DETERMINING DEGRADATION OF FIBERBOARD IN THE 9975 SHIPPING PACKAGE BY MEASURING AXIAL GAP

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ABSTRACT

Currently, thousands of model 9975 transportation packages are in use by the US Department of Energy (DOE); the design of which has been certified by DOE for shipment of Type B radioactive and fissile materials in accordance with Part 71, Title 10 Code of Federal Regulations (CFR), or 10 CFR 71, Packaging and Transportation of Radioactive Material. These transportation packages are also approved for the storage of DOE-STD-3013 containers at the Savannah River Site (SRS). As such, the 9975 has been continuously exposed to the service environment for a period of time greater than the approved transportation service life. In order to ensure the material integrity as specified in the safety basis, an extensive surveillance program is in place in K-Area Complex (KAC) to monitor the structural and thermal properties of the fiberboard of the 9975 shipping packages. The surveillance approach uses a combination of Non-Destructive Examination (NDE) field surveillance and Destructive Examination (DE) lab testing to validate the 9975 performance assumptions. The fiberboard in the 9975 is credited with thermal insulation, criticality control and resistance to crushing. During surveillance monitoring in KAC, an increased axial gap of the fiberboard was discovered on selected items packaged at Rocky Flats Environmental Technology Site (RFETS). Many of these packages were later found to contain excess moisture. Savannah River National Laboratory (SRNL) testing has resulted in a better understanding of the relationship between the fiberboard moisture level and compaction of the fiberboard under storage conditions and during transport. In laboratory testing, the higher moisture content has been shown to correspond to higher total compaction of fiberboard material and compaction rate. The fiberboard height is reduced by compression of the layers. This change is observed directly in the axial gap between the flange and the air shield. The axial gap measurement is made during the pre-use inspection or during the annual recertification process and is a screening measurement for changes in the fiberboard.

INTRODUCTION

Thousands of model 9975 transportation packages are currently used for interim storage of Pu bearing materials in DOE-STD-3013 cans and other types of containers. The use of the shipping package to not only transport but also store nuclear materials has become more common for a variety of reasons. First, shipping packages are robust and have a qualified pedigree for their performance in normal operation and accident conditions. Design and construction of Type B packages are required to abide by two upper tier documents: the DOE Order 460.1C – Packaging and Transportation Safety and 10 CFR Part 71 – Packaging and Transportation of Radioactive Material. These upper tier documents provide strict guidance to ensure the safety and integrity of a Type B shipping package and require adherence to a number of other supporting documents, such as a Certificate of Compliance (CoC) and a Safety Analysis Report for Packaging (SARP) which dictate very stringent inspection criteria at the time of fabrication and during the maintenance program for recertification for shipping.

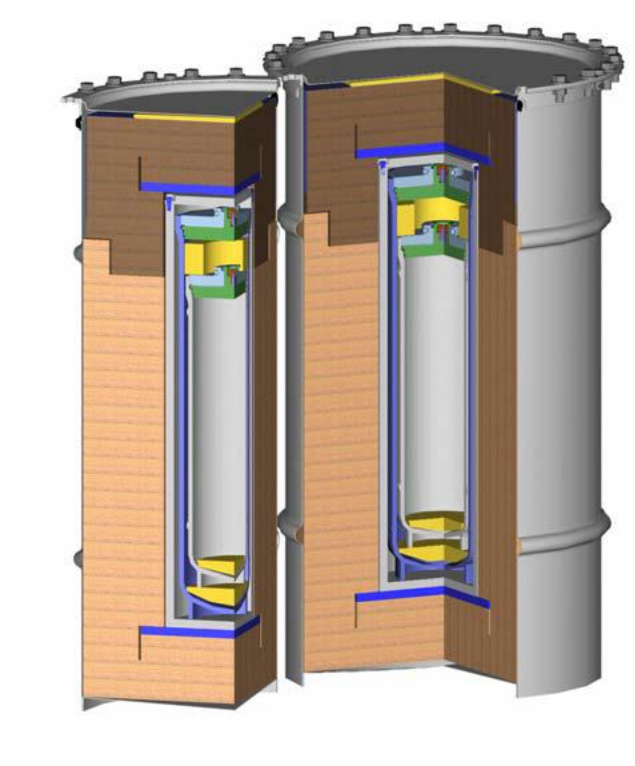


Figure 1. Cutaway of 9975 Shipping Package

Second, the interim and/or extended storage of nuclear materials within the shipping package results in fewer operations for the storage facility. Prior to receipt of any shipping/storage package, a rigorous review of the package is performed by the facility engineering personnel to ensure normal storage conditions are adequately captured in the safety documentation for the facility. With all the required analyses and reviews completed, facility operations can then receive a shipping/storage package and transport it to an approved storage location without opening it. This ability to use the shipping package for storage therefore results in reduced operations handling time during receipt and reduces radiation dose.

