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Technical Basis Update for Design Life Extension of the SAVY-4000 Series Containers

Timothy A. Stone, Kirk P. Reeves, Tristan Karns, Paul H. Smith, Douglas K. Veirs
Los Alamos National Laboratory, Los Alamos, NM 87545

Abstract

The DOE Manual, M441.1-1, Nuclear Material Packaging, provides detailed packaging requirements for protecting workers from exposure to nuclear materials stored outside of an approved engineered contamination barrier. The SAVY-4000 Series (Figure 1) nuclear material packaging system is a DOE Manual 441.1-1 compliant storage system used at Los Alamos National Laboratory and across the DOE complex as the primary storage system for plutonium-containing materials not in 3013 containers. The SAVY-4000 Series containers have a design life of five (5) years that was established in the SAVY-4000 Series Safety Analysis Report (SAR) [1] with clearly defined content limitations. The SAR specifically states that the design life can be extended based on laboratory studies and results from the surveillance program. This report summarizes the technical work from laboratory studies and the Surveillance program relating to the design life of the SAVY Series containers. After review of the information, we recommend to extend the design life of the O-rings, filters and aluminum locking ring to forty (40) years and the stainless steel components to fifteen (15) years. Although evaluation of general and pitting corrosion suggest that a forty year design life for the stainless steel components is justifiable, accelerated corrosion studies suggest that stress corrosion cracking could be a concern, and must be more fully understood. The conservative recommendation of a design life of 15 years for the stainless steel components will allow the accelerated corrosion studies to be completed and the collection and analysis of additional surveillance data. The limiting life component for the container system is the stainless steel, and therefore the design life for the container is extended to fifteen (15) years. This design life extension will apply to all containers at LANL and across the DOE complex either awaiting packaging or currently in-service and packaged in compliance with the approved SAR. To apply the longer design life, the DOE Local Area Office DOE Field Element Manager's approval is required according to M441.1-1.

Figure 1. The SAVY-4000 Series Containers.

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Los Alamos National Laboratory

DOE Approval for Initial Five Year Design Life and Approach to Extend the Design Life

In November 2013, the SAVY-4000 Series Safety Analysis Report [1] was submitted to DOE NA-LA for approval. The review was performed by the DOE Office of Packaging and Transportation (NA-531), and a Safety Evaluation Report [2] was transmitted to NA-LA on April 9, 2014 [3]. To quote from the Safety Evaluation Report: "The review panel recommends the Los Alamos Field Office approve the SAVY 4000 SAR as the safety basis for the storage of solid nuclear materials in accordance with DOE M 441.1-1 for a period of five years from the date of this SER. After completion of extensive accelerated aging studies of the O-ring and non-destructive and destructive evaluations of the O-ring, filter, and other container components as described in the SAVY 4000 Surveillance Program, LANL may request an extension of the SAVY 4000 design life." On April 16, 2014, DOE-NA-LA transmitted the "SAVY 4000 Safety Analysis Report Approval" to Los Alamos [4].

On June 11-15, 2018, a DOE NA-LA Contractor Assessment was performed on LANL's DOE M441.1-1 surveillance and documentation programs [5]. On July 26, 2018, DOE NA-LA transmitted a letter to Los Alamos with the subject "Approval of Nuclear Material Storage Package Surveillances and Process for Documentation" [6]. This letter reaffirmed the existing technical basis, approved the surveillance program and the system for documentation, and requested an update to the technical basis based on surveillance results collected to date. The letter stated:

> "Overall, the assessment team observed excellent performance including three noteworthy practices. Compliance was observed in all areas reviewed, there were no findings or weaknesses identified during the assessment. A few opportunities for the assessment team and the Contractor to continue to work and improve in this area were observed and documented in the report. Based on these results, NA-LA is hereby approving the nuclear material surveillance program and process for documentation. Additionally, NA-LA is reaffirming prior approvals of the technical basis for the SAVY Series and Fuel Storage Outer Containers. Please update the technical basis for the SAVY Series container design based on surveillance results collected for the past few years, and submit to NA-LA for review and approval."

This design life report is an update to the technical basis for the SAVY Series containers, and it will be submitted by LANL to NA-LA for review and approval.

