Los Alamos
NATIONAL LABORATORY
EST. 1943

memorandum

Nuclear Engineering and Nonproliferation Division
International Threat Reduction Group NEN-3
Off-Site Source Recovery Program (OSRP)

To: Justin Griffin, OSRP
From: Andrew Tompkins, McAlpin Ent.
Phone: 404-388-3631
Symbol: NEN3-20-039 *(OSR-SF-019)*
Date: July 20, 2020

Subject: Amersham Model AMC.36 (X.103 capsule) Special Form Evaluation

SCOPE

The purpose of this memorandum is to characterize Amersham International (AI) Model AMC.36 sealed sources (X.103 capsule) as US Dept. of Transportation (DOT) Special Form Radioactive material, with the goal of achieving domestic ground transport for recovery, consolidation, interim storage, and final disposition.

Physical Description

The radioactive sealed source consists of americium (Am-241) oxide which is mechanically blended with a powdered ceramic frit and is heated until molten. The mix is cooled and forms a solid glass / ceramic bead. Multiple beads are inserted into the recess of the tubular shaped capsule having a TIG or laser welded end plug. Ceramic fiber packing material may be placed, as necessary, in between the glass beads for compaction of the beads and to minimize movement. An end plug is inserted into the second opening and it is TIG or laser welded to the capsule to form a seal. The capsule is fabricated with 316 or 316L stainless steel. The overall length is 30.4 mm and 2.9 mm OD, with a wall thickness of 0.45 mm (see attached dwg: RBA 62475 Rev A).

Special Form Character

The X.103 capsule was originally issued a Certificate of Competent Authority in the UK (GB/397/S). The most recent USDOT COCA (USA/0657/S-96, Rev 5) for the X.103 capsule at the time of this memo was issued in June 11, 2018, expiring Nov. 30, 2023. The COCA indicates that the X.103 capsule meets all requirements of IAEA SSR-6 Rev 1 as special form radioactive material. There is also a QSA-Global clause limiting special form character to those sources manufactured on or after December 9, 1991. This limiting clause is due to a lack of QA documentation on X.103 sources not manufactured by QSA-Global, but by AEA Technology, Amersham, or The Radiochemical Corp. The issue at hand is whether or not X.103 capsules manufactured before December 9, 1991 can also be considered as special form radioactive material.

A critical factor in the physical integrity of any sealed source is self-pressurization from the accumulation of helium atoms derived from alpha decay within the source. The self-pressurization potential will be examined for a nominal 0.100 Ci Am-241 source. The self-pressurization could become a factor during a potential 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 encapsulation, the quantity of gas generated between 30 and 60 years, and the mechanical stress within the source cladding.

Void Volume Calculation

The document used for the self-pressurization analysis is the AEAT drawing of the X.103 capsule (RBA 62475) and contents as described in SSDR: MA-1059-S-278-S. Using this drawing, dimensions of the source are established and allow calculation of the internal volume of the source cladding. Attachment A shows the dimensions of the encapsulation of the model X.103 capsule. The volume of the inner capsule contained 10 glass beads containing Am-241 oxide (0.100 Ci) and 11 glass fiber pads.

Inner Volume = $(ID)/2)^2$ x Pi x ($OL-H_T-B_T$)
Inner Volume = $((2.0)/2)^2$ x Pi x (30.0-5.0-5.0) = 63 mm^3 = 0.063 cm^3
Bead Volume = 10 x 4/3 x Pi x $(1.9/2)^3$ = 36 mm^3 = 0.036 cm^3
Glass fiber pads = (20-19) x $(1.9/2)^2$ x Pi) x 0.4 = 1 mm^3 = 0.001 cm^3
Void Volume = 63 mm^3 - 36 mm^3 – 10 mm^3 = 26 mm^3 = 0.026 cm^3

Gas Generated Over time

Self-pressurization of the inner capsule is caused by the accumulation of helium atoms derived from alpha particle decay of the Am-241. The decay rate is approximately 3.7E10 Bq/Ci x 0.1 Ci/source = 3.7E9 decays/second.

Decay events =3.7E9 Bq x (60 sec/min x 60 min/hr x 24 hr/day x 365 days/yr x 60 yr = 7.0E+19

Dividing the number of decay events by Avogadro's number (6.023E23) allows the calculation of mols of helium atoms for a 60 yr. decay period. In this case 1.2E-5 mols/Ci for 60 years of Am-241 decay.

