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A SURVEY OF THE CORROSION OF MARTENSITIC AND FERRITIC STAINLESS STEELS IN PRESSURIZED WATER

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ORNL-TM 539

Contract No. W-7405-eng-26

Metals and Ceramics Division

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Date Issued

JUL 16 1963

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ABSTRACT

This report compares the corrosion resistance of martensitic and ferritic austenitic stainless steels and carbon steels in pressurized water at temperatures ranging between 500 and 600°F. Included are specific out-of-pile data for austenitic stainless steels, AISI types 302, 303, 304, 304L, 316, and 347; the martensitic AISI types 410, 420, 431, and 440C; the ferritic AISI types 430, 442, and 446; the precipitation-hardening type 17-4PH; and carbon steels, ASTM 212 A and 212 B.

Available corrosion results obtained under irradiation at exposures in the range of 7×10^{16} to 3×10^{19} nvt are also included for AISI types 304, 347, 410, 431, and 442.

With the exception of AISI type 431, the types of martensitic and ferritic stainless steels which were evaluated do not contain nickel. For application where it is desirable to minimize $_{27}Co^{58}$ activity produced from nickel, selection of a martensitic or ferritic stainless steel may be more appropriate than choosing the more popular nickel-bearing austenitic stainless steel or a fuel element cladding material.

Interpretation of the data in this report indicates that, on the average, martensitic and ferritic stainless steels corrode more rapidly than austenitic alloys but slower than carbon and low-alloy steels. Under selected controlled water conditions or under irradiation, the corrosion of the nickel-free stainless steels appears to differ little from the austenitics. The corrosion of martensitic and ferritic stainless steels in pressurized-water systems therefore does not appear of such magnitude as to rule out development of these materials as the cladding fuel elements for specific applications.

INTRODUCTION

Within the past several years, austenitic stainless steel has become a very prominent material for the cladding of fuel elements in reactors cooled and moderated with pressurized water in the temperature range of 500 to 600°F. Although its corrosion resistance is outstanding, irradiated austenitic stainless steel contains several gamma-emitting nuclides which, as a result of corrosion product transport, deposit throughout the primary reactor system.[1] It is conceivable that, after several fuel element loadings have been operated within the water environment, a significant buildup of activity may occur, thereby creating serious maintenance problems.

Although $_{26}Fe^{59}$ contributes its portion to the total activity, significant gamma activities accrue from the $_{27}Co^{60}$ due to activation of the cobalt impurity in these steels and $_{27}Co^{58}$, a transmutation product of $_{28}Ni^{58}$. It was observed, for example, after the first ten months' operation of the SM-1 Reactor with austenitic stainless steel fuel elements, that the gamma activity from $_{27}Co^{58}$ represented 40% of the total activity in the primary loop.[1] Activity from $_{27}Co^{60}$ has been generally minimized by selection of steel with less than 0.005 wt % Co (ref 2). The $_{27}Co^{58}$ activity, on the other hand, can be eliminated only by using a steel which does not contain nickel. This consideration leads to the examination of martensitic and ferritic types of stainless steels. Those types whose nominal composition does not include nickel are 403, 405, 410, 416, 420, 430, 440, 446, 501, and 502. Types 414 and 431 contain from 1.25 to 2.50 wt % Ni.

To evaluate the potential of these alloys on the basis of their corrosion resistance compared to austenitic stainless steels, a literature survey was made, and existing data on corrosion resistance in pressurized water at 500 to 600°F were tabulated for each type of stainless steel. These data are included in this report. Again for comparative purposes, data available on carbon steels of interest in the nuclear field were tabulated. The results were analyzed to compare the corrosion resistance of martensitic and ferritic stainless steels as a fuel element cladding material with the corrosion-resistant austenitic stainless steels and the less-corrosion-resistant carbon and low-alloy steels.

DISCUSSION

The corrosion rates in milligram per square decimeter per month (mg/dm^2-month) for austenitic, martensitic, ferritic, and other steels are included in Tables 1 through 20. In general, observation of the surface condition relative to pitting is lacking.

A detailed review of the tabulated data shows the difficulty in arriving at definite and reliable conclusions with respect to specific corrosion rates. This is because of limited data in many cases relative to the effect of water chemistry. Anomalies can be found which cannot be accounted for because of insufficient quantitative results. Also, for any particular type of stainless steel, low and high corrosion rates are reported. Although all tabular results were considered, the data and validity factors presented by D. J. DePaul[3] were most influential in arriving at the trends reported in the conclusions of this report.

Austenitic Stainless Steel

Since it is widely acknowledged that the 300-series stainless steels possess excellent corrosion resistance under virtually all circumstances in pressurized water and since the enormous volume of data makes a complete compilation impractical, only selected data typifying the behavior of AISI types 302, 303, 304, 304ELC, 316, and 347 are presented. These data are listed in Tables 1 through 6.

Only in very special cases does the corrosion rate of austenitic stainless steels exceed 10 mg/dm^2-month and these are usually associated with an unusual set of water conditions or specimen preparation. Generally the corrosion rate was about 5 mg/dm^2-month.

Martensitic, Ferritic, and Precipitation-Hardening Stainless Steels

Detailed results on these stainless steels are listed in Tables 7 through 15.

The martensitic, ferritic, and precipitation-hardening stainless steels can be grouped in a class which appears to have, on the average and without regard for water chemistry, a corrosion rate of 25 mg/dm^2-month. This is a factor of approximately five higher than the rate for austenitic stainless steel. The corrosion results, however, are replete with many instances where, under specific water conditions, the corrosion rate is quite comparable to that of austenitic stainless steel. Other cases exist where the corrosion resistance is poor and approaches that of carbon steels. Although the corrosion products on the surfaces are often reported as adherent, there are more frequent observations showing loose, powdery products than reported for austenitic stainless steel. The data are generally limited to tests of three months or less. However, a corrosion rate of 21 mg/dm^2-month was observed in one experiment in which type 430 stainless steel was tested for 4584 hr at 500°F in water containing 12 cc O_2 per liter and flowing at a rate of 25–30 fps.

Although the out-of-pile corrosion rates of the martensitic, ferritic, and precipitation-hardening stainless steels may be somewhat higher than the austenitic stainless, these alloys appear to have good corrosion resistance and offer reasonable potential as a substitute material for austenitic stainless steels in pressurized-water applications. More intensive corrosion tests, particularly on the nickel-free stainless steels, are needed to clearly define the corrosion resistance of these steels.

Carbon and Low-Alloy Steels

The data on these steels are included in Tables 16 through 20 for comparison. The corrosion rates appear to be an order of magnitude higher than those of the martensitic, ferritic, and age-hardening stainless steels, and it is doubtful whether they can ever be seriously considered as cladding materials for fuel elements in pressurized-water reactors.

