[redacted] SHEET UNCLASSIFIED

X-426 (Rev. 8-55)

OAK RIDGE NATIONAL LABORATORY
Operated By
UNION CARBIDE NUCLEAR COMPANY

UCC

POST OFFICE BOX P
OAK RIDGE, TENNESSEE

C-84 Aircraft Reactors

ORNL
CENTRAL FILES NUMBER
56-10-18

"External Transmittal Authorized"
This document consists of 27 pages.
Copy 38 of 39 copies. Series A.

DATE: October 15, 1956

SUBJECT: NICKEL-MOLYBDENUM ALLOY NEWSLETTER

TO: W. H. Jordan

FROM: W. D. Manly

Distribution

1. W. H. Jordan
2. J. H. Frye, Jr.
3. General D. J. Keirn
4. S. J. Cromer
5. R. A. Charpie
6. J. H. Coobs
7. H. Inouye
8. T. K. Roche
9. D. A. Douglas
10. J. H. DeVan
11. P. Patriarca
12. R. B. Oliver
13. A. Taboada
14. E. E. Hoffman
15. A. P. Frass
16. T. Hikido
17. W. D. Manly
18. H. M. Roth, ORO
19. M. R. Hill
20. Colonel J. V. Hearn, WADC
21. Major M. J. Whitman, ARB
22. B. A. Schmickrath, Pratt and Whitney
23. L. M. Raring, Pratt and Whitney
24. Major Paul Baker, Jr., Chief Technical Branch, East Hartford Area
25. E. M. Simon, BMI
26. D. Kellman, Westinghouse
27. R. R. Clappier, INCO
28. M. J. Skinner
29. G. W. Keilholtz
30. J. C. Wilson
31. M. E. Langston, BMI
32. A. L. Boch

33-37. Laboratory Records

[redacted] 38-39. AEC - TIE

Classification cancelled (~~or changed to~~)
by authority of H. F. Carroll
by ______ date 2-27-72

UNCLASSIFIED

RESTRIC[redacted]ATA

This document conta[redacted]ted Data as defined in the Atomic Energy Act of 1954. [redacted]mittal or the disclosure of its contents in any manner to an un[redacted]orized person is prohibited.

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.

[redacted] SHEET

1 5823

INTRODUCTION

H. Inouye

A review of the data of recent months has permitted some generalizations regarding the properties of the experimental nickel-molybdenum alloys and, what is more ~~significant,~~ the trends with regard to the effects of certain alloying elements. Although some compositions being studied have no possibility of becoming ~~aircraft reactor~~ structural alloys themselves, they provide data from which guide lines for the selection of better compositions can be established.

del

In Fig. 1, the oxidation rates of the nickel-molybdenum alloys are summarized. The data show that in the nickel-molybdenum binary system, a maximum in the oxidation rate is exhibited at around 20% molybdenum.

The dominant role of chromium in determining the oxidation rate of these alloys may be clearly seen in this table which tabulates the data in a decreasing order of oxidation rate. All the other elements appear to have only a slight effect.

A comparison of the oxidation rates of Inor-6 and Inor-7 shows a large difference for these two alloys which have only minor differences in composition. However, this behavior is not unusual in these compositions which are borderline with respect to oxidation since the rate is governed by the type of scale (e.g., NiO, $NiMoO_4$, Cr_2O_3) which predominates.

Figure 2 is a graph showing the effect of carbon on the tensile ductility of annealed nickel-molybdenum alloys. The decrease in the ductility is accompanied by increases in both the yield and ultimate strengths. This relationship appears to hold for both room and elevated temperature tests. The unforgeable alloys are defined as those exhibiting severe cracking during hot rolling and splitting during cold forming operations.

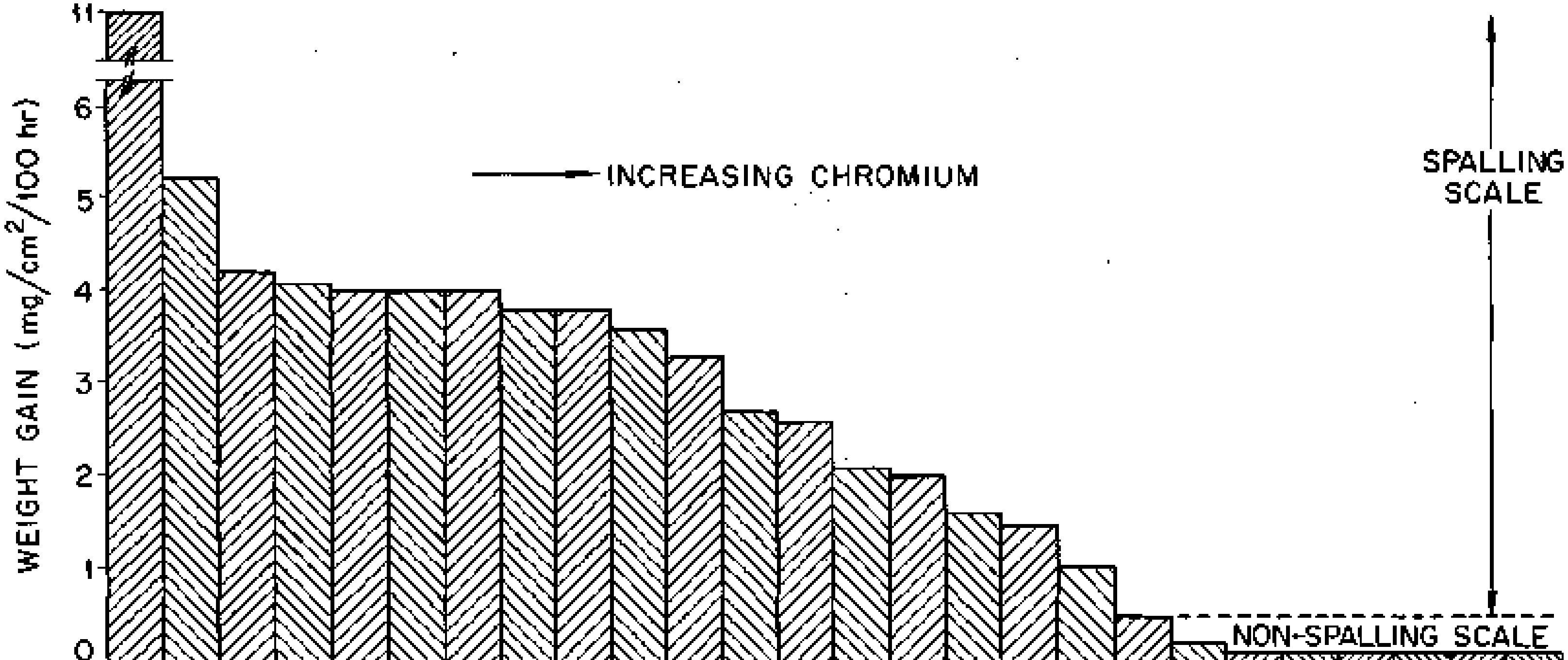
Analysis of the data on the alloys containing Ti and Al reveals no beneficial effect which can be attributed to these elements at this time. The Ti and Al containing alloys are characterized by moderate creep strengths, aluminum pick-up in Fuel 107, and inability to be brazed in hydrogen atmosphere. The data indicate that greater over-all improvement in alloy properties for this application may be achieved by increasing the molybdenum content rather than the Ti and Al since these latter elements impair the forgeability and probably the corrosion resistance.