Third, the material storage area in the K-Area Complex (KAC) is a robust concrete building which lacks a credited confinement ventilation system. As such, Type B shipping packages are very robust for their specified contents and can withstand all of the design basis events for the KAC. To ensure the packages maintain their design features, a surveillance program is established to verify the integrity of age-sensitive materials (containment vessel O-ring seals and fiberboard overpack) over time in the environment they are exposed to in KAC.

The fiberboard used in the 9975 shipping packages provides impact resistance, thermal insulation and criticality control. As shown in Figure 1, the fiberboard surrounds the nested containment vessels and is separated into a lower assembly, which generally stays in the drum, and a removable upper assembly. The fiberboard assemblies can be either cane fiberboard insulation or softwood fiberboard insulation per ASTM C208-95, grade IV wall sheathing which are laminated together with an Elmer's® Professional Carpenters wood glue.

For the fiberboard, the SRS Surveillance Program for the 9975 encompasses three primary activities 1) NDE field surveillance, 2) DE of one 9975 package annually and 3) laboratory accelerated aging studies. The primary objective of the 9975 surveillance program is to monitor material performance and degradation in order to establish a basis for the service life and to provide advance notice of the need for repackaging 9975 shipping packages in KAC. The 9975 shipping packages are expected to maintain safety performance in KAC beyond the normal period of certification as shipping packages based on a combination of material performance data and engineering judgment.

9975 NDE FIELD SURVEILLANCE

NDE surveillance of the 9975 package is performed in KAC in conjunction with the DOE-STD-3013 surveillance program (Reference.4). The NDE of the 9975 package is typically performed during the unloading of the drum to access the 3013 selected for surveillance. During the disassembly, all visible surfaces of the package are inspected for rust or degradation. For fiberboard, the upper assembly is measured, weighed, inspected and photographed. The axial gap is measured and recorded as shown in figure 2a. The measurement is from the top of the heat shield to the top of the open drum as shown in figure 2b. The moisture content of the fiberboard is measured using a GE Protimeter Surveymaster moisture meter. A typical fiberboard assembly will have a moisture content of ~6 – 16 %WME (wood moisture equivalent) or ~7 – 13 wt%.

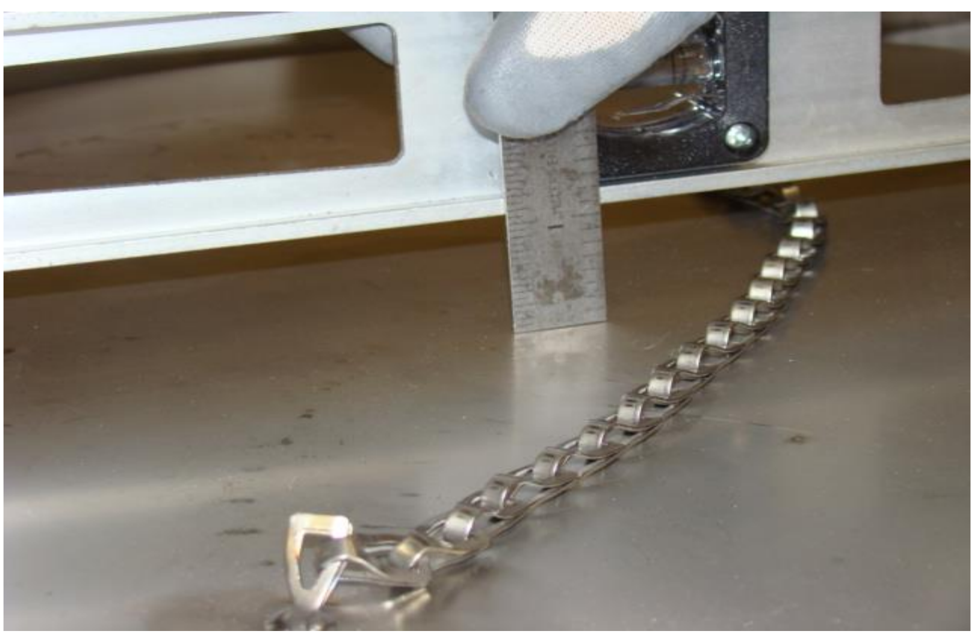
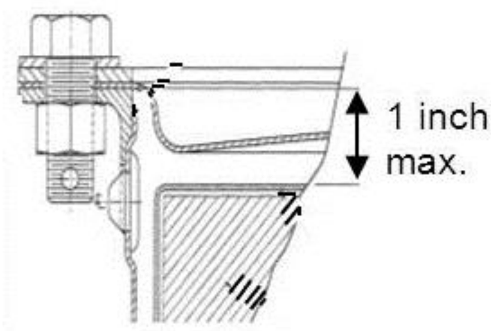


