2.2 5.2.3 5.2.4
Additional tests for Type A packagings designed for liquids and gases.	49 CFR § 173.466: (a) in addition to the 49 CFR § 173.465 tests, packaging designed for liquids and gases must be capable of withstanding the following tests: (1) Free drop from 9 m (30 ft.) (2) Penetration from 1.7 m (5.5 ft.)	5.2.5.2

The four methods for demonstrating compliance with the performance requirements under NCT are discussed below. Note that any single method or combination of methods can be used for a particular package design.

4.1 Testing with Prototype Test Packages

The first and generally the most preferable method for meeting the performance requirements is to perform physical tests with full sized prototype packagings fabricated as close to the design as possible at this stage of development. The use of non-radioactive surrogate contents simulates the form and physical characteristics of the actual radioactive contents except for the radioactive characteristics such as the decay heat and radiation. See Section 5.2 for further discussion of surrogate contents. The thermal aspects of the decay heat and any possible material considerations due to the radiation need to be addressed by the *designer* or *shipper*. Testing packages with actual radioactive content presents complexities and potential radiological concerns.

The packaging should be assembled, loaded with surrogate contents, and closed in accordance with written procedures as though it was being prepared for a shipment. The facilities used for testing should be capable of performing the tests listed in Table 4-1. The target for the free drop test must be a flat, horizontal surface of such mass and rigidity (essentially unyielding) that the kinetic energy of the test package is absorbed by deforming the test package and not movement or deformation of the target. The package *designer* determines how to apply the tests by identifying the SFs and the drop orientations, penetration target locations, and location for dye or effervescent materials to indicate containment failure, and the package *designer* pre-defines how to determine if the pass-fail criteria (i.e., containment/shielding) is met. Pass-fail criteria for Type A packages involve visual inspection and measurements of the test package damage after one or more tests have been completed to determine if containment and shielding has been retained. The package *designer* may identify pass-fail criteria that goes beyond “visible loss of content” for defense in depth reasons. For example: test package containment system failure may be (1) any cracking of the outer packaging skin as a result of vibration or drop testing or (2) any leakage from a primary inner containment system component for liquid content. Procedures should be used to ensure that post-test package inspections, evaluations and disassembly are well thought out and comprehensive.

4.2 Reference to a Similar Package Design

The second compliance method is referencing a similar design that was satisfactorily tested. The package *designer* determines if the previously tested package is sufficiently similar to the new design to reference or carry out a credible technical or structural comparison between the designs. This typically requires the designs to have similar size, shape, materials of construction, weights, and components. A table should be developed to list the features of the previously tested package for a one-to-one comparison and evaluation with the same features of the new design. The *designer* needs to show component-by-component (and holistically) that the new design is as capable, or more capable, than the previously tested package. The following information should be provided:

- dimensions, materials, and configurations of both packages;
- overall weight of both packages; and
- physical characteristics and smallest dispersible particle size of the contents of both packages.

Each of the tests listed in Table 4-1 should be considered. The free drop test is usually the most challenging comparison to make because of the difficulty of structurally evaluating how two different designs deform, bend, or crush when being dropped. The comparison needs to be sufficiently rigorous to ensure that the new design meets the performance requirements.

4.3 Testing with Model Test Packages

The third compliance method is testing with models that differ from the full-sized package design. Scaled models may be used when engineering experience has shown testing is suitable on an appropriate scale model or when test package designs are very costly to build. Since scale models deviate from the actual new design, a comparison or evaluation between the tested scale model unit and the actual unit is required by the package *designer*. The model must be described completely and drawings or figures should be used to show dimensions and materials of construction. Scaling laws applied should be consistent with Reference 4 and documented within the test reports. The tested model should include all features of the package in which a credible failure mode exists (e.g., closure system, fasteners, seals, weld seams, filters, lifting devices).

When scale models are used, test parameters such as the penetration bar diameter, compressive load, drop orientation, or drop height may need to be taken into account.

4.4 Calculations or Reasoned Evaluation

The fourth compliance method is the use of calculations and reasoned evaluations using reliable and conservative procedures and parameters. When using calculations and/or reasoned evaluations, the focus is usually on a particular feature of the packaging. One must be careful to look at all features of the packaging and determine when it is necessary to combine information from separate calculations and evaluations. For example, calculations of drop damage need to be combined with calculations of source movement in order to determine radiation level changes at the surface of the test package.

Calculations and reasoned evaluations are often used for the compression and penetration tests. With the compression test, one must be careful to look at where the compression forces are applied. Remember that the regulation identifies a uniformly distributed load. The intent is that the package be able to withstand other packagings being placed on top. In general, during transportation there is no guarantee that the items placed on the top will be of any particular size; therefore, the uniform load represents a distributed load.

For most packagings, calculations and reasoned evaluations will be difficult for the drop testing. Even with the simplest package, setting up a calculation that deals accurately with the dynamics of a drop test is difficult. The analysis needs to be performed by an experienced analyst who understands how to properly model the impacts of the drop and its effects on the package. When calculations are used for the drop test, it is preferable to have a benchmarked evaluation method.

In many cases, a reasoned evaluation can be made for the water spray test. Care needs to be taken if the water can wet surfaces whose properties change when wetted.

4.5 Combination of Methods

Combining methods works well for many packagings. For example, the regulations state that the water spray test must be conducted prior to each test. When water can be shown to not affect the performance of the packaging, the water test can be carried out one time or not at all. A reasoned evaluation can be made to justify that water tests are not required. When deciding how to utilize multiple compliance methods, consider the packaging design, costs, and available facilities. If the package is straight forward and reasonable to fabricate and testing facilities and procedures are available, then conducting all tests is encouraged. For expensive packagings that are conducive to evaluation (e.g., cylindrical vs. rectangular), it is fully acceptable and more cost effective to conduct a minimum of tests and then utilize other non-test methods and evaluations.

5.0 CARRYING OUT TYPE A PACKAGE TESTS

As discussed in Section 4, the DOT regulations allow various testing, evaluation, and comparison methods for demonstrating that a package meets the performance requirements under NCT. Non-test evaluation methods provide the ability to evaluate performance over a wide variety of conditions by adjusting computational parameters (Ref. 4). Testing may be more limited and can be more costly for expensive packaging designs since variations in testing conditions could require a complete retest. However, testing is generally the preferred method for conditions that are difficult to analyze, such as drop impacts. Also, testing gives a decisive go/no-go answer because the test package either passes the test or does not. Cost considerations, package size and complexity, and facility limitations are generally the considerations that are used to justify non-testing methods. This section provides recommendations for carrying out the package tests listed in Table 4-1. Each packaging design may require a different strategy of testing combined with evaluation to demonstrate compliance.

5.1 Pre-Test Preparations

Testing should be well thought out by the entire package *design team*. The end result of testing is documented evidence (e.g., pictures, hardware, measurements, and videos) that the package design provides containment, shielding, and maintains heat transfer capability under the very worst and most damaging application of the tests. This starts by ensuring that surrogate content weight is maximized, the physical characteristics and smallest particle size of the content is defined to cover all geometries the *shipper* requires, the most damaging orientations for the free drop and puncture tests are identified, and a compliant drop target is available.

Identifying the conditions or orientations that result in “maximum damage to the safety features being tested” requires an initial understanding of the design and packaging components so that “worst case” conditions can be initially and credibly defined. The *design team* needs to identify the SFs that are important to containment, shielding, and heat transfer and then evaluate those SFs under the orientations and conditions of each of the Table 4-1 tests to establish a case for how the SFs would most likely fail. The evaluation need not be complex but should be based on the best insights and understanding of the tests and package features. This early planning can prevent the need for carrying out multiple tests, re-doing tests, or having inadequate compliance justifications.

The criteria to determine if package tests are successful is discussed in Section 6. But stated simply, the tests must show the package meets the performance requirements based on observable test results. Title 49 CFR § 173.24(b)(1) states that, for each hazardous materials package used pursuant to the Hazardous Materials Regulations (49 CFR § 171–180) (HMR), “there will be no identifiable (without the use of instruments) release of hazardous materials” under NCT. This indicates that instrumentation need not be used when evaluating the containment results which is taken to mean that package containment can be based on observable “visual inspections.” Use of sophisticated instrumentation is not a regulatory requirement for Type A packages. The implication is that, after the tests, there is no observable or visual indication of leakage.

The detailed requirements in § 173.461(b) for initial testing conditions and § 173.462 for specimen preparation are discussed in Sections 5.2 and 5.1.4, respectively.

5.1.1 Testing Sequence

There are two instances where the sequence for carrying out the tests is specified: the water spray test and fissile material drop test. In 49 CFR § 173.465(b), the water spray test “must precede each test or test sequence prescribed in [§ 173.465].” In § 173.465(c)(2), for “packages containing fissile material, the free drop test…must be preceded by a free drop from a height of 0.3 m (1 ft.) on each corner, or in the case of cylindrical packages, onto each of the quarters of each rim." Other than the above two sequence requirements, there is no requirement to carry out tests in a particular order or with any particular number of test packages. It is up to the *design team* to determine the test sequence and number of packages used for testing. For example, if multiple drop test orientations are required in order to evaluate different SFs of a drum (e.g., bottom chime, side seam weld, closure ring, or closure ring lug integrity), a new test package may be used for each test or a single package may be used for all tests. The *design team* needs to justify the number of test packages needed. When a single test package is used for all of the tests, the chance of failure is increased.

The requirement that the water spray test precede each test or test sequence is a requirement for all packages. This requirement is of particular importance for packages having materials that are susceptible to mechanical property changes (e.g., softening) when wet such as cardboard or wood. For packages having external materials that are not susceptible to water or moisture (e.g., metal, plastic, and rubber), the *design team* can carry out a reasoned evaluation (compliance method) to justify a reduced number of water spray tests. For packages having waterproof external surfaces (e.g., metal drums or steel waste boxes with polymer seals), the water spray test can be completed as the first test and then followed by the remaining tests as determined by the *design team*. For example, after the water spray test is completed, the free drop test may be performed next, followed by the penetration test, and finally the stacking test; alternatively, the stacking test may be performed first followed by the penetration and free drop tests.

