OAK RIDGE NATIONAL LABORATORY
operated by
UNION CARBIDE CORPORATION
for the
U. S. ATOMIC ENERGY COMMISSION

ORNL – TM – 1017

120

TENSILE AND CREEP PROPERTIES OF INOR-8 FOR THE MOLTEN-SALT REACTOR EXPERIMENT

J. T. Venard

PATENT CLEARANCE OBTAINED. RELEASE TO
THE PUBLIC IS APPROVED. PROCEDURES
ARE ON FILE IN THE RECEIVING SECTION.

NOTICE This document contains information of a preliminary nature and was prepared primarily for internal use at the Oak Ridge National Laboratory. It is subject to revision or correction and therefore does not represent a final report.

ORNL-TM-1017

Contract No. W-7405-eng-26

METALS AND CERAMICS DIVISION

TENSILE AND CREEP PROPERTIES OF INOR-8 FOR THE MOLTEN-SALT REACTOR EXPERIMENT

J. T. Venard

FEBRUARY 1965

OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee
operated by
UNION CARBIDE CORPORATION
for the
U.S. ATOMIC ENERGY COMMISSION

TENSILE AND CREEP PROPERTIES OF INOR-8 FOR THE MOLTEN-SALT REACTOR EXPERIMENT

J. T. Venard

ABSTRACT

Tensile and creep-rupture testing has been carried out on three heats of INOR-8 selected from those used for the Molten-Salt Reactor Experiment construction. The primary aim was to develop strength information representative of the reactor construction material and to compare the data on these commercial heats with that from early experimental heats.

The data reported are ultimate tensile strength, 0.2% offset yield strength, percent elongation, and percent reduction in area vs temperature from room temperature to 982°C (1800°F). Creep-rupture behavior was investigated at 593, 704, and 816°C (1100, 1300, and 1500°F).

In general, the commercial MSRE construction material shows greater strength and ductility than did earlier heats of the alloy. Additional confidence in the MSRE design strength values is thus in order.

INTRODUCTION

The decision to build the Molten-Salt Reactor Experiment necessitated the procurement of some 100 tons of INOR-8 (Ref. 1). Since some minor chemistry changes had been made to ensure weldability in these commercial heats[2] and because of a desire to have strength information representative of MSRE construction material, a series of tensile and creep tests were performed.

Three heats of material were selected from the 27 heats used in the reactor. This material was used for tensile tests in the range of 21°C (70°F) to 982°C (1800°F). Creep-rupture tests were performed at 593, 704, and 816°C (1100, 1300, and 1500°F).

---

[1] Designated as Hastelloy N by Stellite Division of Union Carbide Corporation and as INCO-806 by the International Nickel Company.

[2] R. G. Gilliland and G. M. Slaughter, Influence of Minor Alloying Additions in INOR-8 Welds. Paper presented at Annual Meeting of American Welding Society, Philadelphia, Pa., April 22–26, 1963. (To be submitted to the Welding Journal).

MATERIAL AND SPECIMENS

The alloy INOR-8 was developed especially for use in molten-salt systems.[3] The following tabulation gives the nominal composition of this alloy.

Element	Weight Percent[4]
Nickel	Balance
Molybdenum	15.00–18.00
Chromium	6.00–8.00
Iron	5.00
Carbon	0.04–0.08[5]
Manganese	1.0
Silicon	1.0
Tungsten	0.50
Aluminum + Titanium	0.50
Copper	0.35
Cobalt	0.20
Phosphorus	0.015
Sulfur	0.020
Boron	0.010
Vanadium	0.50

The three heats of material selected for testing were in the form of plate. Their compositions are given in Table 1. Note that there is little difference in the composition of the three heats. The major differences are in the chromium, iron and manganese content of heat 5075.

Metallographically, the three heats of material look quite the same, as is seen in Figs. 1 through 3. Note the stringers of precipitated material which are aligned with the plate rolling direction. This kind of structure is typical of this alloy in the wrought condition.

---

[3] T. K. Roche, The Influence of Composition Upon the 1500°F Creep-Rupture Strength and Microstructure of Molybdenum-Chromium-Iron-Nickel-Base Alloys, ORNL-2524, (June 24, 1958).

[4] Single values are maximum percentages.

[5] 0.02 to 0.08 for pipe and tubing is included.

Table 1. Chemical Analysis From Certified Test Reports

Designation	Composition (wt %)															
	Ni	Mo	Cr	Fe	C	Mn	Si	W	Al	Ti	Cu	Co	P	S	B	V
Heat 5055	Bal	16.20	7.86	3.76	0.06	0.69	0.61	0.03	0.06	0.02	0.01	0.10	0.006	0.008	0.005	0.21
Heat 5075	Bal	16.14	6.76	4.03	0.06	0.42	0.59	0.04	0.01	0.01	0.01	0.08	0.003	0.007	0.001	0.28
Heat 5081	Bal	16.87	7.43	3.35	0.07	0.55	0.60	0.03	0.01	0.01	0.02	0.07	0.001	0.006	0.004	0.26

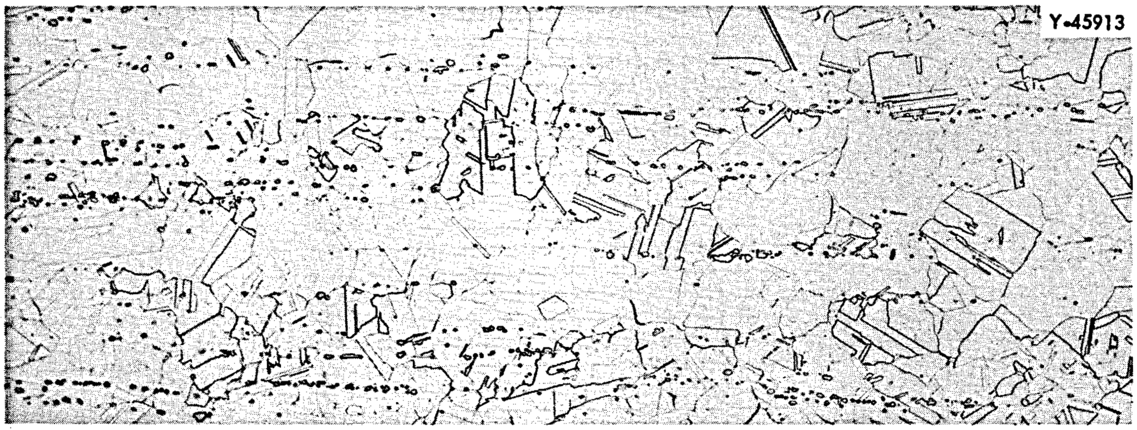

Fig. 1. As-Received INOR-8 Heat 5055. Etchant: aqua regia. 100X.