Corrosion Resistance Under Irradiation

Data reported on the corrosion rates of specimens being irradiated indicate that the martensitic and ferritic stainless steels show rates quite comparable to the austenitic types. These results are tabulated in Table 21. The lone exception is a type 410 specimen which was tested in water with a pH of 11 and containing 500 cc H_2 per liter. Velocity and water chemistry were generally not reported for the in-pile tests, and the corrosion rate was determined on specimens which were not descaled. However, the results are extremely encouraging and a most favorable indicator of the potential of martensitic and ferritic stainless steels as a substitute for austenitic stainless steels.

CONCLUSIONS

Because of anomalies, erratic results, and limited data in many of the corrosion tests, specific conclusions cannot be made comparing the corrosion resistance of the martensitic, ferritic, and precipitation-hardening stainless steels in pressurized 500–600°F water. Neither does this survey attempt to establish trends relative to other corrosion effects such as crevice, stress, and electrochemical corrosion. However, the trends which exist are as follows:

1. With complete disregard to water chemistry and based on unirradiated specimens, the martensitic, ferritic, and precipitation-hardening steels corrode on the average approximately a factor of five faster than austenitic stainless steels and one tenth as fast as low-carbon and low-alloy steels.

2. These steels appear to depend more upon control of water chemistry than austenitic stainless and, in fact, under certain conditions have corrosion rates comparable to austenitic stainless steel. Since water chemistry conditions in any given reactor tend to fluctuate significantly, it is apparent that studies in this area would be advisable.

3. Under irradiation, the corrosion rates of both martensitic and ferritic stainless steels appear equivalent to those of austenitic stainless steels.

Based on these trends, nickel-free stainless steels cannot be ruled out as a potential fuel element cladding for some applications in 500 to 600°F pressurized water.

ACKNOWLEDGMENT

The authors wish to acknowledge the assistance of D. O. Welch for compiling the corrosion data contained in this report, to Sigfred Peterson for review and revision of the manuscript, and to Meredith R. Hill and Frances Scarboro of the Metals and Ceramics Division Reports Office for typing this report.

Table 1. Corrosion of AISI Type 302 Stainless Steel[a] in Pressurized Water at 500°F

Specimen Preparation	Test Duration (hr)[b]	Dissolved Gas (cc/liter) O_2	Dissolved Gas (cc/liter) H_2	pH	Flow Rate (fps)	Corrosion Rate (mg/dm^2-month) Descaled	Corrosion Rate (mg/dm^2-month) Nondescaled	Posttest Appearance	Reference
Machined	2592	Degas	Degas		25		+25	Lustrous, tight film	(4)
Machined	1856	30			25		+3.6	Tight, dark film	(4)
Machined, pickled in HNO_3 solution	500	0.6–3.8		c	30	−7	+3	Thin, black, tight film	(5)
Machined, pickled in HNO_3 solution	1000	0.6–3.8		c	30	−1	+1	Thin, loose film over tight film	(5)
Machined, pickled in HNO_3 solution	500	Degas	Degas	c	30	−18	+4	Greenish tight film	(5)
Machined, pickled in HNO_3 solution	1500	Degas	Degas	c	30	−10	+2	Dark brown	(5)
Machined, pickled in HNO_3 solution	500		89–127	c	30	0	0	Straw-colored film	(5)
Machined, pickled in HNO_3 solution	500		39–77	c	30	0	0	Thin, loose film	(5)
Machined	A	0–5		7	30	−10	+5		(3)
Machined	A		0–21	7	30		−10		(3)
Machined	A		25–100	7	30	−5	−5		(3)

[a]Nominal Composition: 0.15% max C; 17–19% Cr; 8–10% Ni; 2% max Mn; 0.06% max P; 0.03% max S; 1.0% max Si; bal Fe.

[b]In this and subsequent tables, if the data have been evaluated by DePaul (3), his validity factor is given in this column. The validity factor A indicates that the rate given is representative for the conditions cited, B the same based on less extensive data, and C that there is doubt concerning the validity of the corrosion rate, usually indicating inconsistent results or insufficient data.

[c]Cationic corrosion products continuously removed by ion-exchange purification system.

Table 2. Corrosion of AISI Type 303 Stainless Steel[a] in Pressurized Water at 500°F, pH 7, and 30 fps Flow Rate

Specimen Preparation	Test Duration (hr)	Dissolved Gas (cc/liter)		Corrosion Rate (mg/dm^2-month)		Posttest Appearance	Reference
		O_2	H_2	Descaled	Nondescaled		
Machined, pickled in HNO_3 solution	500[b]	0.5–3.7			+2	Black, tight film	(5)
Machined, pickled in HNO_3 solution	1000[b]	0.5–3.7			+1	Black, tight film	(5)
Machined, pickled in HNO_3 solution	500[b]	Degas	Degas	–6	–5		(5)
Machined, pickled in HNO_3 solution	1000[b]	Degas	Degas	0	–3	Glossy blue surface	(5)
Machined, pickled in HNO_3 solution	500[b]		39–77	–5	+2	Thin, loose film	(5)
Machined, pickled in HNO_3 solution	1000[b]		48–88	–3	–3	Thin, loose film	(5)
Machined, pickled in HNO_3 solution	1500[b]		40–88	0	–1	Thin, loose film	(5)
Machined	A	0–5			–5		(3)
Machined	A		0–21		–5		(3)
Machined	A		50	–5	–5		(3)

[a]Nominal Composition: 0.15% max C; 17–19% Cr; 8–10% Ni; 2% max Mn; 0.2% max P; 0.15% min S; 1.0% max Si; bal Fe.

[b]Cationic corrosion products continuously removed by ion-exchange purification system.

