Proceedings of the 18th International Symposium on the Packaging and Transportation of Radioactive Materials
PATRAM 2016
September 18-23, 2016, Kobe, Japan

Paper No. 6026

SAVY- 4000® Meeting the Challenge for Worker Safety

LA-UR-16-26679

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Abstract

Incidents involving release of nuclear materials stored in containers of convenience such as food pack cans, slip lid taped cans, paint cans, etc. has resulted in the U.S. Defense Nuclear Safety Board concerns over the lack of prescriptive performance requirements for interim storage of nuclear materials. Los Alamos National Laboratory (LANL) has shared in these incidents and in response proactively moved into developing a performance based storage container design, the SAVY-4000®. The SAVY-4000® is the first vented general use nuclear material container demonstrated to meet the requirements of DOE M 441.1-1, Nuclear Material Packaging Manual. The SAVY-4000® is an innovative and creative design demonstrated by the fact that it can be opened and closed in a few seconds without torque wrenches or other tools; has a built-in, fire-rated filter that prevents the build-up of hydrogen gas, yet retains 99.97% of plutonium particulates, and prevents release of material even in a 12 foot drop. Finally, it has been fire then drop tested and will reduce the risk to the public in the event of an earthquake/fire scenario. This will allow major nuclear facilities to credit the container towards source term Material at Risk (MAR) reduction. The container was approved

for nuclear material storage in the TA-55 Plutonium Facility on March 15, 2011, and there are currently over 2000 SAVY-4000® containers available for use within the facility. A Safety Analysis Report was developed to demonstrate Manual 441.1-1 compliance and was approved April, 2014. The first four SAVY-4000® containers were packaged with plutonium on August 2, 2011. Key aspects of the SAVY-4000® vented storage container design will be discussed which include design description, qualification and testing, surveillance strategy, and the design life extension program as enhanced by surveillance activities with the intent to extend well beyond the current five year design life.

Introduction

The Department of Energy (DOE) issued DOE M 441.1-1, *Nuclear Material Packaging Manual*, in March 2008 to protect workers who handle nuclear material from exposure due to loss of containment of stored materials. The Manual specifies a detailed approach to achieve high confidence in containers and includes requirements for container design and performance, design-life determinations, material contents, and surveillance and maintenance to ensure container integrity over time. The materials considered within the scope of the Manual include actinides stored outside an approved engineered-contamination barrier that could result in a worker exposure of greater than 5-rem Committed Effective Dose Equivalent (CEDE) if containment is lost.

Nuclear Filter Technology, Inc. (NucFil) and LANL developed the SAVY-4000® container as a simple, robust, and reusable container for storing solid nuclear materials. The SAVY-4000® series of containers includes eight sizes (1, 2, 3, 5, 8, 12 quart, 5 and 10 gallon) and will eventually replace the current “Hagan”-style containers of the same sizes. The design of this container includes a filter to prevent pressurization and to facilitate the release of hydrogen, thus preventing flammable gas mixtures from forming. The filter must also prevent radiological particulate release. The filter ensures that only minimal differential pressure (1 kPa for the quart-size and 2 kPa for the gallon-size containers) is possible during use. In this respect, the container is not a pressure vessel but a lightweight, worker-friendly container.

The SAVY-4000® is a general purpose, reusable container designed for the storage (inside a nuclear facility) of solid nuclear material with a permitted loading of up to 25 watts. This wattage limit applies to all containers, regardless of their size. One of the main features of the design is its simplicity relative to a typical Type B DOT-compliant shipping container. The primary reliance on the HEPA filtered nuclear facility to protect public safety in a design basis accident scenario allows the design features of the container to be specifically (but not exclusively) targeted at protecting nuclear workers from both external and internal radiation dose. The filtered design obviates the need for heavy, pressure-vessel-type construction or welded closures. Thus, the design promotes ease of use and rapid opening and closing to minimize external worker dose during handling, while providing protection from internal worker dose through aerosol particulate containment over a relatively long storage period (five years minimum). Once the container is closed, it provides a credited engineering control and allows workers to handle the containers without the need for respirator protection. It is light enough for hand-carrying, and it protects the worker if the container is accidentally dropped from as high as 3.66 m. The design also includes a nesting feature such that each container fits inside the next larger size. Figure 1 below shows a SAVY-4000® container with labels identifying each of the primary components.