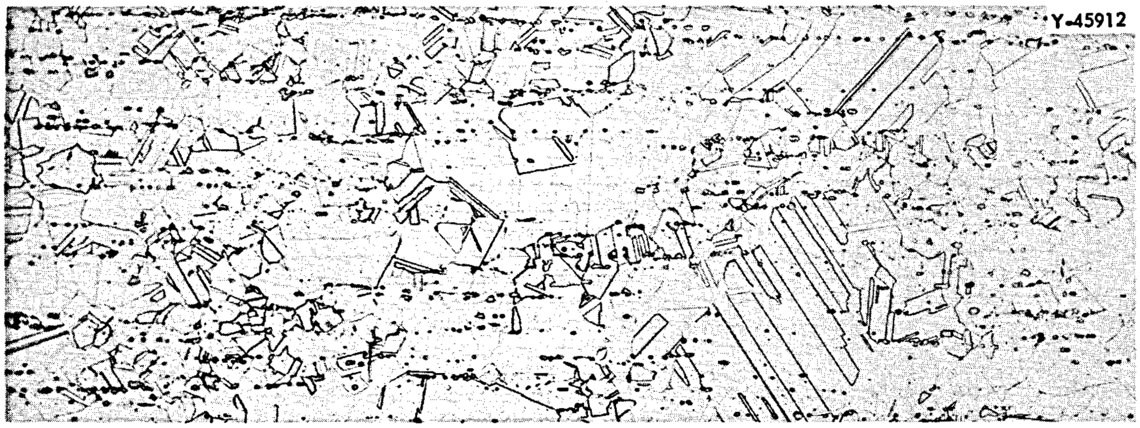

Fig. 2. As-Received INOR-8 Heat 5075. Etchant: aqua regia. 100X.

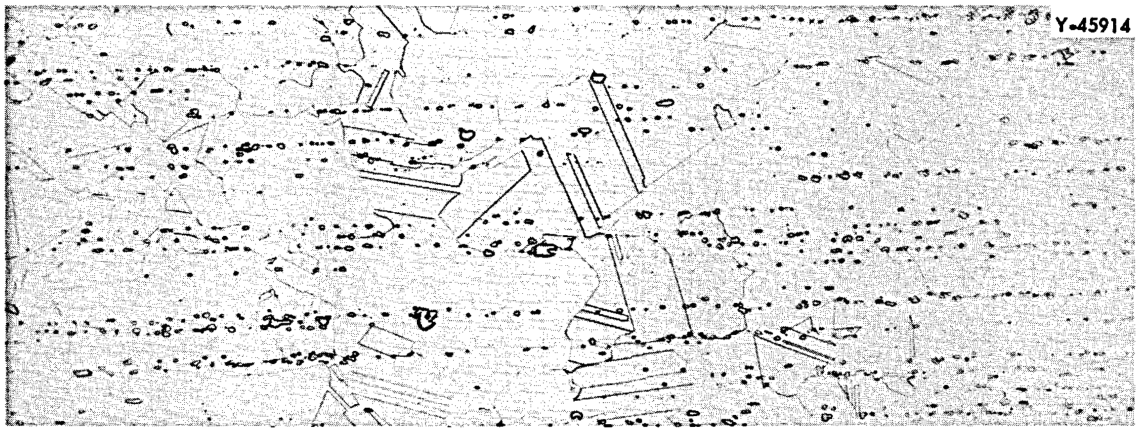

Fig. 3. As-Received INOR-8 Heat 5081. Etchant: aqua regia. 100X.

The specimens for the test program were cut both parallel and normal to the plate rolling direction. A drawing of the specimen is shown in Fig. 4.

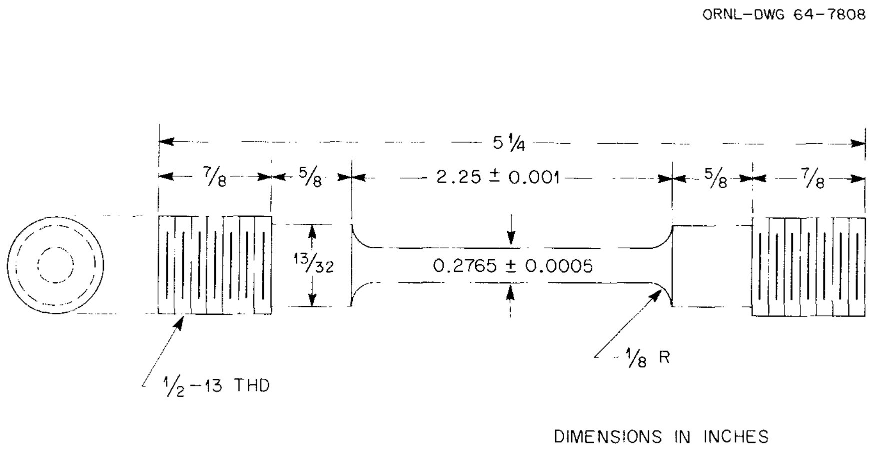

Fig. 4. Creep and Tensile Specimen, INOR-8.

TESTING METHODS AND RESULTS

All tensile tests were run in a 12,000-lb capacity Baldwin Hydraulic Testing Machine at a crosshead speed of 0.05 in./min. Stress-strain curves were obtained through load cell-deflectometer outputs. In the case of elevated-temperature tests, 1/2 hr was allowed for the specimen to reach equilibrium before loading was begun.

Average tensile data for heats 5075 and 5081 are shown in Table 2. Two specimens of each heat were run at every temperature.

Table 2. Average Tensile Properties for INOR-8, Heats 5075 and 5081

Temperature (°C)	Temperature (°F)	Ultimate Tensile Strength (psi)	0.2% Offset Yield Strength (psi)	Elongation (%)	Reduction of Area (%)
21	70	113,600	46,500	53.1	54.0
315	600	103,300	36,000	55.0	50.0
427	800	100,100	35,000	53.3	52.5
538	1000	96,000	33,200	53.3	46.5[a] 52.0[b]
649	1200	74,800	32,600	22.0[a] 35.8[b]	27.9[a] 35.8[b]
760	1400	61,800	31,800	21.0[a] 30.5[b]	22.8[a] 29.8[b]
871	1600	36,400	31,600	23.0[a] 39.8[b]	24.6[a] 43.2[b]
982	1800	20,300	20,000	27.9	28.9

[a] Heat 5075

[b] Heat 5081

Creep tests were run in Arcweld Lever Arm Testing Machines and strain data obtained through dial-gage extensometers attached to the specimen shoulders.

Detailed tabulations of the creep-rupture test results are given in Tables 3, 4, and 5.

