Technical Problems Encountered During Certification of a Type B (Plutonium) Package (U)

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INTRODUCTION

Westinghouse Savannah River Company (WSRC) is the packaging designer for the 5320 Type (B) PuO/AmO Packaging (DPSU79-124-1, "Safety Analysis Report -Packages"). The predecessor to the 5320 Packaging, introduced in 1980, was initially developed in 1973 for shipping plutonium and americium. Since 1980 the 5320 Packaging has undergone numerous design changes to meet changing packaging and transportation regulations. During the current certificate renewal process, WSRC experienced significant technical problems with the packaging design. This paper will discuss the technical problems associated with the design, the technical challenges they presented and the design solutions that were implemented to meet current Department of Energy (DOE) regulations.

DESIGN DESCRIPTION

The initial 5320 Packaging design is shown in Figure 1. The cask is a vertical cylinder, approximately 30 inches in height, 17 inches in diameter, and weighing 325 pounds. The PuO/AmO powder is contained within the 316 SS product canister which is seal welded into the 316 SS primary containment vessel (PCV). The PCV is contained within the flanged secondary containment vessel (SCV). The containment vessels are enclosed by an aluminum tank. The tank conducts decay heat (203 watts) from the product and dissipates it to the surroundings through internal/external cooling fins. Water Extended Polyester (WEP) neutron shielding fills the annulus of the aluminum tank. A 304 SS toroidal impact limiter protects the secondary containment flange from impact damage.

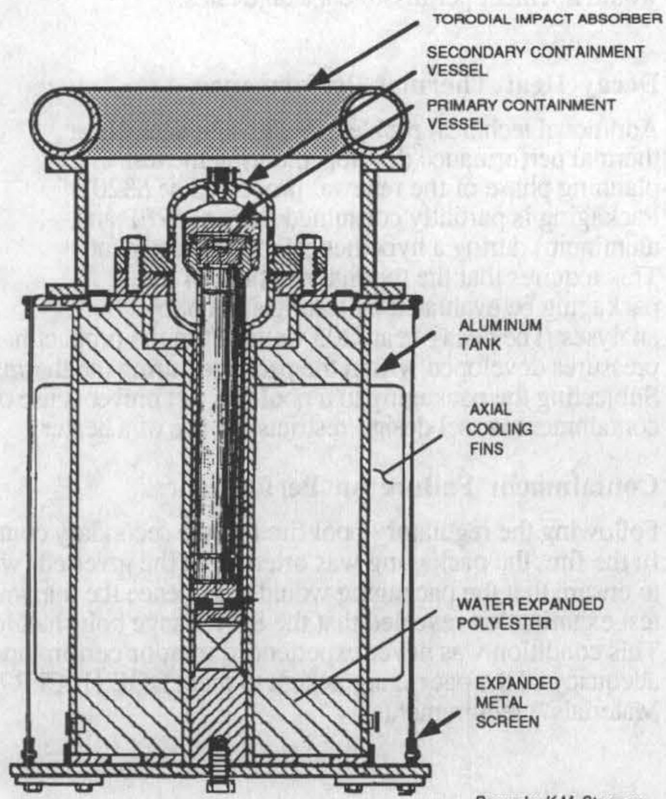

Figure 1. 5320 Packaging design

Some of the difficulties associated with renewing the certificate of an older Type B( ) cask was the limited number of available casks and contamination. A small cask population limits the number of casks that are available for performing the required certification tests. The available casks are highly contaminated and must undergo extensive cleaning prior to testing.

TECHNICAL PROBLEMS

The technical problems associated with the packaging were for the most part addressed early in the certification process. However, the most significant and difficult problem did not appear until near the end of the renewal process.

Impact Limiter Performance

Initially, the major structural problem was the toroidal impact limiter (Figure 1) performance under hypothetical accident conditions. The advantage of the toroidal design was that it could absorb a 30 ft. impact onto a flat horizontal surface without causing significant damage to the packaging. However, the open-top toroidal design did not protect the top of the SCV from impact onto a puncture pin or from the high heat fluxes developed in a hypothetical thermal accident. The open-top design was also a security problem in that it allowed unrestricted access to the SCV flange bolts.

Containment Seal Performance

Another problem identified early in the renewal process was the SCV seal performance. The flange has two inner seals, a Buna N O-Ring for normal conditions and a flexitallic gasket for hypothetical accident conditions. The location of the seals are shown in Figure 2. When the leak test procedure was changed to measure the performance of each seal independently, it was determined that the flexitallic gasket was not sealing properly. Leak tests performed on available containment vessels established that the flexitallic gasket seal design would not meet permissible leakage rates.