Figure 2a. Measuring the Axial Gap



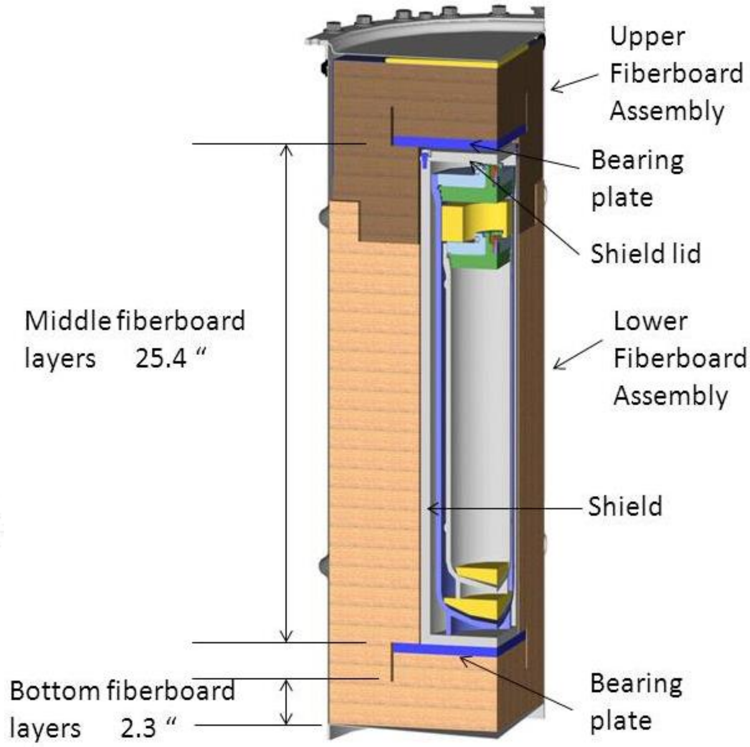


Figure 2b. Sketch of axial gap in the 9975 package (from Reference 2)

Figure 3. Cross section of 9975 package identifying fiberboard assemblies and other relevant features

All cases in which packages opened in K Area exceeded the 1 inch axial gap criterion were further examined to identify the cause of the axial gap. Most of these packages contained elevated moisture in the bottom fiberboard layers. Sufficient data were collected in some of these cases to characterize the approximate degree of compression of the bottom fiberboard layers, as indicated by the extent to which the fiberboard had conformed to the drum bottom.

- 9975-01818 and 9975-01819 both had high moisture levels (100%WME, above saturation) in the bottom fiberboard layers. In both cases, the drum bottom was stepped, and the fiberboard had fully conformed to the drum bottom. These drums had a much higher moisture level than expected in fiberboard probably due to improper storage of the drums prior to use.
- 9975-02130 had a moisture content of 23 – 24 %WME on the fiberboard bottom surface. The drum bottom was stepped, and the fiberboard had conformed to the outer step, but not the interior region.
- Packages 9975-01903 and 9975-02287 both had a moisture content of ~18 %WME in the bottom layers. Both packages had rounded drum bottoms, and in both cases, the fiberboard had conformed to the drum bottom over approximately 2 inches.

Figure 4. 9975-01818 With Excess Moisture resulting in compression and mildew

Figure 5. 9975-02287 fiberboard with only slight increase in moisture

The compression mechanism is due to the following conditions. Within the package the lead shield (and the containment vessels and payload contained within) sits on an aluminum bearing plate embedded within the lower fiberboard assembly (Figure 3). The bearing plate, shield, containment vessels and a typical loaded 3013 container place a load of approximately 263 pounds on the fiberboard.

The bottom of the 9975 outer drum is dished (or stepped) and the fiberboard overpack is fabricated with a flat bottom. Typically, a ring of compressed fiberboard will form around the outer edge of the bottom surface approximately 1½ - 2 inches wide. As the bottom layer(s) compress further (due to package handling or reduced fiberboard strength), this ring will widen until the entire fiberboard bottom surface is in contact with the drum bottom. This has been observed in packages with elevated moisture content, and is illustrated in Figure 6. With the limited contact area, the peak stress in the bottom fiberboard layers is typically no greater than 3.4 psi. As the compressed region widens, the peak stress decreases to 2.7 psi, which is the stress immediately under the bearing plate.