DISCUSSION OF RESULTS

The tensile properties of heats 5075 and 5081 are plotted in Figs. 5, 6, 7, and 8. These figures show ultimate tensile strength, 0.2% offset yield strength, elongation, and reduction of area vs temperature. The scatter bands for experimental heats of INOR-8 shown in these figures were developed from data generated some time ago.[6,7]

The ultimate and yield strengths show no significant variation with the heat tested nor did they vary with specimen-plate orientation. The ductility values, however, indicate that above approximately 538°C (1000°F) heat 5075 is less ductile than heat 5081.

Creep and rupture curves plotted as log time to reach a total strain of 0.2, 0.5, 1.0, 2.0, and 5.0% and log time-to-rupture vs log stress are given in Figs. 9 through 17. The elongation at fracture for each test is noted by the numbers in parentheses.

Comparison of the various creep ductility values show that, as in the tensile tests, heat 5075 was less ductile than the other heats tested.

A stress-rupture plot for all three heats is shown in Fig. 18. The results for heats 5055 and 5081 have been fitted with a single curve, while heat 5075 shows a somewhat lower rupture strength. It should be pointed out that the weakest of these heats, heat 5075, is as strong as the strongest experimental heats previously reported.[6]

It is interesting to note from Fig. 19, which plots log minimum creep rate vs log stress, that the creep rates of all three heats are the same.

---

[6] R. W. Swindeman, Mechanical Properties of INOR-8, ORNL-2780, (Jan. 10, 1961).

[7] R. W. Swindeman, Unpublished Data in Private Communication to J. T. Venard, January, 1963.

Table 3. Creep and Rupture Data for INOR-8 Tested in Air[a]

Test Number	Test Temperature		Stress (psi)	Time to Reach Strain Level (hr)						Minimum Creep Rate (hr^{-1})	Elongation at Fracture (%)
	(°C)	(°F)		0.2%	0.5%	1.0%	2.0%	5.0%	Rupture		
2267	593	1100	81,000					0.80	5.1	7.8×10^{-3}	37.2
2262	593	1100	70,000	0.10	0.15	0.20	0.40	32.2	33.5	6.5×10^{-4}	19.6
2248	593	1100	61,000	0.50	2.0	14.0	53.0		140.4	2.2×10^{-4}	4.6
2201	593	1100	50,000	10.0	18.0	40.0	100.0	875	1040.7	2.3×10^{-5}	6.2
1833	593	1100	35,000	500	1800	3350	5350	9325	9818.7	2.6×10^{-6}	5.4
2273	704	1300	52,000			0.10	0.40	1.6	6.2	3.5×10^{-2}	29.8
2264	704	1300	39,000	0.20	1.0	2.7	6.2	13.8	29.8	3.4×10^{-3}	16.1
2254	704	1300	34,000	0.50	2.5	5.2	11.0	26.2	68.3	1.9×10^{-3}	15.9
2246	704	1300	31,000	2.0	5.0	12.0	25.0	64.0	160.3	7.8×10^{-4}	38.0
1840	704	1300	27,500	4.0	14.0	30.0	60	144	346.7	3.5×10^{-4}	29.1
2200	704	1300	25,000	5.0	15	30	60	160	859.7	3.0×10^{-4}	50.3
2144	704	1300	22,000	5.0	14	34	75	185	526.4	2.6×10^{-4}	14.9
1982	704	1300	20,000	10	30	95	210	530	1707.3	9.4×10^{-5}	26.8
1842	704	1300	18,000	5	70	160	400	950	2682.2	5.0×10^{-5}	25.0
2274	816	1500	23,000	0.1	0.3	0.6	1.2	3.0	13.9	1.8×10^{-2}	48.0
2272	816	1500	15,000	1.0	4.0	6.0	11	22	93.5	2.8×10^{-3}	42.9
2253	816	1500	12,500	1.0	4.0	8.0	16	42	189.0	1.2×10^{-3}	33.7
2239	816	1500	10,500	1.0	5.0	20	40	120	390.9	4.2×10^{-4}	23.2
2188	816	1500	8,200	2.5	5.0	40	120	340	909.1	1.5×10^{-4}	20.5
2263	816	1500	5,600	56	250	550	1250	3500	7593.8	1.1×10^{-5}	20.1
1986	816	1500	5,600	100	280	660	1660		2377.1[b]	9.0×10^{-4}	

[a] Specimens of heat 5055 cut parallel to plate rolling direction.

[b] Discontinued.

Table 4. Creep and Rupture Data for INOR-8 Tested in Air[a]

Test Number[b]	Test Temperature (°C)	Test Temperature (°F)	Stress (psi)	Time to Reach Strain Level (hr) 0.2%	0.5%	1.0%	2.0%	5.0%	Rupture	Minimum Creep Rate (hr^{-1})	Elongation at Fracture (%)
3142(P)	593	1100	64,000		0.1	0.3	0.8	6.7	8.9	6.0×10^{-4}	13.9
3127(P)	593	1100	59,000	0.2	0.5	1.2	3.0	18.0	23.5	2.0×10^{-4}	10.8
2547(T)	593	1100	55,000	0.2	0.3	0.6	1.2	75.0	78.6	5.0×10^{-5}	9.1
2427(P)	593	1100	48,500	33.0	103	133	135		135.6	5.5×10^{-5}	7.8
2564(T)	593	1100	47,000	40.0	130	200	203		205.5	3.5×10^{-5}	4.4
2826(T)	593	1100	42,000	130	465	732			885.2	6.0×10^{-6}	1.6
2782(P)	593	1100	39,000	250	625	732			749.5	3.0×10^{-6}	1.5
3097(T)	593	1100	31,000	400	1400	2600	3890		3927.0	1.6×10^{-6}	3.9
2982(T)	704	1300	35,000	0.3	2.0	4.4	10.0		22.6	2.0×10^{-3}	4.8
2952(P)	704	1300	26,000	1.5	4.5	11.0	50.0		75.7	2.1×10^{-4}	4.4
2944(T)	704	1300	23,000	2.0	10.0	25.0	60.0	133	135.3	1.3×10^{-4}	5.2
2637(P)	704	1300	22,000	25.0	48.0	77.0	114		137.9	1.3×10^{-4}	4.2
2997(T)	704	1300	18,500	1.0	6.0	67.0	193.0	451.0	491.2	8.3×10^{-5}	7.5
2998(P)	704	1300	16,500	10.0	50.0	126	305	645	680.2	5.1×10^{-5}	7.5
2888(T)	704	1300	15,000	10.0	65.0	195	450	855	924.8	4.2×10^{-5}	7.1
2783(P)	704	1300	14,000	10.0	150	350	750	1410	1505.1	2.6×10^{-5}	7.6
2951(P)	704	1300	13,000	10.0	100	300	820	1605	1698.8	1.8×10^{-5}	7.6
3086(T)	816	1500	19,000	0.1	0.4	0.9	2.0	6.5	20.6	6.3×10^{-3}	28.9
3025(P)	816	1500	12,000	0.5	2.0	4.5	11.5	35.0	148.6	1.3×10^{-3}	23.9
2977(T)	816	1500	10,000	2.0	11.0	20.0	46.0	121	358.1	3.9×10^{-4}	19.9
2565(P)	816	1500	7,200	15.0	45.0	90.0	185	385	486.4	5.8×10^{-5}	11.2
2948(T)	816	1500	6,700	1.0	45.0	105	230	555	1034.3	8.3×10^{-5}	12.8
2892(P)	816	1500	4,900	40.0	105	360	930	2175	2757.4	1.9×10^{-5}	10.0

---

[a] Specimens of heat 5075.