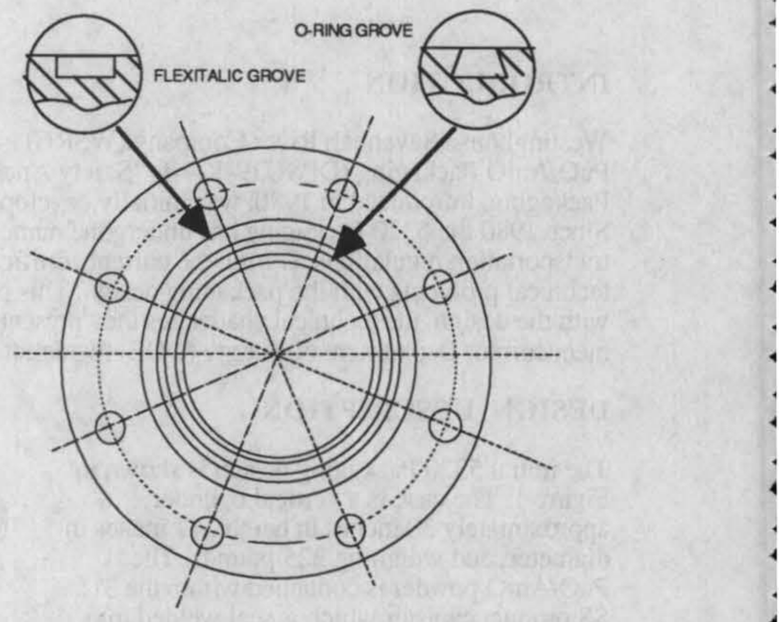

Figure 2. Flange seal design

Decay Heat Thermal Performance

Additional technical problems relative to decay heat thermal performance developed during the test planning phase of the renewal process. The 5320 Packaging is partially consumed (loss of WEP and aluminum) during a hypothetical thermal accident. This requires that the thermal response of the packaging be evaluated by testing and not by analyses. The decay heat (203 watts) from the product has a significant impact on the final temperatures and pressures developed within the package during the thermal test and must be accounted for in the test set-up. Subjecting the packaging to a pool fire test prevents use of the actual product and the compactness of the containment vessel design restricts the use of a heater.

Containment Failure on Performance

Following the regulatory pool fire test the secondary containment vessel failed the subsequent post leak test. In the fire, the packaging was oriented in the inverted (worst case) position as shown in Figure 3. This was to ensure that the packaging would experience the maximum thermal heat fluxes. Following the fire, a post-test examination revealed that the SCV flange bolts had lost their preload, resulting in loss of containment. This condition was never experienced in prior performance tests and raised serious concerns as to the adequacy of the packaging design to meet DOE (10CFR71,"Packaging and Transportation of Radioactive Materials") requirements.

TECHNICAL CHALLENGES

As with most older packagings the renewal of the 5320 shipping cask presented unique and challenging technical problems that required no-nonsense solutions. It was decided early in the renewal process that a practical engineering approach be used to address the various technical problems. Using the practical approach in the solution process relies heavily on incorporating costs, available resources and schedule into the procedure. However, costs are not a significant driver in the solution process when public safety is a concern. The practical engineering approach is best achieved when the proper balance between the solution, resources and schedule is obtained.

Figure 3. Pool fire test set-up.

During the certification renewal process, DOE suspended the packaging certificate, which prevented WSRC from using the cask. This action heightened the awareness to select engineering solutions that could support the renewal process in the shortest period of time. Closely coupled to schedule was available resources. The most important resource was qualified manpower. Since the availability of qualified manpower was limited so was the choice of acceptable solutions.

It was also understood that a totally new packaging design may well be the optimum engineering solution. Even with a practical approach to solving the engineering problems the possibility of starting anew was a distinct possibility. However, a new design would certainly extend beyond the present schedule, requiring the package to be off the road for a considerable amount time. This realization made clear the importance of using a practical engineering approach to finding solutions to the technical problems on hand.

DESIGN SOLUTIONS

Impact Limiter Design

It was decided early in the renewal process to develop a new impact limiter design to better address current requirements. Previous drop tests on the toroidal limiter indicated that it was too rigid, transmitting (not absorbing) the impact energy to the rest of the packaging. In a solid packaging like the 5320 the result was to induce large dynamic stresses in the structural components. Although previous drop tests were successful, a more energy absorbing design was preferred.

