Proceedings of the 17th International Symposium on the Packaging and Transportation of Radioactive Materials
PATRAM 2013
August 18-23, 2013, San Francisco, CA, USA

LEVERAGING AGING MATERIALS DATA TO SUPPORT EXTENSION OF TRANSPORTATION SHIPPING PACKAGES SERVICE LIFE

K.A. Dunn[1], J.S. Bellamy[1], W.L. Daugherty[1], R.L. Sindelar[1], T.E. Skidmore[1]

[1]Savannah River National Laboratory
PO Box 616, Aiken, South Carolina 29808 USA

ABSTRACT

Nuclear material inventories are increasingly being transferred to interim storage locations where they may reside for extended periods of time. Use of a shipping package to store nuclear materials after the transfer has become more common for a variety of reasons. Shipping packages are robust and have a qualified pedigree for performance in normal operation and accident conditions but are only certified over an approved transportation window. The continued use of shipping packages to contain nuclear material during interim storage will result in reduced overall costs and reduced exposure to workers. However, the shipping package materials of construction must maintain integrity as specified by the safety basis of the storage facility throughout the storage period, which is typically well beyond the certified transportation window. In many ways, the certification processes required for interim storage of nuclear materials in shipping packages is similar to life extension programs required for dry cask storage systems for commercial nuclear fuels. The storage of spent nuclear fuel in dry cask storage systems is federally-regulated, and over 1500 individual dry casks have been in successful service up to 20 years in the US. The uncertainty in final disposition will likely require extended storage of this fuel well beyond initial license periods and perhaps multiple re-licenses may be needed. Thus, both the shipping packages and the dry cask storage systems require materials integrity assessments and assurance of continued satisfactory materials performance over times not considered in the original evaluation processes. Test programs for the shipping packages have been established to obtain aging data on materials of construction to demonstrate continued system integrity. The collective data may be coupled with similar data for the dry cask storage systems and used to support extending the service life of shipping packages in both transportation and storage.

INTRODUCTION

The end of the Cold War caused dramatic reductions in the size of the U.S. nuclear arsenal and has resulted in large quantities of excess nuclear materials. The Department of Energy (DOE) is tasked with safely managing these nuclear materials including transportation, interim and/or extended storage, and disposition activities. The use of a 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. Second, the interim and/or extended storage of nuclear materials within the shipping package results in reduced operations for the storage facility. Similarly, the lack of a nuclear materials repository has required commercial nuclear power facilities to prolong use dry storage systems for used nuclear fuels. Therefore, shipping packages and dry storage systems may be used to contain nuclear materials for times beyond their original certification periods and recertification is required.

Most structural materials experience time-dependent degradation during service in their exposure environments. The extent of degradation depends on the conditions of service and, for various combinations of time, temperature and other exposure conditions, the degradation may lead to a partial or total loss of structural integrity of various materials within the system. Extension of the certification periods for nuclear material containers beyond their original license period requires assurance of continued materials integrity throughout the extension period. Recertification activities for dry storage systems are well developed and may be leveraged to support life extension activities for shipping packages.

BACKGROUND

Aging management activities for the Systems, Structures, and Components (SSCs) of nuclear power plants (NPPs) are used to provide assurance that the materials' conditions of the SSCs are acceptable throughout the licensed period of service. The U.S. Nuclear Regulatory Commission staff evaluates generically the programs acceptable to manage aging effects in NPPs as well as the site-specific programs for a licensee. The Generic Aging Lessons Learned Report [1] lists the generic aging management reviews (AMRs) of SSCs that may be in the scope of license renewal applications (LRAs), and identifies aging management programs (AMPs) that are acceptable to manage aging effects of SSCs in the scope of license renewal. The potential for age-related degradation of the fuel and materials in the systems, structures, and components (SSCs) of dry cask storage systems (DCSSs) for independent spent fuel storage installations (ISFSIs) during extended storage and transportation (EST) was evaluated in several recent studies and guidelines for life extension activities have been outlined [2-5]. These activities have been used to guide the life extension activities discussed in this report.