Technical Basis for Design Life Extension Beyond Five Years

Surveillance Program Results

A Surveillance Program is in place to assess how the containers are aging in-service. A Surveillance Plan has been written that details the actions required to carry out the Surveillance Program[7]. The Surveillance Plan is modified as necessary to ensure that any issues identified during surveillance or laboratory studies are examined in future surveillances, and that any lifetime implications are taken into account. Under the Surveillance Plan, overall container integrity is evaluated (visual inspections and photographs), and helium leakage rate, O-ring durometer and compression set, and filter performance are measured. The containers for surveillance are chosen annually based on the previous surveillance program results and observations. The surveillance plan targets items believed to provide the greatest challenge to the SAVY-4000 container integrity.

The surveillance activities to date are documented in two surveillance reports [8] [9]. The latest Surveillance Plan [7] contains a trending analysis (Section 2.2) of the measurements performed during surveillance testing over the past four years (helium leak, O-ring durometer and compression set, and filter performance). Trending analysis of filter performance and O-ring properties showed essentially no change in their performance and properties over the past five-year surveillance period for both Hagan and SAVY O-rings and filters. In addition, no durability issues for the SAVY-4000 O-rings have been identified in surveillance, which is consistent with the results of the durability study[10]. Corrosion of the stainless steel components of both SAVY-4000 and Hagan containers was observed during the surveillance period. The possibility that corrosion might limit the design life was not anticipated when the SAR was written, so a number of corrosion studies have been performed and are summarized in *Evaluation of Corrosion Effects* below.

Accelerated Aging Evaluation of Polymer Components
The 3-year accelerated aging study of the SAVY-4000 O-ring is detailed in [11]. This study culminated at the end of FY16 and showed that changes in O-ring samples subjected to aggressive elevated temperature and radiation conditions could be used to estimate a lifetime under storage conditions. Whole container thermal aging studies followed by helium leakage testing and compression set measurements were used to establish a conservative failure criterion estimate for O-ring compression set of ≥65%. The conclusion from the accelerated aging study was that it would take a minimum of 65 years to attain 65% compression for containers exposed to worst-case storage conditions (Figure 2).

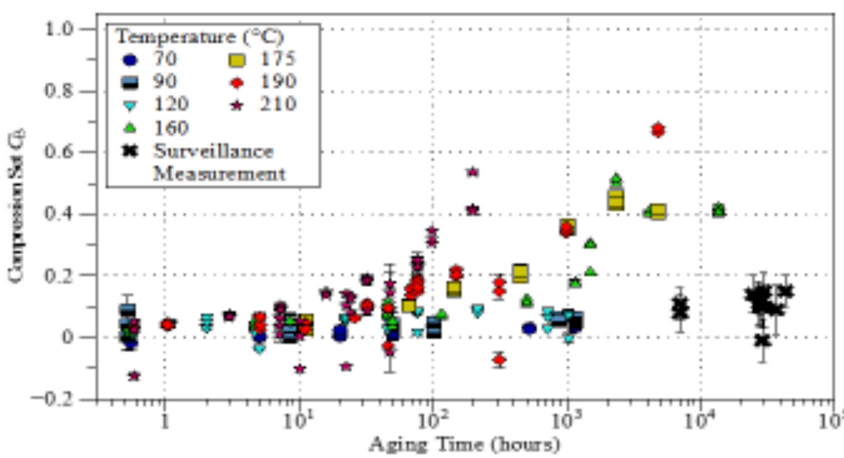
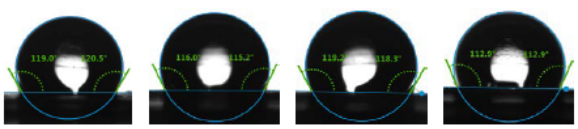


Figure 2. Time-temperature superposition data from accelerated aging study for O-ring suggests >65 years to attain 65% compression set.

Therefore, a conservative lifetime estimate of 40 years for the O-ring was suggested. Additional work in FY17, detailed in [12] further refined the FY16 result and reaffirmed that an O-ring lifetime of at least 40 years is justified even taking into account the synergistic effect of both temperature and radiation. This report also evaluated the same synergistic effect for the filter and suggested that a filter lifetime of 40 years is also justified. The report also stated that the conservative O-ring and filter lifetimes suggested by the report could be extended beyond 40 years if supported by future surveillance results. Furthermore, a gamma radiation study of the SAVY PTFE membrane showed minimal degradation of chemical form and hydrophobic behavior over the expected 40 year dose[13] (Figures 3).

