Design of a Small Type B Package for the Shipment of Radioactive Gas*

A.R. York II, J.M. Freedman, M.A. Kincy, B.J. Joseph

Advanced Systems Department, Sandia National Laboratories, Albuquerque New Mexico, USA

Introduction

Sandia National Laboratories has completed the design and is now fabricating packagings for shipment of tritium gas in conformance with United States Department of Energy (US DOE) Order 5610.1.† The packaging, referred to as the AL-SX, is quite unique in that its contents are a radioactive gas, and a large margin of safety has been demonstrated through overtesting. The AL-SX is small, 42 cm (16.5 in.) in diameter and 55 cm (21.5 in.) tall, as illustrated in Figure 1, and weighs between 55 kg (121 lb) empty and up to a maximum of 60 kg (132 lb) with contents and is designed for a 20-year service life.

This paper describes the design of the AL-SX and certification testing performed on AL-SX packagings and discusses containment of tritium and AL-SX manufacturing considerations.

General Description of the AL-SX

The external structure of the AL-SX is a standard US size 16-gallon stainless steel drum. Progressing from the exterior to the interior (Figure 1), the drum contains thermal insulation, impact-limiting and fire-retarding polyurethane foam, a stainless steel protective liner, and a stainless steel containment vessel, which is the AL-SX tritium containment boundary. The thermal insulation is an alumina-silica blanket, and the polyurethane foam is closed cell with an intumescent additive. The drum lid is secured with a circular locking ring that is easily removed to gain access to the stainless steel covered top foam protector. This protector can then be removed to allow access to the containment vessel.

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† US DOE Order 5610.1 is consistent with Title 10, Part 71 of the Code of Federal Regulations (10 CFR 71) and the International Atomic Energy Agency Safety Series No. 6.