Table 3. Corrosion of AISI Type 304 Stainless Steel[a] in Pressurized Water

Temperature (°F)	Specimen Preparation	Test Duration (hr)	Dissolved Gas (cc/liter) O_2	Dissolved Gas (cc/liter) H_2	pH	Additives	Flow Rate (fps)	Corrosion Rate (mg/dm^2-month) Descaled	Corrosion Rate (mg/dm^2-month) Nondescaled	Posttest Appearance	Irradiation Exposure (nvt)	Reference
500	Vapor blasted	500		104–654	7	d	30		−8	Loose, black film		(5)
500	Vapor blasted	1000		104–654	7	d	30		−3	Loose, black film		(5)
500	Machined	1350	0–5		7	d	30	−3	−6	Steel gray		(5)
500	Machined	1350	0–5			NaOH	30		−5	Brown film		(5)
500	Machined	500	Degas	Degas	7	d	30		−11	Thin, gray film		(5)
500	Machined	1000	Degas	Degas	7	d	30	−8	−8	Thin, gray film		(5)
500	Machined	1500	Degas	Degas	7	d	30	−4	−11	Thin, gray film		(5)
500	Machined	500		24–77	7	d	30	−3	−1	Loose, thin straw film		(5)
500	Machined	1000		24–77	7	d	30		−1	Loose, thin straw film		(5)
500	Machined	500		89–127	7		30		+2	Adherent dull scale		(5)
500	Machined	336	30		7		30		+9	Brown tarnish		(4)
500	Machined	334	Degas	Degas	7		30		−8.1	No change in appearance		(4)
500	Machined, sensitized	A	Degas	Degas	7–10	LiOH	30	−10	−5			(3)
500	Machined	A	1–5		7		30	+5	−5			(3)
500	Welded, sensitized	B	0–5		10	LiOH	30		−10			(3)
500	Machined, electropolished	A		25–500			30		−5			(3)
580	Pickled	2500		500			15	−2				(6)
580	Electro-polished	2500		500			15	−2				(6)
580	Pickled	2500		500			15	−3			c	(6)

Table 3 (continued)

Temperature (°F)	Specimen Preparation	Test Duration (hr)	Dissolved Gas (cc/liter) O_2	Dissolved Gas (cc/liter) H_2	pH	Additives	Flow Rate (fps)	Corrosion Rate (mg/dm^2-month) Descaled	Corrosion Rate (mg/dm^2-month) Nondescaled	Posttest Appearance	Irradiation Exposure (nvt)	Reference
580	Electropolished	2500		500			15	−2				(6)
500		385		100	Start 8.9 End 6.1	H_3BO_3[b]	3.1		−12	Faint, uneven coating		(7)
500		385		100	Start 8.9 End 6.1	H_3BO_3[b]	13.1		−29	Faint, uneven coating		(7)

[a]Nominal composition: 0.08% max C; 18–20% Cr; 8–12% Ni; 2.0% max Mn; 0.045% max P; 0.03% max S; 1.0% max Si; bal Fe.

[b]Boric acid concentration 4.22 g/liter at start of test and 0.70 g/liter at end.

[c]Flux reported as normal for graphite-moderated reactor.

[d]Cationic corrosion products continuously removed by ion-exchange purification system.

Table 4. Corrosion of AISI Type 304L Stainless Steel[a] in Pressurized Water at pH 7 and 30 fps Flow Rate

Temperature (°F)	Specimen Preparation	Test Duration (hr)	Dissolved Gas (cc/liter)		Corrosion Rate (mg/dm^2-month)		Posttest Appearance	Reference
			O_2	H_2	Descaled	Nondescaled		
500	Machined	401	30			+19	Lustrous tarnish	(4)
600	Machined	500[b]	1–5		–4	+4	Thin, tight film	(5)
500	Machined	1000[b]	1–5			+2	Thin, tight film	(5)
500	Machined	1500[b]	1–5		–3	+1	Thin, tight film	(5)
500	Machined	1500[b]	Degassed	Degassed		–4	Light blue film	(5)
500	Machined	1000[b]		24–77	–1	0	Very thin, loose film	(5)
500	Machined	500[b]		104–654		–5		(5)
500	Machined	A	0–1			+5		(3)
500	Malcomized	C	0–1			–15		(3)
500	Malcomized	C	Degas	Degas		–200		(3)
500	Malcomized	C		25–50		–200		(3)
500	Machined	A		25–50		–5		(3)

[a]Nominal composition: 0.03% max C; 18–20% Cr; 8–12% Ni; 2.0% max Mn; 0.045% max P; 0.03% max S; 1.0% max Si; bal Fe.

[b]Cationic corrosion products continuously removed by ion-exchange purification system.

Table 5. Corrosion of AISI Type 316 Stainless Steel[a] in Pressurized Water

Temperature (°F)	Specimen Preparation	Test Duration (hr)	Dissolved Gas (cc/liter)		pH	Additives	Flow Rate (fps)	Corrosion Rate (mg/dm^2-month)		Posttest Appearance	Reference
			O_2	H_2				Descaled	Nondescaled		
500	Machined	324	30		7		25		−5.2	Bright yellow tarnish	(4)
600	Machined	334	Degas	Degas	7		25		+52	Powdery black oxide	(4)
500	Machined	500	0–5		7		30		−17	Steel-gray color	(5)
500	Machined	1350	0–5			NaOH	30		−6.2	Brown-gray	(5)
500	Machined	1500	1–4		7	b	30	−2	+2	Glossy, thin loose film	(5)
500	Machined	1000		39–78	7	b	30	0	0	Very thin, loose film	(5)
500	Machined	500		89–127	7	b	30	0	+2	Light straw tarnish	(5)
500	Machined	500		104–654	7	b	30	0	+2	Very thin, loose film	(5)
500	Welded, sensitized		0–5		7–10		30	−5	+5		(3)
500	Machined	500		25	7		30	−3			(5)
500	Machined			0–500	7		30	−5	−5		(3)

[a]Nominal composition: 0.08% max C; 16–18% Cr; 10–14% Ni; 2–3% Mo; 0.045% max P; 0.03% max S; bal Fe.

[b]Cationic corrosion products continuously removed by ion-exchange purification system.

Table 6. Corrosion of AISI Type 347 Stainless Steel[a] in Pressurized Water

Temperature (°F)	Specimen Preparation	Test Duration (hr)	Dissolved Gas (cc/liter) O_2	Dissolved Gas (cc/liter) H_2	pH	Additives	Flow Rate (fps)	Corrosion Rate (mg/dm^2-month) Descaled	Corrosion Rate (mg/dm^2-month) Nondescaled	Posttest Appearance	Irradiation Exposure (nvt)	Reference
500	Machined	334	Degas	Degas	7		25		+6.5	No change		(4)
500	Machined	353	1500		11		25		−3.9	Lustrous yellow tarnish		(4)
500	Machined	2000	Degas	Degas	7	d	30		0	Light gray tarnish		(5)
500	Machined	353	1500		9		25		−12	Lustrous yellow tarnish		(4)
500	Machined	500		24–51	7	d	30	−3	+1	Thin, loose, gray film		(5)
500	Machined	1500		40–88	7	d	30	−1	0	Thin, loose, gray film		(5)
500	Machined	500		89–127	7	d	30	−5	+1	Light brown film		(5)
500	Machined	2000		104–849	7	d	30	0	+0.5	Bluish gray		(5)
500	Vapor blasted	1500	1–7		7	d	30		−4	Tight, black film		(5)
500	Vapor blasted	1500		104–654	7	d	30		−1	Loose, black film		(5)
600	Sensitized	A		200	7		30		−5			(3)
600	Sensitized	A		200	11	LiOH	30	−5	−5			(3)
500	Machined, annealed, and nicrobrazed	A	0–1	0	7		30	−10	−5			(3)
500	Malcomized	C	0–1		7		30		−25			(3)
500		A	1–5		10	NaOH	30		−5			(3)
600	Machined	C	25		7		30		−5			(3)
500	Machined, electropolished	A	Degassed	Degassed	10.5	LiOH	30		−5			(3)
600	Sensitized, sanded	A		100	7		30	−15	−10			(3)
600	Electropolished, sensitized	A		100	7		30	−5	−5			(3)
540	In-pile	2000					b		−1		3×10^{19}	(8)
580	In-pile, pickled	2500		500	11		15	−1			c	(6)
580	Out-of-pile, pickled	2500		500	11		15	−4				(6)