The reduced external pressure and vibration requirement tests do not have to be preceded by water spray because these two requirements are not listed in § 173.465. If testing is used to evaluate reduced external pressure, or vibration capability, the *design team* determines the sequence for conducting these tests.

5.1.2 Surrogate Contents

When performing package testing for radioactive materials, surrogate non-radioactive contents are used. Surrogate contents should be selected to represent the range of physical characteristics of the radioactive contents that will be shipped. The selection of surrogate contents should be based on (and the documented description should specify) the: (1) physical characteristics of the test content which includes physical form (solid, liquid, and gas), shape, density, size, hardness or softness and (2) smallest dispersible particle size. If inner containers (e.g., cans, vials, and bags) are used to hold the content, then the physical characteristics of those containers should be considered. Some form of inner container is generally required by operations personnel for contamination control reasons and packaging loading and closing operations. Content containers can be identified as components of the "contents" or components of the "packaging," this distinction is up to the *design team*. Identifying content containers as "content" can result in more flexibility and lower costs when procuring and using these components. The one parameter surrogate content does not generally simulate is radioactive decay heat. Content decay heat is generally not a factor for activity levels associated with A_2 values for Type A packages but can be a factor for special form (A_1) activity levels. For example, A_1 activity values for alpha emitting contents (e.g., Pu-238, Cm-244) can result in decay heat levels on the order of 10 watts or more. This can be significant and could result in high internal component temperatures for packaging designs that have materials that are good thermal insulators.

The *designer*, working with the *shipper/offeror*, selects the surrogate content for the test package that best simulates the range of radioactive content physical characteristics and smallest dispersible particle size. Gases and liquids conform to the shape of the packaging components and/or inner containers, so the physical characteristics of these components must be identified and incorporated into the test package. The Type A packaging design must withstand the internal forces produced by the physical characteristics of the content, and the closure system, gaskets, or seals must be able to contain the smallest dispersible particle size under the test conditions.

Solid surrogate contents have historically been identified as Form Numbers 1, 2, or 3 (Ref. 1). The three forms differ in the size of the smallest particle available for leakage. Form 1 content can be of any particle size (from powder to large objects), Form 2 content includes only larger particle sizes (sand, shot, to large objects), and Form 3 content includes no small dispersible particles but can have content of small size (e.g., small to large objects). It is more difficult to contain small dispersible particles than larger dispersible fines. Form 1 content requires a packaging with the most robust gasket sealing system because it has to contain the smallest particles which are more prone to leakage. Form 2 content requires a packaging with a gasket sealing system required to contain the specified larger particles. Form 3 content requires a packaging with a gasket system required to contain larger objects but no dispersible fines. A gasket/seal system may not be necessary for containment of Form 3 content. In summary, all three content forms can have a wide range of physical characteristics, but dispersible particle size increases from small to large, progressing from Form 1 to Form 3. The challenge for the *shipper/offeror* is to ensure by evaluation that the radioactive content being shipped is comparable to the physical characteristics and minimum particle size of the surrogate content used in testing. If a packaging is required to carry content with a range of physical characteristics, then there may need to be multiple package tests with differing surrogate contents.

Table 5-1 provides the *shipper/offeror* with guidance in evaluating and comparing the surrogate content with the shipped content. Column 1 lists examples of content physical characteristics that range from flowable/soft to non-flowable/hard surrogate content. The physical characteristics of the surrogate content impose structural loads and stresses on the packaging and can vary greatly from soft bagged waste to hard steel containers to debris having a range of shapes and rigidity. For example, a flowable/soft content will impose uniform stresses to the packaging with no severe local bending, whereas content that is of a non-flowable and physically hard (contaminated pump, concrete debris) could cause local bending, puncture, and non-uniform stresses to the packaging under drop conditions. Since Form 1, 2, and 3 surrogate content can have a wide range of content physical forms, the *shipper/offeror* should review applicable test reports to identify the particular surrogate content physical characteristics. Column 2 of Table 5-1 provides considerations to assist the *shipper/offeror* in comparing surrogate content with the radioactive content that will be shipped.

In particular, the *shipper/offeror* should compare the size (including minimum particle size), density, hardness, and overall distribution of the materials and components making up the surrogate content with the content being shipped. If the test package shows no indication of deformation due to internal content, then the content was likely flowable or uniform. If there is external deformation, then the content is likely chunk-like and hard. It is ultimately the *shipper/offeror* that must document and ensure that the content being shipped is comparable to the surrogate content that was tested or evaluated.

Table 5-1. Surrogate Content Descriptions and Shipper Consideration

Physical Characteristics of Surrogate Content	Shipper Guidance in Comparing Surrogate Content with Shipped Content
Flowable, Uniform, or Soft—content consists of homogeneous materials that are pourable, can flow, deform, or are physically soft as compared to packaging structure. Content weight is typically distributed throughout the packaging. Content places relatively uniform internal stresses on the packaging and is unlikely to cause point loading, significant deformation, or puncture of the packaging. Examples: sand, gravel, shot, bags of low-level waste, objects surrounded by foam, fiberboard discs. Identify minimum particle size.	Is the content being shipped uniformly distributed throughout the packaging? Is the content relatively soft and pliable as compared to the packaging? Is the content comparable in weight and density to the surrogate content? Is the smallest particle size available for release in the content equal to or larger than the minimum surrogate content particle size? Note: This content form may be appropriate for shipment of hard objects, chunks, or large items provided those items are wrapped or surrounded by dunnage or other means to distribute weight uniformly throughout the package (e.g., foam, sand, fiberboard, or plywood discs).
Hard Object or Chunk—content consists of materials that spread the content weight over many components. Content weight is made up of the sum of the objects/chunks and may or may not be uniformly distributed throughout the packaging. Content may cause denting of packaging skin from internal loading during drop testing. Evidence of denting would be seen in test packages. Examples: bricks, canned content, cut up pieces of activated metal, surface contaminated components, building debris. Identify minimum particle size.	Is the content being shipped made up of individual objects or inner containers of the same or differing weights? Are the objects hard or stiff such that they could dent the packaging outer skin or damage interior elements of the containment system? Is the content comparable in weight, density, and distribution within the packaging to the surrogate content? Is the smallest particle size available for release in the content equal to or larger than the minimum surrogate content particle size? Note: Typically hard rigid content is wrapped to protect the packaging. If for operations reasons this is not possible, then the packaging structure must be robust enough to withstand the internal forces from the hard or chunk-like content.
Large Item—content consists of materials that can fill the packaging with one or a small number of items. Content weight is made up of the items within the packaging and may or may not be uniformly distributed throughout the packaging. Content is considered rigid and not flowable. Examples: cement blocks, pumps, lead pigs, building debris, grouted content. Identify minimum particle size.	This content form is considered specific to the geometry tested and may be harder for the shipper to compare with other large content. The shipper needs to consider sharp edges or points and should utilize internal padding or dunnage per 49 CFR § 173.24a(a).
Liquids	Are surrogate contents of a higher density and weight than the shipped contents? Are inner containers and associated dunnage comparable to the test package? Note: If a Type A packaging is approved for both solid and liquid contents, then both content forms should be tested or evaluated in the testing documentation.
Gases	The actual contents of the test package should be simulated as closely as possible (typically non-radioactive).

5.1.3 Target for Free Drop

As stated in 49 CFR § 173.465(c)(5), “the target for the free drop test must be a flat, horizontal surface of such mass and rigidity that any increase in its resistance to displacement or deformation upon impact by the [package test] specimen would not significantly increase the damage to the specimen.” A target meeting this requirement needs to be rigid as compared to the test package being dropped so the kinetic energy of the test package is absorbed by deformation of the test package and not by deformation of the drop target. What the regulation emphasizes is that the drop target is to be rigid and massive as compared to the test package being dropped; therefore, a drop target suitable for cardboard or fiberboard package testing may be totally inadequate for a steel box. A brief discussion of the drop target regulation is given below.

Target to be flat and horizontal. “The target for the free drop test must be a flat, horizontal surface ….” This can be determined by visual inspection and measured with the use of a tool such as a straight edge and carpenter’s level. Flatness refers to the target surface being smooth and even, without lumps or indentations. Horizontal refers to the target surface being parallel to the plane of the horizon.

Target mass, rigidity, displacement, and deformation. “The target for the free drop must be…of such mass and rigidity that any increase in its resistance to displacement or deformation upon impact by the specimen….” This implies the target must be massive and rigid (compared to the test package); strong—so as not to flex, chip, crack, spall, or dent; and does not move in a horizontal or vertical direction due to impact from the test package. A target of this nature is intended to cause damage to the test package that would be equal to or greater than anticipated impacts on actual surfaces during transport.

Damage to specimen (i.e., test package). The target for the free drop…must be of such mass and rigidity that any increase in its [target] resistance to displacement or deformation…would not significantly increase the damage to the specimen….” This implies that the target has a relatively large mass and rigidity as compared to the test package. Less rigid targets will cause less damage to test packages, and this is not desired. The hardness of the target surface, the thickness of the target plate, and the mass of the supporting base can be compared to the test specimen to show that the kinetic energy from the free-falling test package drop is primarily absorbed by the test package and not the target.

Reference material provided by the IAEA *Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material*, SSG-26, (Ref. 5) and other organizations (Ref. 6 & 7) provide discussion of free drop targets. While not required by the HMR, this material may be used by the *design team* in determining the adequacy of testing facilities. SSG-26 (para. 717.2) provides the following example of an unyielding target:

> One example of an unyielding target is…a 4 cm [centimeter] (1.6 in. [inch]) thick steel plate floated onto a concrete block mounted on firm soil or bedrock. The combined mass of the steel and concrete should be at least 10 times that of the specimen for the tests…unless a different value can be justified. The steel plate should have protruding fixed steel structures on its lower surface to ensure tight contact with the concrete. The hardness of the steel should be considered when testing packages with hard surfaces. To minimize flexure, the concrete should be sufficiently thick, but still allowing for the size of the test sample.

The target also shall be of such external dimensions that when the packaging hits the target and a slap-down occurs, the packaging still remains on the target.