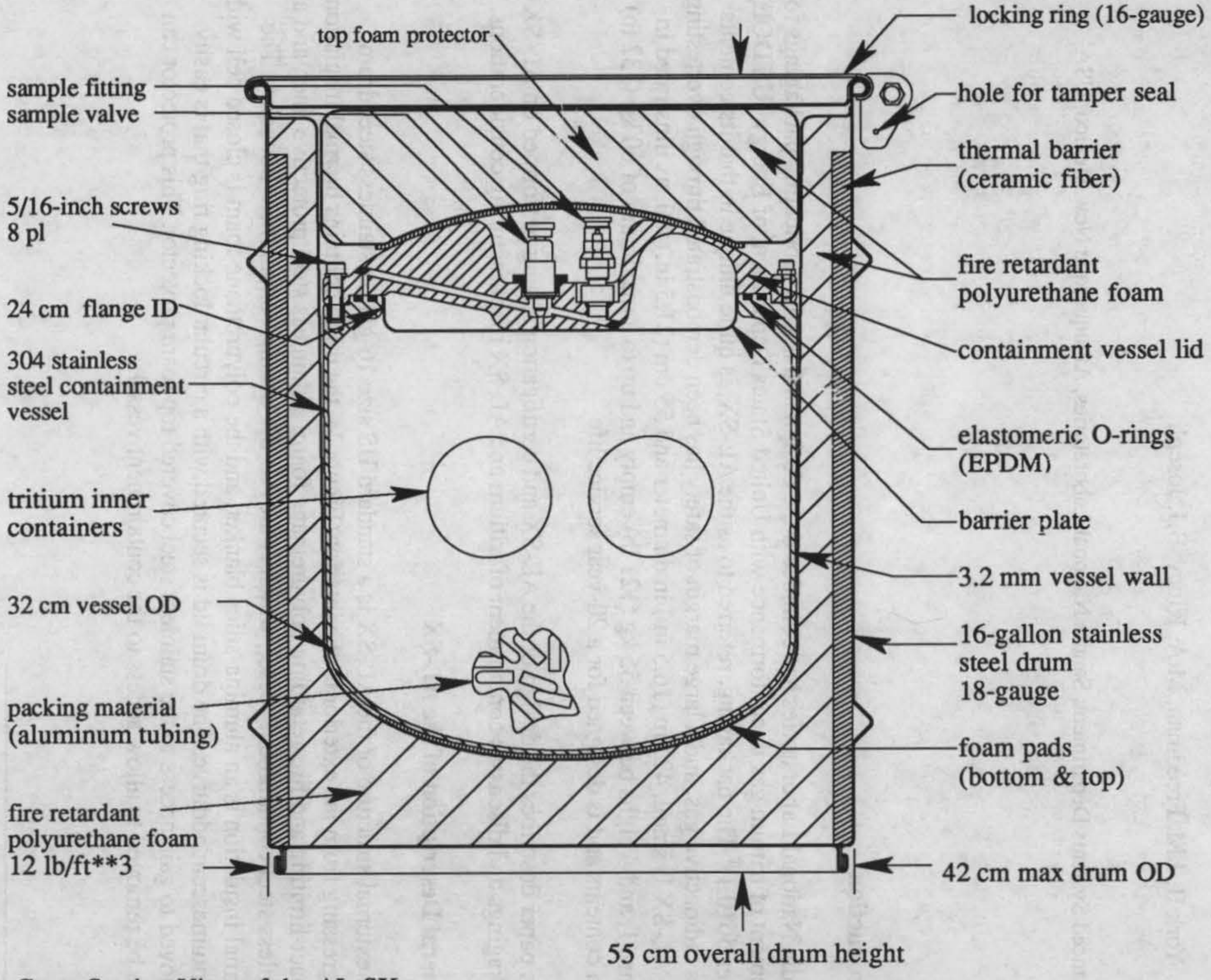

Figure 1. Cross Section View of the AL-SX

The containment vessel walls are 3.2 mm (0.125 in.) thick on both the body and lid. The lid incorporates a valve that is used to sample and backfill the interior volume of the containment vessel. The valve provides a metal seal with a hardened steel ball and has a metal bellows. Two ethylene-propylene-diene-monomer (EPDM) O-rings seal between the body and the lid.

Small thin-walled aluminum tubes (25 mm (1 in.) in length, 12.5 mm (0.5 in.) diameter) are used as packing material to fill the containment vessel. These tubes also provide a thermal path for the removal of decay heat from the tritium inner containers.

The AL-SX packaging is designed for ease of operations. Elastomeric O-rings facilitate assembly of the lid and body. Leak testing of both O-rings and the valve prior to shipment is accomplished by connecting a leak tester to a single quick-connect fitting located in the center of the lid.

Containment of Radioactive Contents

Due to tritium permeation through the EPDM O-rings, an inner container or multiple inner containers are used to comply with the 10 CFR 71 maximum allowed normal condition leak rate of 10^{-6} A_2 per hour or 1×10^{-7} std cc/s of tritium. This inner container must contain tritium for normal conditions of transport and must be leaktight when exposed to vibration and shock normally incident to transport and to normal thermal environments.

Under accident conditions the maximum allowable release rate of tritium is one A_2 per week. The EPDM O-rings will contain tritium under accident conditions so that containment of tritium by the inner container is not required.

Experiments were performed with EPDM O-rings and tritium (Swansiger 1991 and Roth 1992) to determine permeation rates through the O-rings. A functional relationship between permeation rate and temperature was established as illustrated in Figure 2. The tritium permeation rate is obtained by multiplying the permeation coefficient (ordinate of Figure 2) by the tritium pressure differential across the O-ring. Since the outer O-ring has a larger circumference, the permeation coefficient is slightly larger as illustrated in Figure 2.

