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Material Corrosion and Plate-Out Test of Types 304L and 316L Stainless Steel

SAVANNAH RIVER TECHNOLOGY CENTER

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SUMMARY

Corrosion and plate-out tests were performed on 304L and 316L stainless steel in pretreated Envelope B and Envelope C solutions. Flat coupons of the two stainless steels were exposed to 100°C liquid and to 74°C and 88°C vapor above the solutions for 61 days. No significant corrosion was observed either by weight-loss measurements or by microscopic examination. Most coupons had small weight gains due to plate-out of solids, which remained to some extent even after 24-hour immersion in 1 N nitric acid at room temperature. Plate-out was more significant in the Envelope B coupons, with film thickness from less than 0.001 in. to 0.003-inches.

Radioactive contamination levels were assayed with gamma spectroscopy. Envelope B coupons were contaminated with cesium-137 only. The acid cleaning of Envelope B coupons that had been in contact with liquid yielded a decontamination factor of between 2 and 7. Additional mechanical cleaning increased the overall decontamination factors from 9 to 91. Envelope C coupons had lower levels of contamination (in conjunction with less plate-out) that were comprised of cesium-137, cobalt-60, europium-154 and -155, and americium-241. Decontamination factors of several hundred were obtained after acid and mechanical cleaning.

INTRODUCTION

The Hanford Site River Protection Project (RPP) is investigating the effects of contacting candidate materials (i.e. alloy C-22, 304L and 316L stainless steels) with LAW solutions [1]. The Pacific Northwest National Laboratory (PNNL) and the Savannah River Technology Center (SRTC) are jointly conducting this assessment for the RPP. The PNNL conducted immersion tests with coupons of alloy C-22, 304L and 316L stainless steels and pretreated tank 241-AN-107, tank 241-AW-101 LAW solutions, as well as caustic leachate from treatment of a tank 241-C-104 high-level waste sample [2]. The combined PNNL and SRTC work scope completes the corrosion testing requested by the RPP.

Laboratory coupon immersion tests were conducted at SRTC to investigate the effects of two actual low-activity Hanford Site waste solutions on two candidate materials of construction, types 304L and 316L stainless steel. The waste solutions were pretreated low-activity waste solutions identified as Envelope B and Envelope C, described below. The objectives of the testing were (1) to measure the uniform corrosion rate of the materials of construction under different exposure conditions, and (2) to assess the ability of an acid cleaning solution to remove plated-out solids.

EXPERIMENTAL

In accordance with the program test plan, coupon immersion tests were conducted in small volumes of pretreated Envelope B and C solutions [3]. Separate tests were conducted for each stainless steel in each pretreated solution. Only 250 mL of Envelope B solution were available for testing, so special glass flasks were fabricated for testing both envelopes. These flasks permitted full immersion of the standard 1-in. by 2-in. flat specimens prescribed in the test plan. The flasks were equipped with reflux condensers and with polyethylene and polytetrafluoroethylene rods on which to suspend the coupons (Figure 1). (Fluorinated plastic liners were not used in the flasks because the solutions were lower in hydroxide concentration than originally planned.) Coupons were also suspended for partial immersion in liquid and for exposure to vapor immediately above the liquid (termed the vapor position) and to vapor at the entrance to the condenser (termed the condenser position).

Duplicate coupons were exposed in the full-liquid, partial-liquid, and vapor positions. The flasks were heated on hot plates to bring the solution temperature to 100 ± 3°C. The temperature of the vapor immediately above the liquid was 88 ± 3°C, and the temperature at the inlet to the condenser was 74 ± 3°C. Chilled water was recirculated through the condensers, which were linked in series. Thermocouples were used to measure the liquid temperature. The hot plates were adjusted manually to maintain temperature. Distilled water was added weekly to restore evaporative losses.

The four sets of apparatus were located in a radiological hood for radioactive contamination control. Strict material control was required because of the listed-waste nature of the Envelope B and C solutions. Each condenser exhausted to the hood through a glass tube containing about 80 grams of activated carbon to capture hazardous off-gas species. Shallow beakers were placed beneath the flasks as secondary containment around the beakers, and the hotplates were placed in glass pans for additional spill control.

