Engineering Evaluation of New England Nuclear Model NER-478C Sealed Source as Special Form Radioactive Material

by

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May 24, 2001

Problem:

Several New England Nuclear (NEN) Model NER-478C sealed sources have been located across the United States which are eligible for recovery by the Off-Site Source Recovery (OSR) Project Team at Los Alamos National Laboratory (LANL). These devices typically contain up to 2 Curies (0.67 grams) of Americium-241 (Am-241) as an x-ray fluorescence (XRF) photon source. To facilitate recovery and storage of these devices by the OSR Project, it is desirable to transport such sources as "Radioactive Material - Special Form," a designation which allows a Type A shipment. Under US Department of Transportation (DOT) requirements for radioactive material (RAM) transport, no more than 5.41E-3 Curies, which roughly corresponds to 3.14 E-4 grams of Am-241, can be shipped in a Type A container. This A_2 Value from 49CFR173 is the Type A quantity limit for normal form Am-241. This means that transportation of a single normal form NER-478C sealed source (>5.4 mCi) in a Type A shipping container is not allowed. If these sealed sources can be qualified as special form under 49CFR173.469, then the quantity that can be transported in a Type A container (A_1 Value from 49CFR173) increases to 54.1 Curies, which corresponds to 16.4 grams. The following analysis is performed to assure by available documentation and engineering analysis that the subject sources meet the US Department of Transportation (DOT) requirements for Special Form.

Background

The New England Nuclear (NEN) Model NER-478C source consists of up to 2 Ci. of Am-241 as a vitreous ceramic. The ceramic is deposited in the recess of a tungsten insert and fused to the tungsten. The inner container is then encapsulated in a CRES 316L stainless steel capsule which is sealed by tungsten inert gas welding. The capsule dimensions vary from 7.9 mm OD x 5.1 mm to a maximum of 15.2 mm OD x 8.3 mm. The source window is 0.25 mm thick. NEN reported that the Model NER-478C sealed source was tested with a resulting ANSI classification of C66544 per ANSI N542-1977. These devices were classified according to specifications contained in ANSI N542-1977, "Sealed Radioactive Source, Classification" as C66544[1]. This classification describes a series of physical tests used to determine the degree of physical integrity of a sealed source under various testing conditions. The ANSI N542 test severity levels vary considerably depending on the potential end use of the source.

[1] NRC Sealed Source Device Registry No. NR476S133S.

Solution to Problem

The DOT requires, in 49CFR173.476, that

> **"Each offeror of special form Class 7 (radioactive) materials must maintain on file for at least one year after the latest shipment, and provide to the Associate Administrator for Hazardous Materials Safety on request, a complete safety analysis, including documentation of any tests, demonstrating that the special form materials meet the requirements of 173.469….."**

If a comparison is made between ANSI standard N542-1977 testing (at C66544 severity levels) to the testing requirements in 49CFR469, a safety analysis which demonstrates equivalency of testing may be completed.

Comparison

Table 1 summarizes and compares the testing criteria from the ANSI document cited above and the criteria from 49CFR173.469. This comparison shows that:

a. While the test names vary, the purpose of these tests is very similar in their examination of capsule integrity under the various test conditions.
b. The ANSI testing requirements for the capsules were more rigorous than those for special form testing.
c. ANSI required additional testing.

Table I. Comparison of two sets of testing criteria

Test Criteria	**49CFR 173.469[2]**	**ANSI N542-1977[3], C66544**
Impact Test	9 m drop of sealed source	None
Percussion Test	1 drop of a 1.4 kg billet dropped from 1 m	1 drop of a 5.0 kg billet dropped from 1 m
Pressure Test	None	2.9 - 24,656 psia external pressure on capsule
Temperature	800°C for 10 min. No thermal shock test required	-40°C for 20 min. to +800°C for 60 min, Separate thermal shock test +800°C for 60 min, quenched
Leaching Test	Distilled water at 50°C for 4 hr.	None
Vibration Test	None	90 min at 25 – 80 Hz at 1.5 mm amplitude peak to peak, and 80 – 2000 Hz at 20 g
Puncture Test	None	50 grams from 1 m

