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MATERIALS CHARACTERIZATION STUDY

ULTRASONIC LONGITUDINAL AND SHEAR VELOCITIES OF CANDIDATE ISOTOPE ENCAPSULATION MATERIALS

WILLIAM D. JOLLY

OCTOBER, 1967

AEC RESEARCH &
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Ultrasonic Longitudinal and Shear Velocities of Candidate Isotope Encapsulation Materials

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MATERIALS CHARACTERIZATION STUDY

Ultrasonic Longitudinal and Shear Velocities of Candidate Isotope Encapsulation Materials

ABSTRACT

Ultrasonic longitudinal and shear velocities were measured for Inconcel X, Hastelloy X, Hastelloy C, TZM, 304L, 416, L605, Haynes 25, tungsten, tantalum, and molybdenum, which are candidate cladding materials for isotope heat capsules. The specimens used for this program were random samples of several configurations which required the use of different methods for velocity measurements. The differential path method was employed when possible because of its inherent accuracy. The pulse echo method and the through transmission method were required for some specimens, while for others the plate resonance method was used.

Methods used for the velocity measurements are described briefly. Included is a table listing the composition of materials and the method of velocity measurement for each specimen. A table of velocity data for the materials considered is provided which lists velocity in cm/sec and in./sec, and calculated values of acoustic impedance in g/cm^2-sec.

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William D. Jolly

INTRODUCTION

Ultrasonic flaw detection techniques are being used to examine isotope capsule materials, capsule seam welds, and completed isotope capsules. Since the ultrasonic properties of many candidate isotope capsule materials are not known, nondestructive testing of capsules using these materials is inhibited.

This report describes a program to measure the ultrasonic properties of 12 candidate isotope capsule materials selected by the AEC Division of Isotope Development,(1) that are expected to see continuing and future use as encapsulation materials.

SUMMARY

This study provides reference data on the ultrasonic properties of 11 candidate isotope capsule materials. These data will be useful in the selection of isotope capsule materials and in establishing ultrasonic nondestructive testing procedures for use during and after fabrication of isotope capsules.

Longitudinal velocity and shear velocity in the selected materials were measured, and the acoustic impedance of each material was calculated. Four different velocity measurement techniques were selected to accommodate round bar and plate test specimens and to be compatible with available electronic equipment.

Comparison of measurements indicates that, using the selected equipment, longitudinal and shear velocity data are reproducible with ±0.5% accuracy; however, frequency-dependent attenuation and grain-boundary scattering cause pulse distortions that introduce error into the transit time measurements. Since the magnitude of these effects depends, in part, on the manufacturing history of the specimen, the ultrasonic velocities for a given metal can be specified to within only about ±5.0%.

CANDIDATE MATERIALS

Table I lists the materials, their composition, and the methods used for measurement of the longitudinal and shear velocities of each. All of the required candidate materials except T-222 were obtained, but the two samples of rhenium were damaged beyond use while attempting to grind parallel surfaces on the small discs (0.060 in. thick). A sample of Unitemp L-605 was included for comparison with Haynes 25 which has the same alloy composition. Samples of each material were saved for possible metallographic analysis at a later date.

DESCRIPTION OF MEASUREMENT METHODS

Review of techniques for the measurement of ultrasonic velocities in solids exposed a number of methods suitable to this program.(2-7) However, since ultrasonic velocities may vary depending on the manufacturing history of a test specimen, nondestructive testing methods generally employed rely on relative accuracy of velocity measurements rather than absolute accuracy.(6) Since the absolute accuracy required for this program is not great, the measurement techniques were selected to be compatible with test specimen configurations and available equipment.

