Corrosion of Borated Stainless Steel in Water and Humid Air

Xihua (Shē-wă) He,[1] Tae Ahn,[2] Timothy Sippel[2]

[1]Center for Nuclear Waste Regulatory Analyses
Southwest Research Institute®
San Antonio, Texas

[2]Office of Nuclear Material Safety and Safeguards
U.S. Nuclear Regulatory Commission
Washington, DC

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Outline

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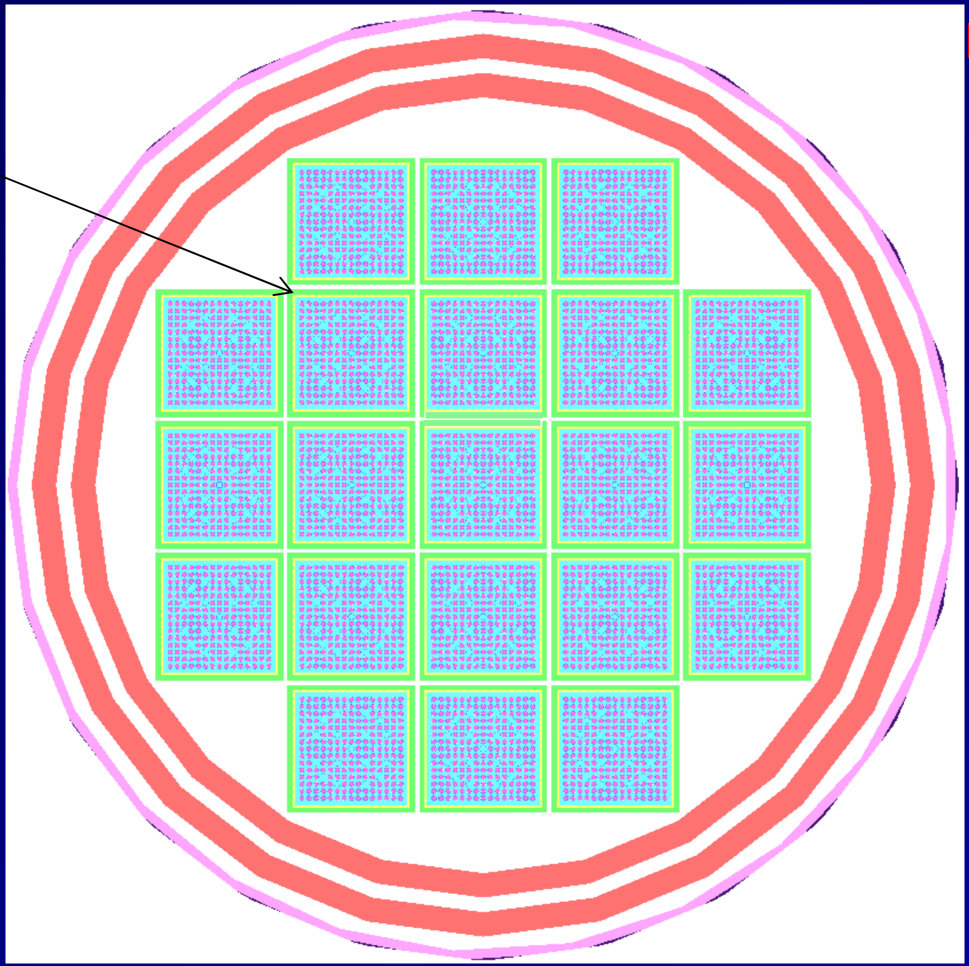
Background

- Borated stainless steel is a candidate neutron absorber material for criticality control in disposal containers or dry storage canisters