[b] (P) indicates specimen cut parallel to plate rolling direction and (T) indicates specimen cut transverse to plate rolling direction.

Table 5. Creep and Rupture Data for INOR-8 Tested in Air[a]

Test Number[b]	Test Temperature (°C)	Test Temperature (°F)	Stress (psi)	Time to Reach Strain Level (hr) 0.2%	0.5%	1.0%	2.0%	5.0%	Rupture	Minimum Creep Rate (hr^{-1})	Elongation at Fracture (%)
3137(T)	593	1100	74,000	0.1	0.2	0.3	0.6	16.0	24.1	1.4×10^{-3}	28.7
3119(P)	593	1100	66,000	0.1	0.3	0.4	0.5	72.0	93.4	2.8×10^{-4}	20.3
3105(T)	593	1100	63,000	5.0	22.0	46.0	88.0	121	122.9	2.1×10^{-4}	14.6
3103(P)	593	1100	57,000			0.1	0.4	340	377.5	3.5×10^{-5}	13.5
2478(P)	593	1100	52,000	20.0	75.0	220	425	602	609.4	3.0×10^{-5}	7.6
2466(T)	593	1100	50,000						786.2	1.8×10^{-5}	8.9
2571(P)	593	1100	46,000		400	800	1300	1612	1615.3	1.2×10^{-5}	7.0
2991(T)	704	1300	48,000		0.1	0.2	0.5	3.0	13.2	1.3×10^{-2}	28.6
2958(P)	704	1300	39,500	0.5	1.5	3.0	6.5	16.0	53.3	3.2×10^{-3}	26.1
2943(T)	704	1300	28,500	2.0	9.0	19.0	39.0	92.0	150.9	5.1×10^{-4}	12.8
2968(P)	704	1300	25,500	5.0	20.0	42.0	82.0	200	469.3	2.6×10^{-4}	17.2
2559(T)	704	1300	20,500	10.0	40.0	80.0	175	460	1194.6	1.1×10^{-4}	23.2
1958(P)	704	1300	20,000	60.0	135	270	425	910	1152.1	3.7×10^{-5}	5.9
2900(P)	704	1300	19,300	10.0	50.0	120	280	735	1596.7	6.8×10^{-5}	17.9
3067(T)	816	1500	21,000		0.2	0.8	2.0	5.0	25.2	9.0×10^{-3}	46.8
3072(P)	816	1500	16,000	0.5	1.0	2.5	5.5	12.0	52.8	4.3×10^{-3}	38.2
3014(T)	816	1500	14,000	1.0	4.5	6.5	13.5	34.0	125.2	1.4×10^{-3}	30.0
2976(T)	816	1500	11,000	2.0	6.0	15.0	35.0	95.0	422.8	5.1×10^{-4}	35.8
2949(P)	816	1500	8,700	5.0	20.0	45.0	100	275	834.2	1.8×10^{-4}	23.2
2575(T)	816	1500	8,000	5.0	30.0	65.0	145	385	1429.8	1.1×10^{-4}	20.3
3071(P)	816	1500	6,300	12.0	50.0	150	325	1330	4896.3	2.3×10^{-5}	26.5

[a] Specimens of heat 5081.

[b] (T) indicates specimen cut transverse to plate rolling direction and (P) indicates specimen cut parallel to plate rolling direction.

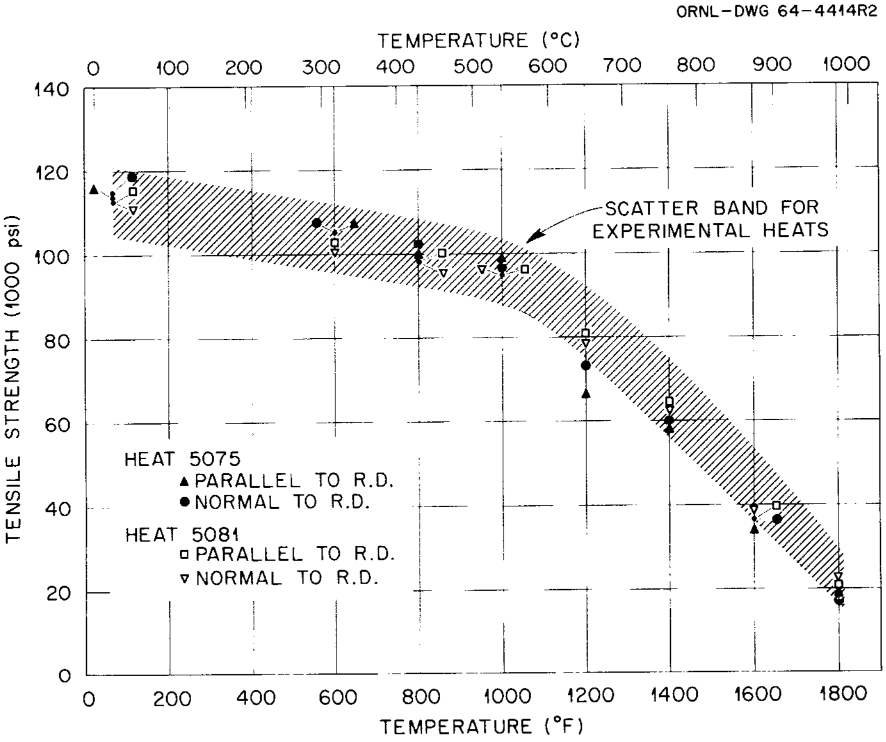

Fig. 5. Ultimate Tensile Strength of MSRE INOR-8.