Figure 1. The SAVY-4000® Series and Primary Components

The SAVY-4000® container is composed of two primary sub-assemblies: the body and the lid. The body and lid are attached to one another with a bayonet-style closure such that the lid fits tightly within a collar attached to the body. The user achieves a leak-tight seal by pushing the lid downward into the collar, resulting in radial compression of the O-ring in a “piston groove” configuration between the body collar and the lid. The lid locks into place by rotating the locking ring made of aluminum until a spring-loaded, stainless steel pin engages with a hole in the collar. No tools are required to open or close the container. The lid has a built-in filter made up of silica and alumina fibers that prevents pressurization and hydrogen build-up inside the container and prevents particulate release. The filter is protected on the outside by a polytetrafluoroethylene (PTFE) membrane that allows gases to pass but blocks water and other liquids, thereby facilitating shedding of water. The containers and lids are interchangeable within a given container size, and the assembly does not need to be checked for leaks at each closure. Four of the filter vent holes are threaded for attaching a fitting for helium leak testing an assembled container at the time of manufacture and during surveillance. An aluminum handle is attached to the lid with stainless steel pins for manual handling and lifting. Holes in the collar allow water to drain off the lid in the event of facility sprinkler activation and allow for the installation of a tamper indicating device (TID). The internal components that form the containment barrier are made of 316L stainless steel for corrosion resistance.

The SAVY-4000® series consists of eight container sizes (1, 2, 3, 5, 8, 12 quart, 5 and 10 gallon, nominal), all of which are addressed in this report. The overall primary dimensions (rounded to the nearest 0.1 cm), inner volumes (rounded to the nearest 0.01 l) and weights (rounded to the nearest 0.1 kg) of the containers can be found in Table 1. The minimum inner diameter is the minimum diameter of the locking collar through which contents must pass. A summary of the allowable material contents is given in Table 2.

Table 1 Overall Primary Dimensions and Weights for the SAVY-4000® Container Series

Size	Overall Diameter (cm)	Overall Height (cm)	Minimum Inner diameter (cm)	Usable Inner Height (cm)	Inner Volume (l)	Gross Weight (kg)	Tare Weight (kg)	Payload Max Weight (kg)[1]
1 qt	12.1	15.0	9.3	11.1	0.96	10.0	1.5	8.5
2 qt	12.1	25.4	9.3	21.5	1.78	12.2	2.0	10.2
3 qt	16.6	20.2	13.8	17.2	3.07	15.0	2.6	12.4
5 qt	19.6	25.3	16.8	22.2	5.19	18.1	3.4	14.7
8 qt	22.5	29.1	19.7	26.1	8.61	20.0	4.3	15.7
12 qt	25.4	35.4	22.6	32.4	13.50	22.2	5.4	16.8
5 gal	29.8	40.5	26.0	35.7	19.40	24.9	8.6	16.3
10 gal	39.3	45.6	35.5	40.5	40.95	39.9	11.9	28.0

[1]Note that drop testing was performed with payloads slightly in excess of the payload maximum weight shown.

Table 2. Overall Primary Dimensions and Weights for the SAVY-4000® Container Series

Content	Bounding Case
Identification and maximum quantity of radioactive material	Any actinide material with A_2 quantity in grams greater than the A_2 value of Heat Source plutonium oxide (0.0020 g) is allowed up to 25 watts or by other existing limits (container weight, criticality , external dose limit)
Maximum heat load	25 watts
Chemical form	Allowed: All materials unless specifically not allowed Allowed with restrictions: metals that can undergo expansion are required to be in hermetically sealed inner containers Not Allowed: Materials with IDC codes C02X, C19X, C39X, C40X, C61X, GXXX, KXXX, LXXX, N69X, R12X, and R59X, MXXJ, and M76X (X is generic for any number or letter).
Physical form	Allowed: Solids; Prohibited: liquids and gases
Maximum Normal Operating Pressure	Differential pressure across container boundary of 1 kPa for quart-size containers, 2 kPa for the gallon-size containers

