

## Lessons Learned During Type-A Packaging Testing\*

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### INTRODUCTION

For the past 6 years, the U.S. Department of Energy (DOE), Office of Facility Safety Analysis (EH-32) has contracted Westinghouse Hanford Company (WHC) to conduct compliance testing on DOE Type A packagings. The packagings are tested for compliance with the U.S. Department of Transportation (DOT) Specification 7A, general packaging, Type A requirements. The DOE has shared the Type A packaging information throughout the nuclear materials transportation community.

During testing, there have been recurring areas of packaging design that resulted in testing delays and/or initial failure. The lessons learned during the testing are considered a valuable resource. DOE requested that WHC share this resource. By sharing what is and can be encountered during packaging testing, individuals will hopefully avoid past mistakes.

The majority of the testing delays are typically due to documentation problems in the areas of configuration control and material acceptability. Delays also result due to design problems in the containment and shielding areas. Identification of these problem areas has resulted in changes in the actions taken before and during testing. A significant before-test change has been made in obtaining and reviewing information from the test sponsor. A checklist has been developed that identifies the requirements and requests information on how the requirements are met by the design. The test facility organization requests that test sponsors supply the checklist information before packagings are accepted for testing. This paper discusses the most common problem areas identified through use of the checklist. Suggestions on how to improve the packaging and how to avoid repeating those mistakes are provided. Besides identifying design problems, the checklist helps to reduce problems encountered during testing.

In spite of the checklist, problems still occur during testing. Some of the more interesting problems that have occurred will be discussed. How the problems were overcome and methods for avoiding them in the future will be identified. Suggestions will be provided in order to reduce the number of problems that can occur during testing as a result of packaging design.

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## DELAYS IN TESTING ACTIVITIES

During the testing process, many things can and do go wrong. The results are delay and, at times, failure. The primary delays encountered before testing result from specific problems in packaging design and documentation. The documentation needed is identified in Title 49, *Code of Federal Regulations* (49 CFR), Part 173.415(a). Testing delays result from configuration control, material acceptability problems, and design problems in the containment and shielding areas. Delays resulting from incomplete documentation were the driving force for the first change implemented by WHC personnel in the Type A test program. The result of this initial effort was the development of a checklist for use by WHC personnel while reviewing sponsor-supplied documentation. The checklist is known as the Packaging Qualification Checklist, or more commonly, the PQCL, and requests identification of how the design meets each listed requirement of 49 CFR 173 and 178. A regulatory guidance document (Kelly 1995) that identifies the DOT packaging design requirements, provides some general guidance, and includes the PQCL, was also developed. Now, when a docket is opened, a copy of the guidance document is sent to the sponsor, who is requested to supply a completed PQCL along with the packaging drawing and, if needed, the packaging specification; design documentation; and if applicable, the operating instruction. This step is taken to overcome the delays caused by the failure of test sponsors to adequately identify the packaging.

The designer/user is requested to address whether the requirements listed in the PQCL apply or do not apply to their packaging. If a requirement applies, the designer/user is instructed to provide the appropriate supporting documentation and identify it on the checklist.

The PQCL leads the designer/user through the following sections:

- 1.0 Characterization of Contents (radiological, physical form, thermal, and chemical)
- 2.0 49 CFR 173.24, *General Requirements for Packagings and Packages* (containment)
- 3.0 49 CFR 173.24a, *Additional General Requirements for Non-Bulk Packagings and Packages* (some portions may not directly apply to a Type A packaging)
- 4.0 49 CFR 173.24b, *Additional General Requirements for Bulk Packagings* (some portions may not directly apply to a Type A packaging)
- 5.0 49 CFR 173.411, *General Design Requirements* (lifting, handling, and tiedown)
- 6.0 49 CFR 173.412, *Additional Design Requirements for Type A Packages* (shielding)
- 7.0 49 CFR 178.3, *Marking of Packages*.