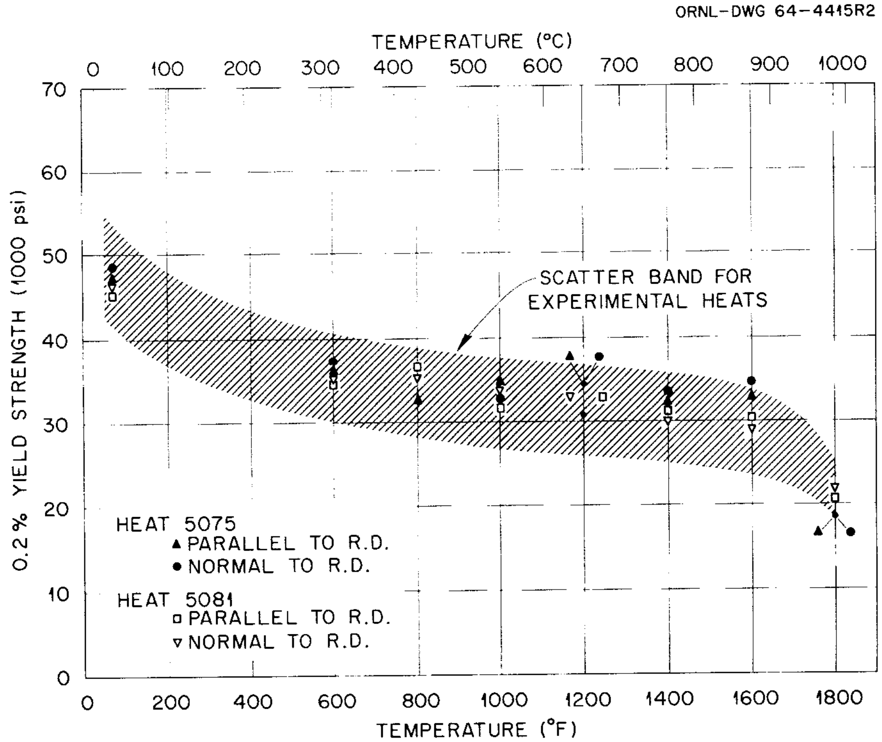

Fig. 6. Two Percent Yield Strength of MSRE INOR-8.

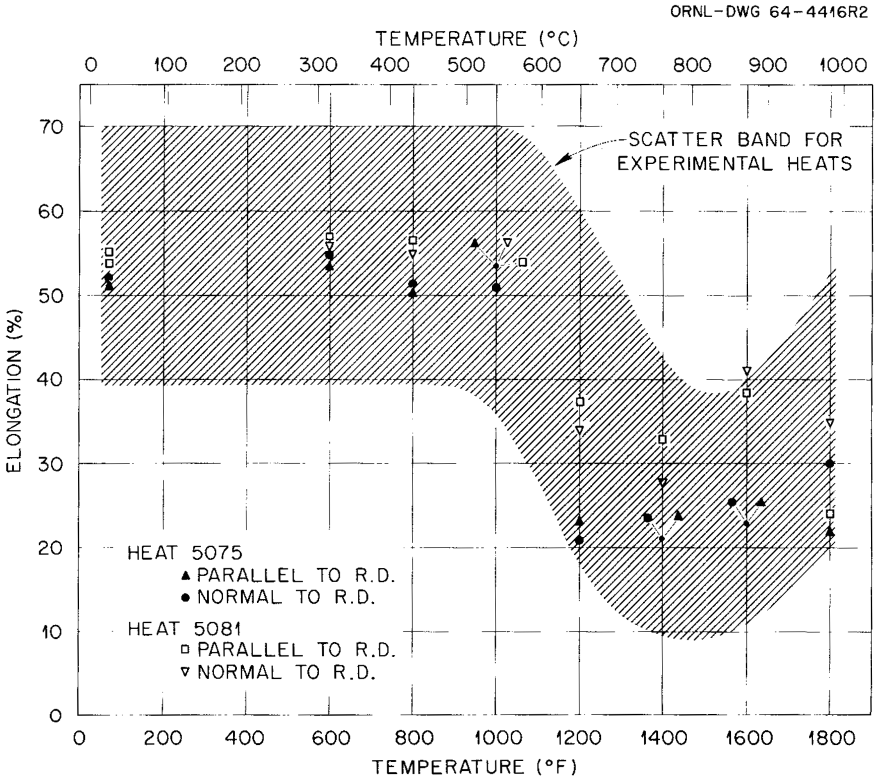

Fig. 7. Elongation in 2 in. of MSRE INOR-8.

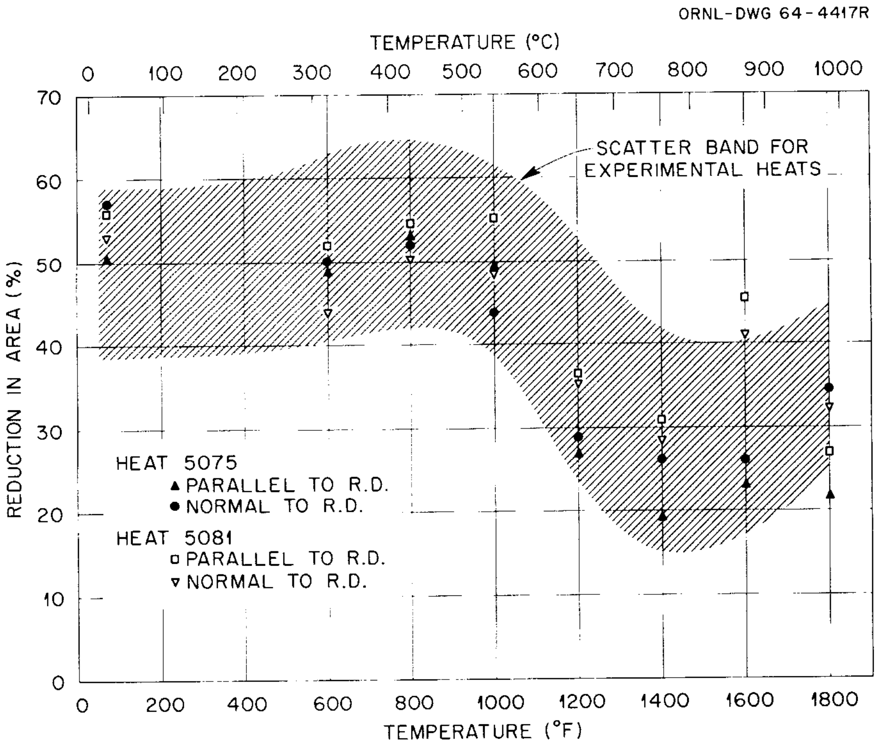

Fig. 8. Reduction of Area of MSRE INOR-8.

