BAW-1402

January 1973

Investigation of Steam Generator Weld Records

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Babcock & Wilcox

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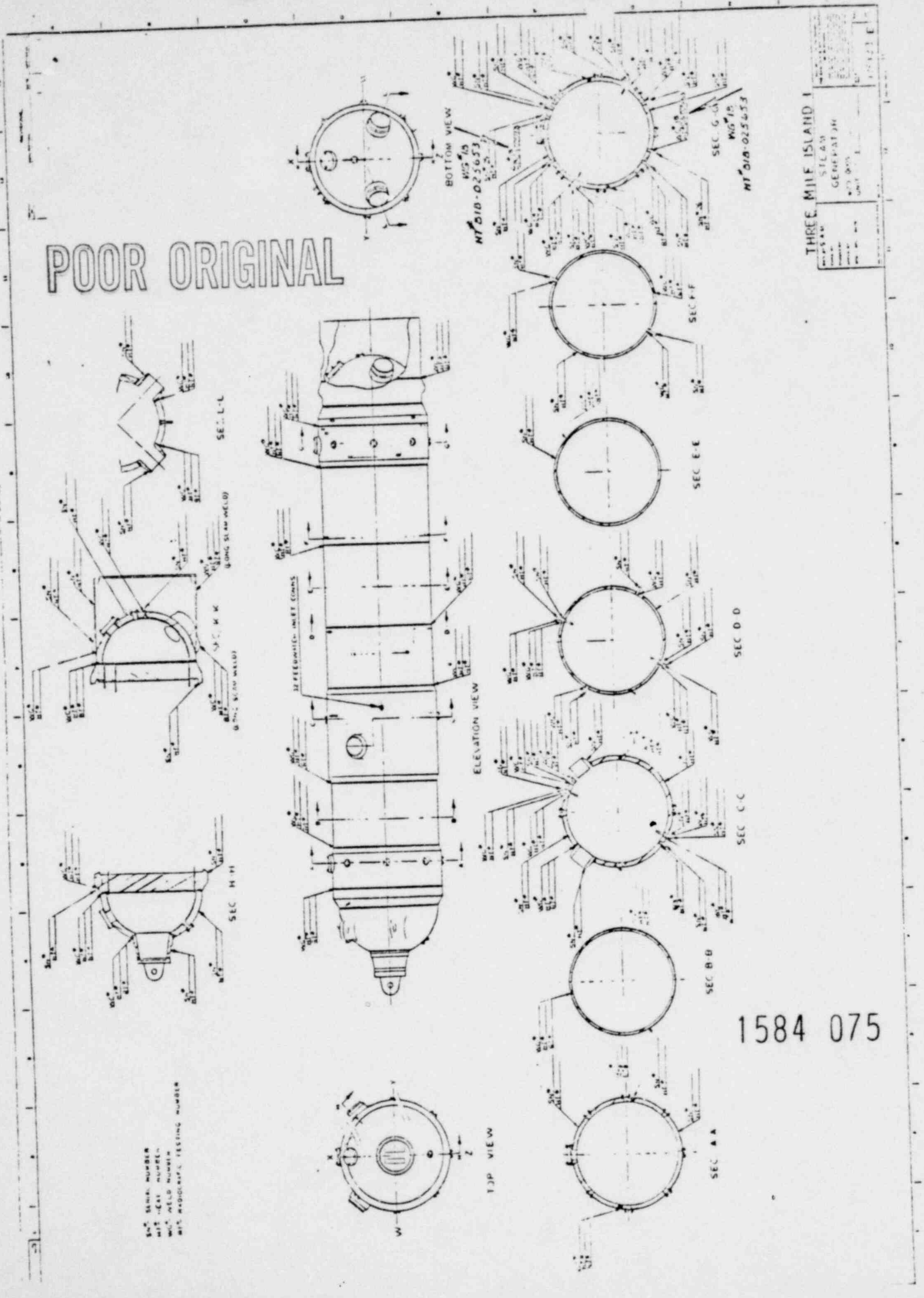

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The Babcock & Wilcox Co.

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1. Background

The steam generators for B&W nuclear steam systems were designed and fabricated in accordance with the requirements of the 1965 or 1968 editions of the ASME Code Section III, and appropriate addenda. The 1965 edition of Section III does not contain requirements for the mechanical testing of weld electrodes. However, beginning with the 1966 winter addenda the Code requires that welding material certification include data relative to mechanical tests in addition to the chemical analysis previously required. The material properties are to be recorded and filed as permanent records.