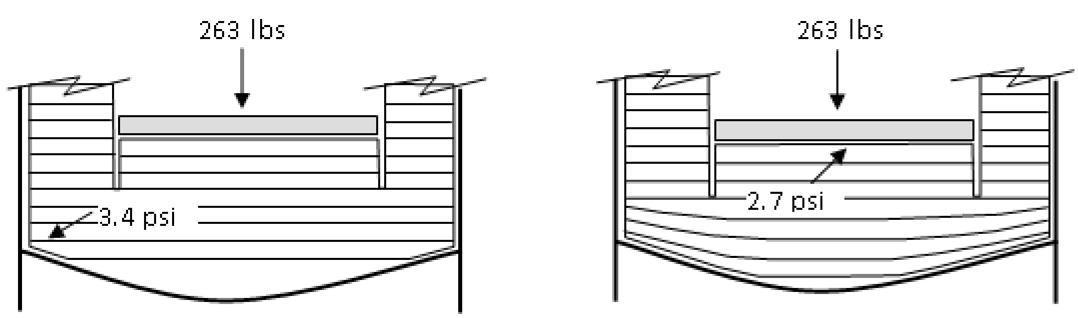


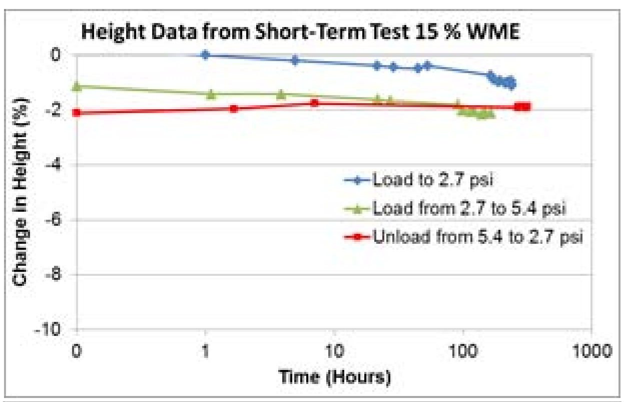
Figure 6. Varying degree of contact between the lower fiberboard assembly and drum bottom. As the contact area increases, the peak fiberboard stress will decrease to that immediately under the bearing plate. NOTE: Degree of curvature exaggerated for visual effect.

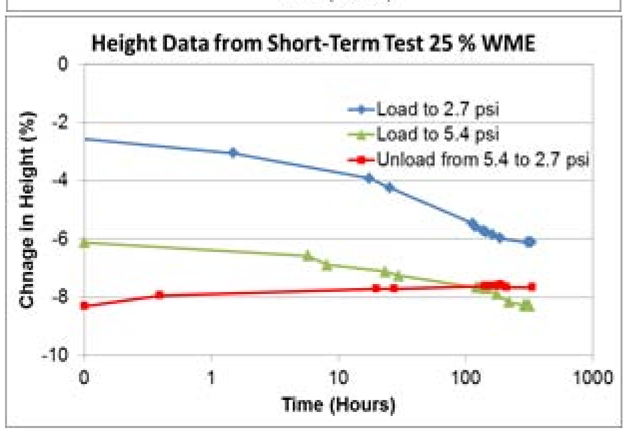
SRNL LABORATORY STUDIES

Experiments have been performed to evaluate the performance of the fiberboard under several different loading scenarios. Fiberboard samples were conditioned to a range of moisture levels. This data is taken from Reference 3. Three scenarios applicable to the storage, handling and transport are

- Short term tests measured the fiberboard compaction under a static load followed by a short term load to double the stress. This additional load is removed to measure the material rebound.
- Dynamic testing involved a static load with weekly dynamic cycles produced by a cart containing samples being moved over a rough track
- Static Testing of samples was done with a continuous load, but without the weekly dynamic cycles.

While a compression test typically extends to high strain levels, the data of current interest includes low compressive strain behavior corresponding to stress levels of < 10 psi.
The results of the short term tests generally confirm that the higher the moisture content, the greater the compaction level.





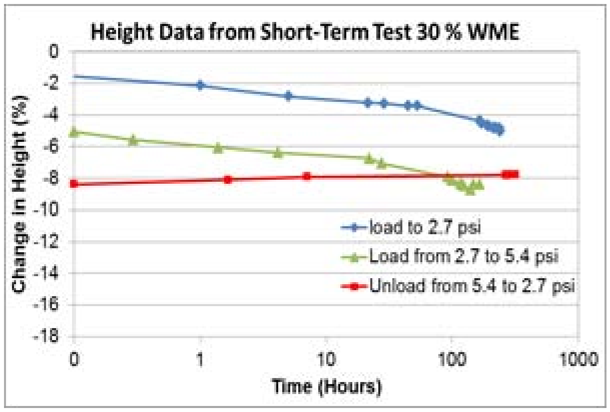


Figure 7. Change in sample height during short-term testing

The dynamic testing which resulted in samples being subjected to up to 47 weeks of cyclic loading showed generally the rate of compression of the samples while between dynamic cycles is less than the rate of compression of the control (static) samples. Here again the higher moisture level leads to a greater compression. There is variation in the dynamic testing results most likely due to the physical properties of the fiberboard itself and the fact that the samples were taken from different regions within the same package.