The design requirements guide/PQCL assists WHC in receiving complete documentation of the packaging design. The PQCL provides the sponsor with an effective means to improve the packaging design and assists in avoiding the mistakes made by others. Additionally, the PQCL helps WHC to identify design problem areas and reduce problems during testing.

Completion and use of the PQCL has resulted in the following benefits:

- Reducing delays prior to testing because the sponsor has a more thorough and better understanding of the required documentation;

- Identifying a test load that accurately represents the actual contents to be shipped;
- Identifying dunnage/bracing required to protect the packaging and containment system;
- Identifying the package configuration likely to be damaged during packaging testing;
- Identifying the packaging orientations that will result in the most severe damage;
- Identifying the intent to ship by air transport. (If appropriate, the test facility checks if the International Air Transport Association and International Civil Aeronautics Organization [IATA and ICAO] regulations have been addressed. For liquid packagings, the ability to meet the reduced pressure requirements for shipment by air can be verified.); and
- Providing information for use when preparing the test and evaluation report.

## **PROBLEMS**

In spite of the checklist, problems still occur during testing. The most common problems identified through use of the checklist are as follows:

- Failure to properly identify the containment system and how containment is achieved;
- Failure to discuss the ability of containment and shielding to resist brittle fracture;
- Failure to identify the physical and chemical compatibility of materials of construction, with themselves and with the proposed contents, including the effects of irradiation on the materials and contents;
- Failure to discuss radiolytic decomposition;
- Failure to identify the ability of the packaging to withstand the reduction of ambient pressure.

The following are some of the more interesting problems that have been encountered. How the problems were overcome, and the methods used for avoiding them in the future, are identified. Suggestions are provided regarding ways to ensure that regulatory compliance is achieved in order to help reduce the number of problems occurring during testing as a result of packaging design.

### **Problem One**

Testing of several differently sized fiberboard drums was conducted in 1990. In reviewing the PQCL, it was noted that the design used a dual-certified packaging, but the information on the DOT/UN packaging was inadequate to identify the packaging design. A delay resulted until proper documentation was supplied. Under the UN performance specification, the clear identification of the packaging design becomes very important. Under the new UN performance requirements, many different materials and designs can be used under the same performance requirements. This compels a packaging developer, using an off-the-shelf UN packaging, to establish a method of ensuring that all future packagings are equivalent. If future packagings are to be built, design documentation, drawings, and/or packaging specifications are required.

No proof testing was conducted by the sponsor. During the water spray test, uneven water resistance of the packaging resulted in increased absorption in some sections of the packaging. This resulted in decreased strength of the fiberboard drum walls. Although there was no in-leakage of water or loss of contents from any testing conducted, the decreased strength of the packaging did result in considerable damage. The most severe damage occurred during the 0.3-m (1-ft) drop testing onto each quarter of each rim. The fiberboard tore completely through over the entire length of the drum. During compression testing, a loss of sidewall strength was noted by permanent compressions. The penetration bar drop resulted in severe tears and holes in the fiberboard material.

The small number of packagings tested did not provide an adequate confidence level to recommend use. Here, water resistance was critical in the design of the packaging. Testing with other fiberboard packagings has shown that water resistance of the fiberboard, and of the seaming and closing methods, is critical. The unevenness of the water resistance suggests that better quality control at the time of fiberboard construction may have resulted in a pass. The packaging designer must ensure that the packagings are built with materials that will provide the needed resistance. Water resistance of fiberboard can be improved by the application of surface treatments. The use of waterproof tape on the seams and closures has worked in the past. However, the ability of the material used in a UN fiberboard packaging to meet the water resistance requirements does not ensure the ability of the packaging to meet the Type A water spray test.

## **Problem Two**

Testing of a concrete container was conducted in 1994. The test sponsor initially sought approval of the packaging through evaluation, but a review of the packaging design documentation identified a variety of problems. By evaluation, it was determined that the container was not likely to withstand drop testing. Additional problems identified were the ability of the packaging to withstand the reduced external pressure and the need for a method for removing water after underwater loading. The sponsor decided to redesign the packaging to be tested.