5.1.4 Preparation of Prototype or Model Packages for Testing

The preparation of packages for testing is influenced by the *design team*'s compliance considerations. If costs allow, it is always preferable to use full sized prototype test packages so that, after testing, no additional scaling or comparative evaluations are needed. The test specimen preparation requirements in 49 CFR § 173.462 place emphasis on ensuring that any test package is thoroughly examined, characterized, and documented before testing so that any changes or damage resulting from testing can be identified. It is important that the test package be assembled, loaded with surrogate content, and closed according to written procedures—in particular, the components of the containment system. If testing is performed with effervescent materials or powders that facilitate post-test leak detection, the effervescent materials need to be thoughtfully loaded to be in the vicinity of any seals, seams, or flanges subject to leakage and remain dry and flowable. For example, if sand is used as surrogate content in a large waste box, care must be taken that the sand is sufficiently dry so it does not cause moisture to migrate to the effervescent material making it wet, cakey, paste-like, and therefore immobile.

Suspending the test package so that it hits the target in the correct orientation can be a challenging operation and often requires trial and error. The test package is often suspended using rigging straps, a harness, or cables wrapped or attached so the package's center of gravity (CG) is aligned over the point of impact and the desired drop angle is achieved. If lifting attachments are added to the test package to facilitate the rigging operations, they should not be at impact points or otherwise affect the test results. Personnel safety is essential when suspending packages for drop tests. Additionally, a mechanical means to hold and release the test package is generally required. The release mechanism should not interfere with or create additional test package damage.

After the packages have been subjected to tests, the resulting damage requires visual inspection of the test package outer surfaces, inspection of the drop target surface for evidence of leakage, and often disassembly. Post-test activities should be considered well before testing begins to ensure that no important information is lost. Test package disassembly steps are important to ensure damage to internal components, when used, is recorded. The *design team* should discuss and agree upon disassembly steps. For example, post-test inspections may be straightforward for single-walled drums or waste boxes where there are no internal packaging structures and, therefore, test package disassembly may not be critical; however, for more complex packages with inner components such as shield assemblies or dunnage, careful disassembly of the test package is essential to ensure that evidence of damage is not lost by disassembly. It is recommended that the *design team* have a post-test plan to ensure a systematic disassembly of the test package is carried out.

5.2 Conducting the Type A Tests

This section discusses the performance tests: water spray, free drop, stacking, and penetration tests. These tests simulate the conditions a package encounters due to weather and handling in the transportation environment. These tests do not include all events that can occur during transportation but are deemed sufficiently adequate by DOT to demonstrate package performance when combined with the other design requirements such as temperature/pressure variations and vibrations.

The initial condition of ambient temperature requirement in 49 CFR § 173.461(b) states, "With respect to the initial conditions for the tests under §§173.465 through 173.469, except for the water immersion tests, compliance must be based upon the assumption that the package is in equilibrium at an ambient temperature of 38 °C (100 °F)."

The design requirement in § 173.412(c) states, "Containment and shielding is maintained during transportation and storage in a temperature range of −40 °C (−40 °F) to 70 °C (158 °F). Special attention shall be given to liquid contents and to the potential degradation of the packaging materials within the temperature range." This necessitates evaluation of the packaging components over the specified temperature range.

5.2.1 Water Spray Test

The water spray test is to be carried out before each of the other three performance tests or test sequence prescribed in 49 CFR § 173.465 and § 173.466. As such, the water spray test is a conditioning step as well as a performance test. The water spray test simulates exposure to rainfall at a rate of about 5 cm (2 in.) per hour for at least 1 hour. The test package should be placed on a flat horizontal surface in the orientation most likely to cause maximum water damage to the package and should not be supported above the surface in order to allow for water to be trapped (and seep in) at the base of the test package. The water spray should be directed from top down and from the sides to simulate rain hitting a moving package. The time interval between the end of the water spray test and the beginning of the next test is to be such that the water has time to soak into the maximum extent without appreciable drying of the exterior of the test package. This allows time for the water to migrate into materials like wood or cardboard, or seep into the interior of the test package where water could create problems such as a reduction in structural strength of materials susceptible to water.

If the *design team* does not identify a time interval, the regulations say that this interval may be assumed to be (1) two hours if the water spray is applied from four different directions simultaneously or (2) no time interval is required before proceeding to the next test if the water spray is applied consecutively to one side of the package at a time (for one hour per side).

This test is primarily intended for packagings that rely on materials that absorb water, are softened by water, or materials bonded by water-soluble glue. For packagings whose outer layers consist of fiberboard, cardboard, or non-coated wood materials, the primary concerns are the retention of water and potential for increase in mass or reduction in strength. The impact of freezing and water expansion may also be an issue for packaging designs that retain water.

The methods defined in § 173.461 may be used to demonstrate compliance with the water spray test. The justification may be through an engineering evaluation or a reasoned argument if the packaging has outer layers consisting entirely of materials that are unaffected by water such as metal, ceramic, plastic, or any combination of these materials. The evaluation needs to show that the design will not retain water, significantly increase mass, or have a reduction in strength.

5.2.2 Free Drop Tests

The free drop test simulates the type of impact or shock that a package would experience if it were to fall off the back of a stationary truck during loading or dropped during handling. In most cases, the package would continue in transport if it were dropped during handling. The water spray test discussed in Section 5.2.1 is to be completed before initiation of the free drop tests. For Type A packages that carry fissile material and are used in accordance with the content limits identified in 10 CFR § 71, Subpart C, there are eight additional drops required as discussed in Section 5.2.2.1. Packagings made from fiberboard and/or wood are also subject to additional drops as discussed in Sections 5.2.2.2, 5.2.2.3, and 5.2.2.4.

The free drop test requirement in 49 CFR § 173.465(c) states, "the specimen must drop on to the target so as to suffer maximum damage to the safety feature being tested." The *design team* must first identify the SF and then justify the most damaging drop orientation for each SF if more than on drop is deemed necessary. Following each drop the package damage is to be evaluated under the two performance criteria of loss or dispersal of contents and change in radiation levels. The test package should be prepared with the heaviest (sometimes referred to as "bounding") surrogate content weight and configuration that would cause maximum damage.

More than one drop orientation may be required to evaluate the package SFs under the most damaging drop test angles or drop orientations. Historically for package designs such as drums and low-level waste boxes with content having uniform physical characteristics, the CG over top rim or CG over top corner has been considered most damaging because this orientation typically results in maximum package deformation (bending and crushing) to the closure system (i.e., SF). However maximum damage to SFs under drop conditions is ultimately a function of the packaging design and the physical characteristics of the content. Also since Type A packagings have no shape, volume or weight limitations, prescribing drop orientations for all packagings is not possible (Ref. 3).

Determining maximum damage to the safety features. The *design team* evaluates the package design to identify the SFs and then determines how each of the SFs is likely to suffer maximum damage from the free drop. To produce the maximum damage, the test package may need to be dropped in more than one orientation so that the impact velocity or deformation of the SF under consideration is maximized. Packages usually are not symmetric, meaning that the features at the top, bottom, and sides differ. This means that damage due to a drop onto the top may or may not be relatable to damage due to a drop onto the bottom of the package; therefore, different drop orientations and multiple test packages may be needed. Multiple drops of a single test package may not be feasible due to damage from previous drops.

The package containment SFs are those items, components, or systems required to keep the solid, liquid, or gaseous contents within the packaging and prevent leakage. Containment SFs may include gaskets, closure bolts, closure rings, the lid-to-body flange system, seal welds, glued joints, ports, internal vials, and/or content containers. The package shielding SFs are those items required to keep penetrating radiation from escaping from the package. Shielding SFs can include the walls, bottom, lid, or lid closure of a poured lead shield, a shield filled with lead shot, a shield assembly nested inside the package containing a gamma emitting source, lead shield curtains or blankets, or light weight poly neutron shielding components. If applicable, the package heat removal SFs required to provide heat removal due to radioactive decay of content need to be identified. For each identified SF, the package *design team* needs to determine the particular number of drops and/or drop orientations that would cause maximum damage or failure of the SF. Damage or failure would constitute leakage of surrogate content, loss or reduction of shielding, or loss or reduction of heat transfer capability. The *design team* can identify the potential SF failures under the performance requirements by using simplistic judgements or more in-depth approaches such as "Failure Mode and Effects Analysis" developed initially by the military in the 1940s.

For all packages, including large size packages such as waste boxes or freight containers, all possible drop test orientations need to be considered. The free drop test states: "the specimen must drop on to the target so as to suffer maximum damage to the SF being tested." There is no regulatory relief for conditions that may be very unlikely or unrealistic in the transportation environment.

The *designer* needs to consider not only the initial impact onto the drop target but also the effects of secondary (slap-down) impacts. Secondary impacts become more important as the aspect ratio of the package (i.e., ratio of length to width) increases. A 55-gallon drum has an aspect ratio of ~1.4 and the secondary impact velocity for certain low angle side drops can be higher than the initial impact velocity. For very large aspect ratio packages such as 40-foot freight containers (40:8 = 5), the secondary impact velocity can be much higher than the initial impact velocity. For example, a 40-foot freight container subject to a CG over corner drop, with the door system at the high end, would experience a ~45 foot rotational drop onto the target. Large aspect ratio freight container designs may require special content considerations such as internal bagging, or packaging considerations such as external impact absorbing structures, to meet the performance requirements. Use of sacrificial impact absorbing materials or components that are meant to deform and absorb the drop test kinetic energy is a method often used to enhance a package's ability to perform under free drops.

Caution when using packages qualified to a free drop distance of less than four feet. The height from which to drop a test package is determined by the gross weight of the package. Table 5-2 identifies the drop height requirements from 49 CFR § 173.465. Historically, packages qualified to a particular weight were used for lower weight content shipments; however, based on a DOT Letter of Interpretation (LOI) issued in 2015 (Ref. 8), this should not be the case. Rather, packages must be used within the weight ranges that they were tested. For example, if a package design is qualified for a 6,800 kilogram (kg) (15,000 pounds [lb.]) gross weight, a three-foot drop test is required. Can this packaging then be used to ship lower weight content that would result in a gross package weight below 5,000 kg (11,000 lb.) for which a four-foot drop is required? The answer is "no." DOT states in the LOI that:

> The package described in [the] scenario cannot be used [for shipments having a package mass less than 5,000 kg (11,000 lb.)] without additional testing or demonstration of compliance. The Type A packaging tests specified in § 173.465 require a free drop distance of [4 feet for packages with a mass less than 5,000 kg (11,000 lb.)]…Thus, a package which has been qualified for the greater mass (and lower drop distance) would need to be re-qualified for the lesser mass (and higher drop distance) per the requirements in § 173.465.