Design and construction of Type B packages are required to abide by three upper tier documents: the DOE Order 460.1C – Packaging and Transportation Safety, the DOT 49 CFR Parts 171-180 – Hazardous Materials Regulations, and 10 CFR Part 71 – Packaging and Transportation of Radioactive Material. These 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 stringent inspection criteria at the time of fabrication and during the maintenance program for recertification for shipping. As such, Type B shipping packages are very robust for their specified contents and are constructed of high quality, tightly controlled materials. Additionally, they are designed, fabricated, tested, operated, and maintained under strict standards of quality control.

The accident scenarios considered for a shipping container used in transportation differ from the scenarios applicable to storage. However, there are considerable similarities between the transportation and storage scenarios and a package authorized for shipment has a solid basis for analyses against the storage facility safety requirements.

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 and that any postulated facility accident scenarios are mitigated by the shipping/storage package. The storage facility conditions are also verified to be compatible with the shipping package environmental requirements. Once the packages are approved for storage, if not before, a surveillance program should be implemented to validate the technical basis for the package analysis and to ensure the materials of construction maintain an acceptable level of integrity throughout the storage period. Storage times are typically well beyond the normal one year transportation window. 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 time during receipt and also eliminates both the labor and material costs of repackaging and the risk of radiation dose to the facility operators.

EXAMPLES

Using a Shipping Container for Storage

Interim safe storage of excess plutonium materials in shipping packages is an ongoing process. The DOE is storing excess plutonium materials in a safe guarded facility (K-Area Complex or the KAC facility) at the Savannah River Site. The materials are stored in DOE-STD-3013 packages that are contained in DOT Type B 9975 shipping packages. Technical details of the engineering/science programs supporting the operation of this facility are given in the Winter and Spring 2010 issues of the Journal of Nuclear Materials Management [6-7].

Consolidation of packaged plutonium-bearing materials in the K-Area Complex (KAC) at the Savannah River Site (SRS) began in 2003. The plutonium materials are packaged using the DOE 3013 Standard which requires two nested, welded stainless steel containers. Within KAC, the welded 3013 containers are stored in DOT Type B 9975 packages. The 9975 shipping/storage package consists of two nested stainless steel containment vessels capped with threaded cone-seal plugs, surrounded by a lead shield and fiberboard overpack, all contained within a 35 gallon stainless steel drum, Figure 1. The 9975 shipping/storage package is part of the approved storage configuration for plutonium materials in KAC. As such, 9975 shipping/storage packages have been continuously exposed to the service environment for a period of time greater than the approved transportation service life. A 9975 Storage Surveillance program was undertaken to verify the integrity of the age-sensitive materials (e.g., containment vessel O-ring seals and fiberboard overpack) over time in the environment they are exposed to in KAC.

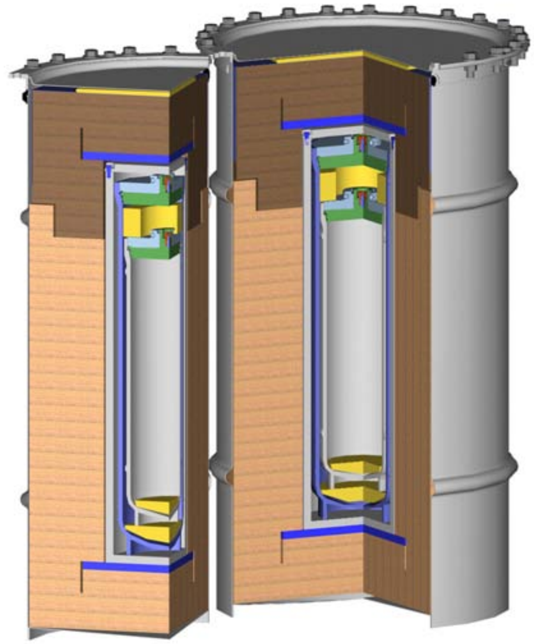

Figure 1. Illustration of 9975 package including drum, fiberboard, lead shielding, and double containment vessels.

Extending the Life of a Dry Storage System

The potential for age-related degradation of the fuel and materials in the systems, structures, and components (SSCs) of dry cask storage systems (DCSSs) for independent spent fuel storage installations (ISFSIs) during extended storage and transportation (EST) was evaluated in several studies [2-5]. The service environments anticipated for the DCSS/ISFSI will affect the material condition of various components and may adversely impact the component's functions, including its safety functions. The degradation of the SSCs, excluding fuel and canister/cask internals, to be addressed during extended storage (storage for greater than approximately 60 years), includes the following:

1. Corrosion-induced pitting and stress corrosion cracking on the external surfaces of dry storage canisters and casks. Such corrosion could cause the loss of the confinement function.