The initial problems resulted from the designer not being aware of all the Type A packaging design requirements. The wording of the DOT regulations is such that an individual with little or no training in use of the regulations can easily miss one or more design requirements. This packaging was designed and evaluated before the sponsor contacted EH-32. The designer did not have a copy of the PQCL to help identify the regulatory requirements. However, use of the PQCL does not guarantee all design requirements will be addressed; some items are still missed.

A document review was conducted on the new packaging design information received. The containment for this packaging design was identified as the concrete container; a polyethylene liner on the lid and body; six bolts; and a permanent, thermal seal. The review identified the need for additional information on the materials of construction. The sponsor failed to identify the ability of the polyethylene liner material to perform over the required temperature range and the ability of this material to withstand the effects of radiation. Sometimes documentation attesting to the abilities of commonly used materials, such as plastics and foams, are not readily available. The packaging designer needs to be aware of the need for having and supplying the documentation for those materials.

The packaging must be designed so there is no loss of material if the package is subjected to a reduced external pressure. In the case of this package, the reduced external pressure results in a 77.2 kPa (11.2 psi) pressure differential from inside the containment boundary to the outside of

the packaging. To verify the design, the packaging was subjected to a hydrostatic pressure test that required the thermal sealing process to close the container. When water was added to the packaging, water leaked from the lid/body interface in several places and took less than 7.6 cm (3 in.) of head to initiate. The sponsor had previously, successfully tested this thermal sealing process on a 0.61-m (2-ft) strip of polyethylene material. The sealing distance around the concrete box was about 4.5 m (14.8 ft). A seal of this length had not been proof-tested. After several attempts, resulting in failure of the thermal seal, two different types of rubber gaskets were tried. The two rubber-gasketed configurations also failed to hold water. A fourth method, a polyethylene gasket, was glued to the chamfered edge of the container lid and successfully passed the test. The failure of the original sealing methods resulted in using about 4 days and two extra test units to resolve the design problem. It also resulted in a delay while new test packagings were obtained. The problems with the seal demonstrate the need for using a known sealing technique or conducting prototype testing that closely represents the expected conditions.

The initial packaging design also incorporated the use of two wooden impact limiters which were fitted around each of the eight corners of the container. This design left the container lid vulnerable. During a flat drop onto the top impact limiter, the lid bolts would be required to resist the forces generated by the lid and the load. The design of the impact limiter was such that the lid bolts had a high probability of loosening upon impact of the container. During the delay to obtain more test packagings, the impact limiter was redesigned. The redesigned impact limiter was used only on the top. This new impact limiter sits around and on the lid of the packaging, and provides support for and protection to the lid. This packaging passed drop testing both with and without the use of the top impact limiter.

The problems observed during this test are a good example of how proof testing before the actual testing would have saved testing time and money. Most packaging designers design to handle the drop test, which is considered to provide the most rigorous challenge to a packaging. As evident from this discussion, a pressure test detected the weakest part of the packaging design in the thermal sealing method. Even the backup seals were inadequate, and a redesign during testing was required.

### **Problem Three**

Testing of a 10-drum overpack was conducted in 1990 and 1993. This packaging did not undergo proof testing. The initial design of the 10-drum overpack successfully completed all Type A testing with the exception of the drop test. During the 1.2-m (4-ft) drop test, two failures occurred, one with each load type tested. During the center-of-gravity over the bottom drop test, a load, consisting of a standard waste box (SWB) filled with simulated contents, punctured the sidewall of the 10-drum overpack, resulting in packaging failure for that load. No dunnage was used to support the SWB during testing. The packaging also failed when multiple drop tests were conducted when a packaging was loaded with 10, 208-L (55-gal) drums filled with simulated contents. During the last drop, several lid bolts were sheared. The packaging was redesigned to incorporate thicker walls and bottom, and a modified seal design. The packaging was retested and underwent the 1.2-m (4-ft) drop test, in several orientations, without failure. It was determined during testing that for large, bulky objects, such as an SWB, dunnage and bracing would need to be utilized by the shipper.