Neutron absorber plates



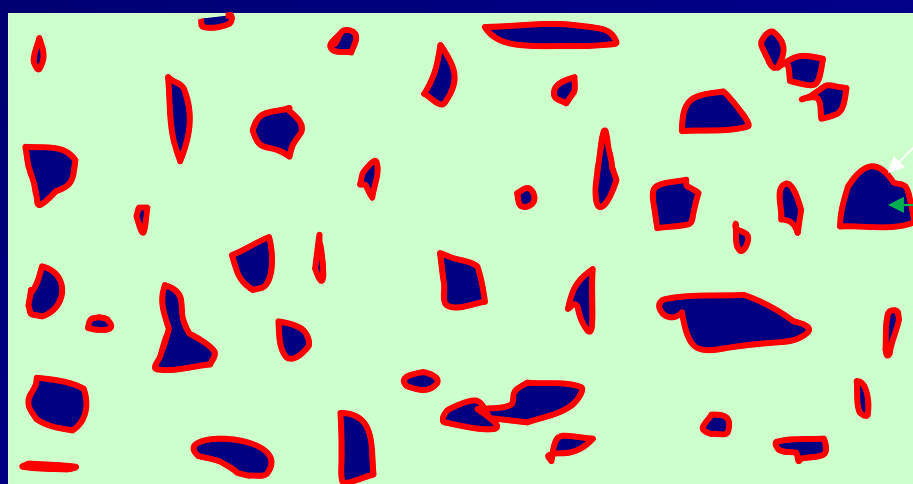
- ASTM A887–89 defines eight types (304B, 304B1–304B7) with boron concentrations from 0.2 to 2.25 wt%

ASTM International. ASTM A887–89, "Standard Specification for Borated Stainless Steel Plate, Sheet, and Strip for Nuclear Application." West Conshohocken, Pennsylvania: ASTM International. 2009.

Background—Microstructure of Borated Stainless Steel

- Boron is essentially insoluble in iron
- Primary austenite with boron-containing secondary phase intergranular particles, Fe_2B and Cr_2B, which leads to
  - Depletion of chromium in regions adjacent to the particles, which may lead to localized corrosion
  - Higher general corrosion rate than austenite stainless steel

Distribution of particles in the austenitic matrix



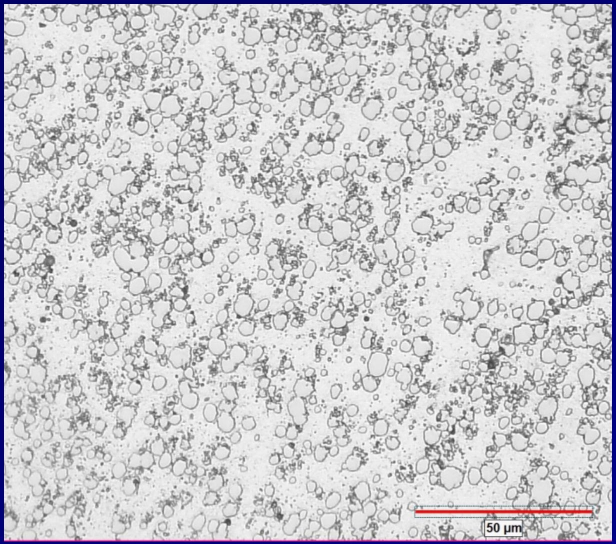
Objective

- During geologic waste disposal and extended storage, corrosion of borated stainless steel could occur in a humid air environment, compromising the neutron absorption function
- Corrosion rate data under humid conditions are scarce
- This work was conducted to measure the general corrosion rate in humid air and determine the likelihood of localized corrosion

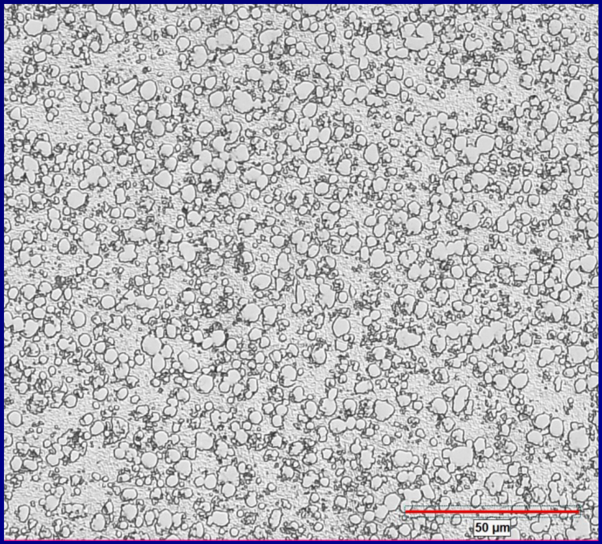
Experimental Tests

- Specimens: 304B4 Grade B and 304B5 Grade A strips (3.2 cm × 10 cm) and thickness as received (3.8 mm)