2. Sealing force reduction coupled with the potential loss of sealing capabilities and confinement may occur in bolted closures with metallic seal materials.

3. Spallation and the potential loss of retrievability, cooling functions, and shielding functions for concrete pads and bare concrete casks

4. Degradation and potential reconfiguration of the polymeric shield materials embedded with an overpack causing the material to slump and lose its shielding function.

Each of these components may require periodic or in-service inspection, preventive maintenance, the monitoring of conditions and/or combinations of these activities. The recommended monitoring, inspection and maintenance activities constitute the principal strategy to manage aging of the DCSS and support the technical and regulatory bases for extended storage. These aging management activities are similar to those being used to support operations in the KAC and illustrate the potential for leveraging life extension operations by considering other life extension programs. For example, corrosion and pitting of austenitic stainless steels must be considered in KAC and in dry storage systems. Clearly the sharing of analysis techniques and data may improve both programs.

APPROACH

A generic approach to materials life management is to understand the baseline properties of the materials of interest and to obtain performance data under anticipated aging conditions. The environmental conditions of the aging tests should bound any conditions that may be experienced within the lifetime of the materials of interest. Bounding conditions may include the highest or lowest temperature and/or humidity, the maximum radiation dose expected, chemical interactions, weight factors, storage configurations, etc.   Figure 2 provides a schematic that represents the many considerations needed when defining a program to validate integrity of the materials during the life of the package. Those considerations are further explained in Table 1.

Figure 2. Schematic of general life extension program considerations for a shipping/storage package life extension program

Table 1. Description of life extension program considerations for a shipping/storage package life extension program

Program Considerations	**Description**
Design & Fabrication	Design and fabrication of packages need to consider the materials of construction relative to its application
Baseline Materials Analysis	An understanding of the baseline materials properties is imperative to know whether behavior in service is normal or related to degradation
Aging Studies	Perform materials aging at bounding conditions for package
Degradation Evaluation	Evaluate materials performance throughout aging tests and determination of "end of life" materials properties
Operational Controls	Implement operational controls to ensure materials integrity is maintained
In-Service Inspection – Service History	Inspect selected packages during service and understand the history of the packages

Integrity Analysis	Ensure materials perform as expected to validate integrity of package
Life Prediction	Use aging study data to predict useful life of materials in packages

As part of the 9975 Storage Surveillance Program the O-rings, fiberboard, and lead shielding body were recognized early on as age-sensitive materials in the shipping package. The performance of these materials to specified minimum levels were credited by the KAC facility to ensure a zero release scenario for the 3013 containers. The predominant facility credit is:

- Lead shielding body – gamma shielding;
- Fiberboard - impact resistance, fire resistance, spacing (criticality control) and;
- O-rings – containment of the contents.

The containment O-rings are based on Viton® GLT (now GLT-S) and the fiberboard is Celotex® (Grade 1, Type IV, ASTM specification C-208-95, cane or softwood, 14 to 16 pound pcf). The O-rings and fiberboard overpack have been studied for lifetime evaluation in KAC storage conditions [8]. O-rings have been subjected to accelerated thermal and radiation aging and evaluated for changes in compression stress-relaxation, compression set, and leakage behavior [9]. Fiberboard was evaluated for changes in dimensions, thermal conductivity, specific heat capacity, and mechanical strength [10]. The lead shield was also inspected and evaluated for thickness changes and slumping within the package [11-12]. Based on all the information from the 9975 Storage Surveillance program, the current approved storage duration for the 9975 shipping/storage package in KAC is 15 years [13], Table 2. It is anticipated that the packages may remain in service as long as the surveillance program shows that the drums are capable of performing their design function.

Aging data obtained from the 9975 Storage Surveillance Program were leveraged to accept the 9977 shipping package as a storage package in the KAC facility. The O-rings are the same material but there are other materials of construction in the 9977 that are being evaluated for extended storage [14]. The current approved storage duration for the 9977 shipping/storage package in KAC is 5 years [13], Table 2.