The new limiter design had to fit the existing packaging without altering the present cask design. The one exception was in the method of attaching the limiter to the aluminum tank flange. The threaded inserts in the aluminum flange would be drilled out and replaced with a through bolt and nut to produce a stronger connection. The practical approach used in re-designing the limiter favored using off-the-shelf hardware that did not require extensive development effort.

The impact limiter design that was selected was the top-hat design shown in Figure 4. The design completely contained and protected the SCV during normal and hypothetical accident conditions. Very little re-work of the packaging was necessary and the limiter was designed to crush on impact, absorbing more of the impact energy. Since the design was a poor thermal insulator it would not adversely affect the steady state temperatures in the containment vessels. The top-hat concept met all of the design requirements with minimal impact on packaging design, available resources and schedule.

Containment Seal Design

The SCV flexitallic gasket design exceeded permissible leakage rates during preliminary testing. Replacement of the flange assembly with a new design was impracticable since the SCV was permanently pressed into the aluminum tank and could not be removed. Any engineering solution would have to be implemented using existing packaging hardware.

Inspections performed on the packaging population revealed that the flange seal surfaces were neglected over the years. There were numerous scratches and indentations over most of the surfaces. The only solution was to re-machine the flange surfaces to meet seal performance requirements. Since the maximum pressure expected in the secondary containment vessel was below the pressure rating of the flange, a maximum of 0.05 in. was allowed to be removed from each flange face.

The final flange design included new surface finishes, groove depths and groove widths. Developmental testing also revealed that the gasket had to be centered in the groove to obtain optimum seal performance. A centering fixture was designed to properly position the gasket in the groove.

Even with these design changes the leak rates showed only a marginal improvement. It was not until flexitallic gaskets with higher filler densities were tried that a significant improvement in leak rate was attained. The leak rates of tested flanges improved to between $5x10^{-5}$ and $1x10^{-7}$ std cc/sec air. The required leak rate for the flexitallic gasket is $1x10^{-4}$ std cc/sec air. While the seal problem required extensive testing and surface re-finishing the final solution had minimal impact on the packaging design, available resources and schedule.

Test (Decay Heat) Design

During preparation for the hypothetical thermal test it was determined that a heater could not be installed in the PCV to simulate decay heating without great difficulty. Designing a heater assembly that would function during a thermal test and not leak would require extensive development time and testing. Regulations require that the containment vessels, following a thermal test, simulate the worst case pressures at temperature. A more practical solution to the decay heat problem was needed.

Pre-heating the entire package prior to the thermal test was considered an alternative solution to the decay heat problem. However, a uniform pre-heat alone would not duplicate the thermal conditions that a package would experience during testing.