TABLE I. Composition of Candidate Materials and Method of Velocity Measurements

		Measurement Method			
Material	Composition, wt%	Differential Path	Plate Resonance	Pulse Echo	Through Transmission
Inconel X	Ni—0.15Cr—0.08Fe—0.02Ti	0 X			
Hastelloy X	Ni—0.2Cr—0.2Fe—0.1Mo	0 X		0	
Hastelloy C	Ni—0.18Mo—0.16Cr—0.06Fe	0 X	0		X
TZM	Mo—0.5Ti—0.08Zr—0.03C	0 X	0	0	X
304 L	Fe—0.2Cr—0.1Ni	0 X			
416	Fe—0.13Cr—0.01Si	0 X			
Haynes 25	Co—0.2Cr—0.15W—0.1Ni		0		X
L-605	Same as Haynes 25 but by Universal Cyclops			0	X
Tungsten	Tungsten		0		X
Tantalum	Tantalum	X		0	
Molybdenum	Molybdenum	X		0	X

0 = Longitudinal Velocity Measured

X = Shear Velocity Measured

The continuous wave method(4) and the pulse overlap interference method(6,7) were not employed because interpretation of data from these methods is difficult and requires accurate measurement of small changes in frequency. Techniques involving the direct measurement of transit time were selected in order to take advantage of the high resolution time readout of a Tektronix 567 oscilloscope.

Four techniques were necessary because several of the materials were available only in plate form, while others were available only as round bar. However, molybdenum, Hastelloy C, and TZM were obtained in both bar and plate stock and were used to cross-correlate results from the four selected methods of velocity measurements (Table I).

DIFFERENTIAL PATH TECHNIQUE

Test specimens were fabricated from materials available as bar stock of large enough diameter to fabricate test specimens with a 3/8 in. reduced section (Figure 1). The differential path technique(2,3) for measurement of longitudinal velocity was used on these specimens. As shown in Figure 2, the difference in transit time (Δt_1) between path A and path B was measured with the digital readout of a Tektronix 567 oscilloscope.

The longitudinal velocity is given by

$$V_L = 2L/\Delta t_1, \qquad (1)$$

where L is the length of the reduced section of the specimen.

The length of the threaded section of the specimen provides a time delay that separates the pertinent reflections from the transmitted pulse and the threads prevent shear wave generation in this section. However, mode conversion does occur in the reduced section of the specimen that has a smooth finish. Shear wave velocity is given by