[2] 49 Code of Federal regulations, Part 173, section 469, Special Form Testing
[3] ANSI, American National Standard N542-1977; Sealed Radioactive Sources, Classification

Discussion

A point by point comparison of the two sets of testing criteria establishes the following differences:

Impact Test: The 9 m drop of the DOT test imparts a terminal velocity of about 13 m/s to the sealed source. The force of the impulse **($F_{impulse}$)** applied to the capsule by this test is equal to:

$$F_{impulse,DOT} = (m \times V)/(g \times \Delta t))$$

where

m is the source capsule mass (23.6 g or 0.052 lb.)
V is the velocity of the hurtling source (50 m/s or 164 ft/s)
g is the gravitational acceleration (32.2 ft/sec^2)
Δt is the contact time (estimated at about 1 ms (0.001 s)

$$F_{impulse,DOT} = (0.052 \text{ lb} \times 164 \text{ ft/s})/(32.2 \text{ ft/sec}^2 \times 0.001 \text{ s})) = 265 \text{ lb}_f$$

$F_{impulse}$ applied to the NER-478C capsule in the DOT impact test would be about 265 lb_f. Since there is not a comparable drop test in the ANSI standard, the minimum force applied in this impact test was compared to the force applied in the ANSI standard percussion type test. As calculated below, the ANSI standard percussion type test generates a Force impulse (**$F_{impulse,ANSI}$**) of about 5000 lb_f. The percussion test applies a minimum of 19 times more force. It is my opinion that the NER-478C capsule would readily pass the DOT Special Form Impact test .

Percussion Tests: The mechanical strength (stress/strain) of the capsule is demonstrated in both testing scenarios. A percussion test is required for both the DOT and ANSI evaluations. In the ANSI Standard, this test is termed an "impact test", however the test conditions are very similar to those used in the DOT percussion test. The only difference is that the ANSI Level 5 Percussion Test (C66544) uses a 5 kg billet instead of the 1.4 kg billet in the DOT test. The equivalency of these two mechanical tests can be evaluated by performing an engineering analysis to determine the normalized stress applied by both test methods.

The percussion test specified in the DOT regulations can be analyzed as an impulse of force applied to the sealed source. The force of the impulse **($F_{impulse}$)** for the DOT test is equal to:

$$\mathbf{F_{impulse,\ DOT} = (m \times V)/(g \times \Delta t))}$$

where

m is the mass of percussion test billet (1.4 kg or 3.08 lb)
V is the velocity of the falling billet (14.6 ft/s)
g is the gravitational constant (32.2 ft/sec^2)
Δt is the contact time (estimated to be 1 ms (0.001 s)

$$F_{impulse,DOT} = (3.08 \text{ lb} \times 14.6 \text{ ft/s})/(32.2 \text{ ft/sec}^2 \times 0.001 \text{ s})) = 1400 \text{ lb.}_f$$

The force of the impulse **($F_{impulse}$)** for the ANSI test is equal to:

$$F_{impulse,\ ANSI} = (m \times V)/(g \times \Delta t))$$

where

m is the mass of percussion test billet (5.0 kg or 11.02 lb)
V is the velocity of the falling billet (14.6 ft/s)
g is the gravitational constant (32.2 ft/sec^2)
Δt is the contact time (estimated to be 1 ms (0.001 s)

$F_{impulse,\ ANSI}$ = (11.02 lb. x 14.6 ft/s)/(32.2 ft/sec^2 x 0.001 s)) = 5000 lb_f.

The resulting kinetic loads are 1400 lb_f vs. 5000 lb_f for DOT and ANSI Level 6 tests, respectively. The kinetic force used in the ANSI test is 3.57 times greater than the DOT Percussion test. Therefore, the ANSI Level 6 test is more stringent than the DOT Special Form Percussion test.