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 = 1.2E-5 mols of gas (for 60 yr.)
R = 0.08208 Liter-Atm/mol-K
T = absolute temperature (degrees K) = 800 + 273 = 1,073 degrees Kelvin
V = 0.026 cm^3 = 0.000026 Liters

P = 40 atmospheres = 592 psi of gas pressure

The gas pressure was based upon the known dimensions of the source model, the calculated number of helium atoms generated from 50 years of decay, and the temperature (800 C) required for the10 minute fire simulation of 49 CFR 173.469 special form testing. Decaying the source over a 60-year lifetime gives the following results: P = 40 atm or 592 psi.

Table 1, X.103 Capsule Pressurization by Decaying Am-241 (100 mCi)

Age (yr)	Decay Events/(100 mCi)	Mols of gas	Pressure (atm) @ 800c	Pressure (psi) @800c
30	3.50E+19	5.81E-06	20	289
40	4.67E+19	7.75E-06	26	386
50	5.83E+19	9.969E-06	33	482
60	7.00E+19	1.16E-05	39	579

The internal gas pressure of a model X.103 source capsule containing 100 mCi of Am-241 in 10 glass beads is 592 psi at 800 degrees C after 60 years of decay. It is conservatively assumed that all helium gas generated in the vitrified beads in the source will immediately diffuse from the beads into the available void space.

Analysis - Stress within Source Cladding Walls

A six-year-old X.103 sealed source could have internal gas pressure as high as 600 psi at 800 degrees C during the 10-minute transportation thermal excursion. To understand the effect of this internal pressure we calculated the stress in the 316 stainless steel cladding wall of the X.103 capsule, using mechanics of solids engineering theory. The calculations were run for the X.103 capsule as a thick-walled pressure vessel (see Table 2).

Table 2, Stress Within an Aged X.103 Source During a 800 C Temperature Transient (10 min)

Age of Source	30 yr	40 yr	50 yr	60 yr
	Stress* (psi)	Stress* (psi)	Stress* (psi)	Stress* (psi)
Sigma Longitudinal	264	355	441	530
Sigma Circumferential	817	1092	1364	1639
Sigma Radial	-289	-386	-482	-579

As calculated above the maximum wall stress for the X.103 capsule is 1,639 psi of circumferential stress at 800 degrees C, during the thermal transient. Since the thermal transient is of 10 minutes duration the maximum stress will be compared to the short time - 0.2% offset yield strength. It is important to note that the use of a short-term yield stress means that we will not be taking account metallic creep, as this is a product of tens or hundreds or thousands of hours of exposure to the thermal environment. Using data from the "High Temperature Characteristics of Stainless Steels," the short time 0.2% offset Yield strength for 316 SS at 800 C was found (ref. D) to be 19,000 psi. This 0.2% offset yield strength is indicative of a material that is transitioning from an elastic to a plastic deformation under stress. While the ultimate strength of 316 stainless steel is much higher (29,000 psi) the use of the offset yield strength is a reliable indicator of the strength of 316 SS in this calculation.

The 0.2% offset yield strength is more than 10 times greater than the calculated circumferential stress, which indicates that the containment of the Am-241 will safely endure the 10-minute thermal transient. Since the plugs that seal each end of the X.103 are very long (5 mm) compared to the diameter of the tubing, (2.9 mm) from which the source is manufactured a stress failure of the Head or Bottom plug is unlikely. This long plug minimizes stress in the head or bottom plug as a mode of failure. The fact that these sources are all laser welded with a weld thickness equal to the tubing wall thickness eliminates weld failure as a source of concern for the X.103 capsule

SUMMARY

The QSA-Global X.103 capsule sealed sources meets the requirements for US DOT special form radioactive material, as demonstrated by testing and issuance of DOT COCA No. USA/0657/S. This COCA has a time limiting statement that source manufactured before December 9, 1991 are not covered by this COCA. Therefore, it was necessary to self-certify these sources by re-evaluating the critical parameter that 60 years of age imposes on this model X.103 source capsule due to self-pressurization. Analysis of the pressure data and comparison to the 0.2% Yield strength data indicates a safety factor of > 5, for a 60-year-old source.

CONCLUSION

The X.103 source capsule as documented in SSDR: MA-1059-S-278-S is certified by USDOT if manufactured after Dec 9, 1991. These same sources can be self-certified for sources manufactured before Dec 9, 1991 as US DOT special form radioactive material in accordance with 49 CFR 173.476, within the limits and scope of this memo until the source exceeds 60 years of age or December 9, 2032.