Optical Metallographs of 304B4 Grade B and 304B5 Grade A Stainless Steels Etched With Kalling's Reagent



304B4

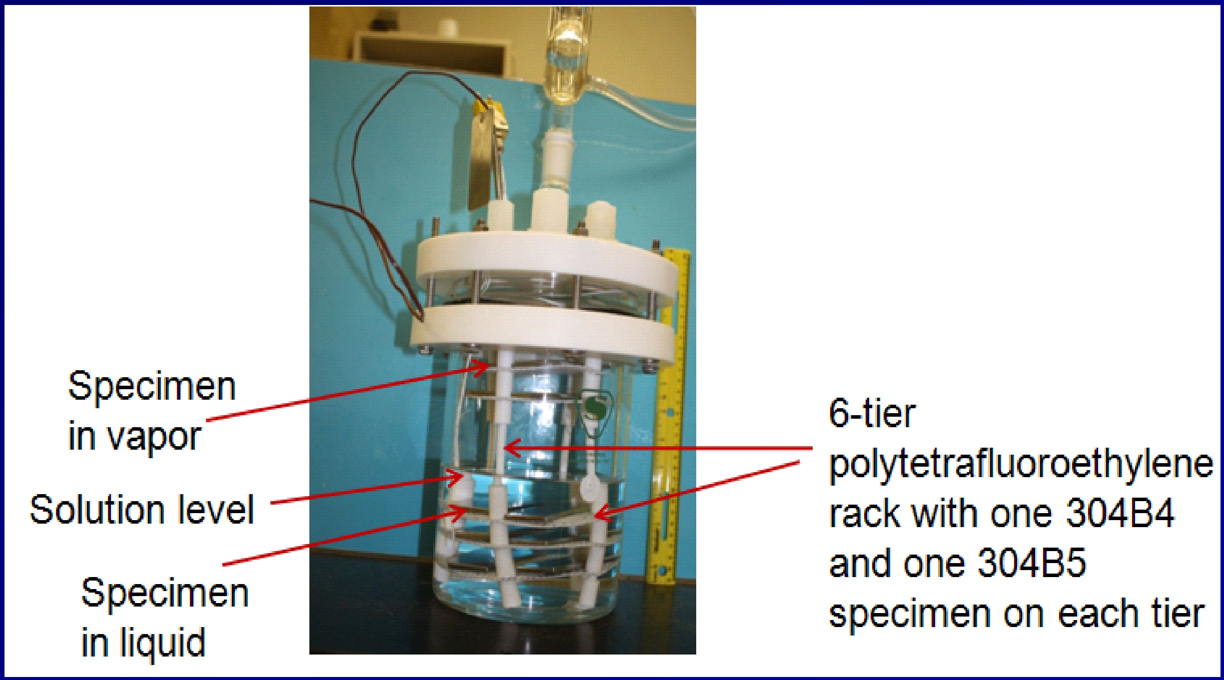


304B5

Composition (wt%)		
Alloy	304B4 Grade B Heat 172862	304B5 Grade A Heat 182019
Cr	19.40	18.28
Ni	14.11	13.61
B	1.04	1.34
C	0.009	0.032
N	0.0054	0.021
P	0.008	0.018
S	0.005	0.001
Co	0.02	0.05
Si	0.59	0.73
Mn	1.65	1.83
Mo	0.01	0.02
Cu	0.01	0.04
Fe	balance	balance