The flat test coupons were of types 304L and 316L stainless steel obtained from Metal Samples Inc., Munford, AL. The 304L coupons were 1/8 in. thick and the 316L coupons were 1/16 in. thick, and were used in their as-received, 600-grit-finish condition. The coupons were degreased in acetone, photographed, and weighed prior to emplacement in the test flasks. Figure 2 shows photographs of a typical pair of coupons before insertion into the test flask.

The Envelope B test solution was obtained from a 3-liter waste sample received from the Hanford Site. The sample was diluted and treated by ion exchange to remove cesium and technetium, then concentrated by evaporation to a sodium molarity of about 2 [4,5]. The Envelope C sample was received from the Hanford Site, diluted, and treated to remove strontium and transuranics by a precipitation process [6]. The filtered product was then treated by ion exchange to remove cesium and technetium. The sample received for corrosion testing was nominally 5 Molar in sodium. The compositions of the tests solutions are shown in Table 1. About 125 mL of each envelope was used in a test flask. Although the ASTM recommends 30 mL of test solution per square centimeter of coupon area in immersion tests, the present configuration (with 2 coupons each having about 30 cm^2 surface area fully immersed) was considered acceptable given the expected low corrosion rates.

The test coupons were exposed for 61 days. Upon completion of the immersion, the coupons were subjected to a decontamination procedure to assess the feasibility of removing plated-out solids. The decontamination procedure was a 24-hour immersion in 1N nitric acid at room temperature. Before decontamination the radionuclide content on each coupon was assessed by a gamma radiation scan, which identified radionuclides and their quantities. The gamma scans were performed again after the 24-hour acid immersion, and finally after a subsequent mechanical cleaning step. The mechanical cleaning step consisted of scraping with plastic-tipped tweezers and wiping with water-soaked paper tissues. Finally, the coupons were weighed again to determine the rate of any corrosion and photographed. The coupons were examined through optical microscopy to assess localized corrosion (pitting).

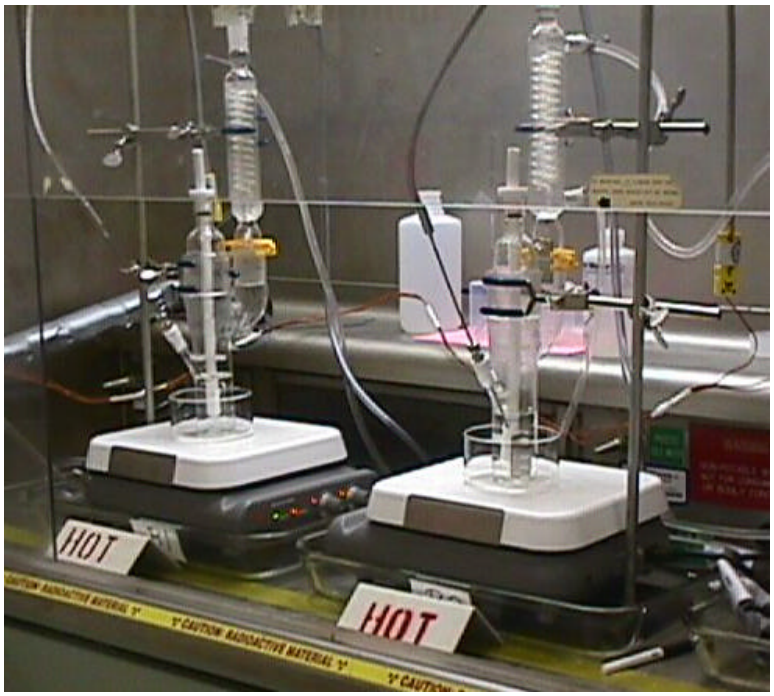

Figure 1. Apparatus for the corrosion and plate-out tests, before addition of solution and placement of coupons.

Figure 2. Front and rear views of 1 in. by 2 in. by 1/16 in. flat type 316L stainless steel coupons before test.