Table 6 (continued)

Temperature (°F)	Specimen Preparation	Test Duration (hr)	Dissolved Gas (cc/liter) O_2	Dissolved Gas (cc/liter) H_2	pH	Additives	Flow Rate (fps)	Corrosion Rate (mg/dm^2-month) Descaled	Corrosion Rate (mg/dm^2-month) Nondescaled	Posttest Appearance	Irradiation Exposure (nvt)	Reference
580	In-pile electropolished	2500		500	11		15	−3			c	(6)
580	Out-of-pile electropolished	2500		500	11		15	−2			3.3×10^{19}	(6)
540	In-pile	1655			Start 8.9 End 6.1	H_3BO_3[e]	b		−2			(9)
500		385		100			3.1		−12	No change in appearance		(7)
500	Annealed	76	2–3				1.5		−74	Purple adherent coating		(4)
500	Annealed	172		500			1.5		−11	Dull metallic luster good		(4)

[a]Nominal composition: 0.08% max C; 17–19% Cr; 9–13% Ni; 2.0% max Mn; 0.045% max P; 0.030% max S; 1.0% max Si; Ta-Nb min ten times C; bal Fe.

[b]Specimen was exposed in the Argonne Pilot Channel.

[c]Neutron flux was normal for a graphite-moderated reactor.

[d]Cationic corrosion products continuously removed by ion-exchange purification system.

[e]Boric acid concentration 4.22 g/liter at start of test and 0.70 g/liter at end.

Table 7. Corrosion of AISI Type 410 Stainless Steel[a] in Pressurized Water

Temperature (°F)	Specimen Preparation	Test Duration (hr)	Dissolved Gas (cc/liter) O_2	Dissolved Gas (cc/liter) H_2	pH	Additives	Flow Rate (fps)	Corrosion Rate (mg/dm^2-month) Descaled	Corrosion Rate (mg/dm^2-month) Nondescaled	Posttest Appearance	Reference
500	Hardened	A	1–5		7–10	NaOH	30		–5		(3)
500	Hardened	1000–2000	Degas	Degas		c	30		–11		(10)
600	Hardened	C	Degas	Degas	8.5	NaOH	30		–100		(3)
500	Hardened	A	Degas	Degas	10	NaOH	20		–10		(3)
500	Hardened	1350		200–500	7		30		–10		(3)
500	Hardened	2000	0–5			NaOH	30		–18	Dull gray, some rust spots	(5)
500	Hardened	2000	0–5			c	30		–22	Medium gray	(5)
500	Hardened	2000	< 0.2			c	30		–4.9	Dull gray	(5)
500	Hardened	2000	< 0.2	350–600	7	c	30		–22	Dull, loose deposit	(5)
500	Hardened	375	30		7		30		–220	Loose rust and black powder	(4)
500	Hardened	101	1500–2300		10		Static		+160		(4)
500	Hardened	1500–2000	0–5			c	30		–52		(11)
580	In-pile	2500		500	11		15	–143			(6)
580	Out-of-pile	2500		500	11		15	–200			(6)
500		310		2–3	~7.0	c	30		–58		(11)
500		290		16	~7.0	c			–84		(11)
500		385		100	Start 8.9	H_3BO_3[b] End 6.1	3.1		–53	Dull gray powdery coating	(7)
600	As-received	1000		500			30	–51	–25		(12)
600	As-received	1992	Degas	Degas	7	c	30	–27	–19		(12)
600	As-received	6882	Degas	Degas	c	NH_3 1–2 ppm	30	–38	–31		(12)
600	As-received	9874	Degas	Degas	c	NH_3 1–2 ppm	30	–18	–1.5		(12)

[a]Nominal composition: 0.15% max C; 11.5–13.5% Cr; 1% max Si; 0.03% max S; 1% max Mn; bal Fe.

[b]Boric acid concentration 4.22 g/liter at start of test and 0.70 g/liter at end.

[c]Cationic corrosion products continuously removed by ion-exchange purification system.

Table 8. Corrosion of Hardened AISI Type 420 Stainless Steel[a] in Pressurized Water at 500°F at 30 fps Flow Rate

Test Duration (hr)	Dissolved Gas (cc/liter)		pH	Additives	Corrosion Rate (mg/dm^2-month)	Posttest Appearance	Reference
	O_2	H_2			Nondescaled		
B	0–1		7		–15		(3)
2000	< 0.2			b	–116	Loose oxide, some pitting	(5)
A	Degas	Degas	7		–5		(3)
A	1–5		10	LiOH	–5		(3)
1350	0–5		7		–8	Steel gray	(5)
2000	0–5			NaOH	–9	Medium gray, brown deposit	(5)
2000	0–5			b	–12	Dull gray, no pitting	(5)
0–500	0–5			b	–60		(10)
3149	3–5				+53	Black tarnish, small amount of rust	(4)

[a]Nominal composition: 0.15% min C; 12–14% Cr; 1.0% max Mn, 1.0% max Si; 0.03% max S; bal Fe.

[b]Cationic corrosion products continuously removed by ion-exchange purification system.