$$V_S = \left[(1/V_L)^2 + (\Delta t_2/d)^2 \right]^{-1/2} \qquad (2)$$

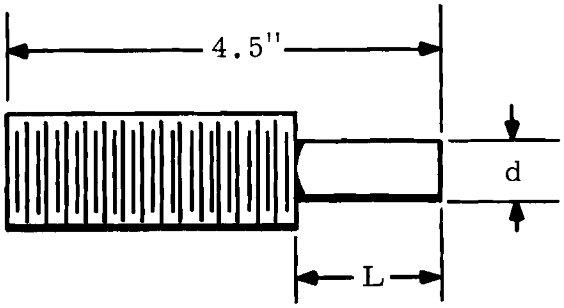

FIGURE 1. Specimen Configuration

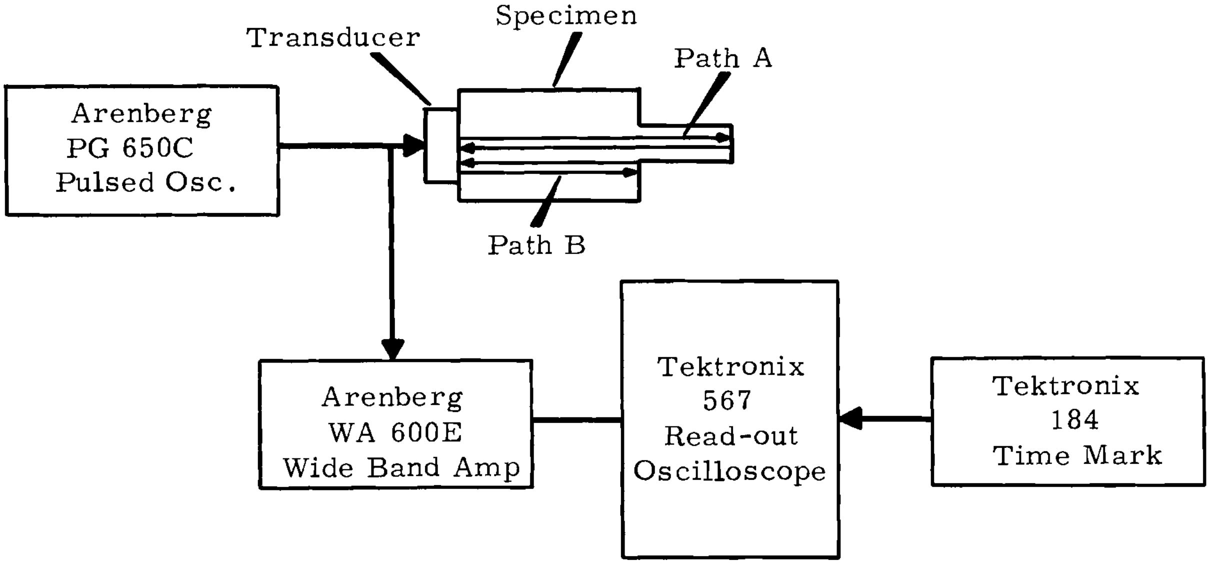

FIGURE 2. Differential Path Technique

where Δt_2 is the time delay between the direct longitudinal wave and the reconverted shear wave and d is the diameter of the reduced section of the specimen (Figure 1).

This technique eliminates errors due to phase shift on reflection from the transducer end of the specimen since all measurements are referenced to the free end of the specimen.

A test specimen of aluminum, in the configuration just described, was used to check the reproducibility of the system. Measurements of longitudinal and shear velocity were reproducible within ±0.5%. This was considered adequate for this program.

PLATE RESONANCE TECHNIQUE

The system for measurement of longitudinal velocity in plate specimens is shown in Figure 3. The fundamental thickness mode ($h = \lambda/2$) is excited in the specimen by a short wave train from the transducer. The transducer output is amplified and detected, and the resonant frequency, which modulates the wave train frequency, is observed following the initial pulse echo. Resonance is sustained within the plate for sufficient time to measure the period of 10 to 20 cycles. The longitudinal velocity is given by

$$V_L = 2\ hn/\Delta t \qquad (3)$$

where h = plate thickness,
n = number of cycles, and
Δt = time for n cycles.

Since the transducer is decoupled from the specimen by a water buffer, error due to phase shift on reflection need not be considered.

PULSE ECHO TECHNIQUE

The pulse echo method was used to measure longitudinal velocity in molybdenum, tantalum, and L-605 because the samples of these materials were either too short or too small in diameter to fabricate the bar sample described in the Differential Path Technique. A bar of TZM, 1 in. diameter by 10 in. long was also measured by this method. Molybdenum, tantalum, and TZM bars were long enough to make negligible the error due to phase shift from the transducer end, but L-605 (0.983 in. long by 2.0 in. diameter) and molybdenum plate (0.3113 in. thick) required the use of a water buffer to eliminate this error (Figure 3).

Longitudinal velocity using the pulse echo method is given by

$$V_L = 2L/\Delta t \tag{4}$$

where L =length of specimen, and
Δt = time between successive echoes.

Shear velocity for the bar specimens was obtained as described in the Differential Path Technique and both longitudinal and shear velocity measurements were made using the system shown in Figure 2.

THROUGH TRANSMISSION TECHNIQUE

Shear wave velocity measurements in plate specimens require rigid coupling of shear wave transducers to the test specimen. Figure 4 shows the system for these measurements. The transmitter and receiver buffer rods are placed in direct contact to establish a zero thickness reference. The specimen is inserted between the buffer rods and the change in transit time (Δt) is recorded. Shear velocity is given by

$$V_s = h/\Delta t \quad . \tag{5}$$

Shear wave transducer-buffer rod assemblies were fabricated with a cap over the transducer so that pressure contact could be used, but Dow Dorning blend 228 shear couplant was used to increase coupling efficiency. This couplant is squeezed out under pressure when the zero thickness reference