Table 1
Chemical Analyses of Envelope B and C Solutions

	Envelope B	Envelope C
Radionuclides		
Cesium-137 (uCi/mL)	0.647	0.0528
Cobalt-60 (uCi/mL)	< 0.0016	0.0399
Europium-154 (uCi/mL)	< 0.0068	0.0342
Europium-155 (uCi/mL)	< 0.0090	0.0232
Technitium-99 (ug/L)	0.0076	not reported
Plutonium-238 (disintegrations/min/mL)	486	not reported
Plutonium-239/240 (disintegrations/min/mL)	1049	not reported
mass 230	< 0.0951	< 0.0033
mass 231	< 0.0951	< 0.0033
mass 232 (Th)	37.3	1.47
mass 233	< 0.0951	< 0.0033
mass 234 (U)	< 0.0951	< 0.0033
mass 235 (U)	27.6	0.0096
mass 236 (U)	< 0.0951	< 0.0033
mass 237 (Np)	136	0.0883
mass 238 (Pu & U)	2339	0.903
mass 239 (Pu)	< 0.0502	0.0145
mass 240 (Pu)	< 0.0502	< 0.0033
mass 241 (Am & Pu)	< 0.0502	0.0075
mass 242 (Pu)	< 0.0502	< 0.0033
mass 243 (Am)	< 0.0502	< 0.0033
mass 244 (Cm)	< 0.0502	< 0.0033
mass 245 (Cm)	< 0.0502	< 0.0033
mass 246	< 0.0502	< 0.0033
Atomic Absorption (mg/L)		
Potassium	2584	951.0
Sodium	50888	not reported
Arsenic	329	0.255
Selenium	407	0.142
Mercury	< 0.11	< 0.019
Total Uranium	not reported	< 1.00
Uranium - (mg/L) by Chem check	1.610	not reported
Ion Chromatography (mg/L)		
Nitrate	13388	85942
Nitrite	26147	36218
Phosphate	245.1	2196
Sulfate	13287	5475
Oxalate	2401	1067
Formate	< 111	4567
Chloride (by IC)	66.8	1575
Fluoride (by IC)	869	766
Chloride (by Ion Specific Electrode)	182	200
Fluoride (by Ion Specific Electrode)	863	< 82.3

Emission Spectroscopy (mg/L)		
Aluminum	402	5360
Boron	1.14	13.4
Barium	1.34	< 0.254
Calcium	0.567	111
Cadmium	< 0.067	19.9
Cobalt	0.139	1.557
Chromium	533	70.3
Copper	< 0.0668	3.583
Iron	< 0.0668	1.931
Lanthanum	< 0.245	< 1.351
Lithium	< 0.0446	< 0.270
Magnesium	< 0.0223	< 0.093
Manganese	< 0.0223	0.798
Molybdenum	43.2	21.48
Sodium	41238	111515
Nickel	< 0.156	124
Phosphorus	139	687
Lead	1.17	44.4
Silicon	99.7	33.9
Tin	7.49	11.0
Strontium	< 0.0223	126
Technetium	not reported	2.52
Titanium	< 0.0446	< 0.358
Vanadium	0.362	< 0.610
Zinc	0.434	1.29
Zirconium	not reported	< 0.399
Aluminate (Moles/Liter)	< 0.0200	not reported
Free Hydroxide (Moles/Liter)	0.223	1.24
Carbon (mg/L)		
Inorganic (TIC)	8616	5838
Organic (TOC)	8344	11399
density (g/mL)	1.097	1.23
wt% Total solids	12.52	31.5
wt.% suspended solids	< 0.0044	< 0.002

RESULTS AND DISCUSSION

Corrosion Measurements

Uniform corrosion rates are calculated from weight loss measurements of exposed coupons. Table 2 lists the initial weights, the final weights after the two cleaning steps, and the weight changes for all coupons. (The initial weights of the clean coupons were measured with a calibrated five-place balance; final weights had to be measured on a calibrated four-place balance located in the radiological hood.) As the table shows, most coupons in this experiment experienced a weight gain rather than a weight loss, due to the adherence of plated-out solids despite the cleaning steps. Therefore corrosion rates were calculated only for the few coupons where a weight loss was recorded. Usually these coupons were those in the vapor or condenser positions, where the absence of contact with liquid made plate-out less likely. The uniform corrosion rates shown are all insignificantly small, not exceeding 0.012 mils per year (0.3-μm/yr.), which is to be expected in the highly alkaline test solutions of Envelopes B and C.

The two control coupons listed at the bottom of Table 2 were exposed to the same 1 N nitric acid cleaning solution for the same 24-period as the Envelope B coupons. The 304L coupon showed a weight loss due to cleaning, while the 316L coupon showed a weight gain, perhaps as a result of contact with a coupon with deposits. The weight loss translated to a low corrosion rate of 0.1 mil per year. Thus the cleaning step was apparently more aggressive than the test exposure itself.