The results of recent thermal convection loop corrosion tests on alloys containing 3 to 10% chromium show that varying the chromium content within this range has no significant effect on the depth of voids formed in 500 hr. These results indicate that the amount of chromium required for oxidation resistance may be tolerated corrosion-wise. Therefore, further tests will be made on compositions containing chromium, molybdenum, and nickel as the principal element.

del

UNCLASSIFIED

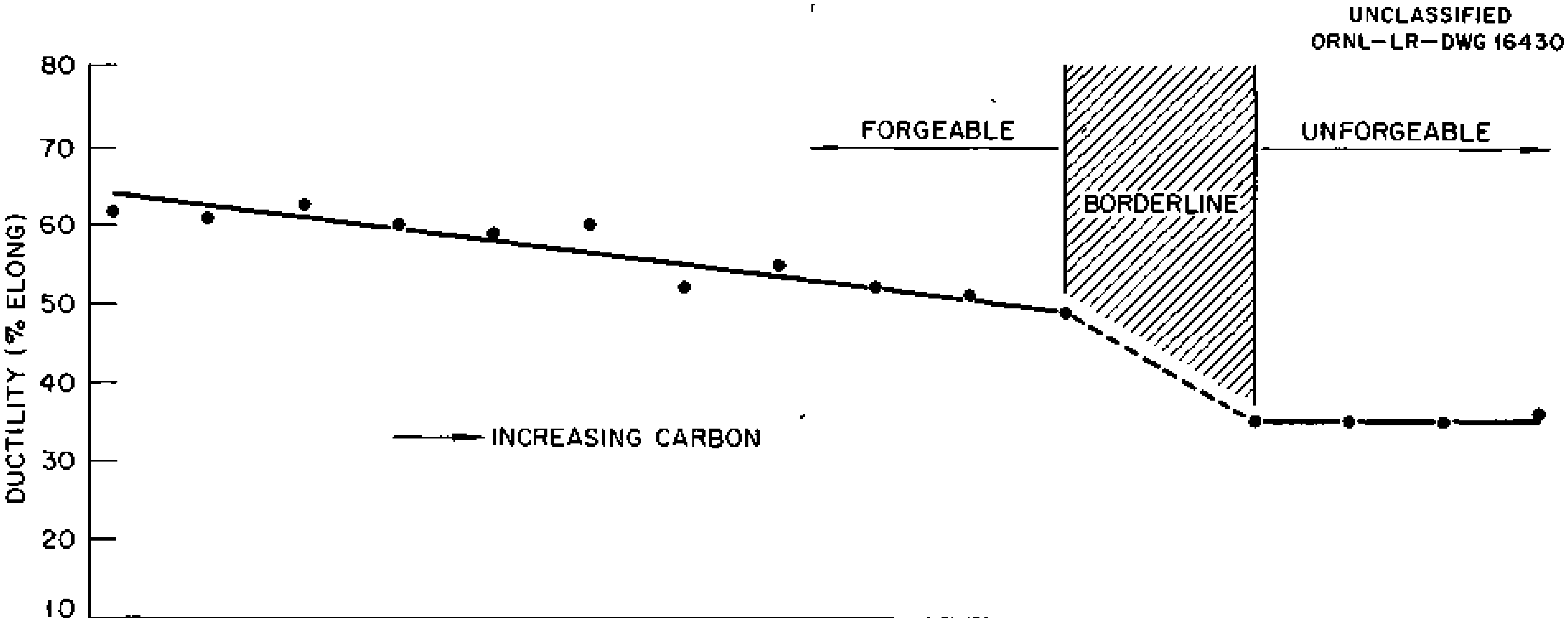
UNCLASSIFIED
ORNL-LR-DWG 16431



Mo	20	20	15	16	15	15	15	15	20	20	24	16	32	16	15	15	20	28	10	20	20	20	20	20	17	
Cr		3												5		6	5		6	7	7	7	7	10	6	15
Fe																4		4	10				1			7
Ti				1.5								1.5		1.5												
Al				1					2			2		1							2		1		1	
W			2		2		3	3																		
V						2				2																
Cb			2		2	2	3	3														2	2		1	
C					.2	.2		.25													.1	.1	.1			
	INOR-1		INOR-5	INOR-3								INOR-4		INOR-6		INOR-8	INOR-2	HAST. B	INOR-8						INOR-7	INCONEL

COMPOSITION

Fig. 1. The Oxidation Rates of Ni–Mo Alloys at 1500°F in Air.