A recent audit by B&W's Quality Control organization at Barberton, Ohio shows that documentation is incomplete for certain lots of weld filler metal used in the fabrication of the steam generators for Oconee Units 1, 2 & 3; Three Mile Island Units 1 & 2; Crystal River Unit 3; Arkansas Nuclear One Unit 1; Rancho Seco; Midland Units 1 & 2; and Davis Besse.

As a result of this audit, an intensive investigation was conducted. This investigation has disclosed that the records are complete for all welds made by submerged arc and electroslag methods. These welding methods were used for the major longitudinal and circumferential welds of the steam generators.

However, complete documentation has not been found for certain lots of weld electrodes used with the manual metal arc welding method utilized in repair welds, weld pad buildups and some nozzle attachment welds. One of these lots has incomplete documentation of both chemical and mechanical properties. The remaining lots have satisfactory documentation of their chemistry but incomplete documentation of mechanical properties. All of these lots were produced by the same methods used in the manufacture of electrodes of the same type that had been tested and found to have the required properties for nuclear construction.

1584 077

This report provides the data necessary to justify the tensile strength and impact properties of the electrodes having incomplete documentation. The justification is based upon comparing the known data from the lots having incomplete documentation with corresponding data for the fully documented lots.

2. Evaluation

A detailed review of all of the steam generator weld records has been completed. The attached drawings show the location of welds in each affected steam generator made with the electrodes having incomplete documentation of the mechanical properties. Table 1 lists, for each affected unit, the type and lot number of those electrodes for which mechanical properties were incompletely documented.

Each of the lots of the 7015 and 8015 type electrodes was manufactured in B&W's Electrode Shop. To obtain the data necessary to justify the mechanical properties of the filler material, a search was made for test certification data of similar electrodes manufactured by B&W during the last five years. This search resulted in the finding of seventy-three production lots of type 7015 and twenty-eight production lots of type 8015 electrodes which had been tested and documented as required for nuclear applications. The chemical analyses, tensile strengths, and charpy V-notch impact strengths (at +10 F, after stress relief at 1100 - 1150 F for a minimum of 48 hours) are tabulated in Tables 2 and 3. The tables also include the "Carbon Equivalent" which has been calculated by the equation...

$$CE = \%C + \frac{\%Mn}{6} + \frac{\%CR + \%Mo}{10} + \frac{\%Ni}{20} \quad . \qquad (1)$$

The Carbon Equivalent is a measure of the hardenability of ferrous materials and is used to define the chemical limits of certain steels with respect to weldability. This Carbon Equivalent is commonly used for evaluating the strength of filler metals, and the data from Tables 2 and 3 were used to plot the tensile strength versus Carbon Equivalent as shown in Figures 1 and 2.

1584 078

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(1) Stout, R. D. & Doty, W. D. "Weldability of Steels," Welding Research Council 1

Tables 4 and 5 list the chemical analyses and Carbon Equivalents of the lots of 7015 and 8015 type electrodes for which mechanical properties were incompletely documented. When using the Carbon Equivalents of the lots of filler material listed in Tables 4 and 5 to determine the minimum expected tensile strength, as shown on Figures 1 and 2, it is evident that all lots with incomplete documentation exceed the minimum specified values shown on Figures 1 and 2.

All of the charpy V-notch impact data shown in Tables 2 and 3 are expressed in ft - lbs of energy absorbed at +10°F. The minimum impact strength permitted by specification at +40 F is 20 or 30 ft - lbs depending upon electrode type. Since all of the data for type 7015 and 8015 electrodes exceed 45 ft - lbs, even at +10 F, it is evident that the lots in question exceed the minimum specified strength by a considerable margin.

Three lots of incompletely documented type 11018 filler metal were used for steam generator base metal and weld metal repairs. The data for these lots are shown in Table 6. This type of filler metal is used in repairs which are quenched and tempered after the weld repair is made, and in order to qualify the filler metal for this application, the weld test pad must receive a quench and temper heat treatment similar to that of the production weldments followed by a stress relief. Table 7 presents in tabular form the tensile and impact data for specimens which have been quenched and tempered and then stress relieved for 30 hours at a temperature of 1100 to 1150 F. The minimum required tensile strength and impact values for this application are 70,000 psi and 20 ft - lbs at +40 F, respectively. When comparing the data for the lots in question with the background data listed in Table 7, it is evident that these lots will exceed the minimum specified values.