The weight gains on the test coupons are attributed to the retention of tightly adhering solids. Plated-out solids on coupons with weight gains may hide metal weight loss due to corrosion. The test coupons were examined with optical microscopy for visible indications of corrosion. When they do corrode, passive alloys such as these stainless steel typically degrade by localized corrosion modes, as the passive film is breached under pitting or crevice corrosion, for example. Microscopic examination in fact revealed no evidence of pitting or crevice corrosion. Apart from some staining of the coupons, the surfaces remained shiny. The polishing marks from the original 600-grit finish were still sharp and prominent (typically shown in Figure 3). Visual examination thus revealed that there was no localized corrosion. The shiny surface condition is consistent with the absence of significant weight loss.

Table 2
Weight Measurements and Corrosion Rates*

Envelope B Coupon No.	Position	Initial Weight, g	Final Weight, g	Weight Change, g	Area, cm^2	Elapsed Time, Hrs	Corrosion Rate, mils per year
304L-21	Condenser	27.70739	27.8081	-0.1007	30.55	1464	-
304L-22	Vapor	28.11807	28.1237	-0.0056	30.55	1464	-
304L-23	Vapor	28.47480	28.4752	-0.0004	30.55	1464	-
304L-24	Partial Liquid	28.03165	28.0403	-0.0086	30.55	1464	-
304L-25	Partial Liquid	28.16975	28.1794	-0.0097	30.55	1464	-
304L-26	Full Liquid	28.14463	28.1469	-0.0023	30.55	1464	-
304L-27	Full Liquid	28.16062	28.1733	-0.0127	30.55	1464	-
316L-03	Condenser	14.28900	14.2880	0.0010	28.15	1464	0.010
316L-04	Vapor	14.31780	14.3242	-0.0064	28.15	1464	-
316L-06	Vapor	14.29614	14.2986	-0.0025	28.15	1464	-
316L-07	Partial Liquid	14.33526	14.3453	-0.0100	28.15	1464	-
316L-08	Partial Liquid	14.27639	14.2828	-0.0064	28.15	1464	-
316L-10	Full Liquid	14.30415	14.3106	-0.0065	28.15	1464	-
316L-20	Full Liquid	14.28111	14.3129	-0.0318	28.15	1464	-

Envelope C Coupon No.	Position	Initial Weight, g	Final Weight, g	Weight Change, g	Area, cm^2	Elapsed Time, Hrs	Corrosion Rate, mils per year
304L-11	Condenser	29.25841	29.2580	0.0004	30.55	1464	0.004
304L-12	Vapor	29.48678	29.4855	0.0013	30.55	1464	0.012
304L-13	Vapor	29.43131	29.4314	-0.0001	30.55	1464	-
304L-14	Partial Liquid	29.31114	29.3156	-0.0045	30.55	1464	-
304L-15	Partial Liquid	29.46739	29.4731	-0.0057	30.55	1464	-
304L-16	Full Liquid	29.46070	29.4614	-0.0007	30.55	1464	-
304L-17	Full Liquid	29.35073	29.3520	-0.0013	30.55	1464	-
316L-11	Condenser	14.20880	14.2085	0.0003	28.15	1464	0.003
316L-14	Vapor	14.19978	14.2007	-0.0009	28.15	1464	-
316L-15	Vapor	14.26658	14.2686	-0.0020	28.15	1464	-
316L-16	Partial Liquid	14.29132	14.2921	-0.0008	28.15	1464	-
316L-17	Partial Liquid	14.27553	14.2766	-0.0011	28.15	1464	-
316L-18	Full Liquid	14.09963	14.0995	0.0001	28.15	1464	0.001
316L-19	Full Liquid	14.31190	14.3135	-0.0016	28.15	1464	-
304L Control	N/A	28.54367	28.5435	0.0002	30.55	24	0.101
316L Control	N/A	14.17793	14.1781	-0.0002	28.15	24	

*Corrosion rates calculated for those test coupons with weight losses only.