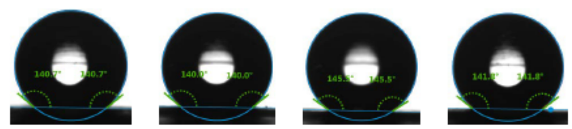
- Polyethylene (PE) – Inner Side
  - Contact Angle
    - Slight Hydrophobicity Loss at Higher Doses



Sample Exposure Details

Modeled Exposure Time	Average Contact Angle (Degrees)
Pristine	120
1 Mrad	116
2 Mrad	118
5 Mrad	112

- Teflon (PTFE) – "Waterproof" Outer Side
  - Contact Angle
    - Mostly Maintains Hydrophobicity



Sample Exposure Details

Modeled Exposure Time	Average Contact Angle (Degrees)
Pristine	140
1 Mrad	142
2 Mrad	146
5 Mrad	140

Figure 3. Contact angle measurements of the polyethylene (PE) and polytetrafluoroethylene (PTFE) sides of the water-resistant membrane show minimal degradation in hydrophobicity at 5 Mrad gamma dose.

Recommendation on O-ring and Filter Design Life

We recommend that the design life of the O-ring and filter be extended to 40 years based on the observation of no change in O-ring and filter performance or properties during service for containers exposed to worst-case conditions, and based on the results of accelerated aging studies. As the lifetime of 40 years is approached in 2054, the design life of these components can be re-assessed, if necessary, using surveillance observations.

Evaluation of Corrosion Effects on Metal Components

Corrosion has been observed in both Hagan and SAVY containers. Chlorine containing gases (HCl and Cl_2) have been identified as the principal cause. The source of the chlorine containing gases is mainly the thermal degradation of the PVC bagout bags and to a lesser extent radiolysis of chloride salts and PVC material. Stainless steel components are subject to three primary corrosion mechanisms when exposed to chlorine; general corrosion, pitting corrosion and stress corrosion cracking (SCC). General corrosion and pitting of the walls of the Hagan container and general corrosion of the walls of the SAVY container have been observed in surveillance as described in [8] [9] and [14]. A 100-year life for the worst observed case of general corrosion in a SAVY container is calculated based on the fact that <1% of the container wall was affected over ~1 year of moist HCl gas, an environmental condition that is more corrosive than storage containers are exposed to. (Note: the container exposed to moist HCl gas was from a special population of containers that must be unloaded within one year.) With respect to pitting corrosion, a conservative lifetime estimate (linear extrapolation of the deepest pit depth to the wall thickness) for the Hagan container wall is >100 years based on the maximum pit depth observed in a Hagan container wall (40 microns deep after 8 years in storage, wall thickness minimum 508 microns and the penetration rate of 5 microns/year, Figure 4). The SAVY container containment barrier is made of 316L SS, which is more resistant to chloride corrosion than 304L SS, the material used in Hagan containers. The SAVY container SS components are expected to have a lifetime greater than 100 years for general and pitting corrosion.

Figure 4. Photographs and photomicrographs of corrosion in a Hagan container (304L SS) resulting from a high americium salt residue packaged in a PVC bag.

Stress corrosion cracking has not been observed in surveillance to date. However, lab studies have shown that stresses are high enough to cause SCC. It is difficult to define a lifetime for SCC from laboratory tests. The lifetime justification with respect to SSC for the SAVY is based on (1) the fact that tensile and hoop stress analyses show the Hagan's have higher stresses and therefore are more likely to have SCC than SAVY containers, (2) boiling $MgCl_2$ experiments show that the Hagan containers are more susceptible to SCC than SAVY containers, (3) literature shows that gas phase corrosion rates are higher for 304L stainless steel than 316L stainless steel under the conditions encountered during storage, and (4) SSC has not been observed visually in SAVY containers in use for over 5 years or in Hagan containers that have been in use for up to 17 years after exposure to worst-case conditions with respect to SCC (high heat load, chlorine containing gases, high radiation, etc.). Although visual inspection to date would only catch major cracks, the inspection procedures in the future will include more rigorous inspection for cracks, e.g. dye penetrant, microscopic examination, etc. In addition, a SAVY-4000 container exposed to moist HCl gas for ~1 year passed helium leakage tests after four sequential drops at the maximum allowed storage height and weight conditions. A conservative design life with respect to SCC of 15 years is justified for SAVY containers, which is 2 years less than the oldest Hagan surveilled. It is noted that the aluminum locking ring of the SAVY container, which is not part of the containment barrier, showed no signs of degradation during surveillance.