Table 8 lists the chemical analyses and carbon equivalents of the seven lots of Type 7018 filler metal for which mechanical properties were incompletely documented. Two of these lots were manufactured by B&W, and the remaining five were produced by two other filler metal vendors, Chemetron Corp. and Reid Avery Co. (RACO). The minimum required tensile strength and impact values for type 7018 filler metal are 70,000 psi and 20 ft - lbs at +40 F, respectively.

1584 079

The two B&W lots, the Chemetron lot and RACO lot 10784, have weld metal chemistry that falls within the limits of the weld metal chemistry for Type 7015 filler metal as shown in Table 2. When using the carbon equivalent of these lots of filler metal to determine the minimum expected tensile strength from Figure 1, and when comparing the data on these lots with the data in Table 2 for determining expected impact strength, it is evident that the minimum tensile and impact requirements exceed the minimum specified values.

Two RACO lots, 93382 and 01972, differ in chemistry from typical 7018 electrodes by the lack of Molybdenum. A review of data on Type 7018 electrodes manufactured by subcontract vendors was made, and the chemistry, tensile strengths, carbon equivalents and impact data of these electrodes are tabulated in Table 9. When comparing the two RACO lots, 93382 and 01972, with the data in Table 9 it is evident that the minimum tensile and impact requirements exceed the minimum specified values.

One heat of 5/32" diameter RACO "HMS" class "E70SG" wire, heat # 661V009, had incomplete documentation of mechanical properties. This wire had the following chemical analysis...

0.09% C; 2.10% Mn; 0.024%P; 0.020%S; 0.47%Mo,
which results in a Carbon Equivalent of 0.49.

A search was made of past records of similar wire used for Tungsten inert gas welding and the results are presented in Table 10. This table shows the vendor certification of the wire and the B&W certification of the weld. The minimum required tensile strength and impact values are 70,000 psi and 20 ft - lbs at +40 F. When the wire chemistry for heat 661V009 is compared to the data on Table 10 it is evident that this heat will exceed the minimum specified values.

One lot of type 70A1 filler metal supplied by McKay, lot number 277T1804, had incomplete documentation of impact properties. This lot had the following chemical analysis...

1584 080

.066%C; 0.67%Mn; .01%Cr; .51%Mo; .12%Ni,
which results in a Carbon Equivalent of 0.23. This material had a tensile strength

of 81,750 psi after stress relief for 2 hours at a temperature of 1100 - 1150 F. The minimum required tensile strength and impact values are 70,000 psi and 20 ft - lbs at +40 F. A search was made of past records of similar type 70A1 filler metal supplied by McKay and the results are presented in Table 11. When the data for lot 277T1804 are compared to the data on Table 11, it is evident that this heat will exceed the minimum specified values.

One lot of Type 7018 filler metal had incomplete documentation of chemical and mechanical properties. This lot, number 51052A, was manufactured by RACO and was satisfactorily tested by B&W for impact properties after a 48 hour stress relief at a temperature of 1100 to 1150 F. Although complete certification has not been found for this lot, the vendor reports that the lot was manufactured to the standard chemical specifications for type 7018 filler metal and had an "as welded" tensile strength of 82,000 psi. A study of the "as welded" versus "stress relieved" tensile strength in Table 9 shows that the maximum reduction in tensile strength is less than 6,000 psi after a stress relief of 48 hours at a temperature of 1100 to 1150 F. Thus, based on this study, it is evident that the lot will exceed the 70,000 psi minimum tensile strength requirement.

In summary, all of the filler metal having incomplete documentation is considered satisfactory and acceptable.

3. Corrective Actions

The following actions which have been taken by B&W will prevent a recurrence of the situation...

1. All weld filler metal intended for use on non-nuclear components has been removed from the areas where the Commercial Nuclear components are fabricated.

2. A review has been made to assure that all of the nuclear weld filler metal currently in use has been properly tested.

3. The system for releasing weld filler metal to the nuclear shops has been revised to assure compliance with the testing requirements of the applicable specifications. A new weld filler metal release form is now in use. This form must accompany the filler metal to the shops and it certifies that all of the required testing has been completed.

4. A listing of acceptable lots of weld filler metal will be available for use on the shop floor and during process upgrading. This listing will enable an in-process review of the acceptability of the lot numbers on Weld Control Records.