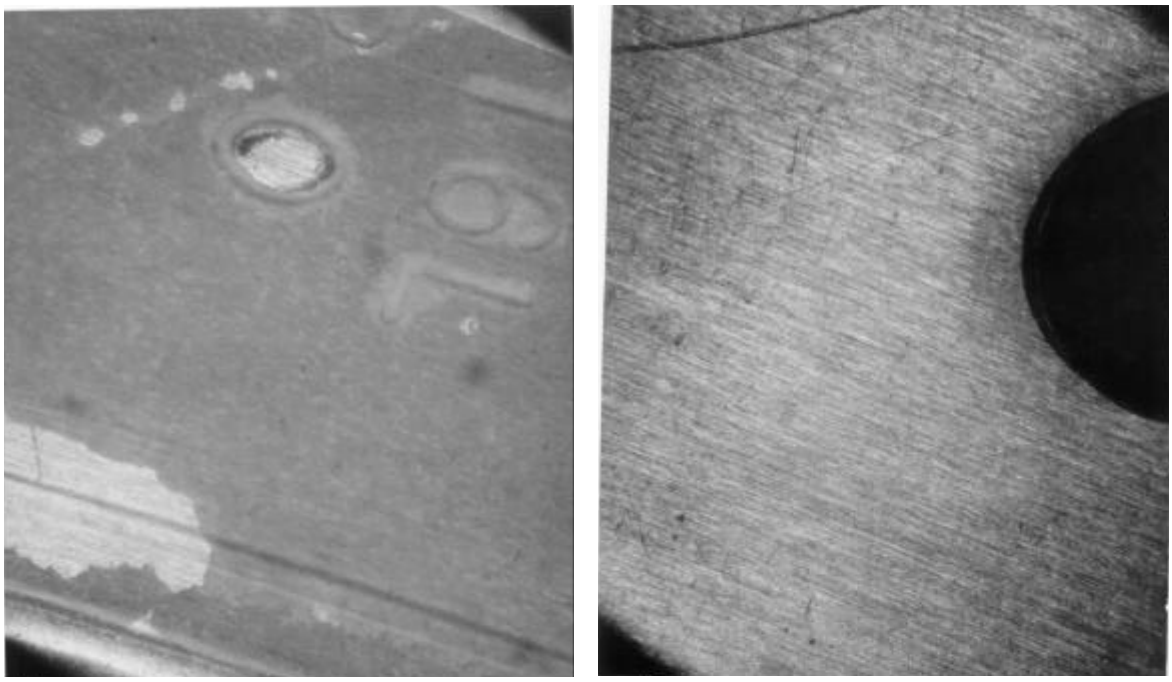

Figure 3. Front (left, mostly covered with plated-out solids) and rear (right,) views of coupon 316L-20 after acid and mechanical cleaning, original magnification 7.8X. The thickness of the plated-out solids is about 0.003 in.

Plate-out of Solids and Coupon Cleaning

There was considerable plate-out of solids in hard, thin films on coupons that were in contact with liquid. Thin films of solids also deposited on the vapor position coupons. Substantial precipitation of solids was seen at the liquid-vapor interface, where solution was contiually evaporating. Figure 4 shows a photograph of these especially prominent deposits on coupons in the partial liquid position. These deposits were not adherent and were easily dislodged mechanically. The materials deposited on the test coupons were not chemically analyzed.

The coupons were soaked in 1 N nitric acid at room temperature for 24 hours for decontamination and dissolution of plated-out solids. As Figure 5 and 6 show, deposits were still quite evident following the acid soak. The whitish, plated-out solids remaining after the mechanical cleaning and wiping consisted of thin films less than 0.001 in. thick to a maximum of about 0.003 in. thick. The thickness was determined with an optical microscope whose stage is equipped with a digital micrometer. The heights of an object or material normal to the plane of the specimen can be measured through the micrometer readout of the distance between in-focus images of the top and bottom of the object. Radioactively contaminated specimens were contained in transparent polyethylene bags during measurement.

Whole coupons were assayed by gamma spectroscopy to identify and quantify the radionuclides adhering to them. Gamma scans were performed before and after acid immersion and also after mechanical cleaning and wiping. For Envelope B, the scans showed counts only for cesium-137. The scan results in disintegrations per minute (dpm) are listed in Table 3. The most contaminated coupons were those in contact with the liquid solution with levels of the order of 5×10^7 dpm for the 304L coupons and 1×10^8 dpm for the 316L coupons. The acid cleaning produced very modest decontamination factors (defined as the ratio of initial to final contamination levels) of about 4 for the 304L coupons and 2 for the 316L coupons. However, after mechanical cleaning and wiping with wet laboratory tissues, the final decontamination factors improved to as much as 91 for the highly contaminated coupons. The less-

contaminated coupons in the vapor and condenser position had varied results from the cleaning steps. Greater variation is expected at the lower contamination levels. It should be noted that the coupons of each

Figure 4 shows 304L stainless steel coupons upon removal from Envelope B solution after 61 days' immersion. This appearance was typical of both envelopes and both stainless steels. The solids attached to the middle pair of coupons (partial liquid position) were especially prominent, although not tightly adherent.