Experimental Tests (continued)

- Test cell: 2-L glass cell partially filled with simulated groundwater and equipped with condenser to prevent solution loss while maintaining atmospheric pressure
  - 3 specimens/each material in vapor and 3 specimens/each material in liquid
  - Polytetrafluoroethylene racks are used to support the specimens
- Temperature: 60, 75, and 90 °C



Experimental Tests (continued)

- Test Solution: Simulated Groundwater[1]

Chemical Composition of Simulated Groundwater								
$[Ca^{2+}]$ mg/L*	$[K^{+}]$ mg/L	$[Mg^{2+}]$ mg/L	$[Na^{+}]$ mg/L	$[SO_4^{2-}]$ mg/L	$[NO_3^{-}]$ mg/L	$[Cl^{-}]$ mg/L	$[F^{-}]$ mg/L	$[HCO_3^{-}]$ mg/L
12.0	3.83	1.70	46.0	19.2	12.4	6.33	1.92	122
*1 mg/L = 8.35×10^{-6} lb/gal								

Measured pH = 8.05

- Test terminated after about 3 months
- Posttest cleaning for weight loss: 10% HNO_3 for 20 minutes at 60 °C following ASTM G1-03[2]

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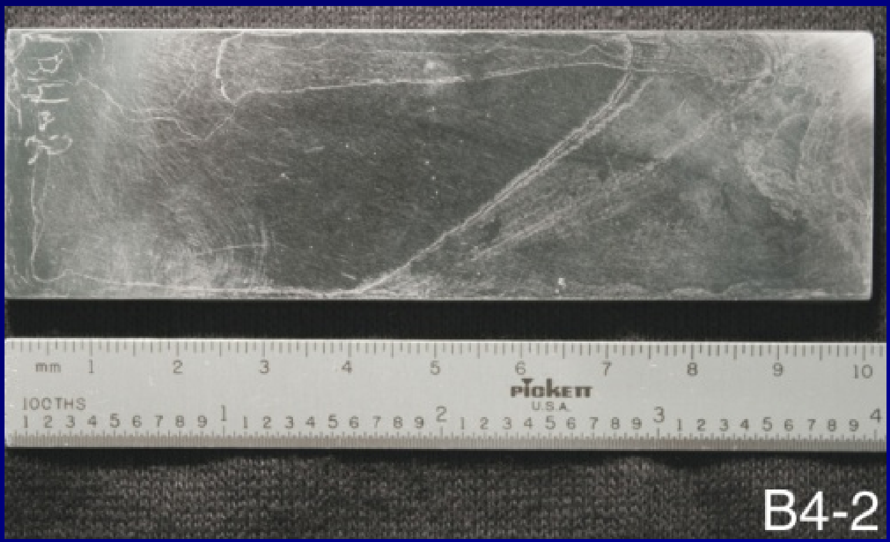
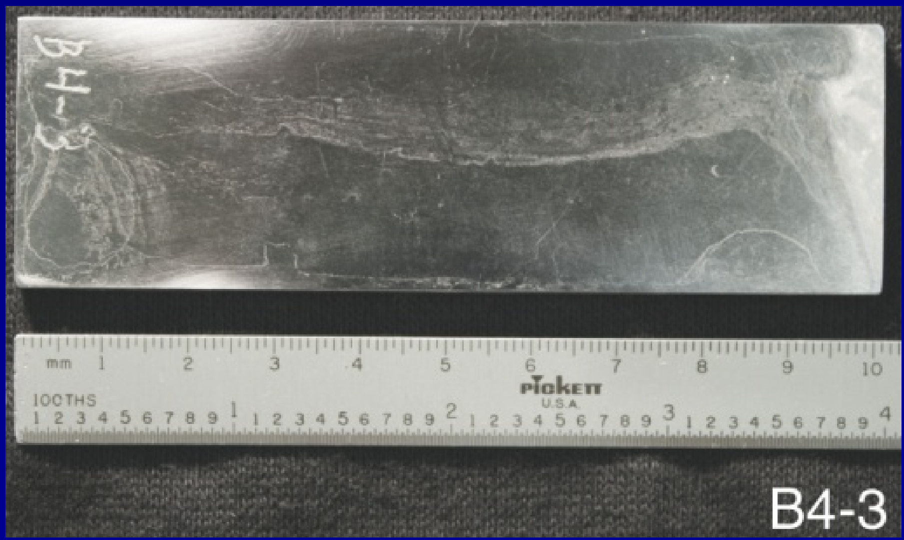
[1]X. He, V. Jain, F.P. Bertetti, and D. Pickett. "Evolution of Fluid Chemistry Inside a Waste Package Due to Carbon Steel and Simulated High-Level Waste Glass Corrosion." San Antonio, Texas: CNWRA. 2007.
[2]ASTM International. ASTM G1–03, "Preparing, Cleaning, and Evaluating Corrosion Test Specimens." West Conshohocken, Pennsylvania: ASTM International. 2003.