Table 2. Examples of Storage Life Extensions

Type	Description	Time	Status	Supporting Information
9975	Storage in KAC	15 Years	Approved	WSRC-SA-2002-00005, Rev. 9, K-Area Complex Documented Safety Analysis
9977	Storage in KAC	5 Years	Approved	WSRC-SA-2002-00005, Rev. 9, K-Area Complex Documented Safety Analysis, working towards 15 years.

Aging data obtained from the 9975 Storage Surveillance Program has also been leveraged to extend shipping packages life cycle for transportation purposes, saving time and money (50-80%

reduction in re-certification costs), and decreasing waste. Additionally, extending the life cycle of the shipping packages improves the flexibility with shipping schedules, avoiding untimely delays due to overly conservative maintenance requirements. Benefits to both the storage and shipping package programs can all be implemented and accomplished without compromising the safety of the environment, the public and workers from the stored and/or shipped nuclear materials. Table 3 outlines those packages that have used 9975 aging data for extension of the certification period for transportation.

It is also recognized that many shipping packages are not needed for use as a storage package. However, by identifying those attributes of a testing program that are required to ensure the integrity of a package is maintained throughout the transportation period, a reasonable testing program can be implemented to obtain technically defensible data which supports certification extension for transportation of shipping packages. Or, a package which may be loaded but unshipped for a period longer than expected would have a basis for an evaluation for shipment outside of its authorization basis. Materials testing for the H1616 shipping package are underway in order to extend the maintenance cycle (Table 3).

Table 3. Examples of Transportation Package Life Extensions

Type	**Description**	**Time**	**Status**	**Supporting Information**
General	ARG-US RFID	TBD	In Review	RFID would establish upper seal temp of 200°F for extending package lifetime
9977	Maintenance Extension	2 years	DOE-EM Certified	SARP Addendum 1, S-SARA-G-00003 Rev. 2, DOE-EM Certified
9977	Maintenance Extension	5 years	DOE-EM Certified	SARP Addendum 4, S-SARA-G-00010 Rev. 5, DOE-EM Certified
9978	Maintenance Extension	5 years	Not DOE-EM Certified	SARP Addendum 1, S-SARA-G-00011 Rev. 4, DOE-EM Certified
H1700	Maintenance Extension	2 years	NNSA Certified	S-SARP-G-00005 Rev. 0
H1616	Maintenance Extension	2-5 years	Not NNSA Certified	Testing in progress

The aging management programs (AMP), regardless of the system/program being supported, are very similar. The purpose of the AMP is to ensure that material degradation does not result in a loss of the intended functions of the SSCs over the term of the anticipated life of the system being reviewed. The elements of a site specific AMP may vary, depending on the specific system. However, the review of the AMP should consider the following elements in determining the adequacy and applicability of the proposed method for managing an aging effect:

1. ***Scope of the program*** - The scope of the program should include the specific structures and components anticipated to be subject to degradation and require an aging

management review. The scope of the AMP may be for a specific SSC or a group of SSCs. If one AMP is selected to manage a group of SSCs, then the AMP must consider the potential variations in materials of construction, design, installation, operating environments, and aging effects within that group.

2. ***Preventive actions*** - Preventive actions should mitigate or at least minimize the adverse impacts of the applicable aging effects and/or repair the age-induced deterioration of the relevant SSC.
3. ***Parameters monitored or inspected*** - Parameters monitored or inspected should be linked to the anticipated effects of aging on the intended functions of the particular structure and component. This AMP element must describe what is being monitored or inspected. These descriptions include the observable parameters or indicators to be monitored or inspected for each aging effect managed. The observable parameters must be linked to the degradation of the material and/or the intended functions of the SSCs during the renewal period.
4. ***Detection of aging effects*** - Detection of aging effects should occur before there is a significant loss of any component function. The inspection method or technique (i.e., visual, volumetric, surface inspection) used, the inspection frequency, sample size, data collection method and timing of inspections, including new/one-time evaluations, must ensure timely detection of aging effects.
5. ***Monitoring and trending*** - Monitoring and trending activities should provide the information required for prediction of the extent of aging and allow for timely corrective or mitigative actions.

The development and application of any AMP should be a cooperative effort and should involve technical, managerial and support personal as well as experts in the materials degradation and inspection arenas. Inspection criteria must be developed before the inspection processes are initiated to avoid the tendency to accept the inspection results as qualifying the material/component for continued service.