SURVEILLANCE PROGRAM

The intent of the surveillance program is to ensure that the SAVY-4000® containers function properly throughout their design life. A field shelf-life surveillance plan coupled with a high confidence statistical sampling scheme forms the basis for the SAVY 4000 Field Surveillance Plan. The different material characteristics, including metal, oxide and residues, are expected to bound both the corrosive properties and the thermal characteristics of the materials in storage. The surveillance program has already proven to be successful by surveying the items that are more likely to exhibit characteristics of degraded performance as was the case in Figure 2. The field shelf-life surveillance consists of 24 DE / NDE containers and 20 DE only container over 5 years. This sampling schedule ensures availability of surveillance data within the initial SAVY-4000® design life of five years to support design life extension. Items-of-opportunity containers will also be evaluated to provide additional data within the overall container population. The surveillance plan sampling is described in Table 3.

Figure 2. Item caught by M441.1-1 surveilance plan showing signs of surface corrosion.

Table 3. Surveillance Sampling Plan

Sample Group	2015	2016	2017	2018	2019	Total
SAVY Field Shelf-Life, NDE-only	4 from 2014 plan	4 from 2015	6 total: 4 from 2015, + 1 BLO, + 1 HATCH/3	6	6	**26**
SAVY Field Shelf-Life, NDE/DE	6 (from 2014 plan)	9	6	6	6	**33**
SAVY I-of-O, NDE-only or NDE/DE if needed	10 (transfer containers)	10	10	10	10	**50**
SAVY EJ, NDE/DE	0	2 total: HATCH container and Transfer container	TBD[2]	TBD	TBD	**2+TBD**
Hagan EJ NDE/ DE	4 (EJ NDE/DE - Heat Load items)	3[3] (Table 3-1-b)	5 Pu-238 Residue Items (Table 3-3-b) (possibly examined after 2019)			**4+TBD**
Hagan I-of-O NDE/DE (up to 6 each year)	0	0	6	6	6	**18**
Total	**24**	**25/28**	**27 + EJs**	**28 + EJs**	**28 + EJs**	**133/136[3] + EJ TBDs**

The surveillance testing includes both non-destructive examinations (NDE) and destructive evaluations (DE), and in-service inspections of containers and O-rings are performed prior to each use. If defects are found the container is removed from service and provided to the

Surveillance Program for evaluation. If defects are found with a component such as the O-ring, the O-ring is replaced and the defective O-ring is provided to the Surveillance Program for evaluation. The goal is to have sufficient data from the surveillance and lifetime extension studies, within the 5-year design life, to gain confidence that the design criteria will be met by all components over an extended lifetime as justified based on the data. It is anticipated that LANL will perform surveillance in support of other DOE sites, which will result in significant costs savings for the DOE Complex Wide. Los Alamos conducts a gap analysis such that the material, usage (T, height, weight) are bounded by LANL SAR. No maintenance program (like a transportation container) is required for the SAVY-4000® if it is within the design lifetime, currently five years for all components, with a proposed extension of 5 additional years being submitted to DOE for review and approval. Lifetime extension efforts also apply to all components of the container, and no maintenance of in-service containers will be required during the extended lifetime

LIFETIME EXTENTION

The O-ring used in the SAVY-4000® has been identified as one of the lifetime limiting components of the design, and it is a part that is vulnerable to wear through repeated use. If scratches or other deformations were to form on the O-ring surface, it may make for a more leak-prone seal. Also, the seal can become compromised by the adherence of dust or hair to the lubricated O-ring surface. Either of these situations could lead to a leak greater than the failure criterion, 1×10^{-5} atm cm^3 s^{-1} of helium into vacuum at a differential pressure of 75 Torr, and to a release of radioactive material.