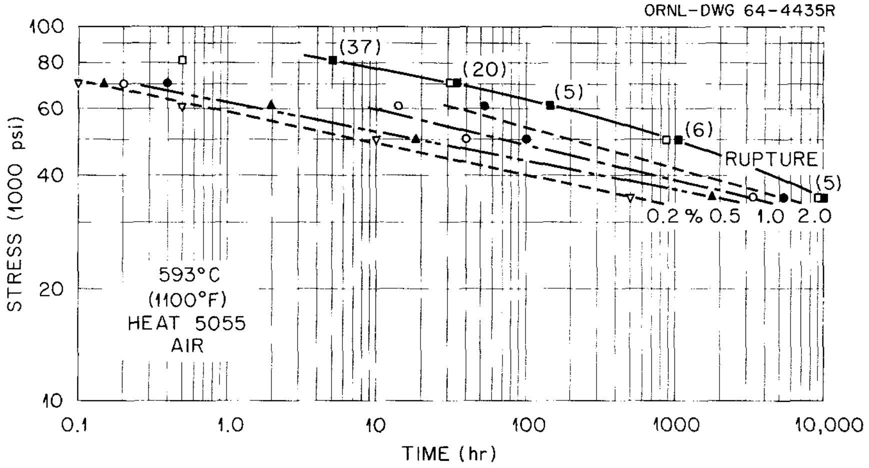

Fig. 9. Creep and Rupture Data for MSRE INOR-8.

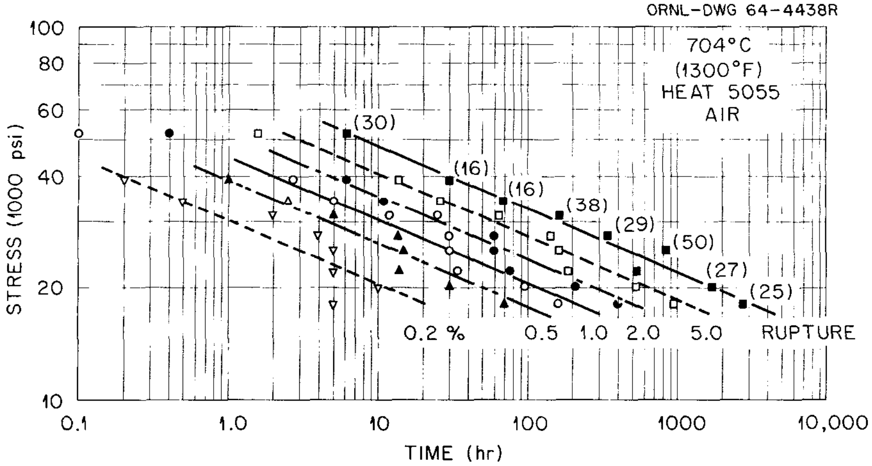

Fig. 10. Creep and Rupture Data for MSRE INOR-8.

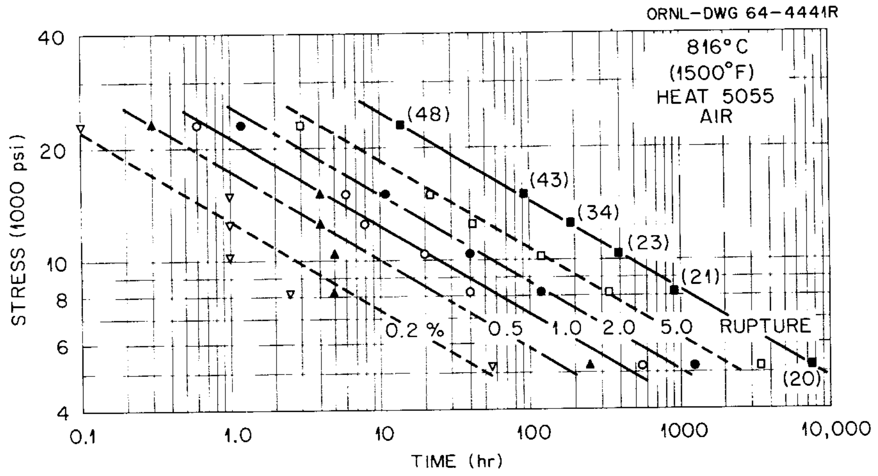

Fig. 11. Creep and Rupture Data for MSRE INOR-8.

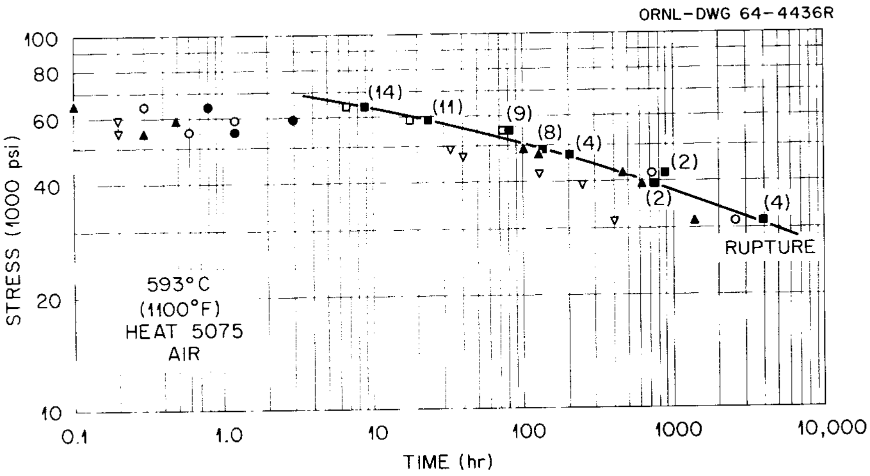

Fig. 12. Creep and Rupture Data for MSRE INOR-8.

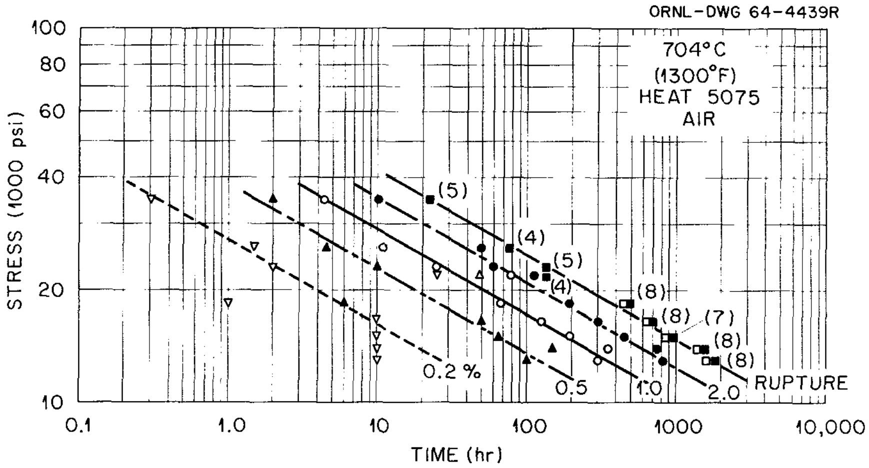

Fig. 13. Creep and Rupture Data for MSRE INOR-8.