Test Results — 60 °C

- At 60 °C for both Types 304B4 and 304B5 materials, in liquid and vapor, some deposits and water staining were observed on some specimens (e.g., specimens B4-2, B4-3). The polishing marks were still visible.
- No localized corrosion was observed.

Examples of posttest samples at 60 °C

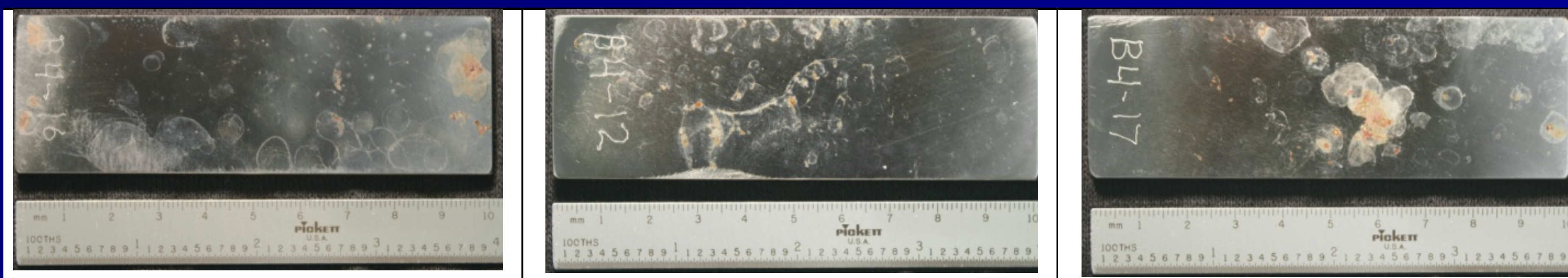




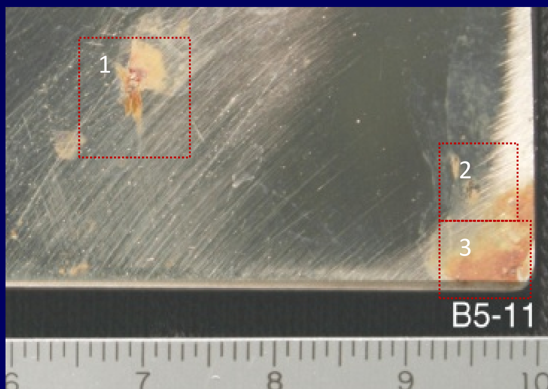
Test Results — Pitting Corrosion at 75 and 90 °C

- Three out of the six 304B4 and two out of the six 304B5 borated stainless steel specimens exposed to humid air at 75 and 90 °C suffered pitting corrosion
- Pitting corrosion was not observed from samples immersed in liquid at 75 and 90 °C