The material the O-ring is made of may deteriorate over time. The O-ring is made of a commercial, proprietary, fluoropolymer, based on Viton®, an FKM-type polymer. Under compression, at an elevated temperature, and exposed to radiation, many chemical and physical changes may take place in the O-ring over the course of years in service. In order to understand how the O-ring will age, we undertook a baseline study of the O-rings, to determine their composition and to provide an accurate description of the unaged material. This has involved infrared spectroscopy, elemental analysis, and electron paramagnetic resonance spectroscopy. As part of the thermal aging study, we have begun tests of compression set, and compression-stress relaxation at 70°C, 90°C, 120°C, 160°C, 175°C, 190°C, and 210°C for periods of time up to 1000 hours, and examined the IR spectra of some compression set samples after aging.

The current set of compression set data now includes values from 153 individual compression set determinations at seven different temperatures. As more data is collected, it is anticipated that the time-temperature superposition method can be used to predict the maximum o-ring lifetime at the expected maximum operating temperature.

PRODUCTION

As the design authority for the SAVY-4000® container, the Los Alamos container management team manages the procurement of containers for the DOE complex. This includes integrating orders from various sites to maximize production efficiency, quality assurance source examinations, quality documentation and receipt inspection. To date NFT, Inc, has manufactured ~2200 SAVY-4000® containers in all eight sizes for six DOE sites, including INL, LANL, LLNL, PNNL, SRS and NNSS. The SAVY-4000® production over the last five years is illustrated in Figure 4.

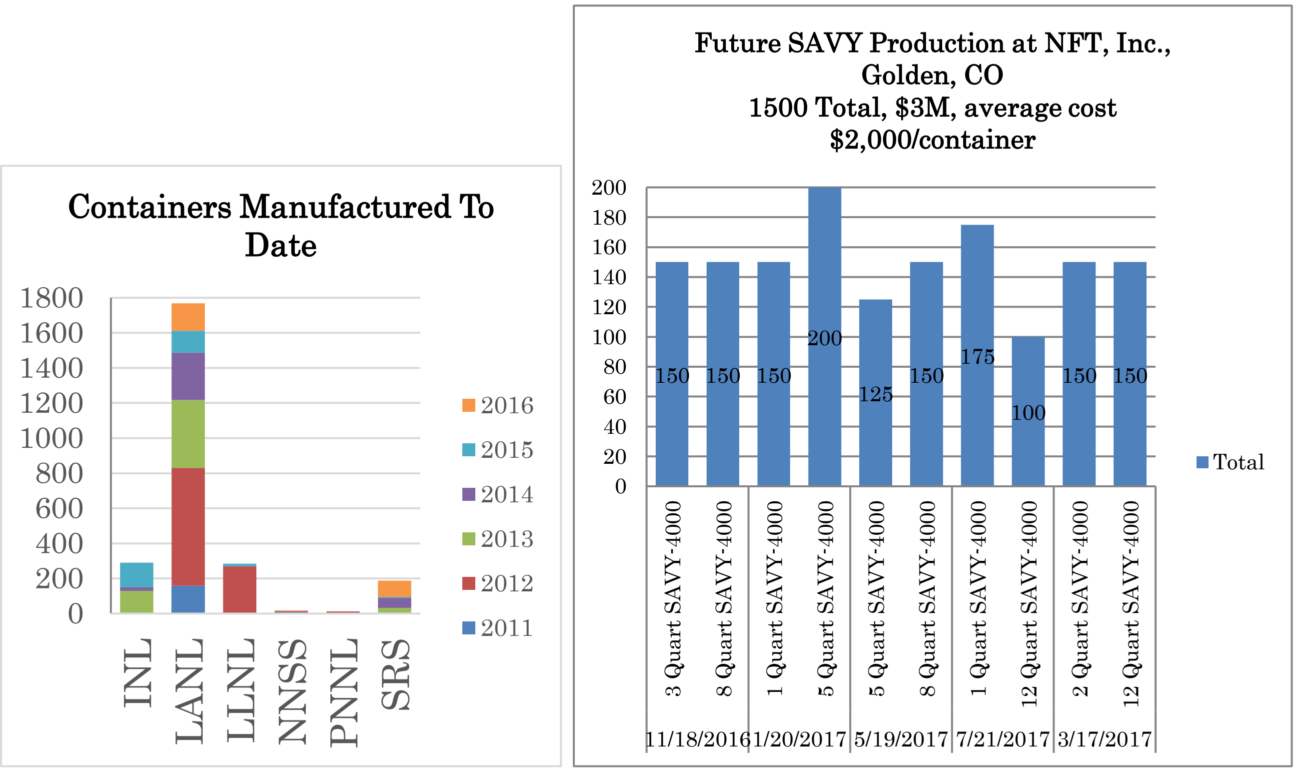

Figure 4. SAVY-4000® Production for DOE Sites (2286 Containers)