CONCLUSIONS

An approach to extending the life cycle of shipping packages and other containment systems for nuclear materials has been presented and may be beneficial for reducing costs, decreasing waste, and increasing the flexibility in use of various nuclear materials packages. The application of this approach to the KAC and the similarities between the life extension approaches for shipping packages and dry storage casks show that leveraging of aging management programs by cooperative efforts among diverse programs is practical.

Use of a shipping package to store nuclear materials in an interim storage location has become attractive for a variety of reasons. Shipping packages are robust and have a qualified pedigree for their performance in normal operation and accident conditions within the approved shipment period and storing nuclear material within these packages results in reduced operations and cost for the storage facility. The 9975 and 9977 shipping packages have been approved for extended storage life in the KAC facility. Data obtained from testing shipping package materials has also been leveraged to support extending the service life of select shipping packages (9977, 9978, and H1700) while in nuclear materials transportation. Additionally, a test program has been implemented to extend the service life of the H1616 shipping package in transportation.

ACKNOWLEDGEMENTS

The authors would like to thank Dr. R. McIntyre Louthan, Jr. for his insightful guidance and advice on this scope of work.

REFERENCES

[1] Generic Aging Lessons Learned (GALL) Report — Final Report (NUREG-1801, Revision 2, December 2010). http://www.nrc.gov/reading-rm/doccollections/nuregs/staff/sr1801/r2/index.html.

[2] NWTRB 2010. Evaluation of the Technical Basis for Extended Dry Storage and Transportation of Used Nuclear Fuel. U.S. Nuclear Waste Technical Review Board, Arlington, Virginia, December 2010.

[3] NUREG/CR-7116, SRNL-STI-2011-00005, Materials Aging Issues and Aging Management for Extended Storage and Transportation of Spent Nuclear Fuel, U.S. Nuclear Regulatory Commission – Office of Nuclear Materials Safety and Safeguards, November 2011.

[4] USED FUEL DISPOSITION CAMPAIGN, Gap Analysis to Support Extended Storage of Used Nuclear Fuel, Rev. 0, Brady Hanson (PNNL), Halim Alsaed (INL), Christine Stockman (SNL), David Enos (SNL), Ryan Meyer (PNNL), Ken Sorenson (SNL), January 31, 2012, FCRD-USED-2011-000136, Rev. 0, PNNL-20509.

[5] Identification and Prioritization of the Technical Information Needs Affecting Potential Regulation of Extended Storage and Transportation of Spent Nuclear Fuel, U.S. NRC, Draft May 2012.

[6] Journal of Nuclear Materials Management, Volume XXXVIII, Number 2, Winter 2010

[7] Journal of Nuclear Materials Management, Volume XXXVIII, Number 3, Spring 2010

[8] Hoffman, E.N., Skidmore, T.E., Daugherty, W.L., Dunn, K.A., "Long-term Aging and Surveillance of 9975 Package Components", *Journal of Nuclear Materials Management*, Winter 2010, Volume XXXVIII, No. 2.

[9] Hoffman, E.N., Skidmore, T.E., Daugherty, W.L., "Long-Term Leak Tightness of O-Ring Seals in the 9975 Shipping Package", *Proceedings of the ASME 2010 Pressure Vessels & Piping Division / K-PVP Conference, PVP 2010,* July 2010.

[10] Daugherty, W.L., Harris, S.P., "Aging Model for Cane Fiberboard Overpack in the 9975 Shipping Package", *Proceedings of the ASME 2010 Pressure Vessels & Piping Division / K-PVP Conference, PVP 2010,* July 2010.

[11] Subramanian, K.H., Dunn, K.A., Murphy, J.L., "Corrosion of Lead Shielding in Nuclear Materials Packages", *Packaging, Transport, Storage and Security of Radioactive Material,* Vol. 19, No. 3, pp.165-172, 2008.

[12] Daugherty, W.L., "Destructive Examination of Shipping Package 9975-03431", SRNL-STI-2012-00257, May 2012.

[13] "K-Area Complex Documented Safety Analysis", WSRC-SA-2002-00005, Rev. 9.

[14] Olson, L.C., "9977 Materials Literature Survey: Useful Lifetimes, Degradation under Various Environmental Conditions, and Property Data", SRNL-TR-2011-00206, July 2011.