Conservative Case. If a package with a gross weight of 5,000 kg (11,000 lb.) or more is drop tested at four feet, then the packaging can be used for any appropriate content of a lesser weight since the testing was carried out at the maximum free drop distance for a Type A package.

Table 5-2. Free Drop Distance for Testing Packages to Normal Conditions of Transport

Package Mass Kilograms (Pounds)	Free Drop Distance	
	Meters	Feet
Less than 5,000 (11,000)	1.2	4
5,000 (11,000) to 10,000 (22,000)	0.9	3
10,000 (22,000) to 15,000 (33,000)	0.6	2
Greater than 15,000 (33,000)	0.3	1

Table from 49 CFR § 173.465(c)(1). Distance is measured from the surface of the target to the lowest part of the test package.

5.2.2.1 Free Drop Tests for Packaging Carrying Fissile Material

With the exception of Type AF packagings which must meet the applicable requirements for fissile material packages in 10 CFR § 71, Type A packages containing quantities of fissile material specified in 10 CFR § 71.22 must pass the free drop tests identified in 49 CFR § 173.465(c)(1); however, before those tests are conducted, the test package must first undergo eight free drop tests from a height of 0.3 m (1 ft.) on each corner, or in the case of a cylindrical package, onto each of the quarters of each rim in accordance with 49 CFR § 173.465(c)(2).

After the eight one-foot fissile material drop tests are completed, and prior to the 49 CFR § 173.465(c)(1) drop, the *designer* determines the drop orientation that will result in the maximum damage to the SFs of the package.

A note of clarification regarding 7A Type A vs. Type AF fissile materials packages as specified in 49 CFR § 173.417(a)(1)(i) and (ii): The package testing discussed in this section apply to 7A Type A packages with fissile materials that are within the limits of 10 CFR § 71, Subpart C. When Type A packages exceed the limits of 10 CFR § 71, Subpart C, then the general requirements for fissile material packages from 10 CFR § 71.55 apply and more extensive testing, documentation, and Competent Authority approval is required. There are no fissile material requirements, additional testing, or documentation for packages that meet the fissile exceptions of 49 CFR § 173.417.

5.2.2.2 Free Drop Tests for Fiberboard or Wood Rectangular Packages

In addition to meeting the one to four-foot free drop requirements of 49 CFR § 173.465 (c)(1), light-weight rectangular packages (i.e., less than 50 kg or 110 lb.) made from materials such as fiberboard or wood require additional drops (on a separate specimen) to simulate repeated impacts due to handling. This regulation is based on the consideration that light-weight packages made from materials such as fiberboard or wood will be handled more and, therefore, subject to repeated impacts. The requirements of § 173.465(c)(3) state: "For fiberboard or wood rectangular packages with a mass of 50 kg (110 pounds) or less, a separate specimen must be subjected to a free drop onto each corner from a height of 0.3 m (1 ft.)."

To summarize, if a fiberboard box is used as a Type A packaging, (1) the 49 CFR § 173.465(c)(1) four-foot drop test will be carried out on test package #1, and then (2) a set of eight corner drops will be carried out on test package #2. When testing is completed, there will be a minimum of two test packages—one having been dropped from four feet per § 173.465(c)(1) and the other having been dropped eight times per § 173.465(c)(3).

5.2.2.3 Free Drop Tests for Cylindrical Fiberboard Packages

In addition to meeting the one- to four-foot free drop requirements of 49 CFR § 173.465 (c)(1), light-weight cylindrical packages (i.e., less than 100 kg or 220 lb.) made from materials such as fiberboard require additional drops (on a separate test package) to simulate repeated impacts due to handling. This regulation is based on the consideration that light-weight packages made from materials such as fiberboard will be handled more and, therefore, subject to repeated impacts. In addition to meeting the requirements of § 173.465(c)(4), "for cylindrical fiberboard packages with a mass of 100 kg (220 pounds) or less, a separate specimen must be subjected to a free drop onto each of the quarters of each rim from a height of 0.3 m (1 ft.)."

To summarize, a minimum of two test packages will be required. The first test package will be subject to the four-foot free drop test per 49 CFR § 173.465(c)(1) and then a second test package will be subjected to the eight, one-foot drops onto each of the quarters of each rim per § 173.465(c)(4). So when testing is completed, there will be a minimum of two test packages; one having been dropped a minimum of one time (4 feet) per § 173.465(c)(1) and the other test package having been dropped eight times per § 173.465(c)(3).

5.2.2.4 Free Drop Test for Fiberboard Packagings Carrying Fissile Material

For the case in which a fiberboard or wood rectangular or a cylindrical fiberboard package is used to ship Type A fissile material as specified in 10 CFR § 71.22, a minimum of two test packages will be required. The first test package would be subject to the eight one-foot fissile free drop tests per 49 CFR § 173.465(c)(2) and then the four-foot free drop per § 173.465(c)(1)—a total of nine drops.

Then if the packages are light-weight (i.e., less than or equal to 50 kg [110 lb.] or 110 kg [220 lb.], respectively) a second test package would be subject to the eight one-foot corner (or rim drops) per § 173.465(c)(3) and § 173.465(c)(4) fiberboard (or wood) packaging requirements.

To summarize free drop testing for fiberboard packagings carrying fissile material: when testing is completed, there will be a minimum of one or two test packages—one having been dropped nine times and the other (for light-weight packages) having been dropped eight times.

5.2.3 Stacking Test

The stacking test is to be carried out for a minimum time period of 24 hours under a compressive load equivalent to the greater of five times the package mass or 13 kPa (1.9 psi) times the vertically projected area of the package. The vertically projected area of the box is equal to the area of the base or shadow of the box projected vertically as though the sun were directly overhead. Remember, the package is required to be water sprayed as a conditioning step prior to conducting this test. In addition, if an evaluation is performed, the effect of the water spray test on the package must be taken into account.

The stacking test is designed to simulate the effect of loads pressing down on a package over a prolonged period of time to ensure the effectiveness of the shielding and containment systems will not be impaired and, in the case of fissile contents, will not adversely affect the criticality control configuration (Ref. 5).

The stacking test is performed by placing the fully loaded test package with its base sitting on an essentially flat surface such as a flat concrete floor or a steel plate. The stacking weight or load is to be applied uniformly to two opposite sides of the package—one of which is to be the base on which the package would typically rest, for a minimum time period of 24 hours. One straightforward method is to place the package in its normal transport configuration and stacking five identical packages on top. When stacking a total of five packages on top of one another, consideration of the materials of construction and safety should be taken into account. For example, if the design being tested is a soft-sided bag (e.g., fabric filled with a flowable solid material such as soil), it would be difficult and dangerous to personnel to attempt stacking five high. Another method would be to uniformly distribute a mass equal to five times the package's maximum mass across the top of the package in its normal transport configuration. This can be done by means of a flat plate with sufficient area to cover the upper surface of the package. In both cases the method used and the mass placed on the package are to be documented.

The following example illustrates whether a compressive load based on five times the package mass, or 13 kPa (1.9 psi) times the vertically projected area, is used.

Example: A rectangular metal package measuring 24 in. high × 36 in. wide × 48 in. long has a maximum weight of 900 lb. and a vertically projected area of 1,728 in^2 (36 in. × 48 in.):

- Five times the package mass results in a compressive load of 4,500 lb. (900 lb. × 5).
- The vertically projected area (1,728 in^2 times 1.9 lb./in^2) results in a compressive load of 3,283 lb.

When comparing the two values for determining the compressive load to be applied, choose the greater of the two values, which in this case is 4,500 lb.

5.2.4 Penetration Test

The penetration test is performed by placing the test package on a rigid, flat, and horizontal surface that will not move significantly while the test is being performed. In accordance with 49 CFR § 173.465(e), the penetration test is intended to ensure that the contents will not escape from the containment system or that the shielding or shield confinement system would not be damaged if a slender object such as a length of tubing were to strike the outer surface of the package. The requirement to do the penetration test is based only on the package content being a Type A quantity of material, and package weight is not a consideration.

The § 173.465(e) penetration test states that a bar 3.2 cm (1.25 in.) in diameter with a hemispherical end and a mass of six kg (13.2 lb.) is dropped so it falls with its longitudinal axis vertical onto the center of the weakest part of the test package so that, if it penetrates far enough, it will hit the containment system. The bar is not to be deformed by the test, and the height of the drop of the bar measured from its lower end to the intended point of impact on the upper surface of the specimen is to be 1 m (3.3 ft.) or greater.

The *design team* should identify the weakest parts of the test package with respect to the penetration test. Even though the penetration test wording in § 173.465(e) references only containment system performance, the *design team* should evaluate the test package for all of the performance requirements (containment, shielding, thermal) as required by § 173.465(a).

5.2.5 Additional Requirements for Type A Packagings Carrying Liquid or Gas Content

The additional design requirements and tests for Type A packagings that ship liquid or gaseous content are imposed because these forms of radioactive material have a greater possibility for leakage as compared to a solid material. Packagings for liquid and gaseous contents must meet all of the design requirements and go through the same tests (water spray, free drop, stack, and penetration) as prescribed for Type A packages carrying solids. Then the additional requirements and tests must be addressed as discussed below.

5.2.5.1 Additional Design Requirements for Packaging Carrying Liquids

For liquid content, the regulations not only have additional and more severe free drop test requirements (30 feet versus one to four feet), but there are also additional design requirements in 49 CFR § 173.412(k)(1) and (3).

Design Requirements. The design requirements from § 173.412(k) for packagings carrying liquids are as follows:

Each packaging designed for liquids will—

(1) Be designed to provide for ullage to accommodate variations in temperature of the contents, dynamic effects and filling dynamics;

(2) Meet the conditions prescribed in paragraph (j) of this section [loss of contents or increase in surface radiation level] when subjected to the tests specified in § 173.466 or evaluated against these tests by any of the methods authorized by § 173.461(a); and

(3) Either—

  (i) Have sufficient suitable absorbent material to absorb twice the volume of the liquid contents. The absorbent material must be compatible with the package contents and suitably positioned to contact the liquid in the event of leakage; or

  (ii) Have a containment system composed of primary inner and secondary outer containment components designed to enclose the liquid contents completely and ensure retention of the liquid within the secondary outer component in the event that the primary inner component leaks.