TWO QUART SAVY-4000®

The one-quart SAVY-4000®, which has passed a helium leak test after a 12 ft drop (Figure 4) has been used in the Type B shipping containers to ship material from INL to NNSS. The SAVY-4000® is used as the “convenience can”, the equivalent of a metal can with a crimped-seal closure, a slip lid closure, or site-specific convenience containers. The one-quart SAVY-4000® has been designed to fit into the inner containment vessel of both the 9975/9977 Type B containers. Because of the 12.1 cm radius of the one-quart SAVY-4000®, it is a perfect size to fit into the 12.7 cm inner diameter of the 9975/9977. Because DOT Type B containers are used to transport relatively large quantities of plutonium, the benefits of using a container that is approved for storage (thus minimizing repackaging upon receipt) are most pronounced.

The ability to ship the materials in the container that they will be stored in will significantly minimize the number of steps needed to safely handle the material, and it will make the overall job of the workers handling these materials easier and safer. An elongated version of the one-quart SAVY-4000® has been designed manufactured to meet the requirements of several different DOE customers. A longer version of the container was needed to fit items taller than the 15.2 cm height of the container. The dimensions for a 9975/9977 are 15.3x38.1 cm and 15.3x50.8 cm respectively; however, any object ever 450g must have a spacer within the container minimizing the diameter to 12.7 cm. The elongated version of the one-quart SAVY-4000® allows users to ship larger materials without the need to break apart or minimize the pieces being shipped. The two-quart container maintains the 12.1 cm diameter, but is elongated to around 20.3 cm in order to fit larger materials.

Figure 5. New 2 Qt. 12 ft. drop test and result.

AMENDMENTS TO SAFETY ANALYSIS REPORT (SAR)

By the end of FY2016 an amendment will be submitted to DOE for review and approval. The pending amendment will include the two quart design, lessons learned from surveillance activities, life extension work and revised packaging constraints. The approval process is anticipated to take up to a year to go through the authorization process.

The proposed changes to the SAR will ensure that the package remains a safe and functional storage option both at LANL facilities and at other sites that may use the SAVY-4000® for storage and transportation. By adding a two quart design to the series it will be possible to package material more efficiently into transportation packages such as the 9975/9977 and allow users more options when storing material for extended periods. Additionally, particular packaging contents have been identified through the surveillance program to exhibit environments that are conducive to the formation of surface oxidation and will be examined in the upcoming amendment.

DOT TYPE A TESTING

The SAVY-4000® must meet a series of requirements before it can be certified for use in shipping environments. In order to be qualified as an acceptable DOT Type A container, the SAVY-4000® must pass four major integrity tests {49 CFR 173.465}. The container must pass the following tests:

- Be "dropped in a matter that will cause the most damage" from a height that is deemed "worst case scenario" {4 feet for non-liquid contents}.
- "Be subjected for a period of at least 24 hours by 5 times the mass of the actual package or the equivalent of 1.9 pounds per square inch"
- Endure a penetration test where a "13.2 pound bar with a diameter of 1.3 inches and a spherical tip must be dropped from a height of 3.3 feet onto the most vulnerable part of the container."
- Water spray test must be run at the beginning of testing and after each of the tests mentioned previously. "The container must be sprayed with water that simulates rainfall of 2 inches per hour".

If the container passes each one of these tests, it may be certified and used as a DOT Type A container. The requirements for use of the SAVY-4000® container as a convenience container inside a Type B 9975/9977 container are that it must be the equivalent of a metal can with a crimped-seal closure, a slip lid closure, or site-specific convenience containers. Obviously, it must also fit inside the Type B inner container.