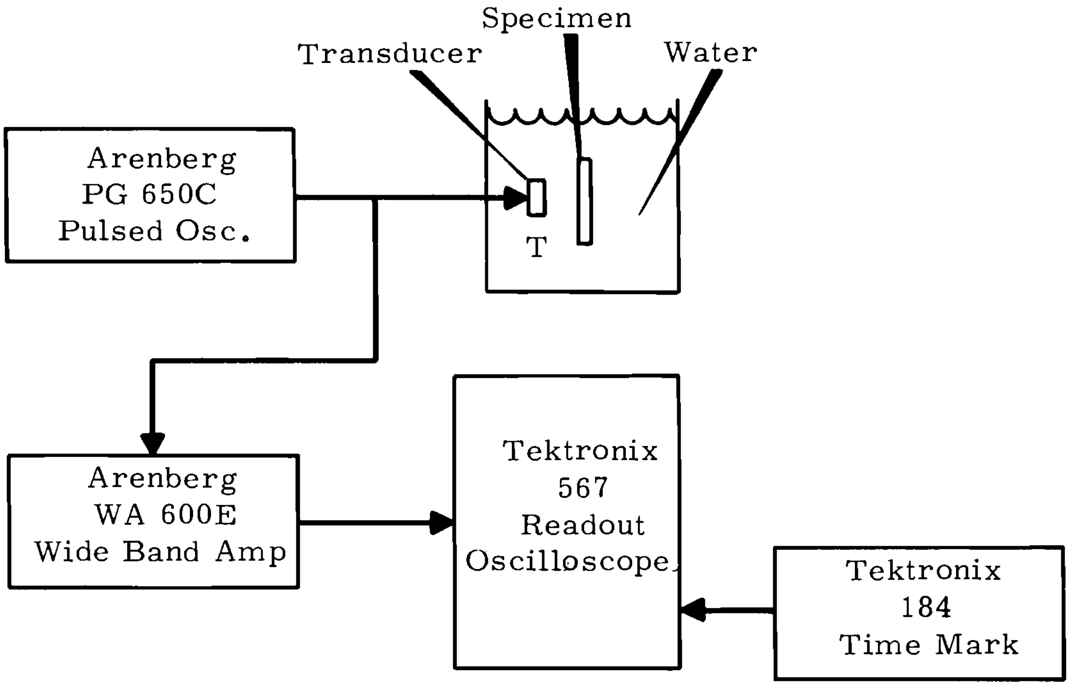

FIGURE 3. Plate Resonance and Pulse Echo System

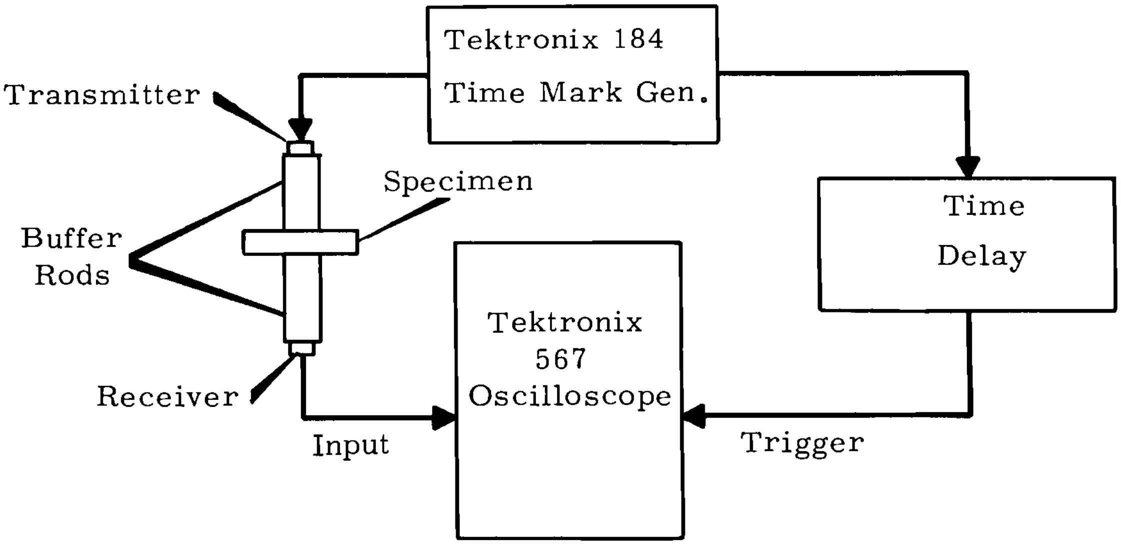

FIGURE 4. Through Transmission System for Shear Velocity

is established so that couplant film thickness does not change significantly when the specimen is inserted between buffer rods. Measurements of Δt with and without couplant agreed to within ±0.1%.

ELECTRONIC SYSTEMS

The measurement procedures of the first three methods use the same electronic system. All velocity measurements are made at frequencies between 3.5 MHz and 5 MHz. A wave train pulse from the Arenberg 650C drives the transducer. Transit time between received pulses is measured using the Tektronix 567 digital readout. The time base of the digital readout is referenced to a Tektronix 184 Time Mark Generator.

Repeatability of this system was established as described in the Differential Path Technique. The overall system accuracy was checked by measurement of the longitudinal velocity in a fused quartz reference block. The velocity measured differed by 0.4% from the listed velocity of fused quartz. This is within the resolution capability of the system.

For the through transmission measurements of shear velocity described in the Through Transmission Technique, the Tektronix 184 time mark pulse was used to drive the transmitting transducer, and the receiver transducer output was coupled directly to the Tektronix 567 oscilloscope. This arrangement provided a well defined pulse for measurement of change in transit time. The arrangement was possible because of the high sensitivity of the shear transducers.

Reproducibility of shear velocity measurements using this system was established at ±0.5% for changes in transit time near 1 μsec.