This test is identified to make a number of points. First, it is not clear that the initial design would not have passed the Type A packaging requirements when loaded with drums. Multiple packagings may be used for testing; however, by using the same packaging for several drops, the potential to suffer a failure due to cumulative damage comes into play. When deciding how many test units are needed, consider the cost of failure due to multiple tests on the same packaging.

Another point is the need to review and address all design requirements and to ensure that all packaging configurations have been evaluated. The initial test resulted in a failure of the packaging when loaded with an SWB. This configuration was also included in the second packaging design. When the design documentation was reviewed, it was observed that the discussion of the ability of the package to resist vibration did not include a review of the SWB configuration. This appears important, as one portion of the SWB rested on a small area of the bottom of the packaging, and another portion of the SWB rested against the side wall of the packaging. The SWB fit loosely and was free to rock inside the 10-drum overpack, but the design did nothing to ensure that the impact on the side walls would not be localized. When the sponsor was requested to provide documentation that the 10-drum overpack would resist the forces resulting from vibration, a decision was made to add dunnage to the packaging. Besides handling vibration, the dunnage changed the load such that dropping the 10-drum overpack loaded with the SWB was unnecessary. The dunnage was added in a manner that made it possible to evaluate the ability of the packaging to pass the drop test requirements.

#### **Problem Four**

Testing of a 1-L liquid packaging was conducted in 1995. This packaging is intended to ship liquids having a specific gravity of 2. The packaging design incorporated two configurations for the 1-L inner container. One configuration consisted of a specific wide-mouth bottle inside a SafeSend<sup>1</sup> container. The second configuration consisted of a specific narrow-mouth bottle inside the SafeSend container. The exterior of the packaging consisted of a fiberboard shipper. During the Type A testing, the packaging suffered several problems.

The first problem occurred during the water spray test. Although the packaging passed the test, the package showed signs of the glued lap joint weakening. The 0.3-m (1-ft) corner drop onto the eight corners confirmed that the fiberboard shipper lacked the strength to remain intact. This was unexpected as the packaging previously passed the water spray test followed by 1.2-m (4-ft) drops during proof testing. As the fiberboard shipper was not required, a decision was made to continue testing without it. The problem with the fiberboard shipper identifies the difficulties that can result from the use of fiberboard. Alternative solutions were possible with this packaging, for example, adding tape to the failed seam and around all the edges of the packaging to add strength.

The next problem occurred during the 9-m (30-ft) drop testing of the wide-mouth bottle configuration. Two separate conditions resulted in a decision not to use this configuration. The first condition observed was the loss of material from the bottle. When the packaging was opened after the test, liquid was observed outside the bottle. The material appeared to be ejected from the bottle during impact. The second condition observed with this configuration was a slight movement of the outer packaging lid. Although the lid remained intact and there was no loss of the simulated load, it was unclear if the radiation levels would have changed due to the material being ejected from the bottle. The uncertainty associated with the configuration resulted in a decision to declare it a failure.

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<sup>1</sup> SafeSend is a trademark of the 3M Company.

Testing of the narrow-mouth bottle was a success. This configuration was considered a pass and recommended for approval.

The movement of the outer packaging lid during testing with the wide-mouth bottle suggests an area of packaging evaluation to consider, and identifies the value of testing. In reviewing the test results, it was noted that the difference in the diameter of the inner bottle lids caused a redistribution of the forces resulting from the drop. This shift of forces was not considered prior to testing. The lid diameter was not considered a critical factor in the design. It should be noted that testing of both configurations was important, and it is unlikely that an evaluation would have identified the importance of the lid diameter.