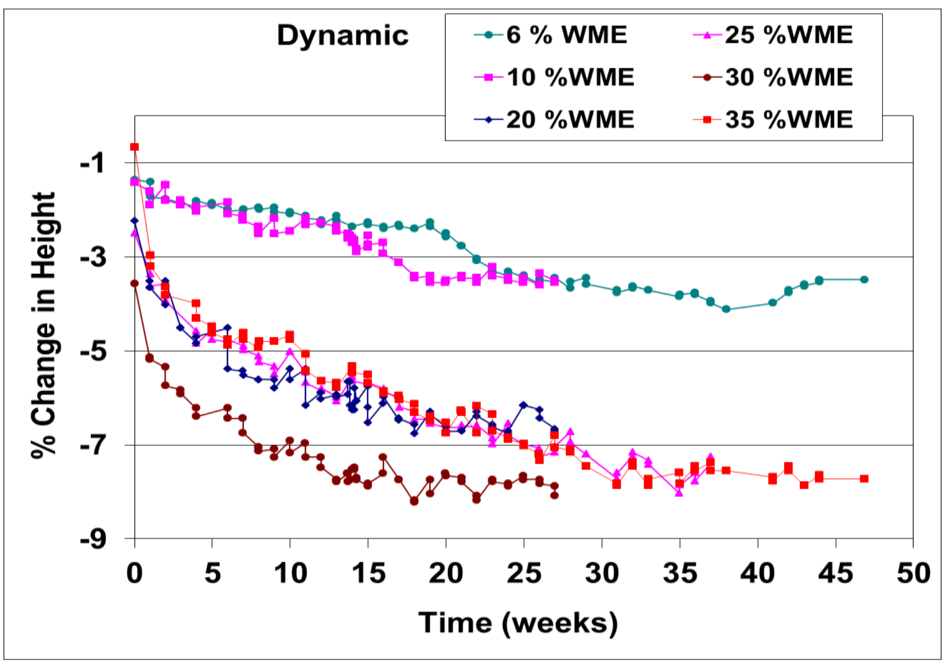


Figure 8. Relative change in height (strain) under load for dynamic test samples.

RESULTS

From the laboratory aging studies it has been shown that moisture present in the fiberboard overpack of the 9975 shipping package can migrate and concentrate when an internal heat load is present. This phenomenon can lead to elevated moisture levels in the bottom fiberboard layers, which can have several effects on the package:

- The lower fiberboard layers will compact under the load of package internal components.
- Regions of the fiberboard assembly that lose moisture will shrink.
- The axial gap at the top of the package (between the drum flange and upper fiberboard assembly, Figure 2b) will increase.

The higher the moisture content, the greater the total compaction, the greater rate of compaction and continued compaction over a longer period of time. Laboratory testing has also shown that at elevated moisture levels ($\geq$ 20 %WME), the strains are higher and continue to increase for a longer period of time. The rate of compression of the dynamic samples is less than the rate of compression of the control (static) samples. As each of the short term samples is unloaded, some recovery of the height occurred.

The correlation between moisture and strain was stronger for moisture levels from 20 %WME to 30 %WME. In addition, as the moisture levels fluctuate, the sample height tends to fluctuate in unison.

Figure 9 shows the final compaction data from the short term and dynamic compaction tests combined into a single chart. There is little difference in compaction between the short-term, dynamic and static samples. The trendline shows the behavior with all of the samples tested at 2.7 psi averaged together. The behavior is linear up to the saturation point, and appears to have little variation with moisture levels above saturation.

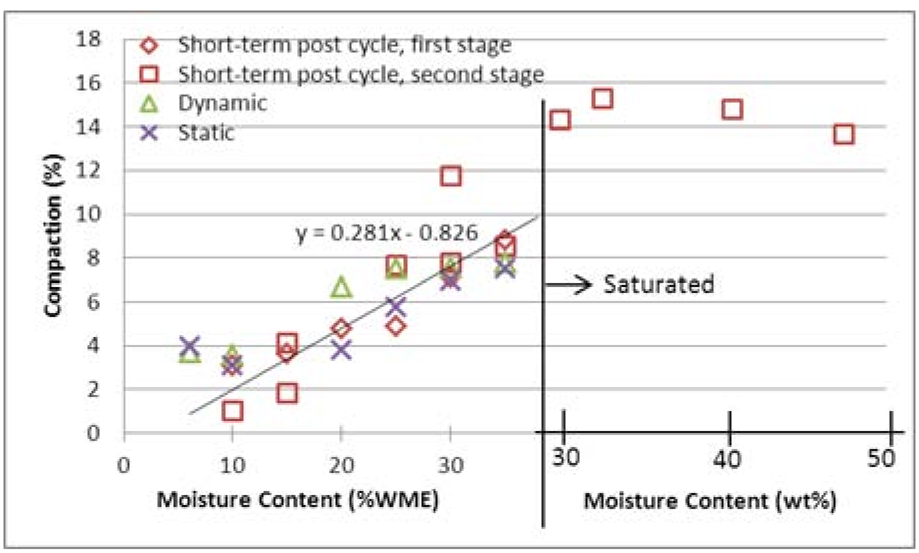


Figure 9. Final compaction data from short-term and dynamic compaction tests. The trendline is a linear fit to all data below the saturation point (~38 %WME) and a stress of 2.7 psi.