Attachment(s):

1. US DOT issued IAEA Certificate of Competent Authority No. USA/0657/S Rev 5 expires 2023.
2. Table 1, Pressure Calculation
3. Table 2, Stress Calculation
4. Figure 3, Short Time – 0.2% Offset Yield Strength Data, "High Temperature Characteristics of Stainless Steel", Designers Handbook No. 9004, American Iron and Steel Institute, pg. 7.

U.S. Department
of Transportation

Pipeline and
Hazardous Materials
Safety Administration

East Building, PHH-23
1200 New Jersey Ave, SE
Washington, D.C. 20590

IAEA CERTIFICATE OF COMPETENT AUTHORITY
SPECIAL FORM RADIOACTIVE MATERIALS

CERTIFICATE USA/0657/S-96, REVISION 5

This certifies that the source described has been demonstrated to meet the regulatory requirements for special form radioactive material as prescribed in the regulations of the International Atomic Energy Agency[1] and the United States of America[2] for the transport of radioactive material.

1. Source Identification - QSA Global, Inc. Model X.103 (Manufactured on or after December 9, 1991).

2. Source Description - Cylindrical single encapsulation made of Type 316 stainless steel and tungsten inert gas seal welded. Approximate exterior dimensions are 2.9 mm (0.11 in.) in diameter and 30.4 mm (1.2 in.) in length. Minimum wall thickness is 0.225 mm (0.009 in.). Construction shall be in accordance with attached AEA Technology QSA, Inc. Drawing No. RBA62475, Rev. A.

3. Radioactive Contents - No more than 5.18 GBq (140.0 mCi) of Americium-241. The Am-241 is in oxide form and combined with molten glass and cooled to form a glass bead.

4. Management System Activities - Records of Management System activities required by Paragraph 306 of the IAEA regulations shall be maintained and made available to the authorized officials for at least three years after the last shipment authorized by this certificate. Consignors in the United States exporting shipments under this certificate shall satisfy the requirements of Subpart H of 10 CFR 71.

5. Expiration Date - This certificate expires on June 30, 2023. Previous editions which have not reached their expiration date may continue to be used.

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[1] "Regulations for the Safe Transport of Radioactive Material, 2012 Edition, No. SSR-6" published by the International Atomic Energy Agency (IAEA), Vienna, Austria.

[2] Title 49, Code of Federal Regulations, Parts 100-199, United States of America.

CERTIFICATE USA/0657/S-96, REVISION 5

This certificate is issued in accordance with paragraph(s) 804 of the IAEA Regulations and Section 173.476 of Title 49 of the Code of Federal Regulations, in response to the June 1, 2018 petition by QSA Global, Inc., Burlington, MA, and in consideration of other information on file in this Office.

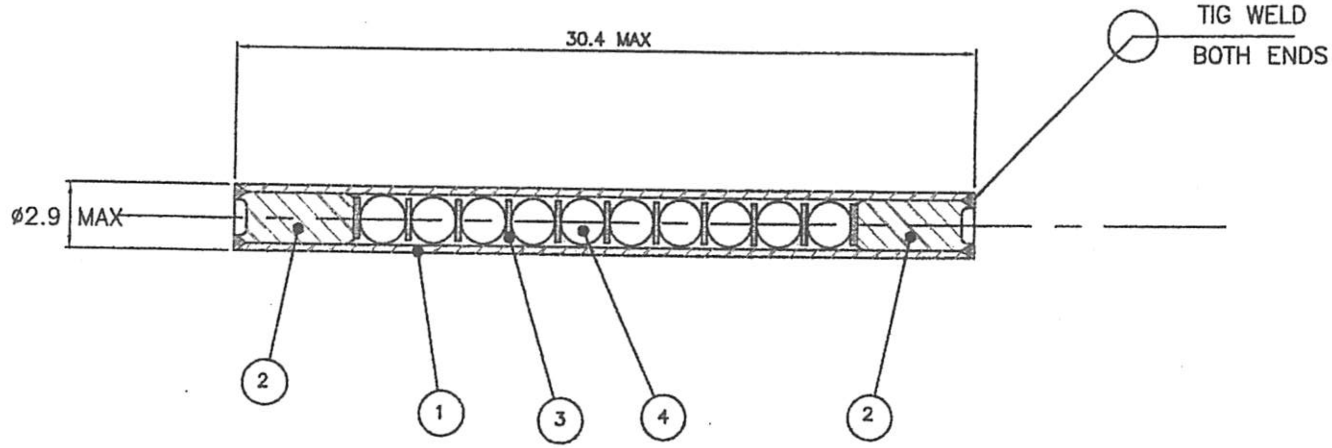
Certified By:

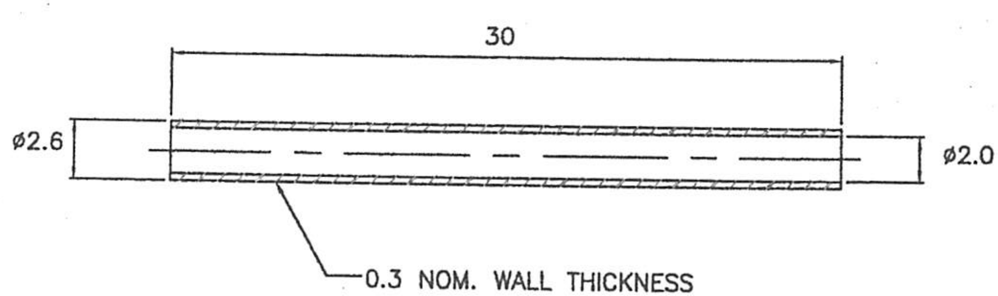
for William Schoonover
Associate Administrator for Hazardous Materials Safety

June 11, 2018
(DATE)

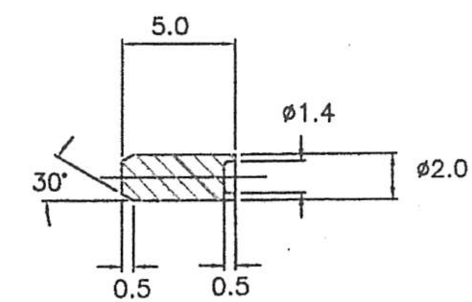
Revision 5 - Issued to extend the expiration date.

ITEM No.	DESCRIPTION	No. OFF
1	BODY	1
2	PLUG	2
3	CERAMIC FIBRE PACKING	A/R
4	Am241 GLASS BEADS ø 1.9 MM	A/R





BODY
MATERIAL – 316/316L STAINLESS STEEL



PLUG
MATERIAL – 316/316L STAINLESS STEEL

APPROVALS	
R. [signature]	18 Nov 03
L. [signature]	21 Nov 03

DIMENSIONS IN MILLIMETERES UNLESS OTHERWISE STATED TOLERANCES:
X ±0.5
X.X ±0.1
X.XX ±0.05
ANGULAR ±5°
INTERNAL N7
EXTERNAL N6

AEA TECHNOLOGY QSA
40 NORTH AVE, BURLINGTON, MA 01803

DESCRIPTIVE DRAWING

TITLE X103 CAPSULE ASSEMBLY

SIZE A | DWG. NO. RBA62475 | REV A
SCALE: NONE | SHEET 1 OF 1

ERF # 710

Table 1., X.103 Capsule Pressurization by Decaying Am-241 (100 n

Age (yr)	Decay Events/(100 mCi)	Mols of gas	Pressure (atm) @ 800C	Pressure (psi) @800C
30	3.50E+19	5.81E-06	20	289
40	4.67E+19	7.75E-06	26	386
50	5.83E+19	9.69E-06	33	482
60	7.00E+19	1.16E-05	39	579

Table 2., Stress in a Thick Walled Pressure Vessel

$$\text{Sigma}_{\text{Longitudinal}} = \frac{(P_i*(r_i)^2-(P_0*(R_0)^2)}{(r_o^2-r_i^2)}$$

$$\text{Sigma}_{\text{Circumfrential (Hoop)}} = \frac{(P_i*(r_i)^2-(P_0*(R_0)^2)}{(r_o^2-r_i^2)} - \frac{r_i^2*r_o^2*(P_o-P_i)}{r^2*(r_o^2-r_i^2)}$$

$$\text{Sigma}_{\text{Radial}} = \frac{(P_i*(r_i)^2-(P_0*(R_0)^2)}{(r_o^2-r_i^2)} + \frac{r_i^2*r_o^2*(P_o-P_i)}{r^2*(r_o^2-r_i^2)}$$

r_i = 1 mm 0.039 in.

r_o = 1.45 mm 0.057 in.