The problems encountered during the testing of this packaging lead to another area of testing where care should be taken--the evaluation of the test results. In some test reports the only information supplied is the word "passed." Such brief documentation is of little use unless the load shipped is identical to that tested. With just a "pass" statement, it is not clear if the judgment is for containment only or for the containment and radiation level change. If the packaging can be used for other loads, the damage to the package resulting from the test should be identified (e.g., damage such as denting or bulging, movement of inner packagings, or reductions in shielding). The fact that the use of a load with the diameter and mass of the failed configuration caused a movement of the outer packaging's lid is subtle but valuable information. The DOE test facility does more than share this information. An operating restriction is placed in the test report. In the case of this packaging, the use of bottles having a lid with a diameter greater than the approved, tested bottle lid diameter is prohibited. The user is cautioned to not place the bottle upside down.

#### **Problem Five**

Testing of a 208-L (55-gal) drum configuration was conducted in 1994. This particular packaging configuration utilizes a special sealing process (bagless transfer system). The initial design incorporated an inner lid, filter, ring, and seal in addition to the 208-L (55-gal) drum, lid, filter, gasket, and bolt closure ring. The sponsor conducted 1.2-m (4-ft) drop tests as a part of proof testing and used a packaging having a gross weight of 363 kg (800 lb). The sponsor used this weight as it was determined this would be the most likely average load; however, all operating instructions identified a gross packaging weight of 454 kg (1000 lb).

The test packagings were loaded to 454 kg (1000 lb). During the 1.2-m (4-ft) drop test, release of simulated contents was detected. The packaging was redesigned by relocating the inner ring and an additional neoprene gasket material was added between the outer and inner lids. Once these design changes were incorporated, the packaging was redropped and successfully passed. In this design, placement of the inner ring and inner gasket is critical in the performance of the packaging.

The problem observed was the failure of the test sponsor to fully evaluate the packaging's ability to meet the design requirement that the packaging maintain containment when subjected to the drop test. When conducting prototype testing, it is important to simulate the load as closely as possible.

Another item of interest occurred during testing. Because of a special closure process, this packaging was loaded at the sponsor's facility and shipped to the test facility. After some initial testing, a package was opened. The flour and fluorescein mixture placed inside the package to simulate loose, powdery material had clumped. All the packagings were examined and revealed the same condition. It was determined that the clumping resulted from the use of damp sand as

part of the simulated load. This problem with the simulated load identifies two steps that should be taken during testing. First, consider the impact of the delay between loading of the simulated contents and actual testing. Second, after testing, verify the condition of the material used as the simulated load.

## **METHODS USED TO AVOID FUTURE PROBLEMS**

Potential problems are never truly known; they can only be anticipated. In anticipation of possible problems, the DOE-approved testing facility, located at the Hanford Site in Richland, Washington, now requests the sponsors to reveal any proof testing they may have conducted. During the design review, if a feature important to safety with no history of use is revealed, proof testing of the feature may be requested. Test sponsors planning to proof test packagings are encouraged to work directly with a test facility in developing the best test sequence. The test facility will make recommendations to ensure the proof testing adequately represents the forces to be seen by the containment and shielding during actual testing. Remember, the purpose of the proof testing is to ensure that the packaging provides containment, with no release of contents, when subjected to the DOT-required testing. Also, any increase in radiation levels are to be insignificant (less than 20%).

## **SUMMARY**

In summary, most problems and delays that occur during testing result from an inadequate understanding of the regulatory requirements. Delays occur most often because of a failure to identify the performance characteristics of some materials of construction. The next most frequent problems result from the containment and shielding not being fully identified and/or not designed to withstand the forces encountered during testing. Through this sharing of information concerning what is and what can be encountered during packaging testing, it is hoped that future first design efforts will produce better packagings. This can be achieved if packaging developers avoid the same or similar mistakes made in the past. Also, it is hoped that this sharing of information will result in a better understanding of the Type A packaging design requirements identified in 49 CFR.

## **REFERENCES**

49 CFR, "Transportation," Parts 100 to 177 and Parts 178 to 199, *Code of Federal Regulations*, as amended.

Kelly, D. L., 1995, *DOT-7A Type A Packaging Design Guide*, WHC-SD-TP-RPT-017, Revision 0, Westinghouse Hanford Company, Richland, Washington.