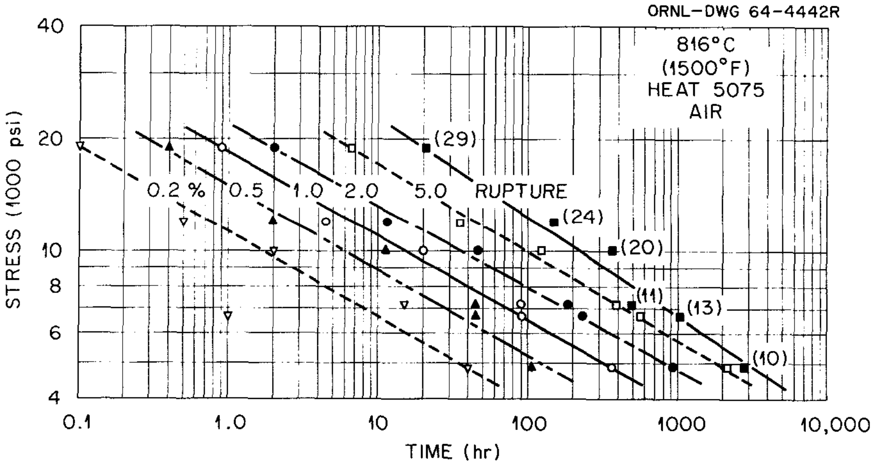

Fig. 14. Creep and Rupture Data for MSRE INOR-8.

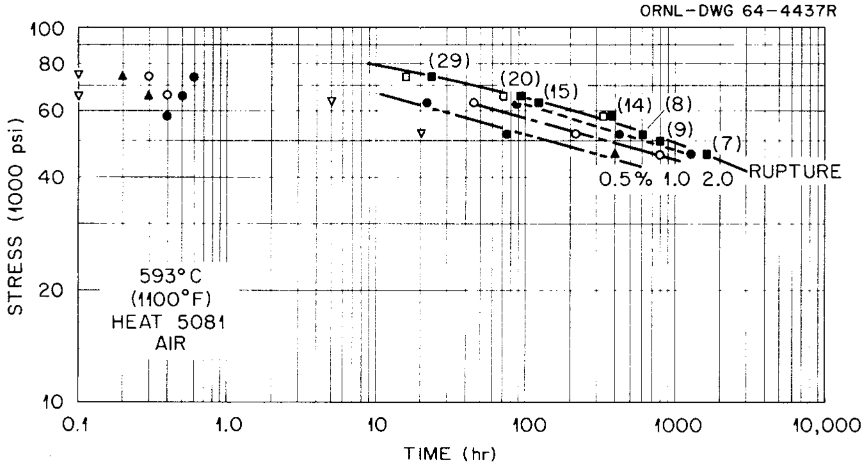

Fig. 15. Creep and Rupture Data for MSRE INOR-8.

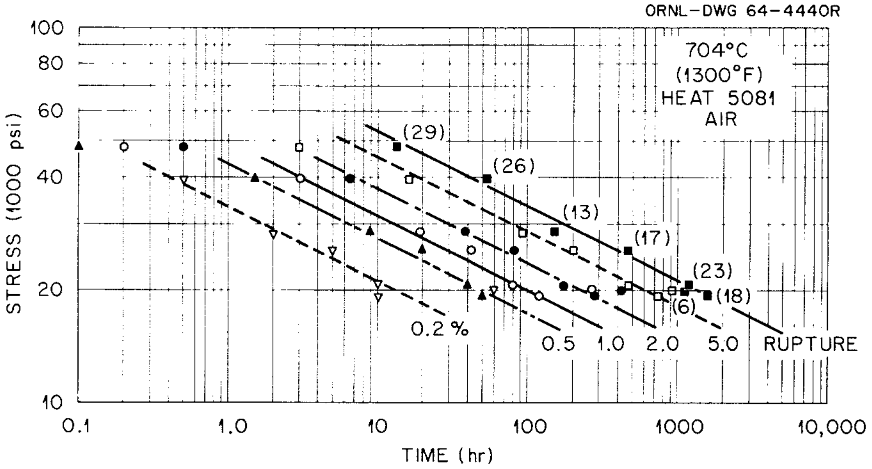

Fig. 16. Creep and Rupture Data for MSRE INOR-8.

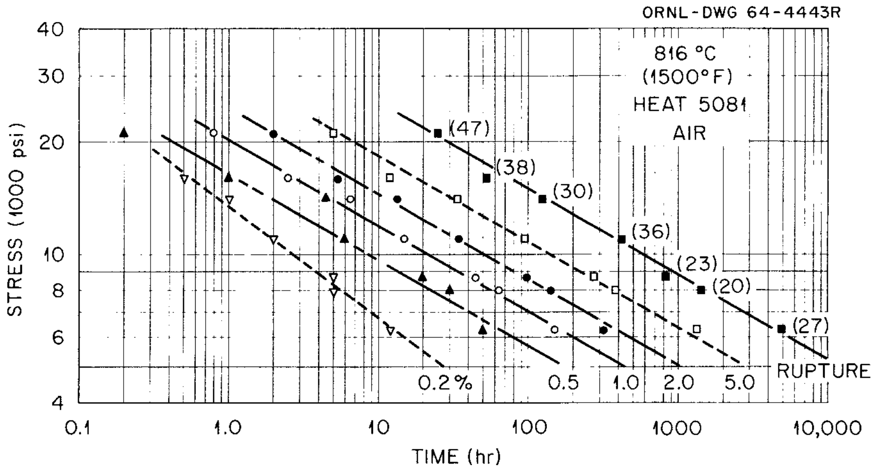

Fig. 17. Creep and Rupture Data for MSRE INOR-8.

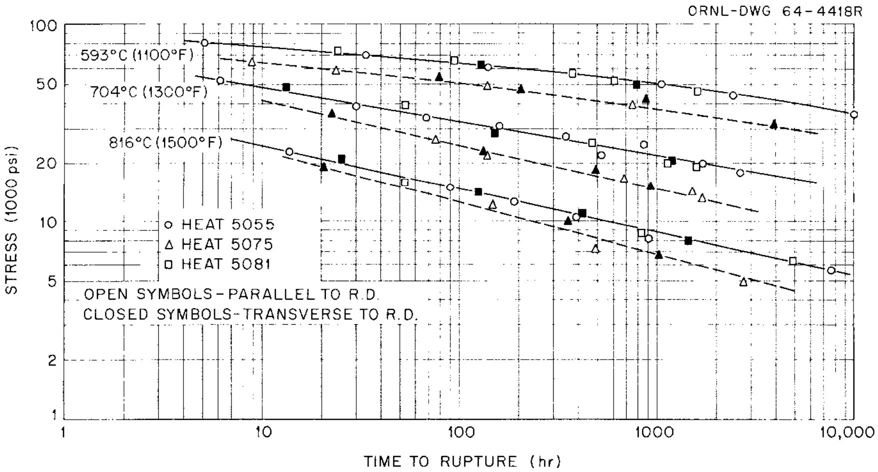

Fig. 18. Stress-Rupture Behavior of MSRE INOR-8.