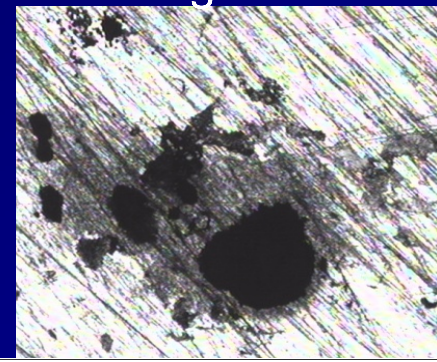
Some specimens with pitting corrosion



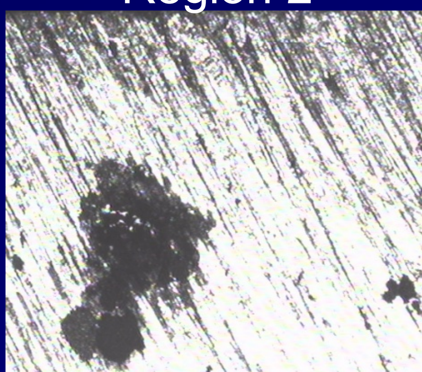
Pitting Corrosion Feature and Depth



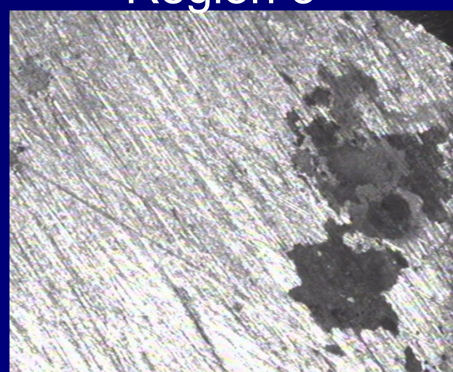
Region 1

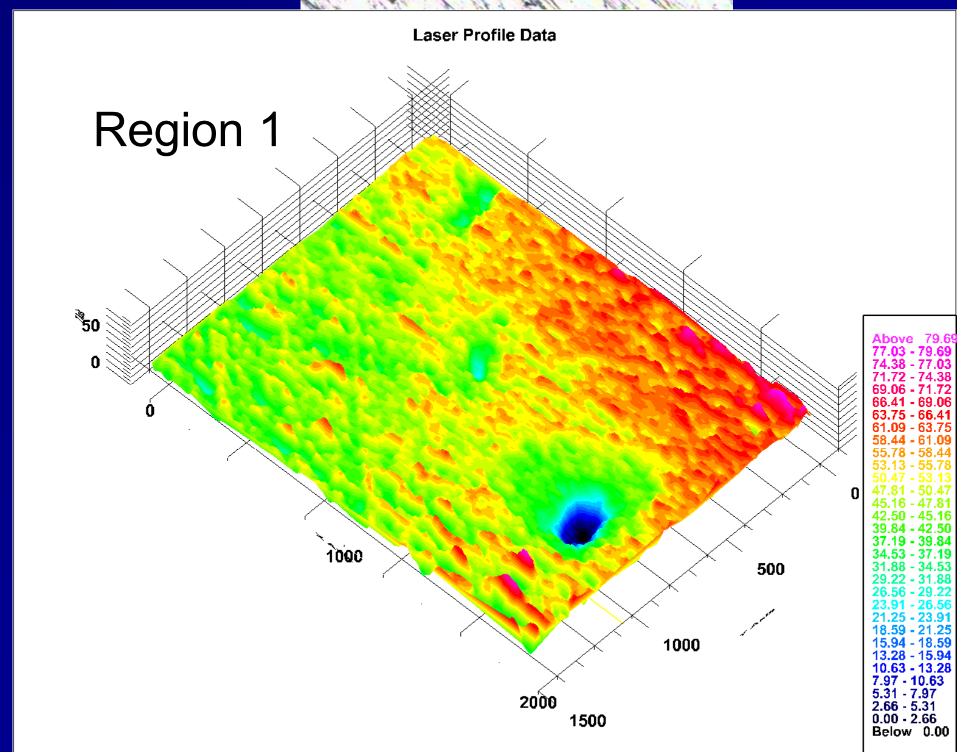


Region 2



Region 3

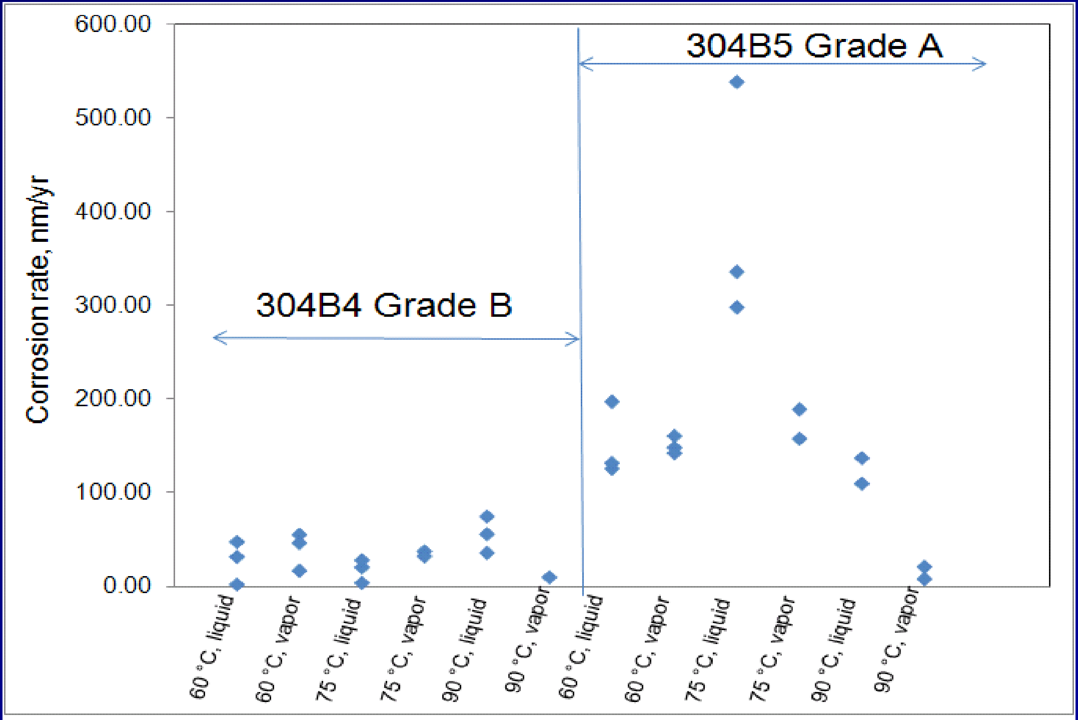




- Most pits were circular
- The maximum pit depth was about 70 μm

Test Results — General Corrosion Rates

- At all three temperatures, the general corrosion rates were less than 80 nm/yr for 304B4 and less than 600 nm/yr for 304B5
- On average, the general corrosion rates of Type 304B5 were higher than those of Type 304B4
- No clear trend was observed for the influence of temperature on general corrosion rates of each material



Effect of General Corrosion and Pitting Corrosion on Criticality Possibility

- Current tests show that pitting corrosion is limited to less than 20% of the area
- However, the following are needed to determine the long-term performance of borated stainless steel and its subsequent effect on the potential for criticality
  – Quantity of moisture present in canister
  – The behavior of pits with time
  – Corrosion behavior in a broader range of water
  – Boron concentration change as a function of time

Summary

- Some specimens exposed to vapor at 75 and 90 °C suffered pitting corrosion, but pitting corrosion was not observed at 60 °C or from liquid exposure at 75 and 90 °C.
- At all three temperatures, the general corrosion rates of Type 304B4 were less than 80 nm/yr and those of Type 304B5 were less than 600 nm/yr. No clear trend was observed for the influence of temperature on general corrosion rates of each material.
- On average, the general corrosion rates of Type 304B5 were higher than those of Type 304B4.
- The possibility of criticality from the measured corrosion rates and observed pitting seems to be limited because the borated stainless steel consumption by general corrosion and pitting is limited from the current tests.

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