The § 173.412(k)(1) requirement for ullage ensures that free space is available above the liquid so that any liquid expansion due to freezing or thermal expansion will not completely fill and potentially burst the liquid containment vessel. Expanding liquids can exert pressure, so it is essential that ullage is present. See related requirements for regarding filling limits in § 173.24(h) and § 173.24a(d).

Secondary Containment Measures. The requirements in § 173.412(k)(3) call for secondary containment measures (absorbent material or outer component) to be in place in the event radioactive liquid content escapes from the primary (inner) container (e.g., vial, bottle, bag, flanged vessel). For packagings with gamma or neutron emitting content that require shielding, the secondary containment measures must account for the flow, migration, or absorption of any leaking liquid and ensure that the leakage remains within shield structures. This can be difficult to address unless the shield structures are liquid tight. Leakage of gamma or neutron emitting liquids from the primary inner container will create a different radiation source geometry depending on where the leaking liquid goes. The packaging design is required to ensure that any leakage from the primary inner container remains within the shielding structures. Any leakage from the primary inner container into either absorbent materials or into a secondary container needs to remain confined within the shielding.

If the § 173.412(k)(3) requirements are being addressed by testing, then the leakage of surrogate liquid content from the primary inner container is to be addressed. It is desired that the primary inner container withstand the free drop tests without leakage. However, in the event the primary inner container leaks, the absorbent material or the secondary outer container must be shown to contain the liquid content. This may require that testing be done with free liquid present within the outer container (i.e., ensure primary inner container leaks). Use of dyes or brightly colored liquid surrogate content aids in the visual inspection of any leakage. It is recommended that free drop tests be carried out to demonstrate primary inner container performance and that additional tests or provisions for testing be carried out to demonstrate the adequacy of secondary absorbent materials and the outer container.

5.2.5.2 Additional Tests for Packagings Carrying Liquid or Gas Content

In addition to the one to four-foot free drop test requirements in 49 CFR § 173.465(c), packages containing liquids and gases must meet the additional free drop and penetration test requirements in § 173.466. The requirement in § 173.412(l) provides an exception from the additional (30 foot) free drop test for tritium not exceeding 40 terabecquerels (TBq) (1,080 curies [Ci]) or noble gases not exceeding the A_2 value appropriate for the noble gas.

Note that Type A packagings carrying liquid or gas contents are subject to not only the § 173.465(c)(1) drop tests for solid content, but also the additional 30-foot free drop, and the 5.5-foot penetration tests specified in § 173.466. So a test package would be subject to the water spray, free drop, stacking, and penetration tests per § 173.465 and then also be subject to the more rigorous free drop and penetration tests per § 173.466.

49 CFR § 173.466(a)(1) 30-Foot Free Drop Test. The height of the drop test as measured from the lowest part of the package to the upper surface of the target is 9 m (30 ft.) or greater. For the additional § 173.466 free drop test, the *designer* needs to assess the test package damage from the initial § 173.465 tests to determine the maximum damage drop orientation for the 30-foot free drop test. The *designer* must consider not only the primary impact but also the effects of any secondary (slap-down) impacts.

49 CFR § 173.466(a)(2) 5.5-Foot Penetration Test. In addition to the penetration test required by § 173.465(e), packages containing liquids and gases must also be capable of withstanding an additional penetration test from a higher bar drop distance (5.5 ft.) as required by § 173.466 (a)(2). For the additional (second) penetration test, the test package is subjected to the penetration test as specified in § 173.465(e) except that the height of the drop is to be 1.7 m (5.5 ft.).

5.3 Conducting Tests to Verify Design Requirements

There are two design requirements that are often verified by testing. They are the ability of the package to withstand acceleration and vibration due to the transportation environment and the ability to withstand a reduction in atmospheric pressure—the result of transport pressure changes such as going over a mountain. The vibrational capability requirement is found in 49 CFR § 173.410(f) and the reduction in external pressure requirement is found in § 173.412(f).

5.3.1 Acceleration and Vibration

The transportation environment causes repeated accelerations, bumps, and vibrational forces that can cause metal fatigue and/or cause nuts and bolts to loosen and components or content to redistribute or settle. The *design team* should evaluate the package design and identify any nuts, bolts, or other retention devices that might work loose during transportation. Vibrations can also cause interactions between internal components that can result in damage or loosening. For larger containers that have internal content, the tie-down and securement of the internal payload under the transport accelerations and vibrations need to be evaluated. Internal payloads coming loose can cause significant damage to larger packagings. Vibrations can cause repeated compression and tension loads on the package that can result in bending, loosening, or cracking that can be difficult to evaluate without testing.

The vibration requirements are as follows:

- The package will be capable of withstanding the effects of any acceleration, vibration or vibration resonance that may arise under normal conditions of transport without any deterioration in the effectiveness of the closing devices on the various receptacles or in the integrity of the package as a whole and without loosening or unintentionally releasing the nuts, bolts, or other securing devices even after repeated use…(49 CFR § 173.410(f)).

- The effectiveness of the package will not be substantially reduced; for example, impact resistance, strength, packaging compatibility, etc. must be maintained for the minimum and maximum temperatures, changes in humidity and pressure, and shocks, loadings and vibrations, normally encountered during transportation (§ 173.24(b)(2)).

- Each non-bulk package must be capable of withstanding, without rupture or leakage, the vibration test procedure specified in § 178.608 of this subchapter (§ 173.24a(a)(5)).

The following vibration standard is listed in the UN performance-oriented packaging requirements of 49 CFR part 178, subpart M, Testing of Non-bulk Packagings and Packages § 178.608:

(a) Each packaging must be capable of withstanding, without rupture or leakage, the vibration test procedure outlined in this section.
(b) Test method.
    (1) Three sample packagings, selected at random, must be filled and closed as for shipment.

(2) The three samples must be placed on a vibrating platform that has a vertical or rotary double-amplitude (peak-to-peak displacement) of one inch. The packages should be constrained horizontally to prevent them from falling off the platform, but must be left free to move vertically, bounce and rotate.

(3) The test must be performed for one hour at a frequency that causes the package to be raised from the vibrating platform to such a degree that a piece of material of approximately 1.6 mm (0.063 in) thickness (such as steel strapping or paperboard) can be passed between the bottom of any package and the platform.

(4) Immediately following the period of vibration, each package must be removed from the platform, turned on its side and observed for any evidence of leakage.

(5) Other methods, at least equally effective, may be used, if approved by the Associate Administrator.

(c) *Criteria for passing the test.* A packaging passes the vibration test if there is no rupture or leakage from any of the packages. No test sample should show any deterioration which could adversely affect transportation safety or any distortion liable to reduce packaging strength.

The capability to withstand vibration is a design capability requirement and may be addressed by any of the compliance methods discussed in Section 4 of this report. As with the performance tests specified in Section 5.2, the regulations do not specifically require physical testing be done. Title 49 CFR § 173.24a(a)(5) identifies a vibration test procedure for non-bulk packages in § 178.608, “Vibration standard.” To demonstrate the ability to meet the vibration requirements, non-bulk radioactive material packagings are often subjected to the vibration standard identified in § 178.608. This is acceptable. Larger radioactive material packagings are sometimes subjected to the vibration test requirements identified for intermediate bulk packagings in § 178.819, “Vibration test.” In either case, the number of packages subjected to the test, the method of determining no loss or dispersal of content material, and the method for determining if there would be an increase in the radiation levels at external surfaces are to be determined by the *design team*. Note that Appendix C to § 173 also provides a “Procedure for Base-level Vibration Testing” that is very similar to the § 178.608 vibration standard.

The test packages for the vibration test should be prepared as discussed in Section 5.1. If testing is not carried out, the ability of the packaging to meet the vibration requirements must be evaluated. The evaluation should look at material fatigue, the ability of the closure to remain tightly closed, and the retention of shielding capabilities. Reference to similar package designs or to actual transportation experience should be made whenever possible. It should be noted the § 178.608 vibration standard is written for non-radioactive hazards and therefore no mention is made of the need to check for changes in radiation levels. When evaluating shielding, the effects of vibration on the internal packaging and content movement should be considered.

After testing, look for not only evidence of loss or dispersal of content but for signs of internal movement of components that could result in increases in the radiation level at the surface of the package. Keep in mind that movement of content, shielding, changes in distance between the content and the package surface, loss of shielding, compaction or change in density, and/or configuration of the content are all factors that can affect the radiation level at the package surface.

Experience and a successful history of package shipments can be used to satisfy the vibration requirement based on a DOT LOI issued in December 2002 (Ref. 9). The LOI states the vibration capability can be demonstrated through performing the vibration test or the “capability can be demonstrated through the packaging performance history using this type of packaging.” When using performance history, the *design team* must document or provide an evaluation of the specific transportation history being used for the comparison.

5.3.2 Reduced External Pressure

The additional design requirement for Type A packages in 49 CFR § 173.412(f) requires the containment system to "retain its radioactive contents under the reduction of ambient pressure to 60 kPa (8.7 psia)." This design requirement is meant to ensure that radioactive content is maintained under conditions where the outside (external) pressure is reduced due to atmospheric pressure or elevation changes during transport. If testing is carried out to demonstrate this capability, then the test package can be fully assembled and placed in an evacuation chamber that produces a reduced pressure external to the package. If using an evacuation chamber is not practical, the *design team* should evaluate the option of internally pressurizing the containment system to produce a pressure differential of 41 kPa (6 psi), i.e., 101 kPa (14.7 psia) – 60 kPa (8.7 psia) = 41 kPa (6 psi).