Table 9. Corrosion of AISI Type 431 Stainless Steel[a] in Pressurized Water

Temperature (°F)	Specimen Preparation	Test Duration (hr)	Dissolved Gas (cc/liter) O_2	Dissolved Gas (cc/liter) H_2	pH	Flow Rate (fps)	Corrosion Rate (mg/dm^2-month) Nondescaled	Posttest Appearance	Irradiation Exposure (nvt)	Reference
540	Hardened	2000	2–3			b	+11		3×10^{19}	(8)
540		2000	2–3			b	–1		3×10^{19}	(8)
500		260	Degas	Degas	7.0–8.8	30	+53			(11)
500		310		2–3	~7.0	30	–74			(11)
500		290		16	~7.0	30	–69			(11)
540	Hardened	1655				b	–7		3.3×10^{19}	(9)
540		1655				b	–6		3.3×10^{19}	(9)
500	Hardened and ground	304	Degas	Degas		25	+62	Loose, black powder		(4)
500	Hardened and ground	304	30			25	–97	Rust film		(4)

[a]Nominal composition: 0.2% max C; 15–17% Cr; 1.25–2.50% Ni; 1% max Mn; 1% max Si; 0.03% max S; bal Fe.

[b]Specimens were exposed in the Argonne Pilot Channel.

Table 10. Corrosion of AISI Type 440C Stainless Steel[a] in Pressurized Water at 500°F

Specimen Preparation	Test Duration (hr)	Dissolved Gas (cc/liter) O_2	Dissolved Gas (cc/liter) H_2	pH	Additives	Flow Rate (fps)	Corrosion Rate (mg/dm^2-month) Nondescaled	Posttest Appearance	Reference
Hardened	B	0–1		7		30	–15		(3)
Hardened	A	0–1		10	NaOH	30	–15		(3)
Hardened	2000	< 0.2			b	30	–6	Dull gray	(5)
Hardened	A	Degas	Degas	7		30	–15		(3)
Hardened	664	Degas	Degas	7		25	+19	Adherent, black film	(4)
Hardened	201	Degas	Degas	7		25	+10	Powdery outer layer	(4)
Hardened	401	Degas	Degas	7		25	–57	Loose, black powder	(4)
Hardened	1000–2000	Degas	Degas		b	30	–12		(10)
Hardened	335	Degas	Degas	12	Na_3PO_4	25	+300	Rust covered	(4)
Hardened	335	Degas	Degas	10	Buffer solution	25	+28	Adherent, black film	(4)
Hardened	2000	0–5			NaOH	30	–10	Loose, brown deposit	(5)
Hardened	1350	0–5		7		30	–8	Gray with rust marks	(5)
Hardened	2000	0–5			b	30	–16	Few rust spots	(5)
Hardened	C	1–5		7		30	–50		(3)
Hardened	1500–2000	0–5			b	30	–30		(10)
Hardened	A		500	7		30	–25		(3)
Hardened	2000	< 0.01	350–600	7		30	–27	Loose, black deposit	(5)
Hardened	170	14		7		25	–140	Rough, brown powder	(4)
Hardened	3149	3–5		7		25	–14	Dull black tarnish	(4)
Hardened	335	Air saturated		12	Na_3PO_4	25	+26	Loose, rust powder	(4)
	260	Degas	Degas	7.0–8.8		30	+19		(14)
	310		2–3		b	30	–62		(14)
	290		16		b	30	–84		(14)

[a]Nominal composition: 0.95–1.20% C; 16.0–18.0% Cr; 0.75% max Mo; 1% max Mn; 1% max Si; 0.03% max S; bal Fe.

[b]Cationic corrosion products continuously removed by ion-exchange purification system.

Table 11. Corrosion of AISI Type 430 Stainless Steel[a] in Pressurized Water at 500°F

Specimen Preparation	Test Duration (hr)	Dissolved Gas (cc/liter)		pH	Additives	Flow Rate (fps)	Corrosion Rate (mg/dm^2-month)		Posttest Appearance	Reference
		O_2	H_2				De-scaled	Nonde-scaled		
Machined	4584	12		7	c	25–30		−20.7	Lustrous black with some loose powder	(14)
Malcomized	375	30				Static		−121	Loose rust	(15)
	385		100	Start 8.9 End 6.1	H_3BO_3[b]	3.1		+24	Lustrous black coating	(7)

[a]Nominal composition: 0.12% max C; 14.0–18.0% Cr; 1% max Mn; 1% max Si; 0.03% max S; bal Fe.

[b]Boric acid concentration 4.22 g/liter at start of test and 0.70 g/liter at end.

[c]Cationic corrosion products continuously removed by ion-exchange purification system.

Table 12. Corrosion of Type 442 Stainless Steel[a] in Pressurized Water at 540°F in the Argonne Pilot Channel

Temperature (°F)	Specimen Preparation	Test Duration (hr)	Corrosion Rate (mg/dm^2-month) Nondescaled	Irradiation Exposure (nvt)	Reference
540	In-pile specimen	2000	+2	3×10^{19}	(8)
540	In-pile specimen	1655	+2	3.3×10^{19}	(9)
540	In-pile specimen	1655	+1	3.3×10^{19}	(9)
540	In-pile specimen	1655	0	3.3×10^{19}	(9)
540	In-pile specimen	1655	+1	3.3×10^{19}	(9)
540	In-pile specimen	1655	+1	3.3×10^{19}	(9)
540	In-pile specimen	1655	+1	3.3×10^{19}	(9)

[a]Nominal composition: 0.20% C; 0.65% Mn; 0.5% Si; 12% Cr; 0.75% Ni; 1% Mo; 1% W; 0.3% V.

Table 13. Corrosion of AISI Type 446 Stainless Steel[a] in Pressurized Water

Temperature (°F)	Specimen Preparation	Test Duration (hr)	Dissolved Gas (cc/liter) O_2	Dissolved Gas (cc/liter) H_2	pH	Additives	Flow Rate (fps)	Corrosion Rate (mg/dm²-month) Nondescaled	Posttest Appearance	Contact Corrosion Resistance with Type 347 Stainless Steel	Reference
500	Malcomized	0–250	2				30	+23			(15)
500	Malcomized	250–750	2				30	+3			(15)
500	Malcomized	460	30				Static	–400–1200	Completely rusted		(15)
500	Malcomized	375	30				Static	40	Large deposits of loose rust		(15)
500	Machined	260	Degas	Degas	7.0–8.8		30	–7	Shiny or dull gray		(11)
500	Machined	310		2–3	~7.0	b	30	–16	Shiny or dull gray		(11)
500	Machined	290		16	~7.0	b	30	–6	Shiny or dull gray		(11)
540	In-pile specimen	1655					c	+1			(9)
540	In-pile specimen	1655					c	+3	Dull gray		(9)
500	In-pile specimen[d]	2000					c	–6			(8)
500		385		100	Start 8.9 End 6.1	H_3BO_3[e]		+32	Faint, even coating		(7)
500	Nitrided and lapped[f]	250	2			b	0.02	+16	Loose scale	Satisfactory	(5)
500	Machined[f]	250	2			b	0.02	+14	Fairly tight	Fair	(5)
500	Nitrided[f]	500	2			b	0.02	+21	Loose scale	Satisfactory	(5)
500	Nitrided and lapped[f]	500	Degas	Degas		b	0.02	–78	Loose scale	Unsatisfactory	(5)
500	Machined[f]	500	Degas	Degas		b	0.02	+36	Loose scale	Unsatisfactory	(5)
500	Nitrided and lapped[f]	250		500		b	0.02	–6	Loose scale	Satisfactory	(5)
500	Machined[f]	250		500		b	0.02	0	Adherent scale	Fair	(5)
500	Nitrided and lapped[g]	750	2			b	0.02	+8	Loose scale	Fair	(5)

