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EST. 1943

Memorandum

Nuclear Nonproliferation Division
International Threat Reduction Group N3
Off-Site Source Recovery (OSR) Project

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Phone/Fax: 770-517-4320
Symbol: N3-2012-059
Date: April 18, 2012

SUBJECT: MRC Model 24107 Special Form Evaluation

SCOPE

The purpose of this memorandum is to characterize Monsanto Research Corporation (MRC) Model 24107 sealed sources as US Dept. of Transportation (DOT) Special Form Radioactive material, with the goal of achieving domestic transport for recovery, consolidation, interim storage, and final disposition.

BACKGROUND

In the early 1970s, MRC fabricated AmBe neutron sources according to MRC drawings for Model 24107 sources. The special form character of these Model 24107 sources was analyzed by Dr. Ed Janzow, and IAEA Certificate of Competent Authority (COCA) for Special Form Radioactive Material Encapsulation was issued by the US DOT as COCA USA/0108/S (enclosure A). MRC subsequently went out of business; the special form certificate was not renewed, and thus expired in April 1983.

A critical factor in the physical integrity of any 30+ year old sealed source is self-pressurization from the accumulation of helium atoms derived from alpha decay within the source. The self-pressurization potential was examined by Dr. Janzow in his original evaluation for a nominal 4.5 Ci AmBe source. Dr. Janzow found that the model 24107 source had a recommended working life of 20 years with a safety factor of 4[1] during the hypothetical fire event (800 degrees C). The recommended working life was influenced by potential transportation events and the assumed working environment of a well logging source, specifically 25,000 psi external pressure, prolonged use at 400 degrees C, and a potentially abusive physical environment. For non-well logging sources, the working environment is not as harsh and thus the working life can be extended. In these cases it is only necessary worry about fire during a transportation event, which requires survival of the source during an 800 degree C thermal excursion for 10 minutes.

In the following discussions we will calculate the void volume available in the inner encapsulation, the quantity of gas generated in 40 years, and the maximum allowable pressure inside of the encapsulation.

Void Volume Calculation

The document used for the self-pressurization analysis is the MRC source sketch from SSDR NR-882-S823-S. Using this model 24107 sketch, dimensions of the source are established and allow calculation of the internal volume of the inner source container. Attachment A shows the dimensions of the inner and outer encapsulations of the model 24107 as well as other similar MRC sources.

$$\text{Volume}_{\text{Inner}} = ((\text{OD}-(2 \times \text{wall thickness}))/2)^2 \times (\text{OL}-H_T-B_T)$$

$$\text{Volume}_{\text{Inner}} = ((0.995-(2 \times 0.123))/2)^2 \times \pi \quad \square 0.375-0.236) = 0.709 \text{ in.}^3 = 11.6 \text{ cm}^3$$

[1] ASME Boiler and Pressure Vessel Construction Code, 1969 standard

The volume of the inner capsule contained 1 gram of Am-241 oxide (3.43 Ci) and 10 grams of beryllium metal powder. The americium oxide and beryllium metal are well mixed. This quantity of beryllium metal powder was selected to completely fill the interior volume of the inner capsule with a 50% packing factor (PF, 50% of theoretical density). This means that 50 % of the interior volume of the capsule is void. In other safety analysis documents, Dr. Janzow detailed that typical PF were closer to 36% and that 50 % was used as a conservative worst case value. The calculated void volume is 50 % of the actual volume.

Void Volume = 11.6 cm^3 x 0.5 = 5.8 cm^3

Gas Generated in 40 years

Self-pressurization of the inner capsule is caused by the accumulation of helium atoms derived from alpha particle decay of the Am-241. In the original safety analysis, the manufacturer simply multiplied the decay rate (3.7E10 Bq/Ci) by the number of seconds in a year and then by the number of years. A more exact solution is the following:

Decay events = N_i = ((3.7E10 x 3600 x 24 x 365)/(0.693/432) x (1-exp(-0.693/432) x Age)))

Decay events = 7.49E-5 mols of gas/curie with 40 yr of decay

Dividing the number of decay events by Avogadro's number (6.023E23) allows the calculation of mols/Ci of helium atoms for a specific decay period. In this case 7.49E-5 mols/Ci for 40 years of Am-241 decay. For the example 3.43 Ci source, multiplying the mols per Ci by the number of Curies gives the mols of gas generated within the inner encapsulation:

Mols Helium gas = 7.49E-5 mols/Ci x 3.43 Ci = 2.57E-4 mols of gas

Once the volume and the number of mols of gas are known, the pressure inside the inner capsule can be calculated using the ideal gas law (PV = nRT). Rearranging and solving the calculation yields:

P = (n x R x T)/V

n = 2.57E-4 mols of gas

R = 0.08208 Liter-Atm/mol-K

T = absolute temperature (degrees K) = 800 + 273 = 1,073 degrees Kelvin

V = 5.8 cm^3 = 0.0058 Liters

P = 3.90 atmospheres = 57 psi

Maximum Allowable Pressure Calculation

The internal pressure of an example model 24107 source containing 3.43 Ci of AmBe powder packed to 50 % (PF) of theoretical density is 57 psi at 800 degrees C after 40 years of decay. This pressure was based upon the known dimensions of the source model, the calculated number of helium atoms generated from 40 years of decay, a packing factor of 50% (Dr. Janzow's Safety Analysis), and the temperature required for the 10 minute fire simulation of 49 CFR 173.469 special form testing.