Recommendation on Metal Components

We recommend that the design life of the stainless steel components be extended to 15 years based on the observation of no SSC in Hagan containers exposed to worst-case conditions. As the lifetime of 15 years is approached in 2029, the design life of these components can be re-assessed, if necessary, using surveillance observations. We also recommend that the design life for the aluminum locking ring be extended to 40 years, and that it may be extended further based on surveillance observations.

Manufacturing Defects

A recent issue identified with the round stainless steel bar stock used to manufacture the SAVY lids could also have lifetime implications for a small subset of containers (Figure 5) [15]. This issue was identified during the helium leakage rate acceptance testing at the manufacturer. A design change has been implemented to address this issue in future containers, and the surveillance plan will be modified to assess this issue for the small subset of containers in the existing population.

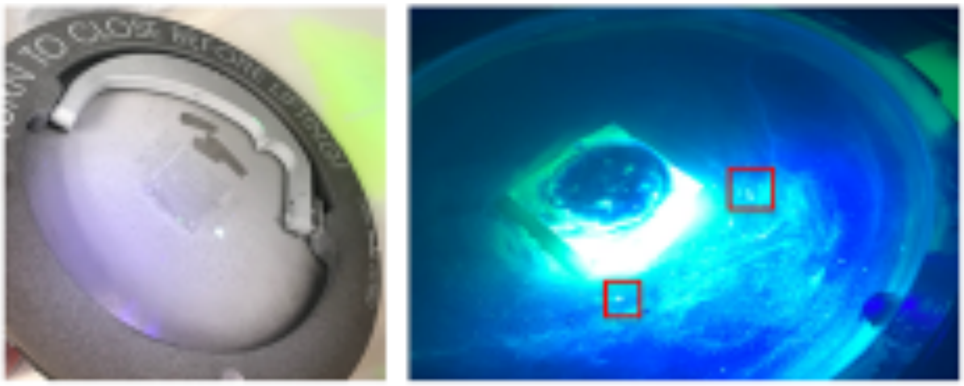


Figure 5. Dye penetration tests showing through-wall penetration of fluorescent dye in a 12 Quart SAVY-4000 lid.

Future Surveillance Program

The surveillance program is evaluated annually and modified as necessary to adjust to observations and conclusions from annual surveillance reports and accelerated aging studies. However, at this five-year mark, it is appropriate to take a slightly broader view of the future surveillance program. First, even though some components can be extended to 40 years based on results to date, surveillance data will continue to be collected and analyzed on all SAVY-4000 components moving forward. The surveillance containers thus far have been chosen entirely by engineering judgement, and although corrosion of the stainless steel components was not anticipated in the original justification for a five-year design life, we have confidence based on earlier surveillance data in our ability to select such containers (high heat load, high gamma dose, small diameter containers, longer storage times). Second, surveillance of both SAVY and Hagan containers will continue. The lifetime extension for the SAVY-4000 currently hinges largely on data collected on Hagan containers and following their behavior with time will further elucidate potential degradation mechanisms for the SAVY container. Consideration will be given to purposely keeping some Hagan containers with corrosion challenging contents in storage as long as may be reasonable so that they may act as “canaries in the coal mine”. Third, consideration will be given to changing the number of annual surveillance containers in order to ensure sufficient older containers are available. Fourth, water penetration testing for the SAVY filter membrane will continue, and the actual radiation dose near the filter will be measured for future surveillance containers. Finally, items-of-opportunity will continue to be an important element of the program.