Table 13 (continued)

Temperature (°F)	Specimen Preparation	Test Duration (hr)	Dissolved Gas (cc/liter) O_2	Dissolved Gas (cc/liter) H_2	pH	Additives	Flow Rate (fps)	Corrosion Rate (mg/dm^2-month) Nondescaled	Posttest Appearance	Contact Corrosion Resistance with Type 347 Stainless Steel	Reference
500	Machined[g]	750	2			b	0.02	+2	Fairly tight scale	Fair	(5)
500	Nitrided[g]	750	2			b	0.02	+27	Loose scale	Fair	(5)
500	Nitrided and lapped[g]	500	Degassed	Degassed		b	0.02	−65	Loose scale	Unsatisfactory	(5)
500	Machined[g]	500	Degassed	Degassed		b	0.02	+3	Loose scale	Unsatisfactory	(5)
500	Nitrided[g]	500	Degassed	Degassed		b	0.02	−17	Loose scale	Unsatisfactory	(5)
500	Nitrided and lapped[g]	250		500		b	0.02	0	Loose scale	Satisfactory	(5)
500	Machined[g]	250		500		b	0.02	+8	Adherent scale	Fair	(5)
500	Nitrided[g]	250		500		b	0.02	+74	Loose scale	Satisfactory	(5)
500	Nitrided and lapped[h]	250	2			b	0.02	+18		Fair	(5)
500	Machined[h]	250	2			b	0.02	+4		Fair	(5)
500	Machined[h]	750	2			b	0.02	−1	Fairly tight scale	Fair	(5)
500	Nitrided and lapped[h]	500	Degassed	Degassed		b	0.02	−97	Loose scale	Unsatisfactory	(5)
500	Machined[h]	500	Degassed	Degassed		b	0.02	+2	Loose scale	Unsatisfactory	(5)
500	Nitrided[h]	500	Degassed	Degassed		b	0.02	−17	Loose scale	Unsatisfactory	(5)
500	Nitrided and lapped[h]	250		500		b	0.02	−8	Loose scale	Satisfactory	(5)
500	Machined[h]	250		500		b	0.02	−6	Adherent scale	Fair	(5)

Table 13 (continued)

Temperature (°F)	Specimen Preparation	Test Duration (hr)	Dissolved Gas (cc/liter) O_2	Dissolved Gas (cc/liter) H_2	pH	Additives	Flow Rate (fps)	Corrosion Rate (mg/dm^2-month) Nondescaled	Posttest Appearance	Contact Corrosion Resistance with Type 347 Stainless Steel	Reference
500	Nitrided[h]	250		500		b	0.02	+74	Loose scale	Satisfactory	(5)
500	Annealed	76	2–3				2	−80 −40	Dull gray, adherent film, good		(4)
500	Annealed	172		500			2	−21	Faint blue adherent film, good		(4)

[a]Nominal composition: 0.20% max C; 23–27% Cr; 1.5% max Mn; 1.0% max Si; 0.03% max S; bal Fe.

[b]Cationic corrosion products continuously removed by ion-exchange purification system.

[c]Specimen was exposed in the Argonne Pilot Channel.

[d]Irradiation exposure – 3.3×10^{19} nvt.

[e]Boric acid concentration 4.22 g/liter at start of test and 0.70 g/liter at end.

[f]Hot rolled, annealed, and machined. Heated to 1500°F for 30 min and water cooled.

[g]Hot rolled, annealed, and machined. Heated to 1500°F for 30 min and water cooled. Heated to 950°F for 50 hr and air cooled.

[h]Hot rolled and machined. Heated to 1500°F for 30 min and water cooled. Heated to 950°F for 50 hr and air cooled. Heated to 1400°F for 50 hr and air cooled.

Table 14. Corrosion of ARMCO 17-4 PH Steel[a] in Pressurized Water at 500°F

Specimen Preparation	Test Duration (hr)	Dissolved Gas (cc/liter)		pH	Additives	Flow Rate (fps)	Corrosion Rate (mg/dm^2-month)		Posttest Appearance	Reference
		O_2	H_2				Descaled	Nondescaled		
Machined, hardened	A	1–5		7		30	–20	–5		(3)
Machined, hardened	B	Degassed	Degassed	7		30		–25		(3)
Machined, hardened	C	Degassed	Degassed	8.5		30		–20		(3)
Machined, hardened	A	Degassed	2.0	9.8–10.5	LiOH	20		–5		(3)
Machined, hardened	B		5–22	7		30		–100		(3)
Machined, hardened	B	Degassed	Degassed	10.0–10.5	LiOH	30		–5		(3)
Machined, hardened	C		50	7		30	–100	–50		(3)
Machined, pickled, and hardened	1000	1–4		7	b	30	–8	0	Thin, loose film	(5)
Machined, pickled, and hardened	1500	Degassed	Degassed	7	b	30		–87	Thin, tight film	(5)
Machined, pickled, and hardened	1500	< 0.1	40–88	7	b	30	–90	–50	Thin, tight film	(5)
Machined, pickled, and hardened	1500	< 0.1–1.4		7	b	30	–12	0	Faint tarnish	(5)
Annealed, hardened	338	Degas	Degas	7		25		+31	Thin, light brown film	(4)

[a]Nominal composition: 0.07% C; 1.00% Mn; 0.04% P; 0.03% S; 1.00% Si; 3.0–5.0% Ni; 0.25–0.45% Ta-Cb; 15.5–17.5% Cr; 3–4% Cu.

[b]Cationic corrosion products continuously removed by ion-exchange purification system.