RESULTS

Although the reproducibility and accuracy of the electronic system have been established, absolute accuracy of velocities in the subject materials can not be established by the techniques described. Frequency-dependent attenuation and grain-boundary scattering cause pulse distortions that introduce error into the transit time measurements. Longitudinal and shear velocities and acoustic impedance values derived from this program are assumed to be sufficiently accurate for use in the selection of isotope capsule materials. Velocity data and calculated values of acoustic impedance are tabulated in Table II along with specimen configurations and density (8,9) for each material. Variation of velocity from specimen-to-specimen of a given material (e.g., TZM) is assumed to be due to different manufacturing histories of the specimens.

TABLE II. Results of Measurements

Material	Configuration	V_S		V_L		Density	Acoustic Impedance
		in./μsec	cm/μsec	in./μsec	cm/μsec	g/cm^3	g/cm^2-sec x 10^5
Inconel X	Shouldered Rod	0.123	0.312	0.234	0.594	8.3	49.3
Hastelloy X	Shouldered Rod	0.108	0.274	0.228	0.579	8.23	47.7
Hastelloy C	Shouldered Rod	0.114	0.290	0.230	0.584	8.94	52.2
	Plate	0.114	0.290	0.230	0.584		52.2
TZM	Shouldered Rod	0.137	0.375	0.252	0.640	10.16	65.0
	Straight Rod	0.136	0.345	0.255	0.648		65.8
	Plate	0.132	0.335	0.234	0.594		60.4
304L	Shouldered Rod	0.121	0.307	0.222	0.564	7.90	44.5
416	Shouldered Rod	0.127	0.323	0.237	0.602	7.70	46.35
Haynes 25	Plate	0.115	0.292	0.222	0.564	9.15	51.6
L-605	Short Rod	0.124	0.315	0.230	0.584	9.20	53.7
Tungsten	Plate	0.110	0.279	0.205	0.521	19.3	100.5
Tantalum	Rod	0.078	0.198	0.163	0.414	16.6	68.7
Molybdenum	Rod	0.137	0.348	0.243	0.617	10.22	63.1
	Plate	0.132	0.335	0.255	0.648		66.2