Figure 5. Type 316L coupons after acid immersion for 24 hours, with deposits especially retained on the partial-liquid position coupon.

envelope were cleaned together in a single acid bath, in order to minimize handling of the coupons (the most radioactive coupon, 316L-20, emitted 396 mrem/hour at contact). This may have allowed contamination to redeposit from one coupon to another.

Figure 6. Type 304L and 316L coupons from Envelope B after acid immersion, rinsing, and drying.

Table 3
Decontamination Results for Envelope B Coupons
(Radionuclide amounts are in units of disintegrations per minute)

Coupon No.	Position	Initial Cesium-137	Post Acid Cesium-137	Acid Decon. Factor	After Wiping Cesium-137	Final Decon. Factor
304L-21 B1	Condenser	1.84E+05	7.88E+04	2.3	9.63E+03	19.1
304L-22 B1	Vapor	2.40E+06	5.02E+05	4.8	1.73E+05	13.9
304L-23 B1	Vapor	2.95E+06	2.67E+05	11.0	1.86E+04	158.6
304L-24 B1	Partial Liquid	3.96E+07	1.37E+07	2.9	1.85E+06	21.4
304L-25 B1	Partial Liquid	4.27E+07	6.47E+06	6.6	7.95E+05	53.7
304L-26 B1	Full Liquid	4.53E+07	1.14E+07	4.0	8.75E+05	51.8
304L-27 B1	Full Liquid	5.25E+07	1.59E+07	3.3	4.60E+06	11.4
316L-03 B2	Condenser	8.54E+04	4.99E+04	1.7	3.43E+03	24.9
316L-04 B2	Vapor	2.24E+06	2.72E+05	8.2	5.52E+04	40.6
316L-06 B2	Vapor	3.74E+06	1.56E+05	24.0	1.63E+04	229.4
316L-07 B2	Partial Liquid	9.55E+07	4.77E+07	2.0	2.33E+06	41.0
316L-08 B2	Partial Liquid	1.04E+08	5.72E+07	1.8	1.14E+06	91.2
316L-10 B2	Full Liquid	1.36E+08	3.60E+07	3.8	2.63E+06	51.7
316L-20 B2	Full Liquid	1.07E+08	5.14E+07	2.1	1.20E+07	8.9

The Envelope C solution as tested was a much less radioactive solution than Envelope B. This difference revealed itself in the overall radiation levels of undetectable to 4 mrem/hour at contact for the liquid-position Envelope C coupons, compared to the 4 to 396 mrem/hour fields of Envelope B. Consequently, the cesium-137 levels measured on the Envelope C coupons of either alloy were several orders of magnitude lower than those of Envelope B. In addition to cesium-137, the radionuclides cobalt-60, europium-154, europium-155, and americium-241 were also measured on the Envelope C coupons, and are listed in Table 4. Where detected, these radionuclides had maximum contamination levels of the order of 10^5 dpm. For coupons in the condenser and vapor positions, the table entries are blank where the particular radionuclide was not detected during any gamma scan. Where the radionuclide was detected in one scan of a particular coupon but not another scan, the other scan result is marked 'ND' for 'not detected'. The undefined decontamination factor for that radionuclide is marked with a '-'. As can be seen in Table 4 the vapor and condenser coupons usually had undetectable contamination from any radionuclide. Subsequent contamination detected after acid cleaning can be attributed to cross-contamination in the common acid bath.

Nitric acid immersion decontaminated the liquid-contact Envelope C coupons to a greater degree than it did the Envelope B coupons, with decontamination factors ranging from 5 to 111. Mechanical cleaning of those coupons increased the decontamination factor to between 10 and 800. The lowest decontamination factors were associated with coupons whose initial contamination level was already low in the 10^4 dpm range.