Conclusion

Surveillance and accelerated aging studies to date indicate that the design life for the SAVY-4000 series can be extended beyond the initial 5 years. Accelerated aging studies on the polymer components (O-ring and filter) indicate that 40 years is conservative for conditions that are bounding with respect to temperature, radiation and the combination of temperature and radiation. No change in these components has been seen in surveillance to date. We recommend a design life of 40 years for these components. Observations of general corrosion and corrosion pitting of the stainless steel components in containers exposed to worst-case conditions suggest that the rate of corrosion would not lead to through-wall penetration within a 40-year period. However, accelerated corrosion studies suggest that stress corrosion cracking could be a concern, and must be more fully understood. Therefore, we recommend conservatively a design life of 15 years for the stainless steel components to allow the accelerated corrosion studies to be completed and to collect additional surveillance data. The lifetime of the stainless steel components should be reevaluated in 10 years (or earlier if surveillance observations warrant). Upon approval, the design life of the O-rings, filters and aluminum locking rings is extended to forty (40) years and the stainless steel components to fifteen (15) years. The limiting life component for the container system is the stainless steel, and therefore the design life for the container is extended to fifteen (15) years. The 15 year design life accounts for the use of PVC bags in the containers. We are currently evaluating the use of plastics without chlorine (polyurethane and polyethylene) for bagout bags which would largely eliminate this primary cause of corrosion. Progress in this area will be detailed in our surveillance reports. This design life extension will apply to all containers at LANL and across the DOE complex, either awaiting packaging or currently in-service and packaged in compliance with the SAR. To apply the longer design life, the DOE Local Area Office DOE Field Element Manager's approval is required according to M441.1-1. On June 11, 2019 the Los Alamos Field Office approved the 15-year design life request for the SAVY-4000 Series Containers.

References

1. Smith, P.H., et al., *Safety Analysis Report for the SAVY 4000 Container Series (LA-CP-13-01502)*, in *DOE/NNSA Review*, 2013, Los Alamos National Laboratory.
2. Nez, D.J., *Safety Evaluation Report for the SAVY 4000 Series of Storage Containers, Revision 0*. 2014, US Department of Energy, National Nuclear Security Administration, Office of Packaging and Transportation.
3. Al Daouk, A.M., *Memorandum for Kim Davis Lebak, Manager*. 2014, US Department of Energy, National Nuclear Security Administration, Office of Packaging and Transportation.
4. Rael, G.J., *SAVY 4000 Safety Analysis Report Approval (4771 NSM:8MH-571107)*. 2014, US Department of Energy, National Nuclear Security Administration, Los Alamos Field Office.
5. Sipes, R.R., *Evaluation of Surveillance and Documentation for the Material Recycle and Recovery, and Storage Programs (ASM-NSM-l .14.2017-766453)*, 2018, US Department of Energy, National Nuclear Security Administration, Los Alamos Field Office.
6. Jung, J.G., William S., *Approval of Nuclear Material Storage Package Surveillances and Process for Documentation (U1800960)*. 2018, US Department of Energy, National Nuclear Security Administration, Los Alamos Field Office.
7. Kelly, E.J., et al., *Los Alamos National Laboratory SAVY-4000 Field Surveillance Plan Update for 2018 (LA-UR-18-24442)*, 2018, Los Alamos National Laboratory. p. 26 p.
8. Reeves, K.P., et al., *Surveillance Report on SAVY-4000 and Hagan Nuclear Material Storage Containers for FY 2017 (LA-UR-17-31263)*, 2017, Los Alamos National Laboratory.
9. Reeves, K.P.W., Eric; Blair, Michael W.; Moore, Murray E.;, et al., *LANL Storage Container Surveillance Report (LA-UR-16-27427)*, 2016, Los Alamos National Laboratory.
10. Weis, E., et al., *Durability and Field Condition Study of the Seal of the SAVY-4000 Storage Container (LA-UR-14-20077)*, 2014, Los Alamos National Laboratory. p. 17 p.

11. Weis, E., et al., *Lifetime Extension Report: Progress on the SAVY-4000 Lifetime Extension Program (LA-UR-16-27168)*, 2016, Los Alamos National Laboratory. p. 26 p.
12. Welch, C.F.W., Eric; Smith, Paul Herrick; Stone, Timothy, et al., *SAVY-4000 O-Ring and Filter Lifetime Extension Report (LA-UR-17-29435)*, 2018, Los Alamos National Laboratory.
13. Labouriau, A., et al., *PVC and PTFE Degradation and Replacement Options for Storage Containers (LA-UR-17-20593),* 2017.
14. Reeves, K.P.K., Tristan; Stone, Timothy Amos; Narlesky,, et al., *Evaluating Corrosion Effects on the Stainless Steel Components of the SAVY-4000/Hagan Nuclear Material Storage Containers (LA-UR-18-25709)*, 2018, Los Alamos National Laboratory.
15. Smith, P.H., et al., *Los Alamos National Laboratory Lessons Learned for Fiscal Year 2018: SAVY-4000 Lid Bar Stock Issue (LA-UR-18-29195)*, 2018, Los Alamos National Laboratory.