Temperature: The initial +800°C soak is 6 times longer in the ANSI Level 6 test than in the DOT Special Form test. The ANSI Level 6 test starts with a soak at –40°C for 20 minutes. The ANSI Level 6 test also requires a separate thermal shock test, which is +800°C quenched to room temperature in 20°C water. Together, these additional thermal tests make the ANSI Level 6 test much more stringent than the DOT Special Form temperature test requirements.

Leaching: The DOT leaching test lasts 4 hrs. at 50°C in distilled water. The ANSI Standard does not require a leaching test. The NER-478C sealed source is double encapsulated in CRES 316L stainless steel. The 316L stainless steels have excellent corrosion resistance to fresh water[4]. Detection of any transported activity would require violation of the shell of the source capsule and leaching from the vitreous ceramic source material, before any contamination could be detected. Therefore, I believe the NER-478C capsule will pass the DOT Special Form leaching test.

Additional Testing Required by ANSI N542-1977

Additional tests required only by the ANSI standard include pressure, vibration and puncture tests. The pressure test is noteworthy in that passing a hydrostatic test of 24,646 psia indicates that forces are well distributed in the shell of the source capsule, particularly with respect to the thin window (0.010 inch or 0.25 mm). These additional tests also demonstrate the ability to sustain lengthy periods of vibration and a level of puncture resistance for the thin window of the capsule.

Results

The comparison of test criteria required for ANSI N542-1977 and 49CFR173.469 indicate that the tests required for the ANSI N542-1977 standard at levels required for classification C66544

[4] Perry's Handbook of Chemical Engineering, 5th Ed., 1973, pp. 23-34, Table 23-4, General Corrosion Properties of Some Metals and Alloys.

are more stringent than those required for DOT special form testing. The ANSI C66544 classification requires additional testing that serves to add additional confidence as to the special form character of the NEN Model NER-478C sealed source.

Conclusion

NEN Model NER-478C sealed sources meet the requirements for special form material under 10CFR172.469.

Attachment A

§49 CFR173.469 ***Requirements for special form Class 7 (radioactive) materials***

Impact Test: The specimen must fall onto the target from a height of 9 meters (30 ft) or greater.

Percussion Test: The specimen must be placed on a sheet of lead that is supported by a smooth solid surface, and struck by the flat face of a steel billet so as to produce an impact equivalent to that resulting from a free drop of 1.4 kg (3 lb.) through 1 meter (3.3 ft.).

Heat Test: The specimen must be heated in air to a temperature of not less than 800°C (1475°F), held at that temperature for a period of 10 minutes, and then allowed to cool.

Leach test: (i)The specimen must be immersed in water at ambient temperature. The water must have a pH of 6-8 and a maximum conductivity of 10 micro-ohm per centimeter. (ii) The water and specimen must be heated to a temperature of 50°C $\pm$5° (122°F $\pm$9°) and maintained at this temperature for four hours.

(iii) The activity of the water must then be determined.

(iv) The specimen must then be stored for at least seven days in still air at a temperature of 30°C (86°F) or greater.

(v). The process in paragraphs (c)(2)(i), (c)(2)(ii), and (c)(1)(iii) of this section must be repeated.

(vi) The activity determined in paragraph (c)(2)(iii) may not exceed 2 kBq (0.05 micro-curie).

Attachment B

ANSI N542-1977, Sealed Radioactive Sources, Classification

The information below is taken from Table 1, Classification of Sealed Source Performance Tests.

Test	Class	Conditions
Temperature	6	-40°C 20 min., followed immediately by +800°C, 1 hr. Separate thermal shock test, +800°C quenched to 20°C in water.
External Pressure	6	2.9 - 24,656 psia external pressure on capsule
Impact	5	5 kg from 1 m.
Vibration	4	90 min at 25 – 80 HZ at 1.5 mm amplitude peak to peak And 80 - 2000 Hz at 20 g
Puncture	4	50 grams from 1 m

Attachment C