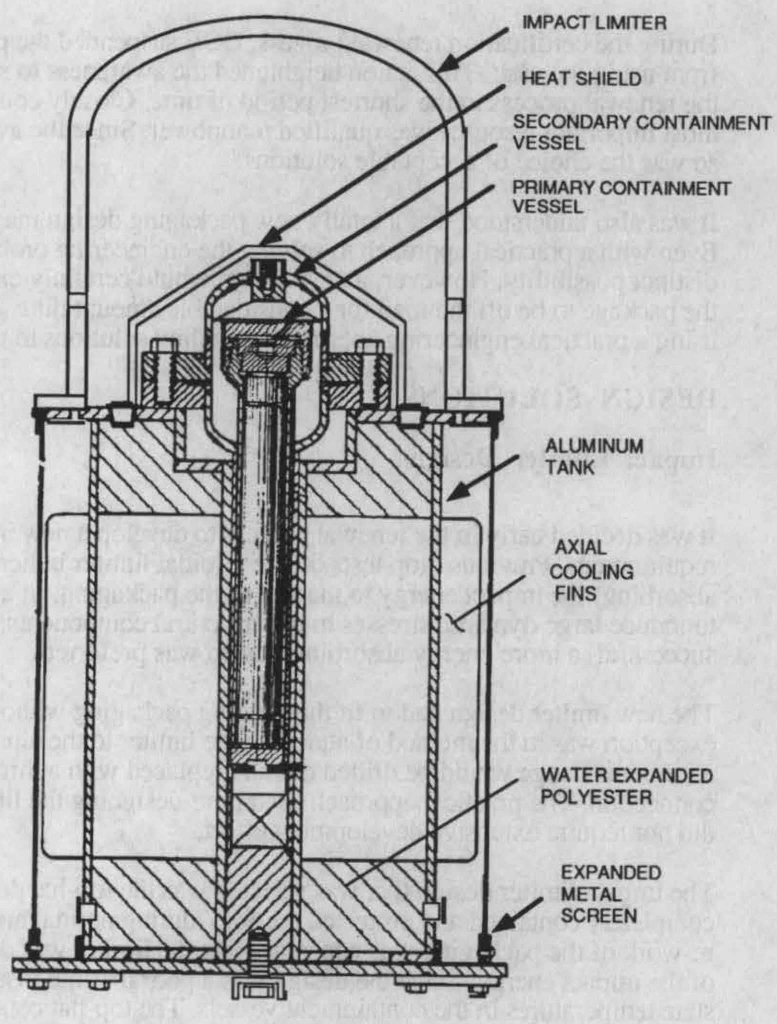

Figure 4. Top-hat limiter design.

An early attempt at pre-heating the packaging in a furnace resulted in a large gas pressure buildup within the WEP container. The packaging was being pre-heated in a furnace at 325°F, the optimum pre-heat temperature, when the incident occurred. It was determined that the increased pressure resulted when water trapped in the WEP turned to a gas at the elevated temperature. To prevent the formation of gasses the pre-heat temperature would have to be limited to 212°F, the boiling point of the water.

Since the lower pre-heat temperature alone would not produce the required temperatures and pressures in the packaging the only solution was to add a pre-charge to the containment vessels. This would assure that the worst case containment pressures where attained during the thermal test. The PCV was pre-charged to 267 psia and the SCV to 41 psia. Following the pool fire test the final pressures and temperatures attained with an initial 200°F pre-heat are given in Table 1, along with the values expected when using normal (steady state) temperature input.

Table 1
Summary of Temperatures and Pressures
Following a Hypothetical Accident Thermal Test

	Initial Package Temperatures			
Vessel	Normal Conditions (calculated)		200°F Pre-heat (measured)	
	Temp. (°F)	Pressure (psia)	Temp. (°F)	Pressure (psia)
PCV	550	443	417	86
SCV	1005	115	1004	108

The final PCV pressure was 9.7% higher than the calculated worst case value and the SCV pressure was 6.1% below the calculated worst case value. The final PCV temperature, as expected from the low pre-heat value, was 133°F below the calculated value but within the design temperature of the component. Although the solution to the decay heating problem did not duplicate the final test conditions the results were judged to be sufficient to evaluate package performance. The alternative solution would have been to develop a costly heater design to obtain more exact temperatures. The practical approach taken was the appropriate solution to a difficult engineering problem.

Thermal Shield (SCV Failure) Design

The previously mentioned technical problems were mainly addressed during the preparation phase of the certificate renewal process. However, the SCV containment failure did not occur until the end of the testing phase of the renewal process and placed a great deal of emphasis on finding an acceptable solution.

Following the failure of the SCV to adequately meet the permissible post-test leak rate, DOE withdrew conditional use of the package. WSRC was immediately tasked to determine the cause of the failure, implement a design fix and prepare the packaging for a thermal retest.

A thorough failure investigation performed by WSRC concluded that the high pool fire temperature (1850°F) annealed the SCV flange bolts. Twenty minutes into the thirty minute fire the aluminum flange melted and the top hat fell off exposing the flange and bolts directly to the fire. Shown in Figure 5 is the SCV flange following the pool fire test. The yield strength of the bolts was reduced from 99,500 psi to 45,000 psi during the test. It was determined that when the bolts reached 1400°F the bolt pre-load equaled the bolt yield strength. At 1500°F the pre-load was reduced by one third and at 1600°F by two thirds. At approximately 1700°F the pressure in the SCV had increased the bolt load until it equaled the reduced bolt pre-load and containment failed. The problem was never experienced during prior analysis and testing because the evaluations were always performed at the regulatory temperature of 1475°F. The thermal response of the packaging to the pool fire was far more damaging than anyone had anticipated.

To verify these results a SCV was tested in the laboratory at simulated pool fire conditions. The results of the test are shown in Figure 6. When the instrumented SCV reached approximately 1695°F the internal pressure suddenly dropped, indicating a loss in containment. The post-test evaluation determined that the flange bolts, like those in the pool fire, were annealed and had lost their pre-load. The test successfully duplicated the pool fire results and established the high SCV temperature (1850°F) as the cause of the failure.