COMPOSITION															
Mo	20	20	20	20	17	15	15	15	16	15	16	15	15	15	15
Cr		3	7	5						6	5				
Fe										4					
Ti						1.5			1.5		1.5				
Al						1			2		1				
W							3	2				3	2		2
V														2	2
Cb							3	2				3	2	2	
C	.01	.01	.01	.01	.03	.03	.05	.06	.06	.06	.06	.21	.2	.2	.2
					INOR–1	INOR–3		INOR–5	INOR–4	INOR–8	NOR–6				

Fig. 2. Room Temperature Tensile Ductility of Annealed Ni–Mo Alloys.

These ternary compositions fall short of the established strength goal, however; and therefore, require an additional strengthener. Consideration of possible deleterious effects on other properties, such as forgeability, brazeability and corrosion resistance, leads to iron as the best strengthening addition to use.

The data on the various properties of the nickel-molybdenum alloys studied to date have indicated the nickel-molybdenum-chromium-iron system to be the most promising for producing the alloy to achieve the optimum overall rating. Alloys containing these four elements will be designated by the generic name Inor-8, which will include all the minor variations in composition within this system.

Three 36-lb melts of the composition, Ni-17 Mo-10 Cr-7 Fe, which represents the maximum Cr + Fe addition which will be made to the Ni-Mo base, have been prepared. These heats will be used to provide material for a forced circulation loop corrosion test to determine whether the favorable thermal convection loop data will be substantiated under conditions of greater flow rate and duration.

FABRICATION OF Ni-Mo BASE ALLOYS

H. Inouye and T. K. Roche

Seamless Tubing

Tubing received this month which was processed at Superior Tube Company from blanks extruded at ORNL is listed in Table I. All the extrusions involved appeared to process satisfactorily; however, the tube blank from alloy No. 30-17 (4% Al) developed open longitudinal cracks during the final anneal and was scrapped. This was the third unsuccessful attempt to draw tubing of this alloy. Thermal convection loops are being fabricated from the tubing of the other three compositions, alloy Nos. 30-15, 30-21, and 30-22.

The sixteen extrusion billets representing four compositions, B-3404, B-3407, B-3412, and B-3418, which were received from Battelle Memorial Institute were successfully extruded to tube blanks at 2150°F at a ratio of 7:1 and were sent to Superior Tube Company for redrawing. From the details shown in Table II, it is seen that two finish tubing sizes have been requested for these alloys. The 0.500-in. OD x 0.035-in. wall tubing is to be tested in thermal convection loops at ORNL and the smaller size tubing 0.380-in. OD x 0.065-in. wall is to help fulfill the requirements for pump loops at Battelle. However, past results indicate that the tube reducing and redrawing properties of alloys of this type with 0.12% C are marginal due to cracking which occurs along carbide stringers. Therefore, if difficulty is encountered in processing these blanks to seamless tubing, weld-drawn tubing will have to be used. Superior Tube Company is now attempting to prepare tubing by this latter method. On the other hand, if no difficulties are encountered, ORNL will extrude additional tube blanks to complete the Battelle tubing needs for pump loops of these alloys.

Although it is readily apparent that the composition Ni-17 Mo-4 Al is of no value to the Alloy Development Program other than for establishing the effect of a high Al content on the corrosion resistance of the base composition, Ni-17 Mo, three additional billets of this alloy prepared from a heat supplied by Superior Tube Company were extruded with only moderate success and returned to Superior Tube Company for processing. L CLOSE (W) p. 9

ORNL Pump Loop

One of the most important alloy additions from the standpoint of rendering oxidation resistance to a Ni-Mo-base alloy is Cr which must be present in quantities of 7% or greater. The effect of Cr additions on the fluoride corrosion, which are discussed in detail in the Corrosion Section of the Newsletter, are such that a more severe test is in order. An alloy whose composition is Ni-17 Mo-10 Cr-7 Fe has been selected for testing in a pump loop. Three 36-lb heats have been cast and are presently being machined into extrusion billets. Tube blanks of this alloy should be available within the next several weeks. This loop should establish more definite trends from a corrosion standpoint.

TABLE I

RESULTS OF REDRAWING ORNL ALLOYS TO 0.500-in. OD x 0.035-in. WALL TUBING AT

SUPERIOR TUBE COMPANY

Alloy No.	Nominal Composition Wt. %	Extruded Tube Blanks	Total Length of Tubing Received	No. of Loops Requested	Remarks
30-17	Ni-17Mo-4Al-0.06C	1	10ft.11in.	0	Tubing Developed Longitudinal Cracks During Final Anneal.
30-15(Inor-5)	Ni-15Mo-2Nb-2W-0.06C	2	21 0	2	--
30-21	Ni-17Mo-5Nb-0.06C	3	34 11	3	--
30-22(Inor-7)	Ni-16Mo-6Cr-1Nb-1Al-0.08C	3	32 0	3	--