The requirement states that the "containment system will retain its radioactive contents under the reduction of ambient pressure." Note the requirement does not say the containment system must *withstand a reduction in external pressure* but rather that the content *be retained*. This means that test packages subject to the reduced external pressure can incorporate components such as filtered vents designed to retain content but allow for the packaging to breathe or vent pressure during the test. This is important for packaging designs with flat surfaces such as single walled rectangular waste boxes. Thin walled (rectangular) containers are not structurally suited for pressure retention. If filtered vents are used to meet this requirement, they must be shown to maintain the ability to vent and not clog or plug up and have sufficient capacity to vent the packaging. The § 173.412(f) requirement does not address the rate of pressure change; however, for packages shipped by highway or rail, altitude changes would be gradual over a period of time.

The pressure differential between the package interior and exterior can also be affected by the production of gas within the containment boundary due to vapor pressure, biodegradation, or radiolytic generation of gases. These pressure sources need to be evaluated for all content. Radiolytic generation of gases is generally not a significant consideration for Type A package content activity levels; however, for packagings carrying liquid or gaseous content, the additional pressure generation from vapor or radiolytic considerations should be addressed.

There is a safety consideration when carrying out pressurization tests due to the stored energy present in compressed gases. It is recommended that an uncompressible hydraulic fluid be used for pressurization whenever possible to minimize the amount of stored energy inside the package. For packagings that do not have an opening through which pressure can be applied, it may be necessary to add a feature. If this is done, the *design team* needs to ensure the added feature is taken into account when evaluating the test results.

Air transport pressure requirements: Air transport regulations require the containment vessel to withstand a pressure differential of 95 kPa (13.8 psi). Unlike the reduction in external pressure discussed in Section 5.3.2, this requirement cannot be met by use of filtered vents. The pressure requirements for aircraft transport include the following statements:

- Packagings must be designed and constructed to prevent leakage that may be caused by changes in altitude and temperature during transportation aboard aircraft (49 CFR § 173.27(c)(1)).

- Packagings for which retention of liquid is a basic function must be capable of withstanding without leakage the greater of—
  - (i) An internal pressure which produces a gauge pressure of not less than 75 kPa (11 psig) for liquids in Packing Group III of Class 3 or Division 6.1; or 95 kPa (14 psig) for other liquids; or [other methods related to the liquid's vapor pressure] (§ 173.27(c)(2)).

- A package containing liquid contents must be capable of withstanding, without leakage, an internal pressure that produces a pressure differential of not less than the maximum normal operating pressure plus 95 kPa (13.8 psi) (§ 173.410(i)(3)).

The most conservative regulation is at § 173.410(i)(3) which clearly requires all liquid-containing packages to meet, at minimum, the 95 kPa (13.8 psi) standard plus the maximum normal operating pressure. The "*Maximum normal operating pressure* means the maximum gauge pressure that would develop in a containment system during a period of one year, in the absence of venting or cooling, under the heat conditions specified in 10 CFR 71.71(c)(1)" (§ 173.403). The air transport requirements for liquids require the packaging to be robust enough to withstand an internal pressure and therefore the use of filtered vents is not an option.

The *design team* should also review the International Air Transport Association (IATA) and International Civil Aviation Organization (ICAO) requirements for air transport of hazardous materials. Even though these are international regulations, most domestic air cargo transporters mandate the IATA/ICAO requirements.

6.0 ACCEPTANCE CRITERIA FOR TESTING

The design for each Type A package shall demonstrate the capability to fulfill all design and performance requirements as specified in 49 CFR § 173.412(j), which are included below:

> When evaluated against the performance requirements of this section and the tests specified in § 173.465 or using any of the methods authorized by § 173.461(a), the packaging will prevent—
>
> (1) Loss or dispersal of the radioactive contents; and
> (2) A significant increase in the radiation levels recorded or calculated at the external surfaces for the condition before the test.

The DOT and IAEA regulations differ in the radiation level acceptance criterion. IAEA *Regulations for the Transport of Radioactive Material*, 2018, SSR-6 (648(b)), specifies that "a *package* shall be so designed…that it would prevent: More than a 20% increase in the maximum [radiation level] at any external surface of the *package*" (Ref. 10). The DOT specifies that a package be designed to prevent a "significant increase in the radiation levels recorded or calculated at the external surfaces."

6.1 Preventing Loss or Dispersal of the Radioactive Contents

The surrogate content used in testing should simulate as closely as possible the physical characteristics of the radioactive material contents and the smallest dispersible particle size that will be shipped. Determining if the surrogate content leaks from the test package can be by visual inspection and/or by using fluorescein dye in conjunction with ultraviolet (UV) light and reduced ambient lighting when possible. The requirement that the package prevent "loss or dispersal" can be addressed in many ways, including the following:

- No visible detection of fine material (representing small particulate materials) such as flour or cement dust on the outside of the test package or test floor area. The sensitivity for identifying fine materials can be increased by the use of fluorescein dye in conjunction with UV light and reduced ambient lighting when possible or application of a light water spray/mist.

- No visible detection of liquid such as red dye on internal absorbent materials or components, the outside of the test package, or on the test floor.

- Post-test verification of seal integrity can be addressed in a number of ways including, but not limited to, pressurizing the containment system and monitoring for pressure decay or by doing a submersion or soap bubble test with the container under pressure. Post-test methods are often used for gaseous contents since this content form is difficult, if not impossible, to detect by visible means.

- No visible rupture of the outer packaging which would permit the release of content-enclosing components from the package.

The physical characteristics, smallest dispersible particle size, and specific activity of the radioactive content should be considered when determining the sensitivity of the leakage or loss-of-content criteria. For example, a high specific activity radioactive material in the form of a fine powder would require a sensitive detection method such as fluorescent powder or dyes and UV light. For a less dispersible content such as activated stainless steel pellets or content sealed in inner containers or bags, small gaps or punctures in the packaging would not necessarily result in a content release. The complexity of containing solids increases as the particle size gets smaller.

There is no Type A requirement allowing for a test package to release content (e.g., “puff” or “burp”) under dynamic conditions during testing and then reseal. If a Type A test package is shown to have leaked any surrogate contents during the test but post-test inspections indicate the container is sealed, then the test should be considered to have failed. There is provision in the UN packaging requirements in § 178.603(f)(5) that allow for slight releases “so long as discharge from a closure is slight and ceases immediately after impact with no further leakage;” however, this is not applicable to radioactive testing.

6.2 Preventing a Significant Increase in the Radiation Levels Recorded or Calculated at the External Surfaces

Radiation level requirements at or near radioactive material package surfaces are governed not only by the maximum allowable values (e.g., 2 mSv/h [200 mrem/h]) but also by limitations in the amount of variation that is allowed (i.e., no significant increase). This requires the packaging design to carefully couple the radioactive contents with the structure and geometry of the packaging design to minimize any relative motion between the content and packaging surfaces. The radioactive content is the source of the penetrating radiation that is present at the package surface. The movement or shifting of contents within the packaging due to gaps between components or content settling due to vibration will result in changes in the surface radiation levels. Similarly, dents or deformation of the package surface due to the free drop tests or penetration can also result in changes to the package surface that can affect the radiation level. It is the responsibility of the package *designer* to ensure that the radioactive contents and packaging hardware configuration prevents unacceptable changes in the radiation levels.

The radiation level change requirements in 49 CFR § 173.412(j)(2) are as follows:

> When evaluated against the performance requirements of this section and the tests specified in §173.465 or using any of the methods authorized by §173.461(a), the packaging will prevent—
> …
> (2) A significant increase in the radiation levels recorded or calculated at the external surfaces for the condition before the test.

This requirement indicates that the change in surface level radiation should be determined by evaluating the package design before and after the package is subjected to the design and test requirements listed in Table 4.1.

The vibration and free drop tests are most likely to cause changes in the internal and external geometry of the package design.

Evaluating the radiation level change at the package surface after testing can be done by (1) geometry measurements and dose rate calculations or (2), if appropriate (e.g., for small radioactive sources), using radioactive contents and performing surveys. Smaller sized packages with physically small or concentrated sources (e.g., special form capsule) will have relatively high radiation level gradients at the package surface and therefore small changes in the package surface or movement of the content can result in significant radiation level changes. Whereas larger sized packages such as drums or boxes carrying larger volume content (e.g., low-level waste) have lower radiation level gradients due to the physically large source volume; larger packages are much less sensitive to changes in the surface or movement of the content. Payload settling can also result in surface radiation level increases (Ref. 11).

The package *designer* is responsible for ensuring that the packaging and associated radioactive material (RAM) contents are engineered to minimize relative movement within the packaging during transport. Following the vibration and free drop tests, the internal movement of content and components and exterior damage are to be documented. Note the regulations say the “increase in the radiation levels recorded or calculated at the external surfaces” is to be determined. This means the use of straight forward point kernel shielding codes or calculations can be used to make the determination of radiation level increase. It is ultimately the *shipper/offeror* that ensures the packaging is properly loaded and content is secured.

Significant Increase: It is imperative to record details of the damage sustained during package testing in order to evaluate compliance with the surface radiation level requirements. This includes photos, descriptions, and dimensions of the actual damage. The *shipper/offeror* has to analyze the proposed contents against the damage that occurred during testing to ensure that radiation levels would not increase significantly if such damage occurred during transport.

The meaning of *significant increase* needs to be addressed by the *shipper/offeror* based on the specifics of the packaging design and content shipped. One approach is to consider *significant* in light of the requirements for the maximum radiation levels at the package surface (i.e., 200 mrem/h per § 173.441(b)(1)). For content resulting in relatively low surface radiation levels (e.g., 10 mrem/h), an increase of 50% (from 10 to 15 mrem/h) may be determined to be *not-significant*. Another approach is to consider *significant* as a change that results in the movement from one § 172.403(c) hazard communication label category to another. The labeling (and placarding) regulations allow for variations in surface radiation levels with no associated safety consequence communications to the public. For example, radiation levels at a package surface ranging from 10 mrem/h to 50 mrem/h (assuming the transport index ≤ 1) are all labeled Yellow-II.

6.3 Heat Removal

Since all radioactive decay is exothermic and releases heat, the removal of decay heat is a packaging design requirement specified somewhat indirectly in the following requirements:

- Containment and shielding is maintained during transportation and storage in a temperature range of -40 ºC (-40 ºF) to 70 ºC (158 ºF) (49 CFR § 173.412(c)).