4. <u>Conclusions</u>

The data presented in Section 2 of this report assures the properties of the weld filler material which is incompletely documented. Therefore, the use of this material in the fabrication of the steam generators does not affect the safety of the plant. The corrective actions listed in Section 3 will prevent a recurrence of the situation disclosed in this report.

TABLE 1

LOTS WITH INCOMPLETE DOCUMENTATION

Electrode Type	Oconee Unit 1 Lot #	Oconee Unit 2 Lot #	Oconee Unit 3 Lot #	TMI Unit 1 Lot #	TMI Unit 2 Lot #	Crystal River Unit 3 Lot #	ANO Unit 1 Lot #	Rancho Seco Lot #	Midland Unit 1 Lot #	Midland Unit 2 Lot #	Davis Besse Lot #
7015:	818-025248 818-025653	818-026520 818-025248 818-025653		818-025653 818-026520 818-026198 818-023108 818-026363	818-025248 818-023108 818-024726	818-026520 818-023108 818-021446	818-026520 818-025653	818-024726 818-025690 818-025249	818-027574	818-027574 818-025690	818-025690 818-025249 818-026205
8015:	818-023004 818-022105 818-022773	818-023008 818-022105 818-023004	818-023006			818-026348					
7018:	51052A	818-024730						818-026931 93382 01972 422B7201	818-026931 10784		818-026931 10784
11018:		83272 8D21B27				212285					
E 70SG:	661V009										
70A1:	277T1804										

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TABLE 2

TYPE 7015 TEST CERTIFICATION BACKGROUND DATA

%Mn	%Cr + % Mo	%Ni	Carbon Equivalent	Tensile Strength PSI	Charpy V - Notch Ft-Lbs at +10 F.
			.03% Carbon		
.70	.57	.01	.205	82,270	86/105/106
.84	.55	.14	.23	82,500	84/84/97
.76	.66	.10	.23	80,250	53/66/74
.78	.55	.01	.215	76,000	105/108/133
			.04% Carbon		
.80	.48	.02	.22	81,500	74/92/102
.82	.55	.01	.235	82,500	69/71/118
.74	.60	.15	.225	79,500	80/87/94
.64	.57	.01	.205	84,000	92/97/110
.75	.59	.01	.225	81,000	100/122/150
.72	.55	.04	.215	85,500	55/58/76
.87	.57	.02	.24	78,500	95/100/105
.69	.57	.04	.21	76,500	45/55/60
.78	.63	.03	.21	78,250	135/180/185
.94	.52	.04	.25	87,500	108/110/125
.75	.63	.01	.23	78,000	100/101/102
.66	.55	.05	.205	79,000	89/92/101
.66	.56	.01	.205	78,000	110/125/126
.78	.58	.11	.235	82,000	95/99/120
.70	.56	.01	.215	80,000	105/107/122
.68	.56	.06	.205	82,000	95/95/100
.77	.54	.01	.225	80,000	110/114/120
.72	.53	.01	.215	76,000	114/129/123
.67	.62	.05	.210	76,500	100/106/110
.89	.60	.12	.255	84,000	95/105/112
.78	.64	.12	.24	82,000	90/94/94
.78	.52	.01	.22	80,000	69/72/84
.98	.70	.11	.275	78,000	113/135/163
.77	.47	.01	.215	78,500	93/94/103
.81	.56	.01	.23	79,000	100/100/114
.69	.65	.03	.22	85,000	91/106/110
.72	.59	.04	.22	78,500	111/115/135
.82	.58	.10	.245	85,000	65/81/84
.81	.58	.01	.235	81,000	88/91/107
.69	.51	.01	.205	79,500	87/111/124
.82	.49	.01	.23	79,250	105/117/119
			.05% Carbon		
.70	.53	.01	.225	78,000	116/31/132
.81	.47	.01	.23	77,300	93/98/130
.85	.51	.04	.24	78,500	95/95/103
.79	.62	.04	.24	77,000	100/103/122

Table 2 (Cont'd)