Table 1. Compaction predictions based on a lower bound fit to all 2.7 psi data

Moisture Content		
%WME	Wt%	% Compaction
15	12.6	1.86
20	16.0	3.27
25	19.4	4.68
30	22.7	6.09
35	26.0	7.50
38	28.1	8.35

With an internal heat load in the package, several changes are expected to occur. The heat load will create a thermal gradient through the fiberboard, and the fiberboard moisture will re-distribute preferentially to the cooler regions of the package. For typical package heat loads and service environments, the degree of moisture re-distribution is modest. However, for maximum heat loads and high external temperatures (especially as the local fiberboard temperature approaches the boiling point of water), a significant amount of moisture can re-distribute to the bottom of the package, up to and beyond the point of fiberboard saturation (~38%WME).

As the moisture content of the bottom layers increases, the compressive strength of those layers will decrease and the layers will compact further. This observed compaction is a net effect of two competing phenomena – the weakened fiberboard compacts under the load of the internal components, and the fiberboard fibers swell from the absorption of additional water. At the same time, the remainder of the fiberboard has lost moisture, and will shrink axially.

At least some of the fiberboard above the bearing plate in the upper assembly is also at elevated temperature, and moisture re-distribution from this area will also occur. The presence of the air shield could reduce the rate of moisture loss, but should not prevent it. However, the periodic measurements of the three life extension packages (laboratory tests to age entire 9975 packages at elevated temperature) do not show a strong indication of consistent shrinkage in the fiberboard above the bearing plate. Therefore, it will be assumed that this region of fiberboard does not contribute significantly to changes in the axial gap for a package in service.

The middle region of the fiberboard assembly (which is typically the hottest) will lose moisture, and will shrink axially, as water migrates to the cooler regions of the package. This region consists of the fiberboard between the two bearing plates (over a nominal height of 25.4 inches, including portions of both the upper and lower fiberboard assemblies). The upper fiberboard assembly initially rests on the lower fiberboard assembly, with a nominal 0.25 inch gap between the shield lid and the upper assembly bearing plate. (With combination of tolerances, this gap can be as low as 0.05 inch.) As the middle fiberboard region shrinks axially, this will also contribute directly to the axial gap at the top of the package, until the upper assembly bearing plate is resting on the shield lid. After that, additional shrinkage will open a gap between the upper and lower fiberboard assemblies. Therefore, shrinkage of the middle fiberboard region can contribute at least 0.05 inch, and up to 0.25 inch for the nominal case, to the axial gap.

Impact on Axial Gap:
From the compaction testing (reference 3), the fiberboard compresses 3.3% under 3.4 psi stress at 10 %WME. Therefore, the bottom 2.3 inches of fiberboard will compress by (2.3 inch x 0.033 =) 0.076 inch, on average. As this occurs, the axial gap will increase by the same amount. It is assumed that this compaction occurs soon after initial assembly of the package, and represents the baseline package configuration.

As the moisture level in the bottom fiberboard layers increases from 10 to 30 %WME (and the contact area increases, reducing the local contact stress), Table 1 indicates a total compaction of 6.09%. This correlates to 0.140 inch compaction, of which 0.076 inch is assumed to have occurred in the baseline configuration. An additional 0.064 inch compaction is realized from this moisture increase in the bottom fiberboard layers. The axial gap increases by the same amount (0.064 inch).

The middle fiberboard region shrinks axially by 0.119 inch as its moisture level decreases. For minimum tolerances of fiberboard and shield, only 0.050 inch of this shrinkage adds to the axial gap. More of this shrinkage contributes to the axial gap for dimensions closer to nominal values. If the initial gap between the upper bearing plate and shield lid is greater than 0.119 inch, then this entire amount will contribute to increasing the axial gap. The total effect on the axial gap therefore ranges from 0.114 inch for minimum tolerances to 0.183 inch for nominal tolerances.

The scenario described above for moisture in the bottom fiberboard layers increasing from 10 to 30 %WME can be repeated for different final moisture levels. Table 2 summarizes the results for scenarios in which an initial 10 %WME moisture level increases to a range of values, up to saturation of the bottom layers (38 %WME). Figure 10 presents these results graphically

Table 2. Predicted change in axial gap for a change in the moisture level of the bottom fiberboard layers from 10 %WME to the stated value.