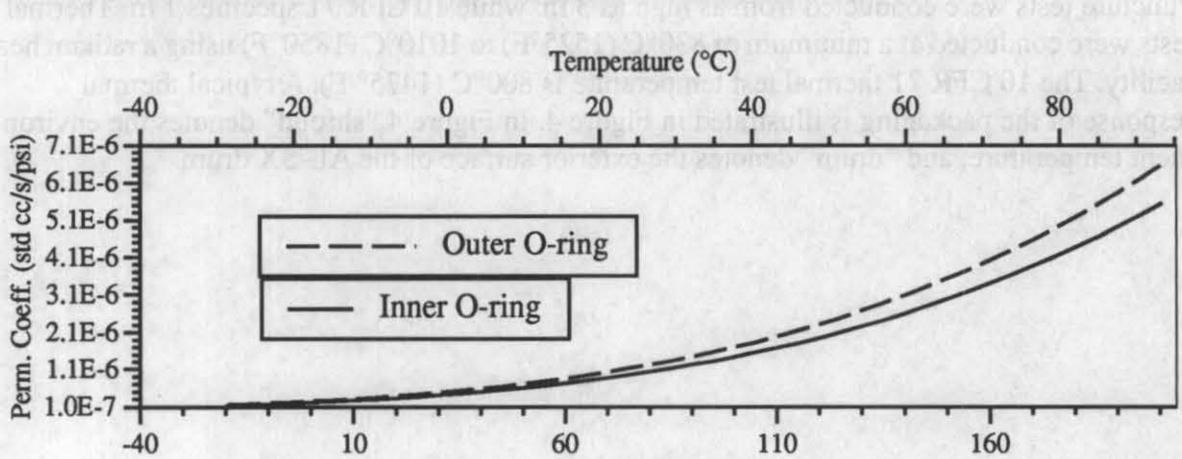

Figure 2. Tritium Permeation Rate of the AL-SX O-rings

If a leaktight inner container was not available or an inner container was damaged, a variation of the previously described AL-SX could then be used with confidence that the normal condition leak rate would not be exceeded. This variation involves installing a tritium getter material (1,4-bis(phenylethynyl)benzene, DEB) between the two O-rings as illustrated in Figure 3.

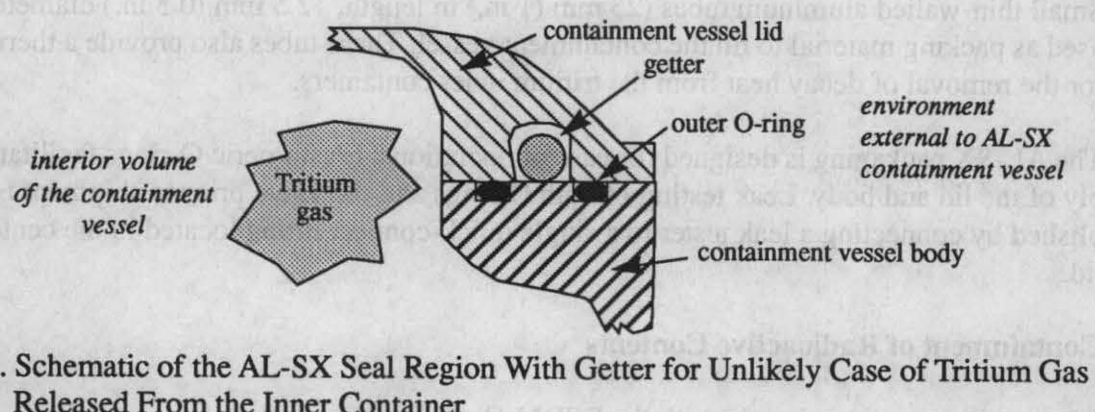

Figure 3. Schematic of the AL-SX Seal Region With Getter for Unlikely Case of Tritium Gas Released From the Inner Container

A full-scale experiment replicating the AL-SX seal geometry was conducted with tritium (Roth 1992). This experiment demonstrated that the getter reacts with tritium at a rate such that the normal condition maximum release rate through the seal system, $1x10^{-7}$ std cc/s as specified in 10 CFR 71 (10^{-6} A_2 per hour), is not exceeded.

Verification Testing of the AL-SX

Conformance of the AL-SX with 10 CFR 71 is based primarily on testing of full-scale prototypes, with some reliance on analysis. The AL-SX was overtested in every category of hypothetical accident tests specified in 10 CFR 71. Drop tests ranged in height from 9 m (30 ft) to 34 m (112 ft) with corresponding impact velocities of 13 m/s (44 ft/s) to 26 m/s (85 ft/s). The 10 CFR 71 specified drop test height is 9 m. The ductile stainless steel drum and impact-limiting foam satisfactorily mitigate impact loads without affecting the containment vessel.

Puncture tests were conducted from as high as 3 m, while 10 CFR 71 specifies 1 m. Thermal tests were conducted at a minimum of 830°C (1525°F) to 1010°C (1850°F) using a radiant heat facility. The 10 CFR 71 thermal test temperature is 800°C (1475° F). A typical thermal response of the packaging is illustrated in Figure 4. In Figure 4 "shroud" denotes the environment temperature, and "drum" denotes the exterior surface of the AL-SX drum.