Table 4
Decontamination Results for Envelope C Coupons
(Radionuclide amounts are in units of disintegrations per minute)

Coupon	Position	Initial Cesium-137	Post Acid Cesium-137	Acid Decon. Factor	After Wiping Cesium-137	Final Decon. Factor
304L-11 C3	Condenser	ND	1.11E+03	-	6.49E+02	-
304L-12 C3	Vapor	ND	9.19E+02	-	1.20E+04	-
304L-13 C3	Vapor	ND	8.44E+02	-	1.33E+03	-
304L-14 C3	Partial Liquid	ND	3.21E+04	-	2.23E+03	-
304L-15 C3	Partial Liquid	1.94E+05	1.50E+04	12.9	2.92E+03	66.4
304L-16 C3	Full Liquid	6.66E+05	2.43E+05	2.7	2.51E+03	265
304L-17 C3	Full Liquid	4.39E+05	2.46E+04	17.8	6.64E+03	66.1
316L-11 C4	condenser	ND	8.29E+02	-	2.80E+02	-
316L-14 C4	Vapor	2.13E+04	4.90E+03	4.3	4.47E+02	47.7
316L-15 C4	Vapor	9.95E+02	2.42E+03	0.4	4.22E+02	2.4
316L-16 C4	Vapor/Liq.	2.46E+05	1.75E+04	14.1	1.36E+03	181
316L-17 C4	Vapor/Liq.	3.29E+05	1.80E+04	18.3	1.82E+03	181
316L-18 C4	Liquid	5.59E+05	5.02E+03	111	6.99E+02	800
316L-19 C4	Liquid	4.60E+05	3.16E+04	14.6	7.71E+02	597

Coupon	Position	Initial Cobalt-60	Post Acid Cobalt-60	Acid Decon. Factor	After Wiping Cobalt-60	Final Decon. Factor
304L-11 C3	Condenser					
304L-12 C3	Vapor					
304L-13 C3	Vapor					
304L-14 C3	Partial Liquid	3.67E+04	4.38E+03	8.4	1.03E+03	35.6
304L-15 C3	Partial Liquid	2.94E+04	2.97E+03	9.9	1.15E+03	25.6
304L-16 C3	Full Liquid	7.84E+04	1.46E+04	5.4	5.83E+02	134
304L-17 C3	Full Liquid	5.43E+04	2.47E+03	22.0	6.71E+02	80.9
316L-11 C4	Condenser					
316L-14 C4	Vapor	ND	3.54E+02	-	ND	-
316L-15 C4	Vapor					
316L-16 C4	Partial Liquid	3.59E+04	2.79E+03	12.9	1.45E+03	24.8
316L-17 C4	Partial Liquid	4.16E+04	2.80E+03	14.9	1.32E+03	31.5
316L-18 C4	Full Liquid	5.71E+04	1.21E+03	47.2	6.50E+02	87.8
316L-19 C4	Full Liquid	5.67E+04	2.69E+03	21.1	7.37E+02	76.9

ND = not detected

Table 4 continued
Decontamination Results for Envelope C Coupons

Coupon	Position	Initial Europium-154	Post Acid Europium-154	Acid Decon. Factor	After Wiping Europium-154	Final Decon. Factor
304L-11 C3	Condenser					
304L-12 C3	Vapor					
304L-13 C3	Vapor					
304L-14 C3	Partial Liquid	2.18E+05	3.50E+04	6.2	1.12E+04	19.5
304L-15 C3	Partial Liquid	1.59E+05	3.23E+04	4.9	1.37E+04	11.6
304L-16 C3	Full Liquid	5.78E+05	1.32E+05	4.4	1.26E+04	45.9
304L-17 C3	Full Liquid	3.80E+05	3.05E+04	12.5	1.22E+04	31.1
316L-11 C4	condenser					
316L-14 C4	Vapor	ND	2.13E+03	-	ND	-
316L-15 C4	Vapor					
316L-16 C4	Vapor/Liq.	1.92E+05	2.97E+04	6.5	1.56E+04	12.3
316L-17 C4	Vapor/Liq.	2.50E+05	4.33E+04	5.8	1.75E+04	14.3
316L-18 C4	Liquid	4.43E+05	3.04E+04	14.6	1.64E+04	27.1
316L-19 C4	Liquid	4.23E+05	4.53E+04	9.3	1.83E+04	23.1