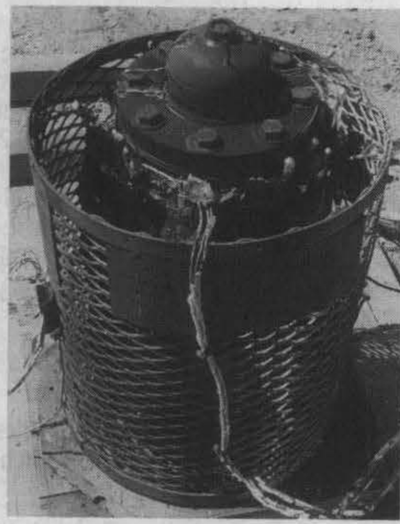

Figure 5. SCV following thermal test

In keeping with the practical approach to solving design problems, the solution to the thermal problem could not adversely impact the packaging design. Other packaging considerations included the effect of added weight on dynamic performance and insulating properties on normal (steady state) condition temperature performance. The design solution would also have to successfully pass a second simulated SCV pool fire test prior to acceptance. Since the certificate was suspended by DOE, scheduling was a very important ingredient in the design process.

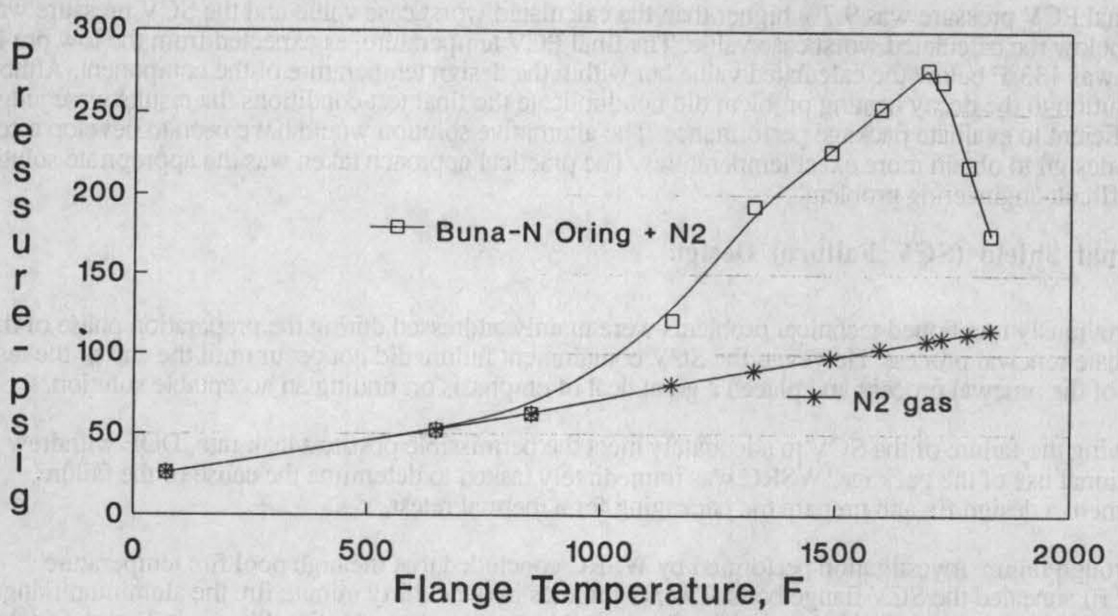

Figure 6. SCV pressure data

The practical approach to solving the problem was to add a thermal shield (hat) to enclose the top of the SCV flange. The selected design is shown in Figure 7. The thermal shield is simply two 304 SS shells enclosing a ceramic insulation one-half inch thick. Total shield weight is approximately 2.5 lbs. The shield is pinned to the lower flange of the SCV to avoid loading the flange bolts during impact.

After the prototype design successfully completed a series of performance tests, the 5320 package was prepared (with thermal shield) for a second regulatory pool fire test. The thermal retest was successfully completed at the SNL pool fire facility.

The packaging, following the thermal test, is shown in Figure 8. The shaded area of the packaging was consumed or lost during the pool fire test. A post test evaluation of the package determined that the thermal shield reduced the flange bolt temperature from 1850 F to 1005 F, well within the structural capabilities of the SCV flange design.