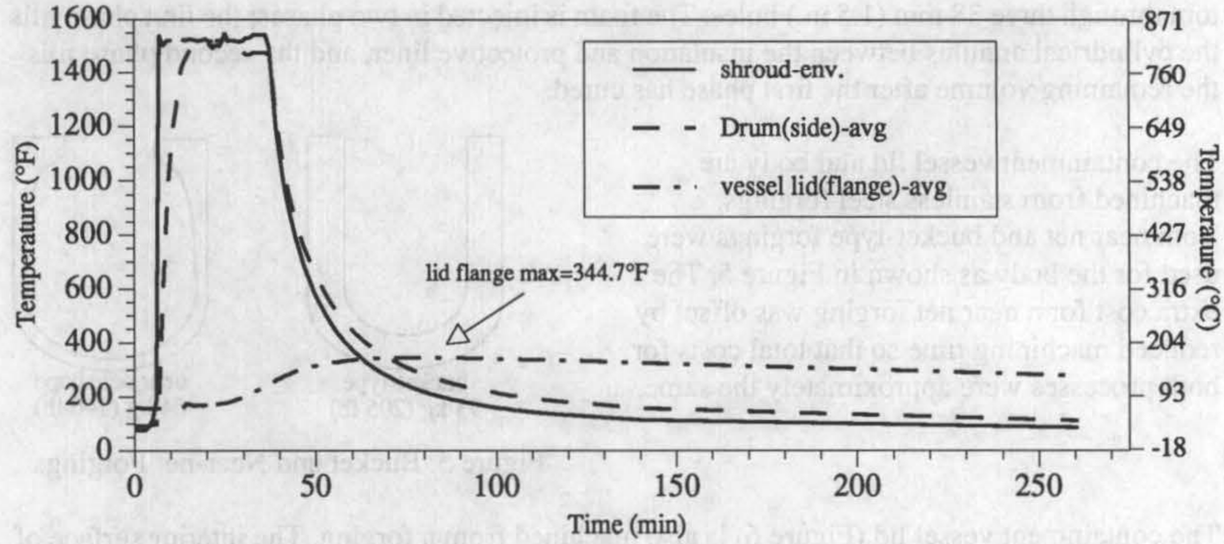

Figure 4. Temperature History of an AL-SX Packaging Subjected to a 830°C Environment

The thermal protection afforded by the thermal insulation and foam provides an acceptable environment for the containment vessel and contents. In the hypothetical accident thermal tests, the maximum lid flange temperature is 173°C (344°F). This lid flange is located quite close to the O-rings and reflects the maximum O-ring temperature. The EPDM O-rings are not affected by this temperature history, and thus, the sealing integrity is preserved. EPDM O-rings in the AL-SX have remained leaktight, as determined by helium leak tests, following exposure to similar time-temperature profiles with a maximum temperature of 316°C (600°F).

Over 12 full-scale AL-SX packagings were tested through the hypothetical accident test sequence.

Production of AL-SX Packagings

Over 2000 AL-SX packagings will be fabricated, and some 800 have already been completed. Before production, a significant effort was made to develop fabrication processes that would yield a good combination of product quality and manufacturing efficiency. Cost, schedule, and performance requirements were the metrics used for pre-production evaluation as well as in-process production monitoring.

The stainless steel protective liner is fabricated from a single piece of metal and conforms to the elliptical shape of the bottom of the containment vessel. The liner is formed using a unique combination of spinning and in-process annealing. The top portion of the liner has two 90 degree bends, the second forming a small flange so that it can be welded to the drum. Dimensions between the flange and drum are critical for an acceptable assembly.

After bonding the thermal insulation to the drum, the liner is fusion welded to the drum in eight places around the diameter. Polyurethane foam is then introduced into the drum from the bottom through three 38 mm (1.5 in.) holes. The foam is injected in two phases; the first phase fills the cylindrical annulus between the insulation and protective liner, and the second phase fills the remaining volume after the first phase has cured.

The containment vessel lid and body are machined from stainless steel forgings. Both near net and bucket-type forgings were used for the body as shown in Figure 5. The extra cost for a near net forging was offset by reduced machining time so that total costs for both processes were approximately the same.