- The heat generated within the package by the radioactive contents will not, during conditions normally incident to transport, affect the integrity of the package; and…The temperature of accessible external surfaces of the loaded package will not…exceed either…(1) 50 ºC (122 ºF) in other than an exclusive use shipment [,] or (2) 85 ºC (185 ºF) in an exclusive use shipment (§ 173.442).

- The effectiveness of the shielding, containment and, when required, the heat transfer characteristics of the package, are within the limits specified for the package design (§ 173.474(b)).

As discussed in Section 5.2.1, Type A activity levels are generally sufficiently low that heat removal is a non-issue; however, there are exceptions as noted when dealing with special form content that can have relatively high A_1 activity values and associated heat production. The *design team* is responsible for evaluating the heat removal capability of the packaging design.

7.0 DOCUMENTATION OF TESTING

7.1 Documentation of Testing

Documentation of the tests in Table 4-1 is the responsibility of the respective members of the *design team* directly involved in the physical tests and/or evaluations. Appendix A of this report provides a template for a Type A test report. The details of testing documentation will vary according to the package design and compliance methods chosen.

The specification for Type A packages listed in 49 CFR § 178.350 requires compliance with a broad range of subparts and sections of the regulations. A compliance summary as discussed in Section 7.3.1 of this report is often used to document some or all of the regulations specified by § 178.350. For example, § 178.350 requires Type A packaging to meet all applicable requirements of 49 CFR:

- § 173 Subpart B-Preparation of Hazardous Materials for Transportation
- § 173 Subpart I-Class 7 (Radioactive) Materials
- § 178.2 Applicability and responsibility. (Includes notification requirements.)
- § 178.3 Marking of packagings.

The *shipper/offeror* documentation requirements from § 173.415(a) are provided in Table 7-1 below with examples of the type of information that can be maintained/provided to demonstrate compliance.

Table 7-1. Documentation Requirements and Examples.

Documentation Requirements	Examples
§ 173.415(a) . . . each offeror of a Specification 7A package must maintain on file for at least two years after the offeror's latest shipment, and shall provide to DOT on request one of the following: (1) A description of the package showing materials of construction, dimensions, weight, closure, and closure materials (including gaskets, tape, etc.) of each item of the containment system, shielding, and packing materials used in normal transportation, and the following:	Design drawings, figures, sketches, component specifications, fabrication documentation, identification of SFs, component specifications, material certifications, surrogate content description, content containers, photographs, video recordings, etc.
(i) If the packaging is subjected to the physical tests of §173.465, and if applicable, §173.466, documentation of testing, including date, place of test, signature of testers, a detailed description of each test performed including equipment used, and the damage to each item of the containment system resulting from the tests, or	Test plans, procedures, and reports; closure instructions; post-test disassembly procedures; method of determining leakage; free drop and puncture deformation measurements and photos; determination of worst case orientations for each SF; determination of drop target adequacy; video of tests and post-test disassembly; photographs; quality inspections, equipment calibration, reports, and specifications; etc.
(ii) For any other demonstration of compliance with tests authorized in §173.461, a detailed analysis which shows that, for the contents being shipped, the package meets the pertinent design and performance requirements for a DOT 7A Type A specification package.	Detailed comparison tables, evaluation report with references, structural evaluations and calculations. The analysis should demonstrate how the packaging complies with the design requirements of § 173.410 and § 173.412—with special emphasis on how the packaging will prevent loss or dispersal of contents, significant increases in radiation, adverse effects arising from acceleration, vibration, pressure changes, etc.
(2) If the offeror has obtained the packaging from another person who meets the definition of "packaging manufacturer" in §178.350(c) of this subchapter, a certification from the packaging manufacturer that the package meets all the requirements of §178.350 for the radioactive contents presented for transport and a copy of documents maintained by the packaging manufacturer that meet the requirements of paragraph (a)(1) of this section.	Manufacturer certification plus the above documents as applicable.

7.2 Closure Instructions and User Requirements

The details of how a packaging is loaded with content and then closed are an important design consideration in the development of a new package. The steps to load a packaging with content are generally carried out by the shipping organization and may vary as a function of the content details.

It is recognized that packaging designs are tested and/or evaluated with certain surrogate content that have particular physical characteristics and minimum particle size (see Table 5-1). It is the *shipper's* responsibility, in conjunction with the test facility, to ensure that a packaging is loaded with content that conforms to the surrogate content details. Once the packaging is loaded with content, the package closure steps must be followed. When a test or evaluation of a new package design is successfully completed, the closure steps are to be documented and formalized to ensure the *shipper/offeror* of the package follows the same closure steps that were used during testing or evaluation.

Title 49 CFR § 178.350 references § 178.2(c)(1)(i) notification requirements are as follows:

> …the manufacturer or other person certifying compliance with the requirements of this part, and each subsequent distributor of that packaging must:
>
> (i) Notify each person to whom that packaging is transferred—
>
> (A) Of all requirements in this part not met at the time of transfer, and
>
> (B) With information specifying the type(s) and dimensions of the closures, including gaskets and any other components needed to ensure that the packaging is capable of successfully passing the applicable performance tests. This information must include any procedures to be followed, including closure instructions for inner packagings and receptacles, to effectively assemble and close the packaging for the purpose of preventing leakage in transportation. Closure instructions must provide for a consistent and repeatable means of closure that is sufficient to ensure the packaging is closed in the same manner as it was tested.

7.3 Quality Control

The DOT QC requirements for radioactive material packagings are listed in 49 CFR § 173.474 and § 173.475 and address the quality of design and construction of the packaging and shipper requirements regarding use of the packaging. Section 173.403 defines quality assurance as "a systematic program of controls and inspections applied by each person involved in the transport of radioactive material which provides confidence that a standard of safety prescribed in this subchapter is achieved in practice." Note that at U.S. Department of Energy (DOE) sites, quality assurance is typically implemented by specific site Quality Assurance (QA) programs; therefore, packaging related activities such as radioactive material content characterization and handling, packaging design, testing, packaging procurement, fabrication, and use of the packaging (including the content loading and packaging closure operations) are carried out under the site-specific QA programs.

7.3.1 QC Prior to First Shipment.

Construction quality focuses on ensuring the packaging is ready before it is used the first time. Two requirements are specified: (1) that the design and construction requirements have been met and (2) that the effectiveness of the shielding, containment, and heat transfer characteristics have been determined.

The design and construction requirements in 49 CFR § 173.474(a) require the *shipper* to ensure that, before first use of a packaging, all applicable design and construction requirements of the HMR have been met. This may be demonstrated by a compliance summary that lists the applicable § 178.350 regulations followed by a statement of how compliance is met. A compliance summary format is given in Reference 1.

The design and construction requirements in § 173.474(b) require the *shipper* to ensure that the effectiveness of shielding, containment, and heat transfer characteristics of the packaging are within the limits specified by the design. This may be demonstrated by analysis or using surrogate or radioactive content.

7.3.2 QC Prior to Each Shipment.

At this juncture, the s*hipper/offeror* has the newly developed packing, all associated documentation, and is now putting the packaging into use. The quality requirements prior to each shipment consist of a check list of items the shipper needs to ensure by examination or appropriate tests. The list from 49 CFR § 173.475 is as follows:

(a) The packaging is proper for the contents to be shipped;
(b) The packaging is in unimpaired physical condition, except for superficial marks;
(c) Each closure device of the packaging, including any required gasket, is properly installed, secured, and free of defects;
(d) For fissile material, each moderator and neutron absorber, if required, is present and in proper condition;
(e) Each special instruction for filling, closing, and preparation of the packaging for shipment has been followed;
(f) Each closure, valve, or other opening of the containment system through which the radioactive content might escape is properly closed and sealed;
(g) Each packaging containing liquid in excess of an A_2 quantity and intended for air shipment has been tested to show that it will not leak under an ambient atmospheric pressure of not more than 25 kPa, absolute (3.6 psia). The test must be conducted on the entire containment system, or on any receptacle or vessel within the containment system, to determine compliance with this requirement; [Note this is not a Type A packaging requirement.]
(h) The internal pressure of the containment system will not exceed the design pressure during transportation; and
(i) External radiation and contamination levels are within the allowable limits specified in this subchapter.

8.0 REFERENCES

1. A*merican National Standard For Radioactive Materials - Guidance for Packaging Type A Quantities of Radioactive Material*s, ANSI N14.7- 2013.
2. *Documentation and Verification Required for Type A Package Use,* U.S. (DOE) Office of Safety, Health and Security (EM-5), WMTS-IP/7A-002, Rev. 0, 2000.
3. *Methodology for Identification of Testing to Conduct on Type A and Industrial Packagings,* U.S. (DOE) Office of Safety, Health and Security (EM-5), WMTS-IP/7A-003 Rev. 0, 2000.
4. *The Radioactive Materials Packaging Handbook, Design, Operations, and Maintenance*, L. B. Shappert, Et. al., ORNL/M-5003.
5. *IAEA Safety Standards, Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material (2012 Edition),* Specific Safety Guide No. SSG-26.
6. *American Standard for Testing Materials, Standard Test Method for Drop Test of Loaded Containers by Free Fall*, ASTM D5276-98.
7. *International Standard, Packaging – Complete, filled transport packages – Vertical impact test by dropping*, ISO 2248, Second edition 1985.
8. *U.S. Department of Transportation, Letter of Interpretation*, T. Glenn Foster to M. B. Hawk, Reference No. 15-038, May 5, 2015, (regarding package weight and drop height).
9. *U.S. Department of Transportation, Letter of Interpretation*, Delmer F. Billings to Peter El-Sabaaly, Reference No. 02-0221, December 4, 2002 (regarding vibration capability through packaging performance history).
10. *IAEA Safety Standards, Regulations for the Safe Transport of Radioactive Material (2012 Edition*), Specific Safety Requirements No. SSR-6.

11. *Radiation level changes at RAM package surfaces*, E. Opperman, M. Hawk, A. Kapoor and R. Natali, Packaging, Transport, Storage & Security of Radioactive Material, International Journal, Volume 22, No. 2, 2011.

APPENDIX A – TEMPLATE FOR TYPE A TEST REPORT.