%Mn	%Cr + %Mo	%Ni	Carbon Equivalent	Tensile Strength PSI	Charpy V - Notch Ft-Lbs at +10 F
			.05% Carbon (Cont'd)		
.98	.55	.01	.265	80,500	91/105/110
.92	.63	.04	.265	79,500	78/86/105
.80	.51	.06	.235	81,500	100/100/115
.82	.55	.01	.245	88,500	108/129/120
.72	.61	.03	.23	78,000	86/106/107
.82	.53	.01	.245	84,000	105/145/150
.66	.55	.01	.215	85,000	99/104/110
.78	.60	.01	.24	80,000	100/120/121
.70	.61	.04	.23	81,250	85/96/102
.76	.59	.02	.24	78,580	113/117/135
.78	.62	.04	.24	74,500	79/95/105
.72	.60	.06	.235	78,500	71/108/110
.82	.51	.02	.24	81,750	90/100/105
.81	.59	.06	.25	80,000	84/98/100
.84	.56	.09	.25	90,000	82/90/102
.81	.45	.01	.23	74,750	132/144/150
.82	.51	.05	.24	82,000	102/109/120
.72	.56	.02	.225	77,000	110/114/149
.82	.52	.03	.24	77,000	115/127/133
.87	.54	.01	.25	81,000	123/127/137
			.06% Carbon		
.95	.54	.03	.275	85,500	77/85/95
.90	.54	.04	.265	79,500	109/115/121
.81	.60	.04	.255	81,000	90/92/96
.74	.51	.01	.23	86,000	110/115/116
.84	.51	.03	.25	80,500	84/98/104
.74	.49	.07	.235	82,000	115/120/137
.72	.53	.01	.235	78,000	106/120/125
.72	.66	.05	.25	80,750	86/102/105
.86	.47	.01	.245	83,800	84/90/110
.83	.61	.03	.27	77,500	103/108/120
.64	.50	.06	.225	78,000	75/85/88
.84	.48	.07	.255	75,000	70/107/118
.84	.50	.01	.25	84,250	108/110/110
			.07% Carbon		
.68	.49	.01	.24	77,750	109/110/111
.70	.49	.02	.24	77,500	100/106/107

1584 086

TABLE 3

TYPE 8015 TEST CERTIFICATION BACKGROUND DATA

%Mn	%Cr + %Mo	%Ni	Carbon Equivalent	Tensile Strength PSI	Charpy V - Notch Ft-Lbs at +10 F
			.03% Carbon		
.61	.55	.85	.225	86,000	91/95/95
.58	.48	.84	.22	82,000	100/101/149
.68	.58	1.01	.25	84,500	65/76/89
			.04% Carbon		
.65	.64	.87	.26	82,000	80/83/105
.79	.56	1.01	.275	87,500	88/90/100
.69	.62	.97	.265	84,750	99/105/105
.75	.61	.92	.27	87,500	70/84/75
.68	.48	1.04	.25	85,500	102/104/107
.82	.51	1.00	.28	86,000	84/92/95
.72	.51	.97	.26	85,000	109/117/120
.68	.49	1.01	.25	83,250	118/118/125
1.06	.58	.97	.33	85,000	90/91/96
.53	.49	.87	.225	86,000	65/90/91
			.05% Carbon		
.81	.61	.82	.285	90,500	91/99/100
1.04	.53	.97	.325	90,500	95/100/103
.77	.45	.88	.27	84,000	94/96/111
.90	.54	.90	.30	87,000	87/94/97
.82	.57	1.04	.295	83,000	94/103/105
.66	.61	1.10	.275	85,500	105/110/118
.86	.64	.92	.30	88,000	95/98/102
.64	.56	.90	.26	83,500	98/98/103
.94	.67	.95	.32	89,750	83/96/102
.66	.44	.87	.25	84,000	105/119/120
			.06% Carbon		
.83	.65	.95	.31	85,500	109/110/112
.75	.47	.96	.28	86,000	95/95/110
.80	.54	1.05	.295	87,000	95/100/104
			.07% Carbon		
.94	.52	1.10	.335	92,250	94/97/99

1584 087

TABLE 4

TYPE 7015 LOTS WITH INCOMPLETE DOCUMENTATION

Lot#	%C	%Mn	%Cr + %Mo	%Ni	Carbon Equivalent
818-026520	.03	.66	.50	---	.19
818-025248	.02	.66	.41	---	.17
818-025653	.05	.80	.45	---	.225
818-023108	.05	.73	.52	---	.22
818-026363	.05	.75	.51	---	.225
818-026198	.03	.81	.62	---	.225
818-024726	.045	.65	.54	---	.21
818-021446	.06	.77	.50	---	.24
818-025690	.05	.72	.51	---	.22
818-025249	.04	.81	.49	---	.225
818-027574	.07	.69	.54	---	.24
818-026205	.03	.81	.48	---	.215