P_i = 500 psi 600 psi

P_o = 0 psi 0 psi

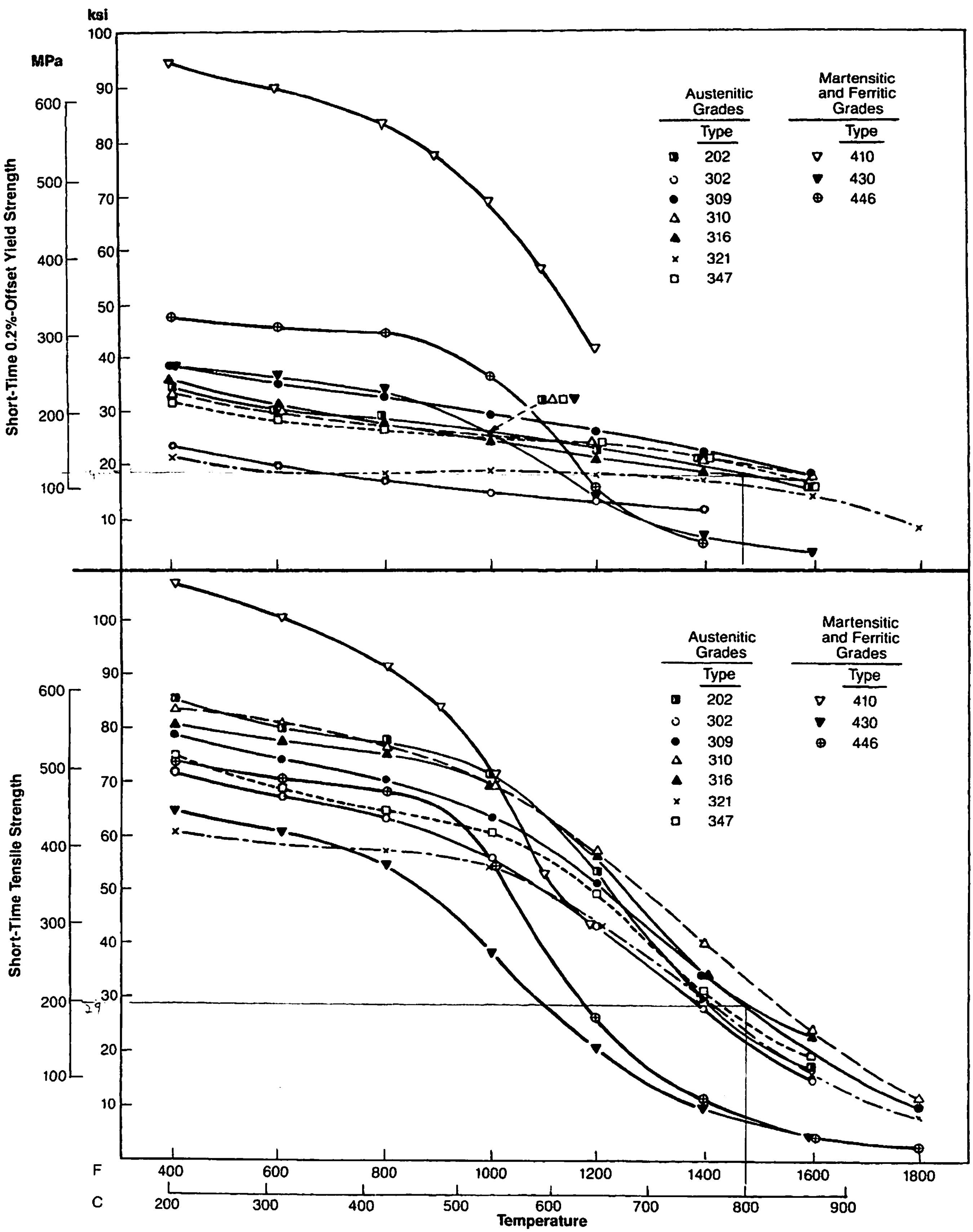
r = r_i = the radius where the greatest radial stress occurs

r = 1 mm 0.0394 in.

Stress Within an Aged X.103 Source During a 800 C Temperature Transient (10 min)

Age of Source	**30 yr**	**40 yr**	**50 yr**	**60 yr**
	Stress* (psi)	Stress* (psi)	Stress* (psi)	Stress* (psi)
$\text{Sigma}_{\text{Longitudinal}}$	264	353	441	530
$\text{Sigma}_{\text{Circumfrential}}$	817	1092	1364	1639
$\text{Sigma}_{\text{Radial}}$	-289	-386	-482	-579

Figure 3 Short-Time Tensile Strengths (1)



Typical short-time tensile strengths of various standard stainless steels at elevated temperature. All steels were tested in the annealed condition except for the martensitic Type 410, which was heat treated by oil quenching from 1800°F (982°C) and tempering at 1200°F (649°C).