New Moisture Level (%WME)	Axial Gap Increase (inch)	
	Nominal Tolerances	Minimum Tolerances
10 %WME	0	0
15 %WME	0	0
20 %WME	0.059	0.049
25 %WME	0.121	0.082
30 %WME	0.183	0.114
35 %WME	0.245	0.146
38 %WME	0.282	0.166
28.1 wt%	0.405	0.288
36.1 wt%	0.476	0.288

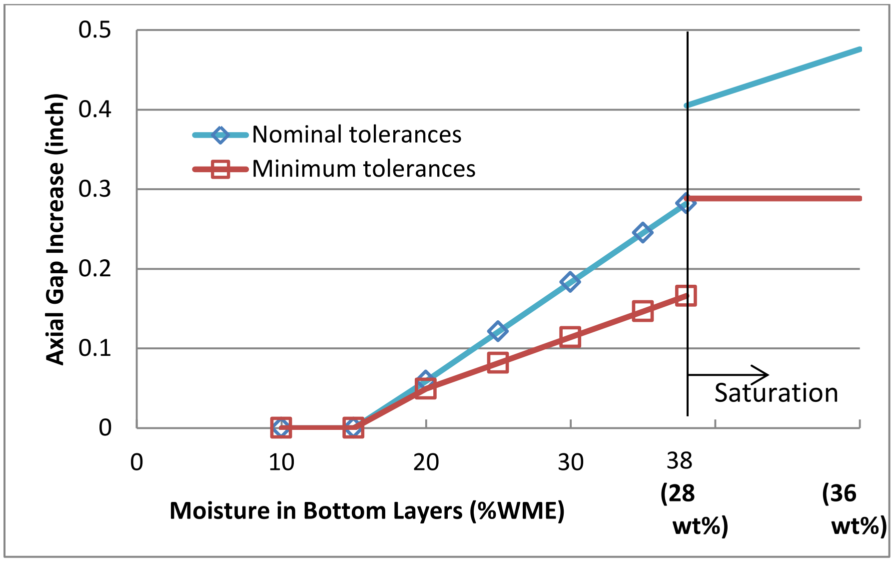


Figure 10. Predicted axial gap increase as a function of moisture level in the bottom fiberboard layers.

At concentrations below saturation (~38 %WME, or 28 wt% water), water is absorbed into the cellular structure of the cellulose. Once the saturation point is reached, any additional water will remain as free liquid, and will adsorb onto fiber surfaces and begin filling cell cavities and other void spaces. Because of this change in behavior, the data developed at moisture levels below the saturation point should not be extrapolated to predict the behavior of saturated fiberboard. For moisture levels above saturation, the data suggest a significant increase in fiberboard compaction, and a constant compression of 13.67% is conservatively assumed, as noted above. Figure 10 suggests an abrupt step change in compaction occurs upon reaching saturation. A period of transition would be expected, but the data suggest that such a transition occurs over a very small range of moisture increase.

Saturation is predicted to produce 0.314 inch compaction in the bottom 2.3 inches of fiberboard, or 0.238 inch compaction beyond the baseline condition. At 28.1 wt% moisture (just above saturation), the bottom layers will have gained 0.467 kg water and the middle fiberboard region has lost this amount, causing 0.167 inch axial shrinkage of the middle fiberboard region. The net increase in axial gap will be 0.405 inch for nominal tolerances, or 0.288 inch for minimum tolerances. This result is also indicated in Table 2 and Figure 10. As the moisture level continues to increase above saturation, additional compaction of the bottom fiberboard layers is not predicted, but additional shrinkage of the middle region will occur.

From the field surveillances performed and from drums undergoing annual certification, the 9975 drums which failed the axial gap measurement were primarily shipped from Rocky Flats Environmental Technology (RFETS). The drums corresponded to the same three month timeframe of packaging at RFETS. From a statistical study of all REFETS packages opened (reference 5), it was concluded that approximately 8% of the drums packaged from that period were expected to exceed the axial gap criteria. Comparing all of the field surveillance findings thus far, has failed to show a strong correlation between heat load inside the drum and axial gap which tends to represent the relatively mild storage environment for the drums in KAC versus the bounding tests performed by the Laboratory.

CONCLUSION

The total axial gap increase resulting from increasing the moisture level of the bottom layers to 30 %WME, due to compaction of the bottom fiberboard layers and shrinkage of the middle fiberboard region, is 0.183 inch. If a package had an initial axial gap of 0.817 inch or greater, an increase of 0.183 inch would be sufficient to fail the axial gap criterion. The axial gap has been recorded for 147 of the packages that underwent field surveillance in K Area (Figure 11). It is assumed that the field surveillance packages had axial gaps essentially unchanged from baseline, since they typically had relatively low heat loads and storage temperatures were relatively mild.