TABLE 5

TYPE 8015 LOTS WITH INCOMPLETE DOCUMENTATION

Lot #	%C	%Mn	%Cr + %Mo	%Ni	Carbon Equivalent
818-022105	.08	.67	.55	.79	.285
818-023004	.043	.68	.61	.93	.26
818-023006	.049	.62	.52	1.15	.255
818-022778	.04	.77	.57	1.07	.28
818-023008	.039	.54	.55	.92	.23
818-026348	.04	.66	.55	.87	.25

TABLE 6

TYPE 11018 LOTS WITH INCOMPLETE DOCUMENTATION

Lot # & Supplier	%C	%Mn	%Cr + %Mo	%Ni	Carbon Equivalent
8D21B27 (Arcos)	.042	1.70	.45	2.16	.477
83272 (RACO)	.08	1.39	.45	2.00	.455
212285 (McKay)	.07	1.60	.40	1.60	.46

TABLE 9

TABULATION OF DATA ON VENDOR SUPPLIED LOTS OF TYPE 7018 FILLER METAL

Supplier, Lot Number, & Stress Relief	C	Mn	Cr + Mo	C.E.	Tensile Strength PSI	Charpy V-Notch Impacts at +10 F
Chemetron 06R891 48 hrs - 1125 F	.08	1.04	.08	.26	80,500	141/153/159
Chemetron 402A4081 48 hrs - 1125 F	.08	.99	.09	.225	72,250	148/213/219
Chemetron 412Z9601 48 hrs - 1125 F	.08	.89	.06	.235	71,500	239/239/240
Chemetron 650X171 48 hrs - 1125 F	.09	1.18	.10	.30	73,500	133/160/201
McKay 421H8321 65 hrs - 1125 F	.09	.89	.11	.25	74,000	110/130/237
McKay 422A8361						
As Welded	.05	1.12	---	.20	77,000	-------------
48 hrs - 1125 F	.05	.94	.03	.21	72,250	240+/240+/240+
RACO 401W9661 50 hrs - 1125 F	.06	.68	.03	.17	72,250	43/44
Murex 029B364 50 hrs - 1125 F	.05	1.06	.10	.24	70,150	240/240/240
McKay L22987						
As Welded	.05	.90	.03	.205	77,000	118.6 (Avg.)
8 hrs - 1100 F	---	---	---	---	73,750	107.7 - 118.6
50 hrs - 1125 F	.07	.89	.04	.225	71,750	232/234/239
West 2076						
As Welded	.05	1.25	.23	.28	84,545	--------------
50 hrs - 1125 F	.06	1.35	.31	.315	82,000	71/78/78
West 2171						
As Welded	.04	1.20	.30	.27	80,160	--------------
50 hrs - 1125 F	.07	1.18	.20	.30	87,750	65/71/81