Table 15. Corrosion of ARMCO 17-7 PH[a] in Pressurized Water

Temperature (°F)	Specimen Preparation	Test Duration (hr)	Dissolved Gas (cc/liter) O_2	Dissolved Gas (cc/liter) H_2	pH	Flow Rate (fps)	Corrosion Rate (mg/dm^2-month) Descaled	Corrosion Rate (mg/dm^2-month) Nondescaled	Posttest Appearance	Reference
500	Machined, hardened	A	0–5		7	30	–5	+5		(3)
500	Malcomized, hardened	C	0–5		7	30		–15		(3)
500	Machined, hardened	B	Degas	Degas	7	30		–5		(3)
500	Machined, malcomized, and hardened	B		0–22	7	30		–50		(3)
500	Malcomized, hardened	B		50	6.4–6.7	30		–100		(3)
500	Machined, hardened	B		100	7	30		–50		(3)
600	Machined, hardened	C	Degas	Degas	8.5	30	–50			(3)
500	Machined, hardened	340	Degas	Degas	7	25		–11	Lustrous black tarnish	(4)
500	Machined, hardened	1500	1–4		b	30	–1	+1	Loose film	(5)
500	Machined, hardened	1500	< 0.01–1.4		b	30	–2	–1	Irregular brown coating	(5)
500	Machined, hardened	1500	Degas	Degas	b	30		–60	Thin, tight film	(5)
500	Machined, hardened	500	< 0.01	34–59	b	30		–73	Thin, tight film	(5)
500	Machined, hardened	1500	< 0.01	40–127	b	30		–36	Thin, tight film	(5)

[a]Nominal composition: 0.09% C; 1.00% Mn; 0.04% P; 0.03% S; 1.00% Si; 6.50–7.8% Ni; 16–18% Cr; 0.75–1.5% Al.

[b]Cationic corrosion products continuously removed by ion-exchange purification system.

Table 16. Corrosion of Low-Alloy Steels in Pressurized Water at 600°C (3)

Alloy	Specimen Preparation	Validity Factor	Dissolved Gas (cc/liter) O_2	Dissolved Gas (cc/liter) H_2	pH	Additives	Flow Rate (fps)	Corrosion Rate (mg/dm^2-month) Descaled
a	Electropolished	A	Degas	Degas	11	LiOH	30	−15
a	Ground	A	Degas	Degas	11	LiOH	30	−25
a	Electropolished	C		20	11	LiOH	30	−150
a	Surface ground	B		20	11	LiOH	30	−200
a	Shaped	B		500	11	LiOH	30	−50
b	Pickled, sanded	C	200–1000		9–10	NH_4OH	30	−50
b	Electropolished	A	200–1000		9–10	NH_4OH	30	−25
b	Ground	C	Degas	Degas	11	LiOH	30	−200
b	Electropolished	C	Degas	Degas	11	LiOH	30	−100
b	Machined	C		100	7		20	−200
b	Pickled, sanded, and electropolished	A		500	11	LiOH	30	−25
b	Ground	C		500	11	NH_4OH	30	−200

[a]Nominal composition: 0.15% C; 0.3–0.6% Mn; 0.03% P; 0.03% S; 0.5% Si; 2.0–2.5% Cr; 0.9–1.1% Mo (Croloy $2\frac{1}{4}$).

[b]Nominal composition: 0.15% C; 0.3–0.6% Mn; 0.03% S; 0.03% P; 0.5–1.0% Si; 1.0–1.5% Cr; 0.45–0.65% Mo (Croloy $1\frac{1}{4}$).

Table 17. Corrosion of Carbon Steel[a] in Pressurized Water

Temperature (°F)	Specimen Preparation	Test Duration (hr)	Dissolved Gas (cc/liter) O_2	Dissolved Gas (cc/liter) H_2	pH	Additives	Flow Rate (fps)	Corrosion Rate (mg/dm^2-month) Descaled	Corrosion Rate (mg/dm^2-month) Nondescaled	Reference
600	Machined	2500	< 0.1	20	9.5	1–2 ppm NH_3 NH_4OH	20	220		(3)
600	Machined	2000	< 0.1	70	9	10 ppm NH_3 NH_4OH	21	180		(3)
600	Machined	1500	< 0.1	30	10	5 ppm HN_3 LiOH	21	130		(3)
600	Pickled, air exposed at 950°F	1000	< 0.1	20	9.5	NH_4OH	36	220		(3)
600	Exposed to steam at 750°F for 48 hr	500	< 0.1	30	7–9	1–2 ppm NH_3 NH_4OH	33	720		(3)
500		500	< 0.1	10	10	LiOH	21	210		(3)
600	Machined, air exposed at 950°F, morpholine preconditioned	500	< 0.1	30	10	LiOH	21	290		(3)
600	Heat treated in air at 600°F, steam pretreated 15 hr	500	< 0.1	20	7		20–25	400		(3)
600	Machined	500	< 0.1	20	7		15	430		(3)
600	Steam pretreated for 15 hr at 700°F, heated in air at 800°F for 25 hr	500	< 0.1	20	7	LiOH	21	500		(3)
600		200	< 0.1	20	10	LiOH	21	180		(3)
600	Electropolished	798		100	b		30	–199	–135	(12)
600	Pickled	798		100	b		30	–238	–150	(12)
600	Surface ground	798		100	b		30	–260	–189	(12)
600	Sanded	798		100	b		30	–242	–160	(12)

[a]Nominal composition: 0.27% C; 0.62% Mn; 0.26% Si; 0.012% P; 0.04% S (ASTM 212 A).

[b]Cationic corrosion products continuously removed by ion-exchange purification system.

Table 18. Corrosion of Carbon Steel[a] in Pressurized Water

Temperature (°F)	Specimen Preparation	Test Duration (hr)	Dissolved Gas (cc/liter) O_2	Dissolved Gas (cc/liter) H_2	pH	Additives	Flow Rate (fps)	Corrosion Rate (mg/dm^2-month) Descaled	Corrosion Rate (mg/dm^2-month) Nondescaled	Posttest Appearance	Reference
500	Machined	338	Degas	Degas	7		25			Loose, black coating, rust spots	(4)
500	Machined	338	30		7		25		−320	Very loose, black film	(4)
500	Machined	340	240		7		25		−44	Tight, black film	(4)
500	Machined	338		18	7		25		−350	Loose, black film	(4)
600	Machined	330	Degas	Degas	7		25		+16	Tight, black oxide film	(4)
600	Machined, sanded, and electropolished	4000	< 0.1		11	LiOH	30	30			(3)
600	Sanded, electropolished, and pickled	2800	< 0.1	500	11	LiOH	30	35			(3)
600	Sanded, electropolished, and pickled	2000	< 0.1		11	LiOH	30	45			(3)
600	Machined	2000	< 0.3	Equilibrium	7–10	LiOH	30	320			(3)
600	Sanded, electropolished, and pickled	2000	< 0.2	20	7–10	1 ppm NH_3 NH_4OH	30	360			(3)
600	Sanded, electropolished, and pickled	1500	< 0.1	500	11	100 ppm NH_3 NH_4OH	30	85			(3)
600	Sanded, electropolished, and pickled	2000	< 0.1	20	9	NH_4OH	30	230			(3)
600	Ground, machined, sanded, and pickled	1000	< 0.01	500	11	LiOH NH_4OH	30	150			(3)
500	Sanded, electropolished, pickled, and machined	1000	< 0.01		11	LiOH	30	180			(3)
600	Sanded, electropolished, pickled, and machined	1000	< 0.14	20	7–10	NH_4OH 2 ppm NH_3	30	430			(3)
600	Pickled	1000	< 0.1	40	7		30	720			(3)
600	Ground, sanded, electropolished, pickled, and annealed	800	< 0.2	100	11	LiOH	30	180			(3)