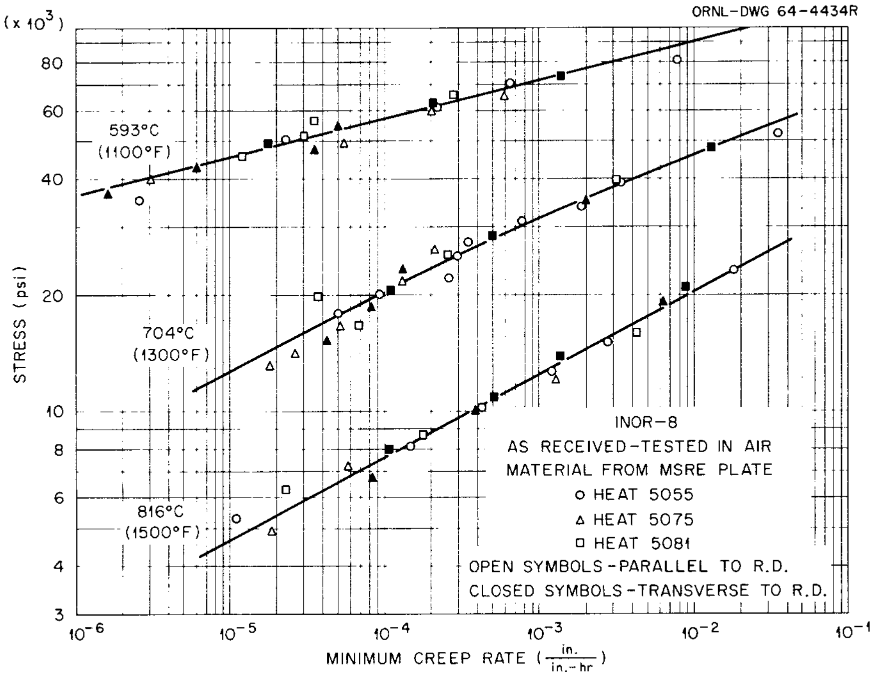

Fig. 19. Creep Behavior of MSRE INOR-8.

CONCLUSIONS

These experiments on three heats of INOR-8 used in the MSRE construction can be summarized with the following conclusions:

1. The tensile properties are equivalent to those for earlier experimental heats of INOR-8.

2. The three heats tested show no tensile strength variation with plate orientation or with heat.

3. One heat (5075) exhibited somewhat less ductility at temperatures above approximately 538°C (1000°F) compared with heats 5055 and 5081.

4. Rupture strength in creep for these 3 heats is somewhat better than those for the earlier heats.

5. The minimum creep rate behavior of all three heats is the same.

Since the design of the MSRE was based on the data from earlier experimental heats of INOR-8, it would appear that an extra measure of confidence in the integrity of the INOR-8 components of the reactor components is in order.

ACKNOWLEDGEMENTS

The author wishes to express his appreciation to the Graphic Arts Department and the Metals and Ceramics Division Reports Office for their help in preparing this document. The work of C. W. Walker, who ran the creep experiments; C. W. Dollins, who ran the tensile tests; and V. G. Lane, who helped prepare the data, is also appreciated.

INTERNAL DISTRIBUTION

1–2. Central Research Library
3. ORNL – Y-12 Technical Library
Document Reference Section
4–6. Laboratory Records
7. Laboratory Records, ORNL RC
8. ORNL Patent Office
9. G. M. Adamson, Jr.
10. L. G. Alexander
11. S. E. Beall
12. C. E. Bettis
13. E. S. Bettis
14. D. S. Billington
15. F. F. Blankenship
16. G. E. Boyd
17. A. L. Boch
18. S. E. Bolt
19. C. J. Borkowski
20. E. J. Breeding
21. F. R. Bruce
22. O. W. Burke
23. D. O. Campbell
24. S. Cantor
25. W. G. Cobb
26. J. A. Conlin
27. W. H. Cook
28. L. T. Corbin
29. G. A. Cristy
30. J. L. Crowley
31. F. L. Culler
32. J. E. Cunningham
33. W. W. Davis
34. J. H. DeVan
35. C. W. Dollins
36. R. G. Donnelly
37. D. A. Douglas, Jr.
38. E. P. Epler
39. W. K. Ergen
40. A. P. Fraas
41. J. H Frye, Jr.
42. C. H. Gabbard
43. W. R. Gall
44. R. B. Gallaher
45. R. G. Gilliland
46. W. R. Grimes
47. A. G. Grindell
48. D. G. Harmon
49. C. S. Harrill
50–52. M. R. Hill
53. E. C. Hise
54. H. W. Hoffman
55. P. P. Holz
56. L. N. Howell
57. P. R. Kasten
58. R. J. Kedl
59. C. R. Kennedy
60. B. W. Kinyon
61. R. W. Knight
62. V. G. Lane
63. M. I. Lundin
64. H. G. MacPherson
65. E. R. Mann
66. W. R. Martin
67. H. E. McCoy
68. W. B. McDonald
69. C. K. McGlothlan
70–72. E. C. Miller
73. R. L. Moore
74. J. C. Moyers
75. C. W. Nestor
76. T. E. Northup
77. L. F. Parsly
78. P. Patriarca
79. H. R. Payne
80. W. B. Pike
81. M. Richardson
82. R. C. Robertson
83. T. K. Roche
84. H. W. Savage
85. J. H. Shaffer
86. G. M. Slaughter
87. A. N. Smith
88. P. G. Smith
89. I. Spiewak
90. R. L. Stephenson
91. R. W. Swindeman
92. A. Taboada
93. J. R. Tallackson
94. A. E. Thoma
95. D. B. Trauger
96–101. J. T. Venard
102. W. C. Ulrich
103. J. R. Weir
104. C. W. Walker
105. D. C. Watkin
106. A. M. Weinberg
107. J. H. Westsik

108. L. V. Wilson
109. C. H. Wodtke
110. J. W. Woods

EXTERNAL DISTRIBUTION

111. C. M. Adams, Jr., Massachusetts Institute of Technology
112–113. A. E. Carden, University of Alabama
114–115. David F. Cope, AEC, ORO
116–118. J. Simmons, AEC, Washington
119. Research and Development, AEC, ORO
120–134. Division of Technical Information Extension