1584 089

TABLE 10

TABULATION OF DATA ON VENDOR SUPPLIED LOTS OF E70SG WIRE

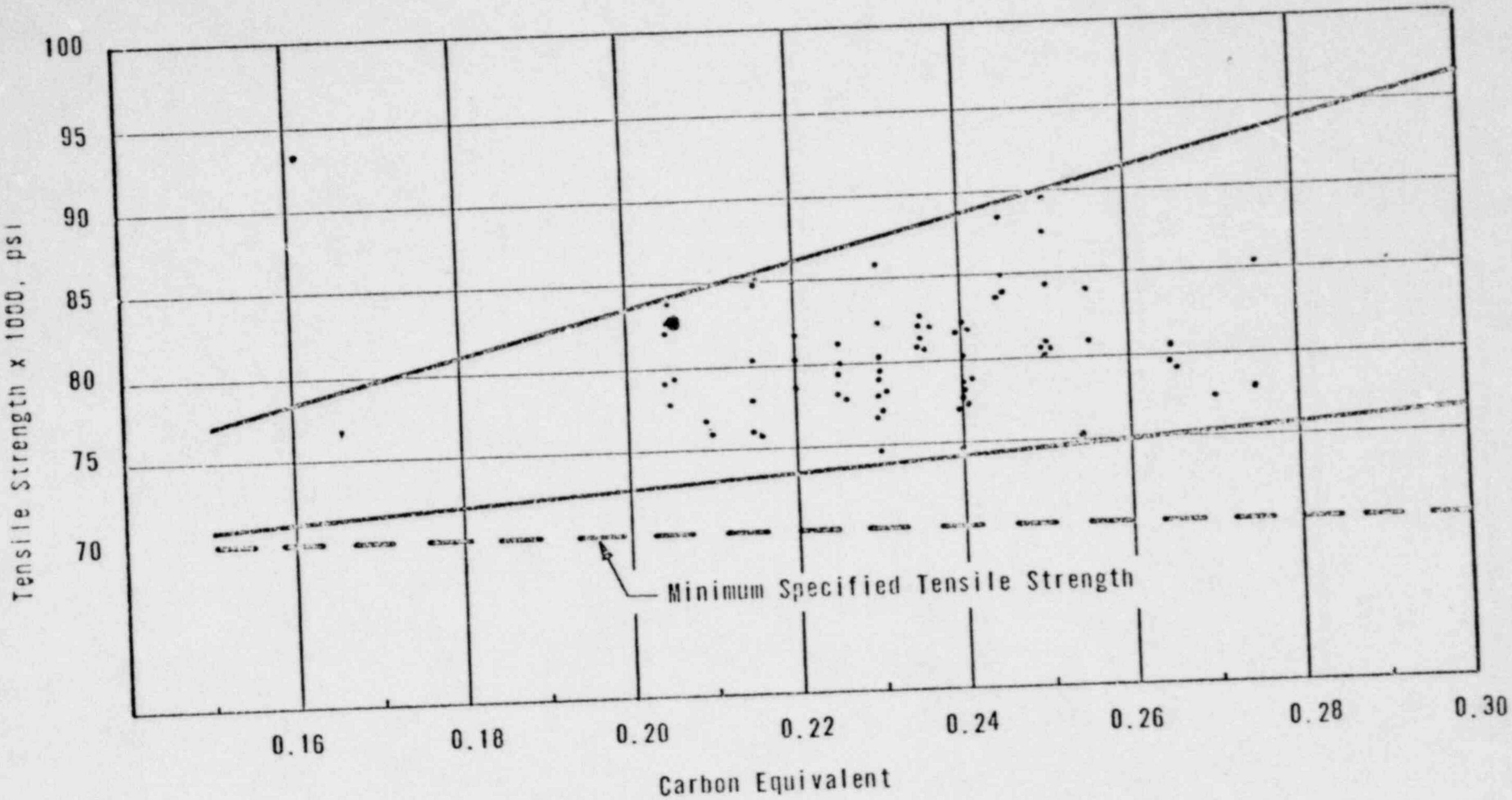
Supplier Wire Lot & Stress Relief	Condition Tested	%C	%Mn	%Cr + %Mo	C.E.	Tensile Strength PSI	Charpy V-Notch at +10 F
RACO-3P1925	Wire	.09	1.84	.42	.44	--------	---------
--- 48 Hrs 1125 F	Weld	.06	1.83	.54	.45	89,300	85/85/86
Page 20712	Wire	.11	2.01	.48	.495	--------	---------
--- 50 hrs 1125 F	Weld	.07	1.74	.54	.365	89,000	27/45/38
RACO 5814	Wire	.07	2.10	.48	.47	--------	---------
--- 48 hrs 1125 F	Weld	.07	1.50	.59	.38	89,500	40/42/52
Page 70715	Wire	.09	1.94	.50	.46	--------	--------
--- 48 hrs 1125 F	Weld	.07	1.35	.58	.355	89,500	68/88/96
Page 85146	Wire	.10	1.91	.46	.465	--------	---------
--- 50 hrs 1125 F	Weld	.05	1.50	.57	.555	92,700	55/57/59
Page 70748	Wire	.09	1.92	.48	.46	--------	---------
--- 48 hrs 1125 F	Weld	.07	1.55	.57	.385	88,000	50/65/78
Page 62234	Wire	.10	2.06	.46	.485	--------	----------
--- 48 hrs 1125 F	Weld	.07	1.94	.53	.445	93,120	45/56/96
Page 20717	Wire	.10	1.84	.47	.455	--------	----------
--- 65 hrs 1125 F	Weld	.09	1.40	.60	.38	89,000	63/65/76

TABLE 11

TABULATION OF DATA ON MCKAY SUPPLIED LOTS OF TYPE 70A1 FILLER METAL (After Stress Relief of 48 - 65 Hours at 1100 - 1150 F)