TABLE II

TUBE BLANKS SUBMITTED TO SUPERIOR TUBE COMPANY FOR REDRAWING

Alloy No.	Nominal Composition Wt. %	Extruded Tube Blanks	Finish Size
Stc-5525	Ni-17Mo-4Al	3	0.500 in. OD x 0.035 in. Wall
B-3404	Ni-20Mo-7Cr-2Al-0.8Mn-0.12C	2	0.380 in. OD x 0.065 in. Wall
B-3404	Ni-20Mo-7Cr-2Al-0.8Mn-0.12C	2	0.500 in. OD x 0.035 in. Wall
B-3407	Ni-20Mo-7Cr-1Al-2Nb-1Fe-0.8Mn-0.12C	2	0.380 in. OD x 0.065 in. Wall
B-3407	Ni-20Mo-7Cr-1Al-2Nb-1Fe-0.8Mn-0.12C	2	0.500 in. OD x 0.035 in. Wall
B-3412	Ni-20Mo-2Al-1Nb-0.5Fe-0.8Mn-0.12C	2	0.380 in. OD x 0.065 in. Wall
B-3412	Ni-20Mo-2Al-1Nb-0.5Fe-0.8Mn-0.12C	2	0.500 in. OD x 0.035 in. Wall
B-3418	Ni-20Mo-2Nb-1Fe-0.8Mn-0.12C	2	0.380 in. OD x 0.065 in. Wall
B-3418	Ni-20Mo-2Nb-1Fe-0.8Mn-0.12C	2	0.500 in. OD x 0.035 in. Wall
30-24	Ni-17Mo-7Cr-0.5Al-0.5Mn-0.06C	1	0.375 in. OD x 0.035 in. Wall
46A	Ni-20Mo-10Cr	1	0.500 in. OD x 0.035 in. Wall

Weld Wire and Mechanical Property Specimens

Table III shows the fabrication status of experimental quantities of 1/8-in. OD weld wire and 0.065-in. thick strip which are being prepared for welding and stress-rupture evaluation. Approximately 8 lb of weld wire of both the INOR-3 and the INOR-4 compositions were submitted to the Welding and Brazing Group this month. Stress-rupture specimen blanks of INOR-5 were also completed. Two rods of the alloy Ni-17 Mo-7 Cr, which was melted by the consumable-electrode method, were extruded and will be processed to strip material for mechanical property tests. Vacuum-induction melted material of this same composition was previously submitted for stress-rupture evaluation. Comparison of results may establish trends which will be a function of melting practice.

TABLE III

RESULTS OF FABRICATING 1/8-in. OD WELD WIRE AND 0.065-in. THICK STRIP FROM ORNL ALLOYS

Alloy No.	Nominal Composition Wt. %	Extruded Shape	Proposed Use **	Results
30-23 (INOR-7)	Ni-16Mo-6Cr-1Al-1Nb-0.5Mn-0.08C	7/8-in. Rod	1/8-in. Weld Wire	Processing incomplete
		7/8-in. Rod	1/8-in. Weld Wire	Processing incomplete
30-26 (INOR-3)	Ni-16Mo-1.5Ti-1Al-0.5Mn-0.06C	1 1/4-in. Rod	1/8-in. Weld Wire	Cold Swaged to 1/8-in. OD
		7/8-in. Rod	1/8-in. Weld Wire	Cold Swaged to 1/8-in. OD
30-27 (INOR-4)	Ni-16Mo-1.5Ti-2Al-0.5Mn-0.06C	7/8-in. Rod	1/8-in. Weld Wire	Cold Swaged to 1/8-in. OD
		7/8-in. Rod	1/8-in. Weld Wire	Cold Swaged to 1/8-in. OD
30-28 (INOR-5)	Ni-16Mo-2Nb-2W-0.5Al-0.5MN-0.1C	7/8-in. Rod	1/8-in. Weld Wire	Processing incomplete
		1 1/2-in. Rod	0.065-in. Strip	Hot Rolled Successfully to 0.250-in. Cold Rolled to 0.065-in.
30-29 (INOR-6)	Ni-16Mo-5Cr-1.5Ti-1Al-0.5Mn-0.06C	7/8-in. Rod	1/8-in. Weld Wire	Processing incomplete
		1 1/4-in.Sq.Rod	0.065-in. Strip	Processing incomplete
-	Ni-17Mo-7Cr-0.06C*	1 1/2-in. Rod	0.065-in. Strip	Processing incomplete
		1 1/2-in. Rod	0.065-in. Strip	Processing incomplete

* Vacuum Induction Melted and Remelted by Consummable Electrode Method.

** Mechanical Property Specimens to be Machined from 0.065-in. Thick Strip.

TENSILE TESTS

H. Inouye

The data on the tensile properties of various Ni-Mo alloys at 1300°F which were accumulated during the past month are tabulated in Table IV. INOR-4, which is known to age, shows low ductility at this temperature.

OXIDATION STUDIES

H. Inouye

The oxidation rates of the alloys listed in Table V were determined this month. At 1500°F in static air, INOR-7 compares favorably with Inconel with respect to oxidation resistance.