TABLE II. Results of Measurements (Revised 1968)

Material	Composition, wt%	V_S		V_L		Density	Acoustic Impedance	Configuration	Measurement Method			
		in./μsec	cm/μsec	in./μsec	cm/μsec	g/cm^3	g/cm^2-sec x 10^5		Differential Path	Plate Resonance	Pulse Echo	Through Transmiss
Haynes 25 (1)	Co–20Cr–15W–10Ni	0.115	0.292	0.222	0.564	9.15	51.6	Plate		0		X
(2)		0.114	0.290	0.230	0.584		53.4	Rod			0	X
Haynes 188	Co–23Cr–21Ni–13W–2Fe–0.5Mn	0.116	0.295	0.234	0.594	9.22	54.8	Plate		0		X
Haynes Stellite 21	Co–27Cr–5.5Mo–3Ni–2Fe	0.130	0.330	0.245	0.622	8.30	51.6	Thick Disc			0	X
Haynes Ta 782	Ta–10W	0.084	0.213	0.165	0.419	16.78	70.3	Plate		0		X
Hastelloy C (1)	Ni–18Mo–16Cr–6Fe–1Si–1Mn	0.114	0.290	0.230	0.584	8.94	52.2	Shouldered Rod	0 X			
(2)		0.114	0.290	0.230	0.584		52.2	Plate		0		X
(3)		0.116	0.295	0.229	0.582		52.0	Rod	X		0	
Hastelloy X (1)	Ni–20Cr–20Fe–10Mo	0.118*	0.300*	0.228	0.579	8.23	47.7	Shouldered Rod	0 X		0	
(2)		0.119	0.302	0.228	0.579		47.7	Rod	X		0	
Incoloy 825	Ni–21Cr–3Mo–2Cu–1Ti–1Mn	0.116	0.295	0.228	0.579	8.14	77.1	Plate		0		X
Inconel	Ni–16Cr–8Fe–1Mn	0.124	0.315	0.229	0.582	8.43	49.1	Rod			0	X
Inconel X	Ni–15Cr–8Fe–2Ti	0.123	0.312	0.234	0.594	8.30	49.3	Shouldered Rod	0 X			
Inconel 600	Ni–16Cr–7Fe–2Nb+Ta	0.124	0.315	0.232	0.589	8.45	49.8	Shouldered Rod	0 X			
L-605	Co–20Cr–15W–10Ni	0.124	0.315	0.230	0.584	9.20	53.7	Thick Disc			0	X
Molybdenum (1)	Molybdenum	0.137	0.348	0.243	0.617	10.22	63.1	Rod	X		0	
(2)		0.132	0.335	0.255	0.648		66.2	Plate		0		X
Stainless Steel												
304L	Fe–20Cr–10Ni	0.121	0.307	0.222	0.564	7.90	44.5	Shouldered Rod	0 X			
316	Fe–18Cr–13Ni–2Mo	0.121	0.307	0.225	0.572	7.98	45.6	Shouldered Rod	0 X			
416	Fe–13Cr–1Si	0.127	0.323	0.237	0.602	7.70	46.4	Shouldered Rod	0 X			
Tantalum	Tantalum	0.078	0.198	0.163	0.414	16.60	68.7	Rod	X		0	
TD Nickel	Ni–2ThO_2	0.112	0.284	0.207	0.526	8.91	46.9	Rod				
TD Nickel Chrome	Ni–20Cr–2ThO_2	0.116	0.295	0.213	0.541	8.44	45.7	Rod				
Tungsten	Tungsten	0.110	0.279	0.205	0.521	19.3	100.5	Plate		0		X
Tungsten Rhenium	W–25Re	0.111	0.282	0.204	0.518	19.56	101.4	Rod			0	X
TZM (1)	Mo–50Ti–8Zr–3C	0.137	0.348*	0.252	0.640	10.16	65.0	Shouldered Rod	0 X			
(2)		0.136	0.345	0.255	0.648		65.8	Rod			0	
(3)		0.132	0.335	0.234	0.594		60.4	Plate		0		X