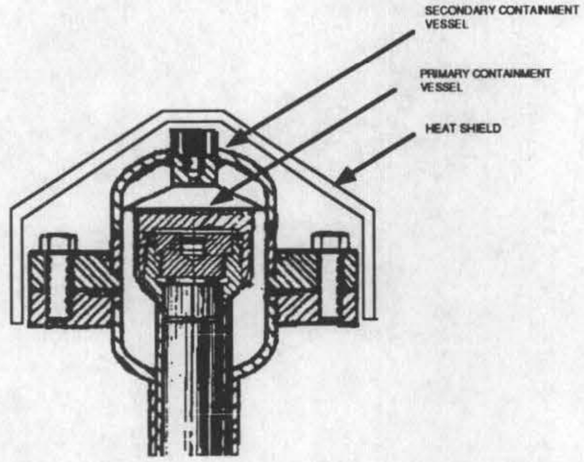

Figure 7. Thermal shield design

CONCLUSION

Renewing the certificate of an older packaging can result in technical challenges that require a practical approach to problem solving. Packages such as the 5320 that experience significant structural loss due to melting and thermal decomposition add to the challenges. In the present solution process the flange seal design was improved, the impact limiter design was changed and a thermal shield was added. An internal heater was not added; an alternative solution was chosen instead. The result of taking a practical approach to problem solving was that the packaging met all of the regulatory requirements. The 5320 Packaging passed the hypothetical accident test sequence and the revised SARP is currently being reviewed by the DOE.

An alternative solution would have been to design a totally new packaging to meet the current regulations. Instead, WSRC commitment to addressing problems using a practical engineering approach resulted in the successful redesign and continued use of the 5230 Packaging.

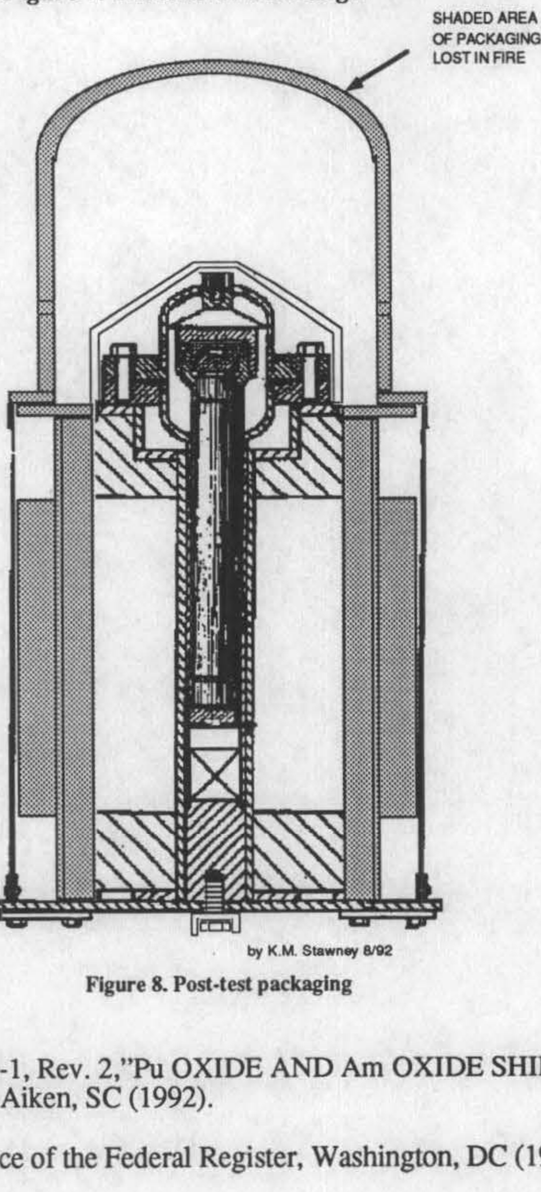

Figure 8. Post-test packaging

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the many engineers and technicians whose efforts and dedication greatly contributed to the successful renewal of the 5320 certificate and to the Savannah River Technology Center and HB-Line Operations organizations for their assistance. WSRC, as the packaging designer, recognizes that the recertification of the 5320 Packaging was a major engineering accomplishment.

REFERENCES

Safety Analysis Report - Packages, DPSPU 79-124-1, Rev. 2,"Pu OXIDE AND Am OXIDE SHIPPING CASK", Westinghouse Savannah River Company, Aiken, SC (1992).

Title 10, Code of Federal Regulations, Part 71, Office of the Federal Register, Washington, DC (1984).

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