TABLE IV

TENSILE PROPERTIES OF NICKEL-MOLYBDENUM ALLOYS AT 1300°F

Alloy Designation	Composition, Wt. % (Nickel Base)	Condition*	0.2% Offset Y.P., Psi	UTS Psi	Elongation %
INOR-1	17Mo-5Al	Annealed	25,000	61,200	37.5
INOR-3	15Mo-1.5Ti-1Al	Annealed	27,000	63,600	30
		Aged	26,700	65,800	41
INOR-4	16Mo-1.5Ti-2Al	Aged	--	87,000	2
INOR-5	15Mo-2Cb-2W-.06C	Aged	27,800	49,200	11.0
	15Mo-3Cb-3W	Annealed	37,100	79,100	17.5
		Aged	42,100	78,300	19.7
	15Mo-3Cb-3W-.25C	Annealed	57,700	89,000	14.5
		Aged	58,000	87,700	13.7
	15Mo-2Cb-2W-.2C	Annealed	47,000	66,900	6.5
		Aged	44,400	71,700	7.5
INOR-8	15Mo-6Cr-4Fe	Annealed	31,300	63,600	13.7
		Aged	32,300	73,000	21.0
	18Mo-2Cb-.25Be	Annealed	42,100	65,200	16.5
		Aged	59,400	87,750	20
	18Mo-.5Be	Annealed	82,700	≥ 82,700	Failed at Pin
		Aged	71,600	80,600	5
	15Mo-2Cb-2V-.2C	Annealed	47,800	75,200	10.0
		Aged	50,000	81,700	8.7
	15Mo-2V-2W-.2C	Annealed	44,600	68,500	8.7
		Aged	43,900	76,400	11.7

* Annealed 2000°F, 1/2 hr, Aged 100 hr 1300°F

TABLE V

OXIDATION RATES OF Ni-Mo ALLOYS AT 1500°F IN STATIC AIR

Alloy Designation	Nominal Composition Wt. %	Wt Gain mg/cm^2/100hr	Adherence of Oxide Scale On Cooling
Vt-36	15Mo-2Cb-2V-.2C	5.21	Spalls
Vt-37	15Mo-2Cb-2W-.2C	4.00	Spalls
INOR-7	17Mo-1Cb-1Al-6Cr	0.07	No Spalling
Vt-38	15Mo-2V-2W-.2C	3.62	Spalls

delete to page 20

delete

Dynamic Corrosion Studies

J. H. DeVan and E. A. Kovacevich

Corrosion tests in Fluoride 107 have been completed for ten additional experimental nickel-molybdenum alloys. The tests, conducted by means of thermal convection loops, all operated for a period of 500 hours with a maximum fluid temperature of 1500°F. Metallographic examination of the loops, reported in Table VI, showed slight surface attack in the form of pitting in all alloys, with depths ranging to one mil. Loop 1081, which contained chromium as well as niobium, tungsten, and aluminum additions, revealed heavy subsurface void formation to a depth of 2 1/2 mils. No evidence of mass transferred deposits could be found in any of the loops tested.

These tests indicate the addition of chromium to have little effect on fluoride attack in thermal convection loops up to amounts of 10%. Whether such additions will give rise to mass transfer under higher system flow rates, however, constitutes an important question and can only be resolved by tests of longer duration and more drastic flow conditions.

In the presence of additions of niobium, aluminum, and tungsten, chromium does appear to adversely affect corrosion, as evidenced by comparison of loops 1081 and 1082; however, the effect is slight.

The operating variables of special alloy loops started during the report period and their respective compositions are listed in Tables VII and VIII. Of the 30 convection loops placed in operation since the first newsletter, 3 of the loops have been terminated because of leaks. All of the leaks occurred in loops circulating sodium; two were near weld areas, and one was centered in a length of tubing comprising the loop cold leg. Because of material limitations, loops are necessarily being constructed of relatively thin walled tubing to provide a maximum number of loops per alloy composition. Consequently tubing and weld defects become quite critical insofar as contributing to failure.

Unfortunately, with a sodium leak it is usually impossible to determine the nature of a defect, since melting of the loop wall occurs in the area of the failure. In one loop, however, it was possible to correlate the leak with a flaw indicated by inspection reports which were obtained during assembly of the loop. In this case, X-rays taken of weld areas revealed longitudinal cracks extending along the tubing proper and ending at the weld area. Such cracks would not appear to have resulted from welding, but rather are characteristic of defects developed during tube drawing. Thus the leaks near welds in two of the loops, as well as the one leak in the cold leg, very possibly resulted from tubing defects produced during tubing fabrication. This suggestion is further substantiated by the relatively large number of defect indications being found on dye penetrant inspection of the tubing.

delete

Table VI Metallographic Results on Completed Ni-Mo Thermal Convection Loops

Maximum Fluid Temperature 1500°F

Loop No.	Alloy (Heat No.)	Coolant	Metallography Hot Leg	Metallography Cold Leg
1067	17% Mo - 3% Cr	107	Few pits - 1 mil	No attack
1068	17% Mo - 5% Cr	107	Surface pitting-1 mil	Few voids-1 mil
1069	20% Mo - 3% Cr	107	Few pits - 1 mil	Light surface roughening - 1 mil
1070	17% Mo - 1/2% Al	107	Few subsurface voids- <1 mil	No attack
1076	17% Mo - 10% Cr	107	Heavy subsurface voids- <1 mil	Light surface roughening
1078	20% Mo - 1% Nb - 1% Ti - 0.8% Mn	107	Few voids - 1 mil	No attack
1079	20% Mo - 7% Cr	107	Few pits - 1 mil	No attack
1080	15% Mo - 1% Al - 1 1/2% Ti	107	Few voids - 1 mil	Light surface roughening
1081	15% Mo - 5% Cr - 3% Nb - 0.5% Al - 3% W	107	Heavy subsurface voids- 2 1/2	No attack
1082	15% Mo - 3% Nb - 0.5% Al - 3% W	107	Heavy surface roughening- <1 mil	No attack

delete (OF NO USE IN DELETED REPORT)