Dr. Janzow based his maximum permissible pressure calculations for the MRC 24107 source on the ASME Pressure Vessel Construction Code[2]. The allowable pressure calculation is done exactly as described by Dr. Janzow in a typical MRC safety analysis (i.e., Model 24120). An example of an MRC

Safety Analysis can be found in enclosure E, a submission to US DOT for Model 24112 and 24120 Sources.

A section of this example is excerpted below:

> *Section 5.0 Stress Analysis of the Internal Capsule*
>
> *Accordingly, the allowable internal pressure, P_H (or P_B) in psig are limited to stress in the end plug, is taken to be related to the thickness of the plug t (inches), in the manner specified in the code for fig UG-34(h); namely (p. 21), $t = D \times (CxP_H/S)^{1/2}$, where D is the diameter of the plug (inches), C is a dimensionless factor dependent upon such considerations as the method of attachment of the head and the shell dimensions, and S is the maximum allowable stress value in the code.*
>
> *Solving for P_H (or P_B)*
>
> $t = D \times (C \times P_H/S)^{1/2}$
>
> $P_H = (t^2 / (C \times D^2)) \times S$

For the example of the MRC model 24107, the dimensions for calculating the stress in the inner capsule follow:

t = 0.236-0.100 = 0.136 in. (the lesser of t_H and t_B was chosen, minus 0.100 for a bit devit)

D = 0.995- (2 x 0.123) = 0.749 in.

C = 0.5 a dimensionless joint factor

S = 9,900 psi (304 SS at 1500 degrees F (815 degrees C)

P_H = 653 psi Maximum Allowable Internal Pressure in source inner capsule

As calculated above the maximum permissible internal pressure for the model 24107 inner capsule is 653 psi at 815 degrees C. This calculation is exactly as many others performed by Dr. Janzow of MRC with one exception. Dr. Janzow would have de-rated the 9,900 psi strength of material for 304 SS at 815 degrees C to 7,900 psi (20 %) for the purpose of MRC corporate risk reduction. This additional risk reduction factor of 20% was not incorporated in these calculations.

Thus, a sources made in 1975 will only be at 9% of the maximum allowable internal pressure (57psi/653 psi) an additional 10 years of DOT special form lifetime is quite possible. However, since the present objective is simply to insure that these sources are transported compliantly and dispositioned safely, a date of June 1, 2016 is set as the arbitrarily selected date for loss of special form character under this memo of self-certification.

SUMMARY

[2] Rules for the Construction of Pressure Vessels, Div 1, 1971 edition, ASME Boiler and Pressure Vessel Code, Section VIII.

MRC model 24107 sealed sources meet the requirements for US DOT special form radioactive material, as demonstrated by testing and issuance of DOT COCA No. USA/108/S. This COCA was allowed to expire in April 1983. Therefore it was necessary to self certify this source by re-evaluating the critical parameter that 40 years of age imposes on this model 24107 MRC source due to self pressurization.

The age of the MRC model 24107 was considered with respect to special form character. Using the original very conservative pressurization calculations of Dr. Janzow it was possible to determine that a MRC model 24107, containing 3.43 Ci of AmBe, with packing factor of 50% has an internal pressure of 57 psi at 800 degrees C, which is less than the maximum permissible internal pressure of 653 psi calculated using the ASME Code for Construction of Pressure Vessels (safety factor of 4).

CONCLUSION

The MRC model 24107 neutron source as documented in SSDR: NR-882-S-823-S can be self-certified as US DOT special form radioactive material in accordance with 49 CFR 173.476, within the limits and scope of this memo until June 1 of 2016. After June 1, 2016 all MRC model 24107 sources can no longer be qualified as special form.

ATTACHMENTS

A. Table 1, Dimensional Comparison of MRC Neutron Sources

B. US DOT issued IAEA Certificate of Competent Authority No. USA/108/S, expired April 1983

C. Internal Pressure Calculation

D. Maximum Permissible Internal Pressure Calculation

Example of MRC Maximum Permissible Pressure Calculation – Submission to US DOT for Model 24112 and 24120 Sour