The SAVY-4000® container was subjected to a series of preliminary scoping tests intended to bound the accident conditions required by the DOT Type A requirements. A series of drop, penetration and a water spray test were performed. The pass/fail criteria for both material release and water penetration was a helium leak test of 1.47x10-s std cm3/s at 10kPa which corresponds to a worker dose rate of <5 Rem CEDE. Drop Testing. The SAVY-4000® was dropped from 12 feet in the orientations as described above. This is the drop height required for storage at LANL's Plutonium Facility, and it exceeds by a factor of three the drop height required by the Type A criterion for non-liquid contents. These orientations are believed to encompass the worst-case drop scenario, including the four 0.3 m free drop tests (preconditioning) required for fissile material. A single container was dropped successively in 4 different orientations, and a second container was dropped successively in the remaining orientations. For each test, the container maintained its seal and passed a helium leak test.

Finally, Los Alamos has recently contracted with Nuclear Filter Technology, Inc. to perform testing to certify the SAVY-4000® container as a DOT Type A liquid transport container.

Penetration Test. A 13.2 pound bar with a diameter of 1.3 inches and a spherical tip was dropped from a height of 4 feet onto 3 different points on the container (the filter, a point near the weld and the bottom, see Figure 6) that are expected to be the most vulnerable parts of the container. A helium leak test was performed on the container following the penetration and water spray test. The helium leak rate measured after the penetration and water spray tests was 9.1×10^{-8} atm cc/sec. The SAVY-4000® also passed a water spray test after the penetration insults, and no water was found inside the container. Figures 7-9 illustrate the results of Type A liquid testing, including vibration, stacking, bar penetration and 30 ft drop tests, respectively. Because the filter allows liquid to escape the container, PVC tape was placed over the filter port. Under these conditions, all results were passing with the exception of the bar penetration test. A cap was developed for the SAVY-4000® to prevent the escape of liquid through the filter. The cap can also be used to create a hermetically sealed container for packaging content in inert environments and ensuring that oxygen cannot contact the material packaged inside. The hermetic cap is comprised of two 316L Stainless Steel components and a Viton® o-ring. The four threaded holes located on the outside of the filter act as the anchor points for the cap and the o-ring seal encompasses the rest of the diffusion holes in the lid, shown in figure 10.

Figure 6. Damage caused by penetration bar test.

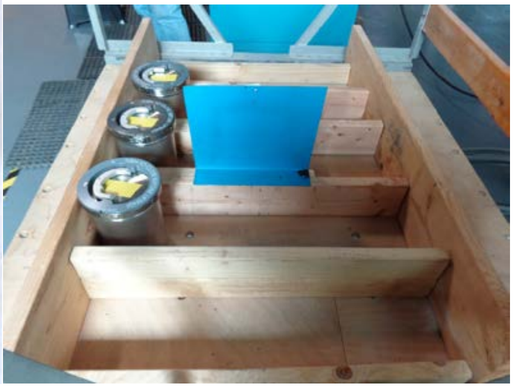

Figure 7. Pre-vibration test

Figure 8. Post vibration test

Figure 9. Results of the stacking, penetration and 30 Ft. drop tests

Figure 10. Hermetic Cap installed on a 3 Quart SAVY-4000®

CONCLUSIONS

This paper provides an overview of the Los Alamos SAVY 4000 Storage Program, various testing regimes to which the SAVY-4000® container has been subjected, and describes the resulting versatility of the container for nuclear material containment. The container meets DOE M441.1-1 requirements for storage, and thus prevents worker dose in the event of a dropped container. Accelerated aging experiments and surveillance testing is being conducted at LANL to extend the design life and to meet the Manual requirements. Los Alamos has also managed container procurement and provided quality assurance oversight of NFT, Inc., which has manufactured over 2,200 SAVY-4000® containers for use at six DOE facilities. An update to the Safety Analysis Report is planned to broaden the allowed nuclear material contents, to incorporate a new 2-Quart design, and to request an extended design life for the container series. Finally, the containers have been subjected to Type A solid and liquid testing regimes, and have been found to pass all tests with the exception of the bar penetration test with the filter port sealed with PVC tape and the -40C O-ring test.

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