Table 18 (continued)

Temperature (°F)	Specimen Preparation	Test Duration (hr)	Dissolved Gas (cc/liter) O_2	Dissolved Gas (cc/liter) H_2	pH	Additives	Flow Rate (fps)	Corrosion Rate (mg/dm^2-month) Descaled	Corrosion Rate (mg/dm^2-month) Nondescaled	Posttest Appearance	Reference
540	Sanded, ground	500	< 0.1	500	7		30	270			(3)
600	Sanded, electropolished, and pickled	500	400	low	7–9	2 ppm NH_3 NH_4OH	30	85		Heavy reddish scale	(3)
600	Sanded, electropolished, and pickled	500	400	low	7–9	40 ppm NH_3 NH_4OH	30	210		Heavy reddish scale	(3)
500	Sanded, ground	500	< 0.01		11	NH_4OH	30	190			(3)
600		2000		100	9.5–10	NH_3[b]	15	158			(13)
600		2600			6.8–11.6		15	45			(13)
600		2000			7.1–9.8		15	650			(13)
600		2000			7.1–9.8		15	320			(13)
600		1000			6.1–10.9		15	97			(13)
600	In-pile specimen	1900	0–30	100	8–10		30	120 min 150 av 180 max		Specimens were coated with an even, black deposit. No signs of pitting or corrosion cracking.	(16)
600		1900	0–30	100	7.0		30	270 min 300 av 330 max			(16)

[a]Nominal composition: 0.35% C; 0.90% Mn; 0.15–0.30% Si; 0.04% P; 0.04% S (ASTM 212 B).

[b]Cationic corrosion products continuously removed by ion-exchange purification system.

Table 19. Corrosion of Sanded, Electropolished, and Machined Carbon Steel[a] in Pressurized Water (3)

Temperature (°F)	Test Duration (hr)	Dissolved Gas (cc/liter)		pH	Additives	Flow Rate (fps)	Corrosion Rate (mg/dm^2-month)	Posttest Appearance
		O_2	H_2				Descaled	
600	4000	< 0.1	Degas	11	LiOH	30	30	
600	2800	< 0.3	500	11	LiOH	30	80	
600	2000	< 0.01	500	11	LiOH	30	35	
600	2000	< 0.3	20	11	LiOH	30	70	
600	2000	< 0.2	20	7–10	NH_4OH	30	350	
600	1500	< 0.2	500	11	NH_4OH 100 ppm NH_3	30	70	
600	1000	< 0.2	20	7–10	NH_4OH	30	450	
600	1000	< 0.1		11	LiOH	30	180	
200–600	500	400	low	7–9	NH_4OH	30	145	Heavy reddish scale

[a]Nominal composition: 0.04% C; 0.41% Mn; 0.009% P; 0.036% S; 0.01% Si.

Table 20. Corrosion of Machined Carbon Steel[a] in Pressurized Water (3)

Temperature (°F)	Alloy	Test Duration (hr)	Dissolved Gas (cc/liter)		pH	Additives	Flow Rate (fps)	Corrosion Rate (mg/dm^2-month)
			O_2	H_2				Descaled
600	a	2500	< 0.1	20	9.5	NH_4OH	20	220
600	a	2000	< 0.1	70	9	NH_4OH	21	140
500	a	1500	< 0.10	20	9.5	NH_4OH	12	95
600	b	2500	< 0.1	20	9.5	NH_4OH	20	220
600	b	1500	< 0.1	20	11	LiOH	12	140
600	b	500	< 0.1	21	10	LiOH 5 ppm NH_3	21	290

[a]Nominal composition: 0.25% C; 0.14% Mn; 0.012% P; 0.015% S; 0.17% Si; 0.10% Al; 0.46% Ti.

[b]Nominal composition: 0.06% C; 0.08% Mn; 0.008% P; 0.015% S; 0.09% Si; 0.40% Cu; 0.31% Zr.

Table 21. Comparison of Corrosion Rates of Austenitic, Martensitic, and Ferritic Stainless Steels Under Irradiation in 500–600°F Pressurized Water

Type of Steel	Surface Preparation	Water Temperature (°F)	Flow Rate (fps)	Test Duration (hr)	Estimated Irradiation Exposure (nvt)	Corrosion Rate (mg/dm^2-month) De-scaled	Corrosion Rate (mg/dm^2-month) Nonde-scaled	Remarks
				Austenitic Stainless Steel				
304	Pickled	580	15	2500	7.5×10^{16}	−3		
304	Electropolished	580	15	2500	7.5×10^{16}	−2		
347		540		2000	3.0×10^{19}		−1	Flow rate not reported
347	Electropolished	540		1655	3.3×10^{19}		−2	Flow rate not reported
347	Pickled	580	15	2500	7.5×10^{16}	−1		500 cc/liter H_2 pH 11
347	Electropolished	580	15	2500	7.5×10^{16}	−3		500 cc/liter H_2 pH 11
				Martensitic Stainless Steel				
410		580	15	2500	7.5×10^{16}		−143	500 cc/liter H_2 pH 11
431		540		2000	3.0×10^{19}		+11	Flow rate not reported 2–3 cc O_2/liter
431		540		2000	3.0×10^{19}		−1	Flow rate not reported 2–3 cc O_2/liter
431		540		1655	3.3×10^{19}		−7	Flow rate not reported
431		540		1655	3.3×10^{19}		−6	Flow rate not reported
				Ferritic Stainless Steel				
442		540		2000			+2	Flow rate not reported
442		540		1655	3.0×10^{19}		+2	Flow rate not reported
442		540		1655	3.0×10^{19}		+1	Flow rate not reported
442		540		1655	3.3×10^{19}		0	Flow rate not reported
442		540		1655	3.3×10^{19}		+1	Flow rate not reported
442		540		1655	3.3×10^{19}		+1	Flow rate not reported
442		540		1655	3.3×10^{19}		+1	Flow rate not reported

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