Notes: (1) Items with asterisk (*) are 49 CFR § 173.415(a) documentation requirements for Shipper/Offeror.
(2) This template is available in Word Format on the PMC Home Page

1. **Test Package Identification – List:**
    a. Test package number:
    b. Part number:
    c. Serial number:
2. **Test Package Description – List/Describe:**
    a. General Test Packaging and Contents:
    b. Drawing number and revision:
    c. Component specifications:
    d. Nut/bolt type:
    e. Gasket:
    f. Vents:
    g. *Materials of construction:
        i. *Each item in containment system
        ii. *Shielding materials
        iii. *Packing materials (e.g., dunnage, content cans, spacers)
    h. *Dimensions:
        i. Outside/external dimensions, e.g., L x W x H, or H and Dia.,
        ii. Internal dimensions and/or containment internal dimensions
        iii. Component dimensions (if not shown on drawing), e.g., lead pig, content vials
    i. Seam construction as applicable for each component:
    j. *Closure details
        i. Define closure
        ii. List closure materials:
3. **Contents Used for Testing – List/Describe:**
    a. Surrogate contents:
        i. Identify surrogate “content” (e.g., surrogate content, test can, inner bags, spacers, internal dunnage):
    b. Overall form and physical characteristics of Surrogate Contents:
        i. Solids – shape, density, size, hardness or softness:

1. Flowable or uniform, e.g., sand, pea gravel, bagged LLW,
2. Chunks, e.g., brick, sealed cans
3. Large items, e.g., pumps, lead pigs, inner containment vessels
4. Smallest particle size, e.g., talcum powder, oxides, sand, pea gravel:

ii. Liquid:, or

iii. Gas:

4. Gross weight of Test Package:

a. Packaging weight:

b. Content weight:

c. Component weights:

5. Pre-test Inspections, Assembly and Disassembly

a. Inspection. Document inspection of test package in accordance with § 173.462, *Preparation of specimens for testing*.

b. Assembly, Testing and Post-test Disassembly Procedures. Ensure testing procedures are written to guide test package assembly and that testing in carried out in accordance with § 173.461, *Demonstration of compliance with tests*, and that post-test disassembly and inspection criteria have been documented.

6. Tests: If Type A design requirements or construction quality control requirements are addressed by testing, then document, as applicable the following:

a. Vibration. Provide results of vibration tests and details of test package used for testing. Document that the package is capable of withstanding the vibration standard in § 178.608 (§ 173.410(f)).

b. Reduction of ambient pressure. Provide results the containment system will retain its radioactive contents under the reduction of ambient pressure to 60 kPa (8.7 psia) (§ 173.412(f)).

c. Quality control for construction of packaging (prior to first use). Provide results that the effectiveness of the shielding, containment and, when required, the heat transfer characteristics of the package are within the limits specified for the package design (§ 173.474).

d. For each test above, document

i. *Date and time of tests:

ii. *Place of test and *signature of testers:

iii. *Description of each test and Test Sequence number:

iv. *Equipment used for each test:, and

v. *Damage to each item in containment resulting from the tests**:**

7. **Tests: Type A Testing per Part 173.- Document the following:**
   a. Water spray test. Note the water spray test must precede each test or test sequence prescribed in § 173.465 (§ 173.465(b)).
      i. *Date and time of tests:
      ii. *Place of test and *signature of testers:
      iii. *Description of test and Test Sequence #:
      iv. *Equipment used for tests:
      v. Spray Duration and water spray directions onto package:
      vi. Soak Duration (time between water spray and beginning of next test):
      vii. Illustrate how package is closed and location of Fluorescein dye and other indicators of water intrusion as applicable:
      viii. Test photographs:
      ix. Test videos:
      x. Results, document the following:
         1. That there was no leakage of surrogate content, no reduction in shielding, or no damage (softening, dissolution, property changes) to packaging components that could affect subsequent tests.
         2. *Damage to each item of containment.
   b. Free Drop tests (§ 173.465(c)(1)).
      i. *Date and time of test:
      ii. *Place of test and *signature of testers:
      iii. *Description of test and Test Sequence #:
      iv. *Equipment used for test:
      v. Drop Height:
      vi. Identify SFs being tested and drop orientation that provides maximum damage to the SF being tested:
         1. If one foot fissile drop tests are performed prior to the (c)(1) drop tests, then damage resulting from the (8) fissile drop tests are to be considered when determining the (c)(1) drop orientation:
      vii. Results – document the following:
         1. That there was no surrogate content leakage, or reduction in shielding
         2. *Damage to each item of containment system
      viii. Maximum external crush depth or indentations to external surfaces:

ix. Internal movement of content relative to external surface:

x. Test photographs:

xi. Test videos:

c. Free Drop tests for packages containing fissile material, the free drop test specified in (c)(1) must be proceeded by eight (8) one-foot drops (§ 173.465(c)(2)).

i. *Date and time of test:

ii. *Place of test and *signature of testers:

iii. *Description of test and Test Sequence #:

iv. *Equipment used for tests:

v. Drop Height:

vi. Identify drop orientation of test package:

vii. Results:

viii. Maximum top crush pattern:

ix. Maximum bottom crush pattern:

x. Test photographs:

xi. Test videos:

d. Free Drop tests for fiberboard or wood rectangular packages with a mass of 100 lb. or less. Note – these tests are in addition to applicable (c)(1) and (c)(2) tests, and are to be performed on a separate test package (i.e., the test package used in (c)(1) and (c)(2) is not to be used for these tests) (§ 173.465(c)(3)).

i. *Date and time of test:

ii. *Place of test and *signature of testers:

iii. *Description of test and Test Sequence #:

iv. *Equipment used for tests:

v. Drop Height:

vi. Identify drop orientation of test package:

vii. Results:

viii. Maximum top crush pattern:

ix. Maximum bottom crush pattern:

x. Test photographs:

xi. Test videos:

e. Free Drop tests for cylindrical fiberboard packages with a mass of 100 kg (220 lb.) or less. Note – these tests are in addition to applicable (c)(1) and (c)(2) tests, and are to be performed on a separate test package (i.e., the test package used in (c)(1) and (c)(2) is not to be used for these tests) (§ 173.465(c)(4)).

i. *Date and time of test:

ii. *Place of test and *signature of testers:

iii. *Description of test and Test Sequence #:

iv. Equipment used for tests:

v. Drop Height:

vi. Identify drop orientation of test package:

vii. Results:

viii. Maximum top crush pattern:

ix. Maximum bottom crush pattern:

x. Test photographs:

xi. Test videos:

f. Target for free drop tests (§ 173.465(c)(5)).

i. Demonstration of target compliance should include, but is not limited to the following information:

1. Drawings, figures, photographs, and any evaluations of target.

2. Justification target is flat:

3. Justification target is a horizontal surface:

4. Justify that the mass and rigidity of target is sufficient so that any increase in targets resistance to displacement or deformation would not result in a significant increase in damage to the test package:

g. Stacking test (§ 173.465(d)).

i. *Date and time of test:

ii. *Place of test and *signature of testers:

iii. *Description of test and Test Sequence #:

iv. *Equipment used for tests:

v. Compressive load calculation. Use the greater of:

1. 5 times gross mass of package, or

2. 13 kPa (1.9 psi) X vertically projected area of test package:

vi. Method for applying the compressive load to the test packaging with contents:

vii. Test duration:

viii. Results:

1. That there was no surrogate content leakage, or reduction in shielding
2. *Damage to each item in containment resulting from the tests**:**

ix. Test photographs:

x. Test videos:

h. Penetration test (§ 173.465(e)).

i. *Date and time of test:

ii. *Place of test and *signature of testers:

iii. *Description of test and Test Sequence #:

iv. *Equipment used for tests:

v. Penetration bar verification (diameter, mass and hemispherical end):

vi. Test package to be placed on a rigid, flat, horizontal surface and test package shall not move significantly during penetration test:

vii. Penetration Bar Drop Height:

viii. Identify SFs being challenged by impact of penetration bar:

ix. Results:

1. That there was no surrogate content leakage, or reduction in shielding
2. *Damage to each item in containment resulting from the tests**:**

x. Maximum indentation patterns:

xi. Test photographs:

xii. Test videos:

8. Additional tests for Type A packagings designed for liquids and gases (§ 173.466).

a. In addition to the tests prescribed in § 173.465 packagings designed for liquids and gases must be capable of withstanding the following tests (§ 173.466(a)):

b. Free drop test (30 foot) (§ 173.466(a)(1)).

i. *Date and time of test:

ii. *Place of test and *signature of testers:

iii. *Description of test and Test Sequence #:

iv. Equipment used for tests:

v. Drop Height:

vi. Identify SFs being tested, and drop orientation that provides maximum damage to the SF being tested):

1. The evaluation of SFs and selection of drop orientation for the 30-foot free drop test must consider damage to the test package that already resulted from the 173.465 water spray,

free drop, stacking and penetration tests already carried out. To state another way – the 30-foot free drop test is carried out on the same test package that has already been subjected to the Type A package designed for solid contents.

vii. Results:

1. Meets containment and shielding per § 173.412 (j)(1) and (j)(2), <u>and:</u>
2. Has sufficient absorbent material to absorb twice the volume of the liquid contents per § 173.412((k)(3)(i):, <u>or</u>
3. Has a containment system composed of primary inner and secondary outer containment components designed to ensure retention of liquid within the secondary outer component in the event the primary inner component leaks per § 173.412((k)(3)(ii):
4. *Damage to each item in containment resulting from the tests**:**

viii. Maximum external crush or indentations to external surfaces:

ix. Internal movement of content relative to external surface:

x. Liquid content remained within containment shielding:

xi. Test photographs:

xii. Test videos:

c. Penetration test (5.5 feet) (§ 173.466(a)(2)).

i. Date:

ii. Time:

iii. Test Sequence #:

iv. Equipment used for tests:

v. Penetration bar verification (diameter, mass and hemispherical end):

vi. Test package to be placed on a rigid, flat, horizontal surface and test package shall not move significantly during penetration test:

vii. Penetration Bar Drop Height:

viii. Identify SFs being challenged by penetration test. Evaluation is to consider damage already done to test package from the § 173.465 water spray, free drop, stacking and penetration tests already carried out.

ix. Results:

1. That there was no surrogate content leakage, or reduction in shielding
2. *Damage to each item in containment resulting from the tests

x. Maximum indentation patterns:

xi. Test photographs:

xii Test video: