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Digital Radiography of a Drop Tested 9975 Radioactive Materials Packaging

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ABSTRACT

This paper discusses the use of radiography as a tool for evaluating damage to radioactive material packaging subjected to regulatory accident conditions. The Code of Federal Regulations, 10 CFR 71, presents the performance based requirements that must be used in the development (design, fabrication and testing) of a radioactive material packaging. The use of various non-destructive examination techniques in the fabrication of packages is common. One such technique is the use of conventional radiography in the examination of welds. Radiography is conventional in the sense that images are caught one at a time on film stock. Most recently, digital radiography has been used to characterize internal damage to a package subjected to the 30-foot hypothetical accident conditions (HAC) drop. Digital radiography allows for real time evaluation of the item being inspected. This paper presents a summary discussion of the digital radiographic technique and an example of radiographic results of a 9975 package following the HAC 30-foot drop.

BACKGROUND

In March 2001, a certificate of compliance (CoC) was issued for the 9975 package for shipment of plutonium bearing metals. Prior to the issuance of the 9975 certificate normal conditions of transport (NCT) and HAC tests were conducted to demonstrate the safety performance of the package. Some of these tests were focused on challenging the banded lid closure of the drum overpack. The outcome of testing targeted at challenging the banded style closure ultimately lead to a redesign of the closure. However, prior to the redesign decision it was decided that a regulatory burn test of the damaged package might increase the likelihood of obtaining an early CoC for the package. It was hoped that a burn test of the damaged package would eliminate regulatory concerns surrounding the 9975 overpack drum closure and redesign could be avoided. The purpose of the burn test was to demonstrate that the drum damage due to the 30-foot drop would not affect the performance of the package as compared to previous burn tests of undamaged packages, which formed the safety basis position for the 9975 package. After further consideration, it was realized that a large number of damage scenarios could be postulated, including that of complete drum lid loss. Given these postulated damage scenarios, a burn test was deemed of no significant benefit for obtaining an early 9975 CoC and preparation for a thermal test was discontinued. It was decided that the package overpack closure would be redesigned to ensure that no damage from a 30-foot drop would compromise the existing package safety basis.

The decision to burn test the 9975 package required that the damaged package be fitted with instrumentation prior to the test. Temperature data in combination with physical condition would be required to demonstrate the continuing safety performance of the package. The damaged configuration of the package made it difficult to accurately position needed instrumentation. To ensure test success, digital radiography was chosen as the method for ensuring accurate instrument placement. By utilizing this technique to determine the condition of the inner package components, accurate placement of instrumentation could be assured.

9975 PACKAGE DESCRIPTION

The 9975 radioactive material shipping package is designed for the shipment of plutonium and uranium metals and oxides. It features two containment vessels nested inside a ½-inch thick cylinder of lead used as a gamma shield. The drum style packaging is a 35 gallon DOT Specification drum fabricated from 304 stainless steel. Between the drum and lead shielding is approximately 4 inches of Celotex® fiberboard which serves as an impact, and thermal insulating material for the packaging containment. Positioned directly above and below the gamma shielding are ½-inch thick aluminum disks. The disks distribute the impact load from axial drops preventing gross fiberboard damage. Figure 1 pictures an early 9975 package design. With the exception of the drums banded closure, and minor design enhancements to the lead shielding it is identical to the certified 9975 package illustrated in Figure 2. Figure 1 is best used for comparison to radiographic images presented in this paper. Figure 1 is illustrated with mock plutonium oxide contents packed in convenience containers. Figure 2 is illustrated with the DOE Standard 3013-storage container. Both content configurations are presented in the 9975 Safety Analysis Report for Packages (SARP), Reference 1.

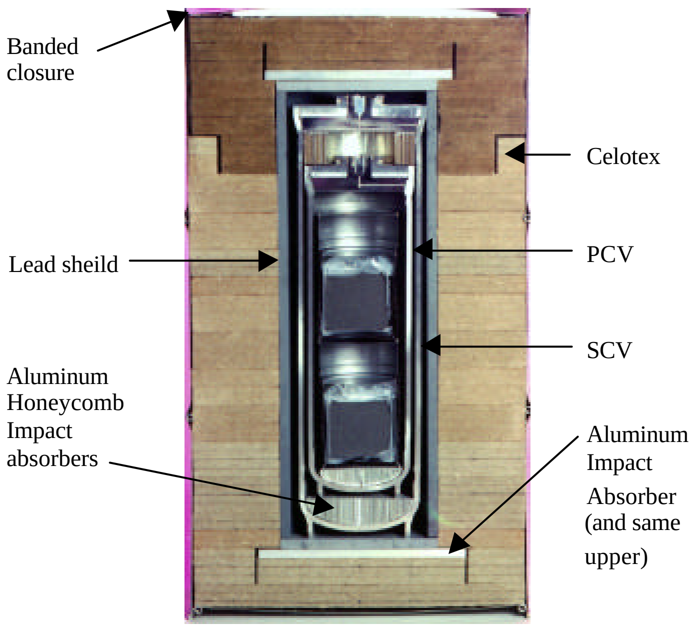

Figure 1. 9975 Facsimile

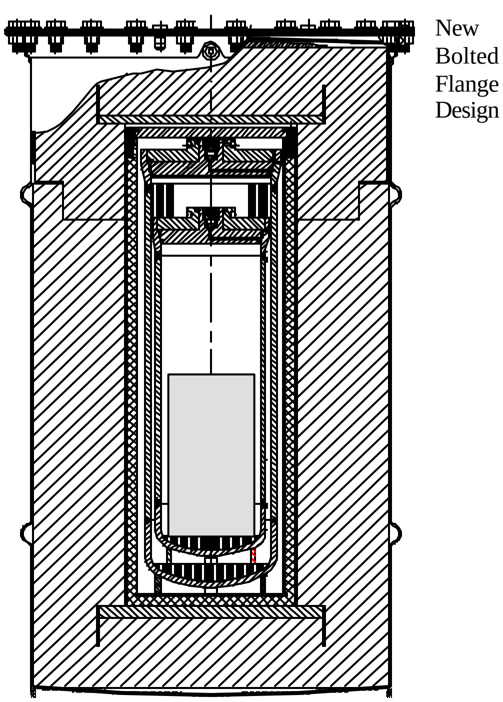

Figure 2. Certified 9975 Package Design

DROP CONFIGURATION AND DAMAGE

The 9975 package design as depicted in Figure 1 was dropped from a NCT drop height of 4-feet followed by the HAC 30-foot drop and 40-inch puncture pin drop, Reference 2. The purpose of the preconditioning NCT drop was to maximize weakening of the closure system so that the effects of the subsequent HAC drops would be maximized. In each drop the axis of the package was oriented 17.5° from horizontal. The shallow drop angle and impact positions were selected to maximize damage to the drum closure. The test sequence, the dual 17.5° drops, resulted in a partial separation of the lid from the drum rim, as shown in Figure 3. The puncture drop did not appreciably increase drum damage, rather the opening between the drum lid and drum wall were found to close slightly.

Figure 3. 9975 Package Drop Damage

DRUM EXAMINATION

After examining the damage to the package closure it was determined that the pass/fail criteria that had been established for the test had been exceeded. Though the physical gap criteria established for the test was exceeded, evidence existed that indicated the package would survive the regulatory thermal test. With this information and the strategy that a CoC could most easily be obtained by completing the regulatory HAC test sequence, the damaged package shown in Figure 3 was prepared for a regulatory thermal test.

Radiography Techniques

Both conventional and digital radiographic images were made of the damaged 9975 to help facilitate instrument placement, Reference 3. Four conventional x-rays were made to compare against the digital radiographs. One hundred and twenty-five digitized radiographic images were recorded of the damaged drum. On average, the conventional X-rays took about 4 minutes per each exposure. Digital imaging took approximately 1 minutes per exposure, a four-fold reduction in time.

Figure 4 provides a schematic of the digital radiography equipment setup. It includes an X-ray source, scintillator, mirror and high resolution CCD camera. The scintillator converts X-ray photons into visible light. The mirror redirects the image to the camera outside the high-intensity X-ray beam where the filmless images are captured. The file size for each captured image ranges from 94 to 645 Kbytes. Still images can be combined to form a complete composite of the item being examined. Composites can be a single larger image or an x-ray "movie" of the packaging from different perspectives (i.e., in rotation).

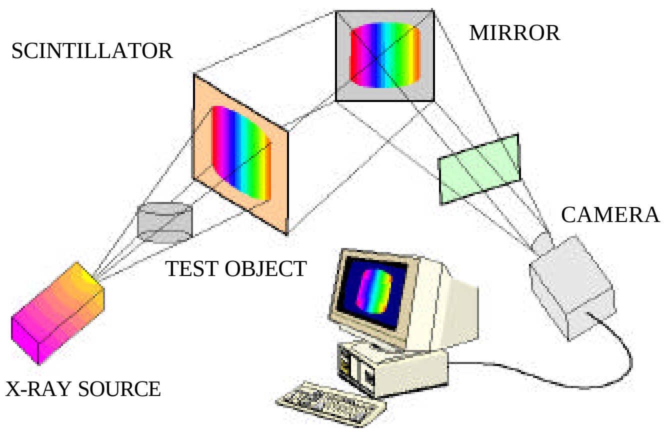

Figure 4. Digital Radiography Setup

Figure 5 shows the actual hardware configuration used to digitally radiograph the package. The drum is pictured standing on a turntable positioned between the digital radiographic imaging hardware (DR) and the X-ray source. The DR hardware, scintillator, mirror and camera are all housed in the shielded metal box illustrated in the figure. The turntable was manually operated during image acquisition.

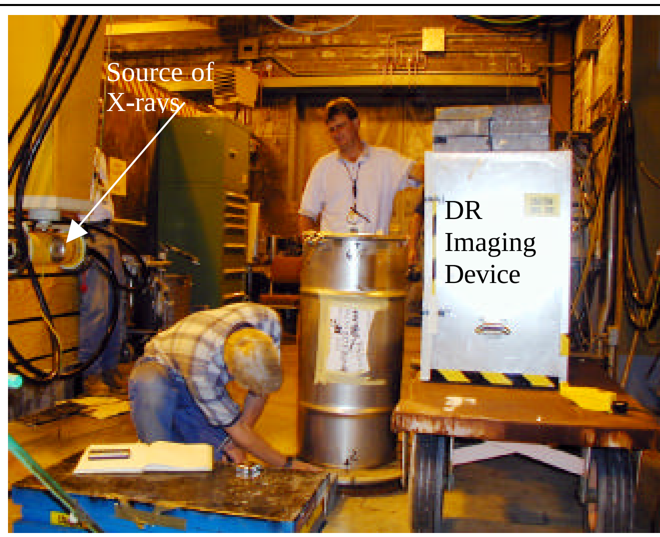

Figure 5. Radiography Configuration

Radiographic Results

One hundred and twenty-five (125) still image radiographs were taken of the damaged drum and were assembled into a dynamic composite of the drum. The digital film permits the drum to be viewed turning radially or translating axially. To achieve the radial dynamic composite, the drum was divided into quarters axially. Twenty-four still images were captured of each quarter as the drum was manually rotated every 7.5 degrees, from a total of 180 degrees of rotation. Seven video clips of the damaged drum are available upon request from the Authors.

Selected digital images are presented below. These images demonstrate the capability of this method of non-destructive examination. The radiographic images were made with the specific purpose of characterizing the packaging components outside the lead shielding. There are, therefore, no images that depict the package components internal to the lead shield.

Figure 6 depicts a composite image of the 9975 package. It is composed of 8 digital images taken along each half of the package. The axial positions in which the images were acquired do not permit a 1 to 1 match up of the drum. All images were taken when the drum was resting horizontally, down is the left side of this image.

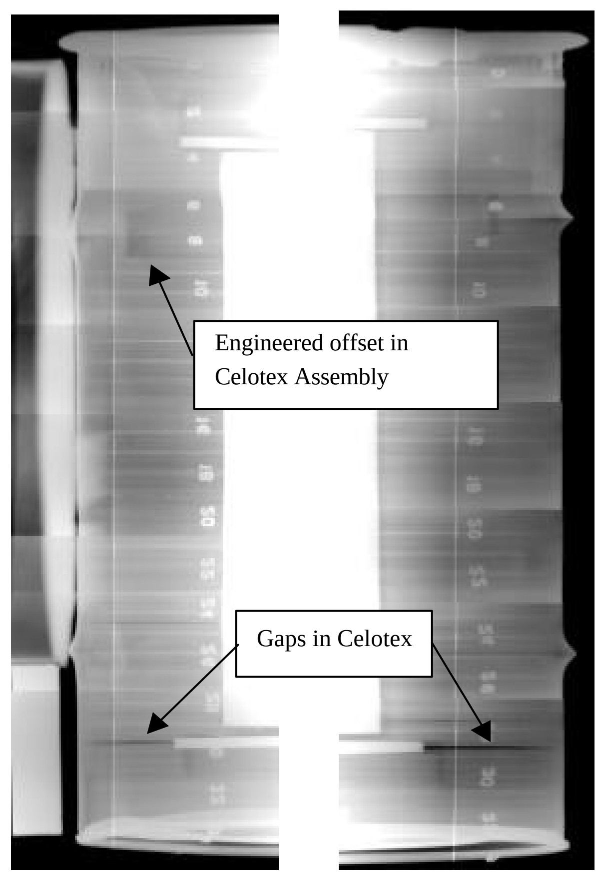

Figure 6. Digital Composite of 9975 Package

Figure 7 depicts a digital shot of the 9975 lid closure. The X-ray was shot looking from the rear of the drum and pointed to the "#8" as shown in Figure 3. The drum was in an upright position. From the X-ray the dislodged lid gasket that serpentines across the gapped lid can be readily distinguished. The engineered gap between the lead shield and top bearing plate is also observable and is seen as a light shaded area which is representative of the gap. This gap also extends along the lead shielding. This gap beside the lead shield is a result of the Celotex being crushed during the side drop. A slight bulge in the lead shield due to the impact of SCV can is evident.

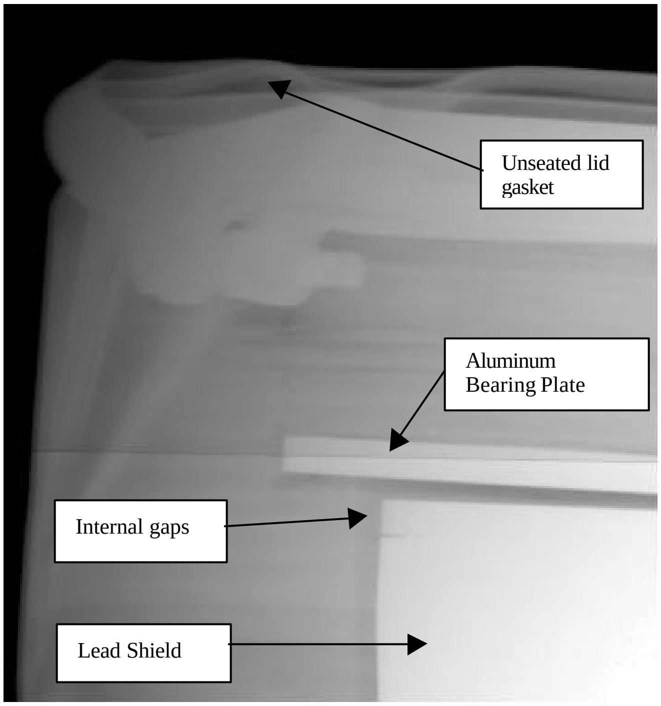

Figure 7. Drum Lid Closure

Figure 8 illustrates a bottom view of the drum radiographed in an upright position. The left side of the lead shield is imbedded in the Celotex and is preventing it from contacting the bottom bearing plate which would be its nominal position during normal transport. Drum damage in the form of small ripples can be seen on the left side of the radiograph, indicating the direction of the side impact. Since this drum was dropped in a slight top down orientation the shield was probably positioned fully forward in the package before the drop as evidenced by the position of the lead shield after the drop. Celotex gapping can also be seen in this view. Note the position of the bottom bearing plate appears to have shifted towards the impact side. Because the mass of the aluminum bearing plate is small, it seems likely that the body of the lead shield must have been in contact with the plate at some time during the impact and forced the shield sideways through the Celotex.

Figures 9 and 10 illustrate specific package damage from the drop test. Figure 9 blows up a section of Figure 8 slightly rotated that shows a fairly large gap just adjacent to the bearing plate and a what appears to be a tear in the Celotex extending from the engineered relief below the bearing plate. When Figure 9 is viewed dynamically, the gap extends radially from the plate's edge for the most part the full circumference of the drum. However, the gap does not stay as nearly as pronounced (wide or long) as observed in the Figure. The tear at the bottom of the designed relief demonstrates that the relief performs as expected by translating damage away from the edge of the bearing plate thereby reducing Celotex separation adjacent to the bearing plate.

Figure 10 illustrates an additional separation area in the Celotex. There is a slight gap in the Celotex adjacent to the top bearing plate, similar to the one shown in Figure 9. The gaps appear to form along the glue plane. Figure 10 is interesting in that the gap formed by the mating top and bottom Celotex assemblies is evident. The combination of the offset between the Celotex assemblies, the design relief above the bearing plate and the top Celotex assembly air shield minimizes Celotex damage at the top of the package.

Indications of gaps in the Celotex (black lines in Figure 6 and 10 and light colored lines in Figures 8 and 9) that were discovered in the radiographic examinations of the damaged package resulted in package thermal analysis. Thermal analyses were performed for the 9975 with the assumption of a bounding 1.38 inch circumferential radial gap through the Celotex insulation to determine the effect of such a large gap in the hypothetical fire test, Reference 4. Results from the analysis showed that the 9975 package safety basis was not effected.

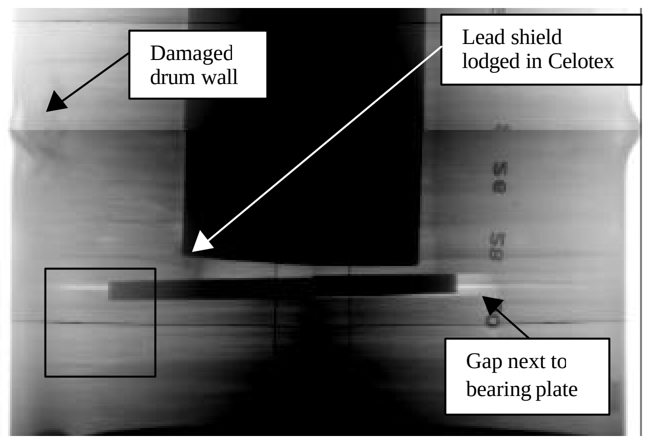

Figure 8. Bottom Radiograph of 9975 Drum

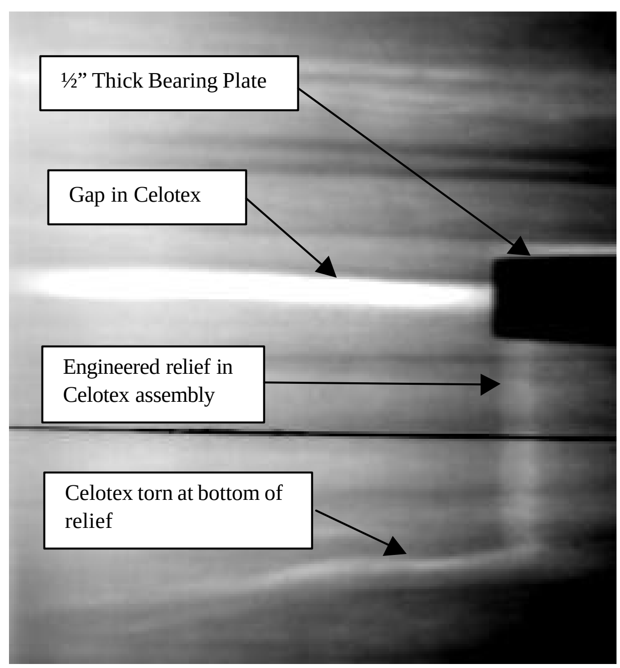

Figure 9. Damaged Celotex Adjacent to the Bottom Bearing Plate

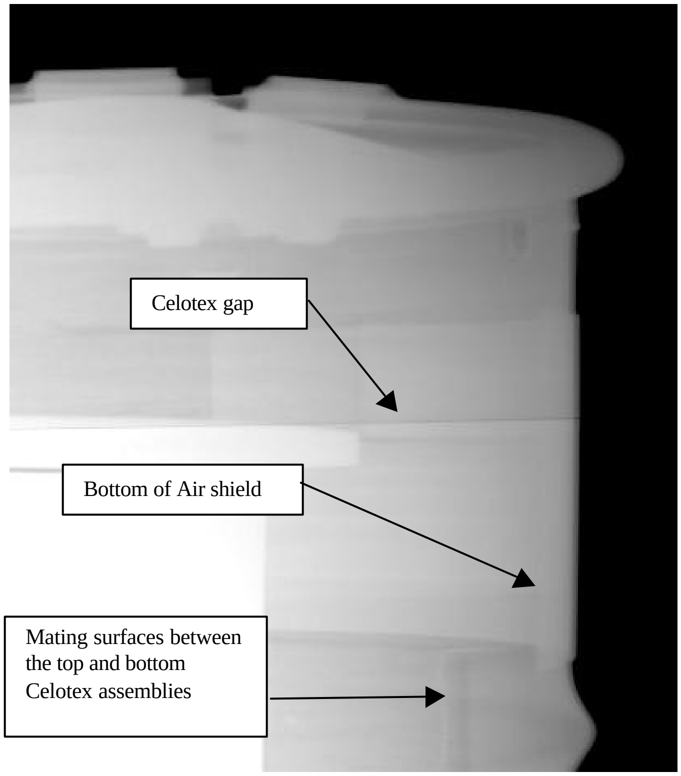

Figure 10. Top Section of Drum

CONCLUSIONS

Digital radiography of a damaged 9975 package was performed to determine the conditions of certain internal package components to facilitate placement of thermal instrumentation. This technique allows full non-destructive evaluation of internal package components following regulatory NCT and HAC tests. The radiographic illustrations presented in this report of a damaged 9975 demonstrate the usefulness digital radiography can have on package development from design through testing. The conversion of 2D radiographic images into a dynamic 3D representation of the package provides information into the response of radioactive material packages due to regulatory testing not easily achievable though normal destructive techniques.

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