Table VII Compositions of Thermal Convection Loop Alloys

	Composition Wt.% (Bal Ni)									
Heat No.	Mo	Cr	Nb	Al	Ti	V	W	Mn	Fe	C
30-6	17	7	-	-	-	-	-	-	-	0.06
B 3276	20	7	2	-	-	-	-	-	1	-
30-8	17	-	-	-	2	-	-	-	-	0.06
B 3277	20	7	2	1	-	-	-	-	1	-
30-10	17	-	-	-	-	2	-	-	-	0.06
30-16	16	5	-	1	1.5	-	-	-	-	0.06
30-13	16	-	-	1	1.5	-	-	-	-	0.06
30-14	16	-	-	2	1.5	-	-	-	-	0.06
30-7	15	-	3	0.5	-	-	3	-	-	-
30-11	17	-	-	-	-	-	-	-	4	0.06
30-9	17	-	-	-	-	-	2	-	-	-
30-12	17	-	3	-	-	-	-	-	-	-

delett

Table VIII Operating Conditions of Thermal Convection Loops Constructed of Special Nickel-Molybdenum Alloys

Maximum Fluid Temperature - 1500°F
Wall Temperature - ~1650°F

Loop No.	Alloy* (Heat No.)	Coolant	Time (hr)	Status
1092	30-6	Na	122(leaked)	Metallography
1093	30-6	107	500	Operating
1094	B 3276	107	500	Operating
1098	30-8	107	500	Operating
1099	B 3277	107	500	Operating
1100	30-10	107	500	Operating
1101	30-16	107	500	Operating
1102	30-16	Na	1000	Operating
1103	30-13	107	500	Operating
1104	30-13	Na	1000	Operating
1105	30-14	107	500	Operating
1106	30-10	Na	1000	Operating
1108	30-7	107	500	Operating
1110	30-8	Na	1000	Operating
1111	30-11	107	500	Operating
1112	30-11	Na	1000	Operating
1113	30-9	107	500	Operating
1117	30-9	Na	1000	Operating
1126	30-12	107	500	Operating

* See Table VII.

delete

Pump Loop Tests

Hastelloy B pump loops now in operation at ORNL and their operating conditions are shown in Table IX. A 1000 hr Hastelloy B - sodium loop, described in last month's newsletter, has been examined metallographically. Hot leg attack appeared as uniform surface removal to a depth of 1 1/2 mils. Much of the second phase material present in the grain boundaries and as precipitates throughout the metal was quite resistant to attack and remained unaltered in the corroded areas, although the surrounding metal had been entirely removed. Metal deposits were seen in the cold leg and reached a maximum thickness at the point of lowest temperature in the cooler.

Table IX Operating Variables of Hastelloy B Pump Loops

Loop No.	Fluid	Fluid ΔT °F	Max.Fluid Temp. °F	Max.Wall Temp. °F	Reynolds No.	Flow GPM	Method of Heating	Scheduled Operating Time
7641-1B	107	270	1625	1750	20,000	1.7	Direct Resistance	1000 hrs.
7641-2	107	300	1650	1700	15,000	1.5	Direct Resistance	1000 hrs.

DECLASSIFIED

delete

STRESS-RUPTURE PROPERTIES

D. A. Douglas, C. R. Kennedy, J. R. Weir

Creep testing of the various nickel-molybdenum alloy compositions was confined mainly to the evaluation of some air-melted heats from the Battelle Memorial Institute. The specimens were tested in both the solution annealed (1 hr at 2000°F) and solution annealed and aged (50 hr at 1300°F) conditions. The results are presented in Table X.

TABLE X

STRESS-RUPTURE PROPERTIES OF Ni-Mo ALLOYS IN FLUID 107

Alloy No.	Composition (bal Ni) Wt %	Rupture Time	% Elongation
B-3275	20Mo - 7Cr - 0.8Mn - 0.12C	290 hr	15.0
B-3275(a)	20Mo - 7Cr - 0.8Mn - 0.12C	280	20.0
B-3276	20Mo - 7Cr - 0.8Mn - 0.12C - 2Nb - 1Fe	440	25.0
B-3276(a)	20Mo - 7Cr - 0.8Mn - 0.12C - 2Nb - 1Fe	(b)	--
B-3277	20Mo - 7Cr - 0.8Mn - 0.12C - 2Nb - 1Fe - 1Al	750	8.0
B-3277(a)	20Mo - 7Cr - 0.8Mn - 0.12C - 2Nb - 1Fe - 1Al	(b)	--
B-3278	20Mo - 7Cr - 0.8Mn - 0.12C - 2Al	690	60.0
B-3278(a)	20Mo - 7Cr - 0.8Mn - 0.12C - 2Al	790	58.0

(a) Specimens aged 50 hr at 1300°F in addition to solution anneal.

(b) Aged specimens are still in test but the creep curves show good correlation with those of the solution annealed specimens so no significant difference in rupture life is expected.

PRODUCTION OF COMMERCIAL SIZE HEATS OF Ni-Mo BASE ALLOYS

H. Inouye and T. K. Roche

Correspondence received from INCO listed the estimated delivery dates of the products of the commercial size heats of the INOR alloys 1 through 6. This information is shown in Table XI. It has been established that this development will not be expedited; but INCO indicated that they will try to meet or better the delivery estimates if possible to do so.

Contract agreements between Westinghouse and Union Carbide Nuclear Company are progressing and should be completed within the next few weeks.