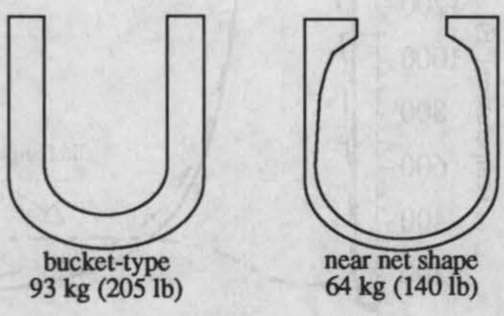

Figure 5. Bucket and Near-net Forgings

The containment vessel lid (Figure 6) is also machined from a forging. The interior surface of the lid does not require machining. Two webs are integral to the lid forging. A passage is drilled through one web to connect the volume between the O-rings to the volume leading to the quick-connect fitting. The entry hole for drilling the passage on the external surface of the lid is then welded closed.

A sample valve, also located in the lid cavity, seals the containment vessel volume with a metal ball seal. The sample valve is connected to a quick-connect fitting through the internal passage that is drilled from the bottom (inside surface) of the lid. Again the passage is sealed by welding the hole closed. This lid construction maximizes protection of the valve and leak test fitting by locating them in the lid cavity recess away from damaging mechanical environments. A leak test for both O-rings and the valve is performed by attaching a leak tester to the quick-connect fitting in the lid cavity.

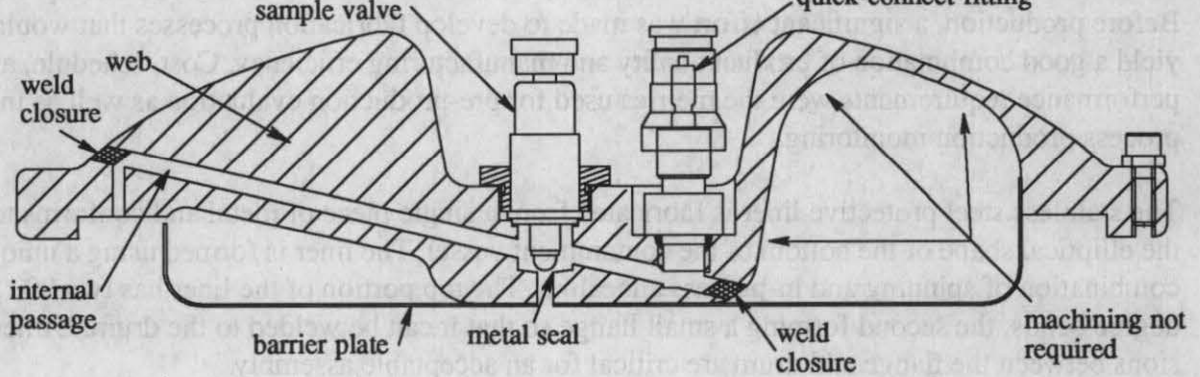

Figure 6. AL-SX Lid Configuration

A rigorous quality assurance plan that conforms to 10 CFR 71 (NQA-1[*]) ensures that all components are manufactured according to the part drawings. Destructive tests such as sectioning forgings to inspect grain flow and sectioning drums to inspect the foaming process are routine activities included in the quality plan. Weld inspection is according to Section VIII of the ASME[†] Boiler and Pressure Vessel Code, and the 1×10^{-7} std cc/s fabrication verification helium leak test on the containment vessel is conducted according to ANSI[‡] N14.5.

References

DOE 5610.1, *Packaging and Transporting of Nuclear Explosives, Nuclear Components, and Special Assemblies*, U.S. Department of Energy, Albuquerque, NM (1980).

Title 10, *Code of Federal Regulations*, Part 71, Office of the Federal Register, Washington, DC (1990).

Roth, Robert, W., *AL-SX Permeation Studies and Evaluation Using Tritium Gas*, SAND92-7276, Sandia National Laboratories (April 1992).

Swansiger, W.A., *Tritium, Deuterium, and Helium Permeation Through EPDM O-rings*, SAND91-8591, Sandia National Laboratories (July 1991).

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[*] Nuclear Quality Assurance, Level 1.

[†] American Society of Mechanical Engineers.

[‡] American National Standards Institute.