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* *Previously published value in error*

0 = Longitudinal Velocity Measured

X = Shear Velocity Measured

TABLE 11. Results of Measurements (Revised 1968)

		V_S		V_L					Measurement Method			
terial	Composition, wt%	in./µsec	cm/µsec	in./µsec	cm/µsec	Density g/cm^3	Acoustic Impedance g/cm^2-sec x 10^5	Configuration	Differential Path	Plate Resonance	Pulse Echo	Through Transmission
25 (1)	Co–20Cr–15W–10Ni	0.115	0.292	0.222	0.564	9.15	51.6	Plate		0		X
(2)		0.114	0.290	0.230	0.584		53.4	Rod			0	X
188	Co–23Cr–21Ni–13W–2Fe–0.5Mn	0.116	0.295	0.234	0.594	9.22	54.8	Plate		0		X
Stellite 21	Co–27Cr–5.5Mo–3Ni–2Fe	0.130	0.330	0.245	0.622	8.30	51.6	Thick Disc			0	X
Ta 782	Ta–10W	0.084	0.213	0.165	0.419	16.78	70.3	Plate		0		X
oy C (1)	Ni–18Mo–16Cr–6Fe–1Si–1Mn	0.114	0.290	0.230	0.584	8.94	52.2	Shouldered Rod	0 X			
(2)		0.114	0.290	0.230	0.584		52.2	Plate		0		X
(3)		0.116	0.295	0.229	0.582		52.0	Rod	X		0	
oy X (1)	Ni–20Cr–20Fe–10Mo	0.118*	0.300*	0.228	0.579	8.23	47.7	Shouldered Rod	0 X		0	
(2)		0.119	0.302	0.228	0.579		47.7	Rod	X		0	
825	Ni–21Cr–3Mo–2Cu–1Ti–1Mn	0.116	0.295	0.228	0.579	8.14	77.1	Plate		0		X
	Ni–16Cr–8Fe–1Mn	0.124	0.315	0.229	0.582	8.43	49.1	Rod			0	X
X	Ni–15Cr–8Fe–2Ti	0.123	0.312	0.234	0.594	8.30	49.3	Shouldered Rod	0 X			
600	Ni–16Cr–7Fe–2Nb+Ta	0.124	0.315	0.232	0.589	8.45	49.8	Shouldered Rod	0 X			
	Co–20Cr–15W–10Ni	0.124	0.315	0.230	0.584	9.20	53.7	Thick Disc			0	X
num (1)	Molybdenum	0.137	0.348	0.243	0.617	10.22	63.1	Rod	X		0	
(2)		0.132	0.335	0.255	0.648		66.2	Plate		0		X
ss Steel												
	Fe–20Cr–10Ni	0.121	0.307	0.222	0.564	7.90	44.5	Shouldered Rod	0 X			
	Fe–18Cr–13Ni–2Mo	0.121	0.307	0.225	0.572	7.98	45.6	Shouldered Rod	0 X			
	Fe–13Cr–1Si	0.127	0.323	0.237	0.602	7.70	46.4	Shouldered Rod	0 X			
n	Tantalum	0.078	0.198	0.163	0.414	16.60	68.7	Rod	X		0	
el	Ni–2ThO$_2$	0.112	0.284	0.207	0.526	8.91	46.9	Rod				
el Chrome	Ni–20Cr–2ThO$_2$	0.116	0.295	0.213	0.541	8.44	45.7	Rod				
n	Tungsten	0.110	0.279	0.205	0.521	19.3	100.5	Plate		0		X
n Rhenium	W–25Re	0.111	0.282	0.204	0.518	19.56	101.4	Rod			0	X
	Mo–50Ti–8Zr–3C	0.137	0.348*	0.252	0.640	10.16	65.0	Shouldered Rod	0 X			
		0.136	0.345	0.255	0.648		65.8	Rod			0	
		0.132	0.335	0.234	0.594		60.4	Plate		0		X

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ously published value in error

gitudinal Velocity Measured

ar Velocity Measured

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