SECRET

TABLE XI

STATUS OF COMMERCIAL SIZE HEATS OF Ni-Mo BASE ALLOYS PRODUCED BY INCO

Conversion of:	Alloy No.**	Est. Delivery
3 1/4-in. O.D. x 1/2-in Wall Extruded Shells to 2-in. O.D. x 0.187-in. Wall Tubing.*		
1 Billet Per Heat -	INOR 3 and 6	10-31-56
2 Billets Per Heat -	INOR 1, 2, and 5	
Blooms to Hot Rolled Flats		
1/2-in. x 6-in. x 12-in. -	INOR 1 and 3	10-5-56
1/2-in. x 3-in. x 12-in. -	INOR 2, 4, 5, and 6	
Blooms to Cold Rolled and Annealed Strip		
0.065-in. x 6-in. x 12-in. -	INOR 1 and 3	12-7-56
0.065-in. x 3-in. x 12-in. -	INOR 2, 4, 5, and 6	
Blooms to Billets to 1/8-in. Dia. Cold Drawn Wire. -	INOR 1, 2, 3, 5, and 6	11-30-56
Blooms to Billets to 3/32-in. Dia. Cold Drawn Wire. -	INOR 1, 2, 3, 5, and 6	11-30-56
Blooms to Billets to 3/8-in. Dia. Hot Rolled Rod. -	INOR 1, 2, 3, 5, and 6	11-30-56
Blooms to Forged and Rough Turned Rods 2 7/8-in. Dia. x 3 ft.	INOR 1, 2, 3, 5, and 6	11-30-56

* 2-in. OD x 0.187-in. Wall Tubing to be subsequently reduced to small diameter tubing by the Superior Tube Company.

** For Compositions See Table V, Page 12, Ni-Mo Alloy Newsletter, August 16, 1956.

SECRET

WELDABILITY OF Ni-Mo ALLOYS

R. E. Clausing, P. Patriarca

The following Nickel-Molybdenum alloy test plates have been welded and are now being machined into longitudinal and transverse mechanical test specimens:

Plate No.	Plate Material	Filler Wire
NiMo No. 12	BMI heat 3405 (20Mo-2Al-7Cr-0.12C-Bal Ni)	BMI heat 3405 (20Mo-2Al-7Cr-0.12C-Bal Ni)
NiMo No. 13	BMI heat 3408 (20Mo-2Cb-1Al-7Cr-0.12C-Bal Ni)	BMI heat 3408 (20Mo-2Cb-1Al-7Cr-0.12C-Bal Ni)
NiMo No. 14	Hastelloy W	Inor No. 3 (16Mo-1.5Ti-1Al-Bal Ni)

No unusual problems were encountered during the welding of these test plates. Radiographic and visual inspection revealed no significant defects in any of the weldments.

Mechanical property tests on plate Nos. 1 to 10 are underway and a quantity of test data is available. However only room-temperature and 1500°F all-weld metal tensile data (as-welded) is presented in tabular form in this report. The results for other conditions of test are incomplete at this time, and will be presented in the next report. The data are presented in Table XII.

Hardness studies of aged welded joints reported in the previous newsletter are being continued. Previous data[1] showed that for aging times of 200 hr Hastelloy B hardened most rapidly at 1300°F. Subsequent results are plotted in Figure 3 illustrating the effect of time at 1300°F upon the hardness level attained. It should be noted that aging times up to 500 hr have a marked effect on hardness. However, it appears that the 200 hr data is indicative of the aging rate. Results similar to that shown in Figure 3 were also obtained for the 1500°F aging temperature. It can be seen that the 200 hr aging time produces approximately 50% of the hardness increase resulting in 500 hr.