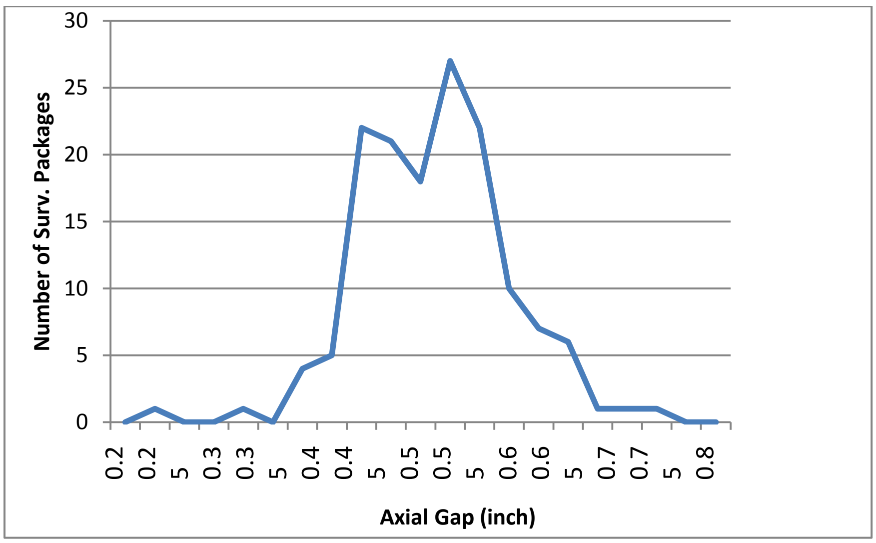


Figure 11. Summary of axial gap measurements from field surveillance activities. The number of packages having an axial gap within each interval is shown. Total number of packages is 147.

The reasonableness of this assumption is seen by comparing the average measured axial gap (0.75 inch) to the nominal value (0.8 inch) Of these 147 packages, 40 packages, or 27%, had an axial gap of 0.817 inch or greater. Similarly, 12% of the packages would fail the axial gap criterion in the event that minimum tolerances limit the axial gap increase to 0.114 inch. Similar percentages of packages to fail the axial gap criterion for a range of moisture content are shown in Figure 12. For nominal packages in which the bottom fiberboard layers exceed saturation, the likelihood of failing the axial gap criterion is very high (>92%).

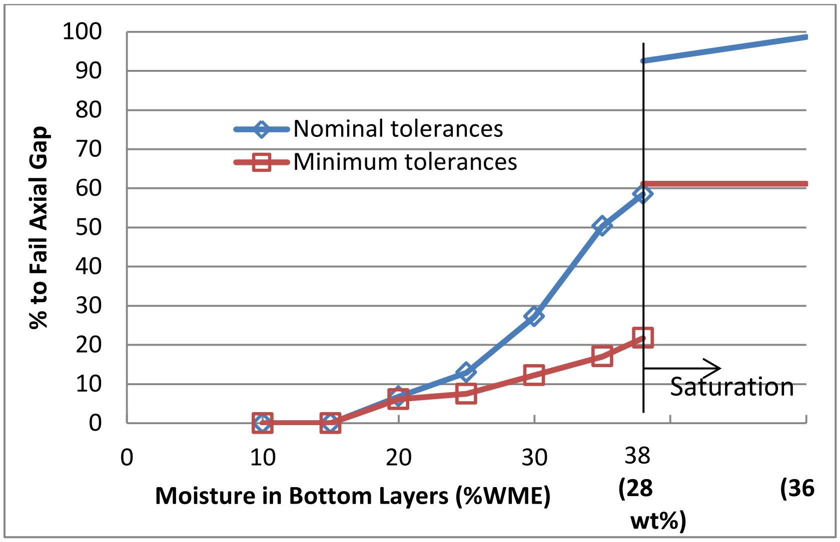


Figure 12. Estimated percentage of packages to fail the axial gap criterion as a function of moisture content in the bottom fiberboard layers.

As a result the axial gap is a good indicator of degradation due to the migration of moisture within the fiberboard assembly. In addition, the proper storage of 9975s is critical to the integrity of the fiberboard to minimize extreme temperatures or the introduction or any moisture.

REFERENCES

[1] SRNL-STI-2012-00429 "Analysis of the Axial Gap vs Fiberboard Moisture Content in a 9975 Shipping Package, W.L. Daugherty"

[2] Drawing R-R@-F-0025, Rev. 5 "9975 Drum with Flange Closure Subassembly & Details"

[3] SRNL-STI-2012-00347, "Final Report for Moisture Effects on Compaction of Fiberboard in a 9975 Shipping Package", T. M. Stefek, W. L. Daugherty and E. G. Estochen, March 2013.

[4] WSRC-TR-2001-00286, "SRS Surveillance Program for Storage of Pu Material in KAMS", Rev 6, October 2011

[5] SRNL-STI-2010-00329, " Statistical Analysis of the 9975 Axial Gap Issue (U)", S.P. Harris, June 1, 2010