Lot Number	C	Mn	Cr + Mo	C.E.	Tensile Strength PSI	Charpy V-Notch Impacts at +10 F
210T7025	.05	.86	.51	.24	79,750	97/99/100
328T4607	.06	.80	.60	.25	75,500	155/120/145
249T5422	.06	.78	.60	.25	78,500	95/121/122
252T2840	.06	.78	.64	.25	77,750	74/69/70
232T2513	.06	.75	.55	.24	78,500	80/85/84
308T4296	.07	.82	.61	.27	87,000*	92/81/84
291T1238	.07	.66	.67	.25	78,000	81/88/83
289T6098	.09	.80	.62	.28	87,000	69/62/62
210T7341	.09	1.00	.63	.31	83,000	100/100/110
217T0792	.09	.72	.56	.25	85,500	59/45/55
262T3119	.10	.70	.64	.28	76,060	87/91/112
232T2412	.10	.86	.72	.31	89,000	45/45/39

* As welded tensile strength was 91,250 psi.

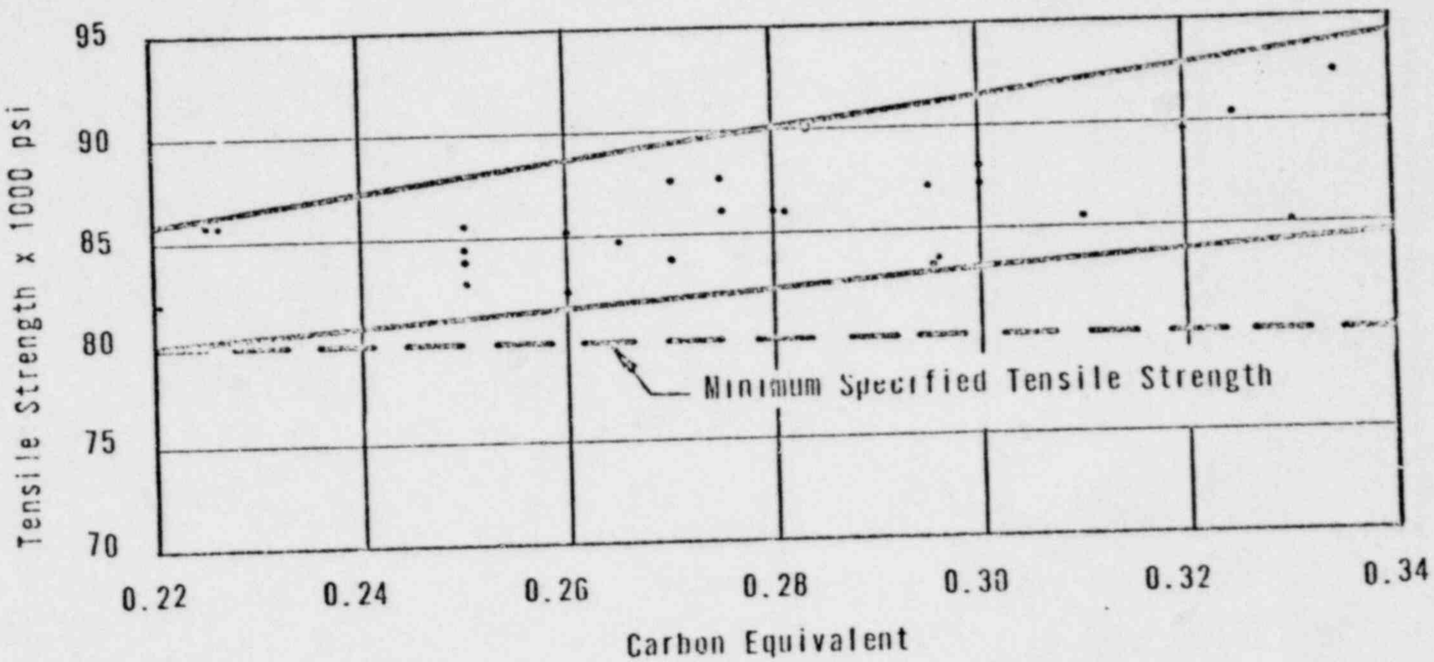


$$CE = \%C + \frac{\%Mn}{6} + \frac{\%Cr + \%Mo}{10} + \frac{\%Ni}{20}$$

TENSILE STRENGTH VS CARBON EQUIVALENT
FOR B&W TYPE 7015 ELECTRODES

Figure 1

1584 092



$$CE = \%C + \frac{\%Mn}{6} + \frac{\%Cr + \%Mo}{10} + \frac{\%Ni}{20}$$

TENSILE STRENGTH VS CARBON EQUIVALENT
FOR B&W TYPE 8015 ELECTRODES

Figure 2

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