1 Newsletter ORNL 56-9-80 (Sept. 20, 1956).

DECLASSIFIED

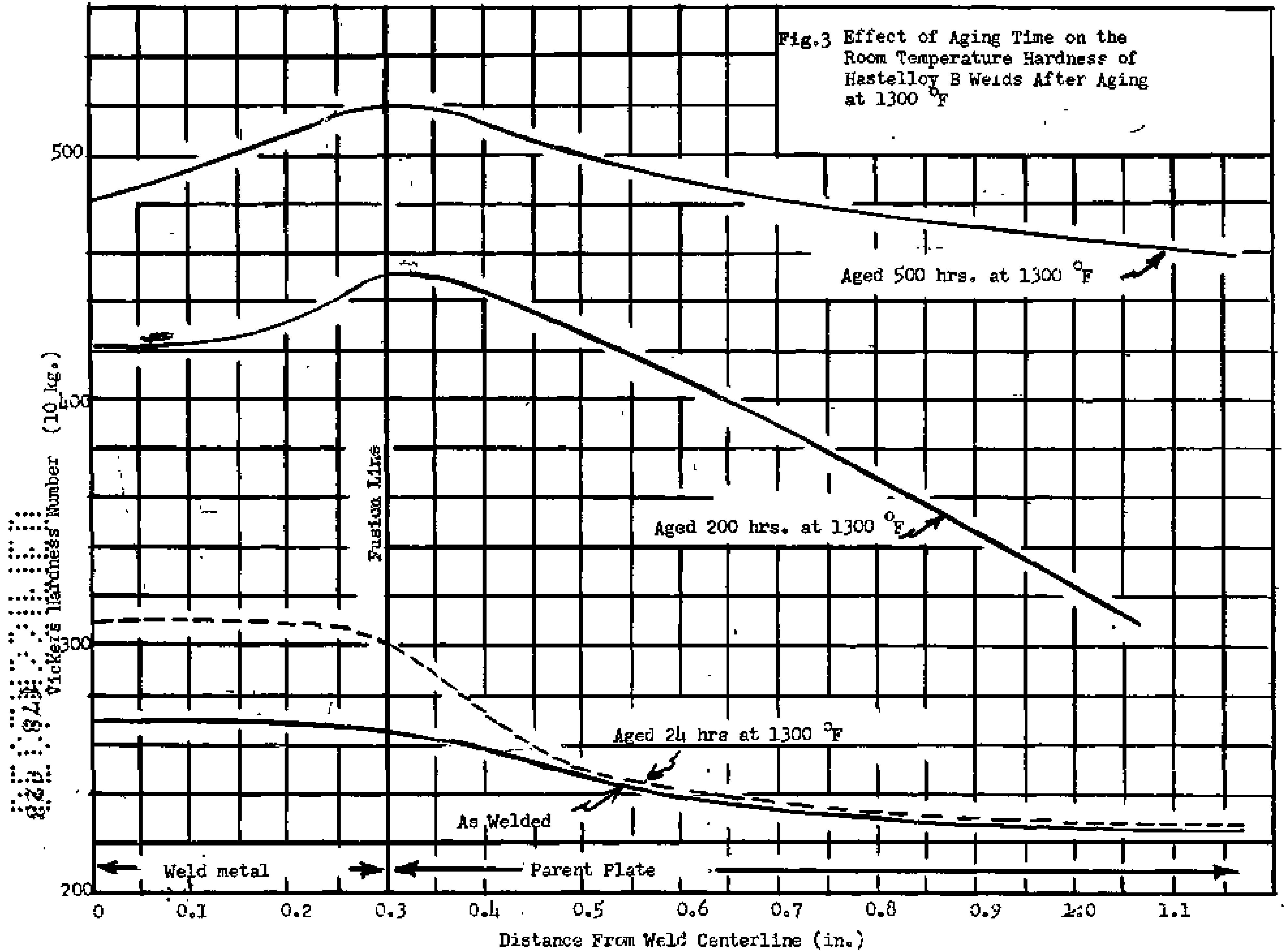


Fig.3 Effect of Aging Time on the Room Temperature Hardness of Hastelloy B Welds After Aging at 1300 °F

DECLASSIFIED

TABLE XII

MECHANICAL PROPERTIES OF AS-WELDED NICKEL-MOLYBDENUM ALLOY JOINTS

Specimen	Temp. of Test °F	Tensile Strength Psi	Yield Strength .2% Offset Psi	Elongation % one-inch Gage
*85% Ni-15% Mo weld metal	Room	16,170	14,150	1.2
on Hastelloy B plate	Room	14,230	13,885	1.0
	1500	5,578	--	0
	1500	10,650	10,650	0
Hastelloy B weld metal	Room	118,300	84,220	25.0
on Hastelloy B plate	Room	124,040	80,450	22.5
	1500	66,690	52,550	9.5
	1500	62,300	55,570	12.5
Hastelloy W weld metal	Room	126,100	75,380	40.0
on Hastelloy W plate	Room	127,950	80,990	34.5
	1500	71,110	47,370	31.0
	1500	69,780	46,120	20.0

* Very poor properties due to extreme porosity in weld.

BRAZING OF ALLOYS

E. A. Franco-Ferreira, R. E. Clausing, G. M. Slaughter

An exploratory investigation of furnace brazing in a hydrogen atmosphere using flux is being undertaken as a possible solution to the problem of brazing nickel-molybdenum alloys containing appreciable amounts of titanium, aluminum and beryllium. Resulting joints will be examined for flux entrapment or other possible deleterious effects. Methods of flux removal will be studied in conjunction with corrosion tests in air, fused salts and sodium.

UNCLASSIFIED

SECRET

delete

FABRICATION OF THERMAL CONVECTION LOOPS

R. E. Clausing, P. Patriarca, G. M. Slaughter

Table XIII lists the thermal convection corrosion test loops which have been fabricated in the last two months. These loops were fabricated from 0.500-in. OD x 0.035-in. wall tubing by heliarc welding with Hastelloy W filler wire. No special problems have been encountered and the fabrication of these loops is routine.

UNCLASSIFIED

SECRET

delete

TABLE XIII

COMPLETED NICKEL-MOLYBDENUM THERMAL CONVECTION LOOPS

Loop No.	Composition				
	Heat No.	Ni	Mo	Cr	Other
34	30-7	Bal	17	--	2Al, .06C
35	30-7	Bal	17	--	2Al, .06C
36	30-7	Bal	17	--	2Al, .06C
37	30-6	Bal	17	7	.06C
38	30-6	Bal	17	7	.06C
39	30-13	Bal	16	--	1.0Al, 1.5Ti, .06C
40	30-13	Bal	16	--	1.0Al, 1.5Ti, .06C
41	30-14	Bal	16	--	1.0Al, 1.5Ti, .06C
42	30-14	Bal	16	--	1.0Al, 1.5Ti, .06C
43	B-3276	Bal	20	7	2Cb, 1Fe
44	B-3277	Bal	20	7	1Al, 2Cb, 1Fe
45	30-8	Bal	17	--	2Ti, .06C
46	30-8	Bal	17	--	2Ti, .06C
47	30-8	Bal	17	--	2Ti, .06C
48	30-10	Bal	17	--	2V, .06C
49	30-10	Bal	17	--	2V, .06C
50	30-10	Bal	17	--	2V, .06C
51	30-11	Bal	17	--	4Fe, .06C
52	30-11	Bal	17	--	4Fe, .06C
53	30-16	Bal	16	5	1.5Ti, 1Al, .06C
54	30-16	Bal	16	5	1.5Ti, 1Al, .06C
55	30-9	Bal	17	--	2W
56	30-9	Bal	17	--	2W
57	30-9	Bal	17	--	2W
58	30-11	Bal	17	--	4Fe
59	30-19	Bal	17	--	4W
60	30-19	Bal	17	--	4W
61	30-19	Bal	17	--	4W
65	30-12	Bal	17	--	3Cb
66	30-12	Bal	17	--	3Cb
67	30-12	Bal	17	--	3Cb

DECLASSIFIED