Coupon	Position	Initial Europium-155	Post Acid Europium-155	Acid Decon. Factor	After Wiping Eurpopium-155	Final Decon. Factor
304L-11 C3	Condenser					
304L-12 C3	Vapor					
304L-13 C3	Vapor					
304L-14 C3	Partial Liquid	1.24E+04	1.73E+04	0.7	6.83E+03	1.8
304L-15 C3	Partial Liquid	8.62E+04	1.67E+04	5.2	7.61E+03	11.3
304L-16 C3	Full Liquid	3.12E+05	4.07E+04	7.7	6.84E+03	45.6
304L-17 C3	Full Liquid	1.98E+05	1.47E+04	13.5	7.19E+03	27.5
316L-11 C4	Condenser					
316L-14 C4	Vapor	ND	1.01E+03	-	ND	-
316L-15 C4	Vapor					
316L-16 C4	Vapor/Liq.	1.00E+05	1.52E+04	6.6	9.59E+03	10.4
316L-17 C4	Vapor/Liq.	1.32E+05	2.42E+04	5.5	1.15E+04	11.5
316L-18 C4	Liquid	2.48E+05	1.76E+04	14.1	9.82E+03	25.3
316L-19 C4	Liquid	2.10E+05	2.28E+04	9.2	1.16E+04	18.1

ND = not detected

Table 4 continued
Decontamination Results for Envelope C Coupons

Coupon	Location	Initial Amercium-241	Post Acid Americium-241	Acid Decon. Factor	After Wiping Amercium-241	Final Decon. Factor
304L-11 C3	Condenser					
304L-12 C3	Vapor					
304L-13 C3	Vapor					
304L-14 C3	Vapor/Liq.	9.49E+04	1.27E+04	7.5	ND	-
304L-15 C3	Vapor/Liq.	ND	1.44E+04	-	6.40E+03	-
304L-16 C3	Liquid	2.33E+05	2.06E+04	11.3	7.00E+03	33.3
304L-17 C3	Liquid	ND	1.18E+04	-	6.76E+03	-
316L-11 C4	Condenser					
316L-14 C4	Vapor					
316L-15 C4	Vapor					
316L-16 C4	Vapor/Liq.	9.36E+04	1.48E+04	6.3	7.40E+03	12.6
316L-17 C4	Vapor/Liq.	9.13E+04	2.22E+04	4.1	1.17E+04	7.8
316L-18 C4	Liquid	1.39E+05	1.55E+04	9.0	8.70E+03	16.0
316L-19 C4	Liquid	1.76E+05	2.30E+04	7.7	1.17E+04	15.0

ND = not detected

The high decontamination factors and the overall low level of contamination of the cleaned Envelope C coupons were revealed visually in the absence of the substantial deposits of the type seen on Envelope B coupon 316L-20. Envelope C coupons were generally shiny with some areas of staining and few slight plated-out solids.

CONCLUSIONS

Long-term immersion tests of type 304L and 316L stainless steel in pretreated Envelope B and C solutions indicate that these alloys will not experience any significant corrosion in handling these solutions. However, the corrosion effects from cyclic accumulation of deposits followed by cleaning need to be evaluated to confirm selection of these materials. The tests exposed flat coupons to full-liquid immersion, to partial-liquid immersion (coupons suspended at the liquid-vapor interface), and to vapor above the hot (100°C) liquid. Measured corrosion rates were less than 0.001 in. per year. Most coupons showed weight gains due to plated-out solids, and so were not available for corrosion rate measurements based on weight loss. However, optical microscopy did show essentially pristine surface conditions (sharp, prominent finishing marks) on all coupons. No evidence of general or localized corrosion was seen under microscopic examination.

Hard white solid films plated out on the coupons of both steels that were in contact with liquid. These films were much more pronounced in the Envelope B coupons compared with the Envelope C coupons, and in Envelope B they were not completely removed through 24 hours' immersion in 1N nitric acid at room temperature. Irregular patches of the films up to 0.003 in. thick remained on the Envelope B coupons after acid cleaning and mechanical cleaning. However, the acid cleaning was very effective with the Envelope C coupons, which were free of all but slight residual plate-out after cleaning. Gamma spectroscopy scans revealed that the acid cleaning step decontaminated the most contaminated Envelope B coupons by a factor of 2 to 7. Mechanical cleaning improved the decontamination factors up to 90 for Envelope B coupons that had been in liquid contact and 800 for the Envelope C coupons. After final cleaning, Envelope B coupons retained 2 to 5 orders of magnitude more cesium-137 than Envelope C coupons.

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