BSC

Scientific Analysis Administrative Change Notice

Complete only applicable items.

1. Document Number:	ANL-DSD-MD-000001	2. Revision:	01	3. ACN:	01
4. Title:	Aqueous Corrosion Rates for Waste Package Materials				
5. No. of Pages Attached:	11				

6. Approvals:		
Preparer:	Patricia Bernot (Print Name and Sign)	3/30/06 (Date)
Checker:	William Downs (Print name and sign)	3/30/06 (Date)
QER:	Darrell Svalstad (Print name and sign)	3/30/06 (Date)
Responsible Manager:	Kevin Mon for David Stahl (Print name and sign) Kevin Mon	3/30/06 (Date)

7. Affected Pages	8. Description of Change:
iiia	Editorial change. New page iiia inserted to add "ACKNOWLEDGEMENTS" to the report, add: **ACKNOWLEDGEMENTS** This analysis report was developed through the contributions of the following individuals, listed in alphabetical order: • Sara Arthur, AREVA. Author Section 4.1.3.5 of REV 00. Lead author of REV 01. • Patricia Bernot, BSC. Originator and lead author on REV 00. Co-author of REV 01 • Kevin Mon, Framatome. Co-author Section 6.5 of REV 01 • Kaveh Zarrabi, BSC. Author Sections 4.1.3.6 and 6.1.6 of REV 00 This change was self-identified

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6-2	Added text for clarification (Correct DIRS as appropriate) Section 6 "**SCIENTIFIC ANALYSIS DISCUSSION",** page 6-2, 1st paragraph, 2nd sentence, change: Corrosion of materials at pH extremes (below 4 and above 10) is not included in this analysis since this is a special condition for which materials commonly display different corrosion behaviors. To This report investigates the corrosion of materials between pH 4 to 10. This range is supported by *In-Package Chemistry Abstraction* (BSC 2005 [DIRS 174583] Sections 6.9 and 8.2), which indicates that the in-package pH will be between the range of 4.5 and 8.5. *Dike/Drift Interactions* (BSC 2004 [DIRS 170028] Section 8.2.4), and *Engineered Barrier System: Physical and Chemical Environment* (BSC 2005 [DIRS 175083] Sections 6.9 and 8.2) extend the pH range to 4 to 10. The pH value resulting from water interacting with a basalt block after an igneous intrusion is between 7.6 and 9.9 (BSC 2004 [DIRS 170028]). Although *Engineered Barrier System: Physical and Chemical Environment* (BSC 2005 [DIRS 175083]) predicts possible pH values above 10 and below 4, these cases are of short duration and under unusual circumstances. Additionally, *In-Package Chemistry Abstraction* (BSC 2005 [DIRS 174583]) shows that, though it has an effect on the chemistry, the incoming water composition is not the primary parameter controlling in-package pH values, rather the degradation of the waste package materials themselves. Corrosion rates of materials at pH extremes (below 4 and above 10) are not included in this analysis since this is a special condition for which materials commonly display different corrosion behaviors and a full analysis is not justified because of the rarity of these cases. In addition to extreme pH values, values for other conditions were also not included. One of these includes cases where there was extensive biofouling on the test specimen. The corrosion of materials due to biofouling is much different than corrosion of materials exposed to groundwater. Because this report deals only with corrosion due to contact of metals with water, excluding cases where biofouling occurred is justified. Other values rejected for use in this report were those containing the influence of localized corrosion (as indicated in Section 6.1.2) and values that were outliers. The exception to this is for aluminum. Pitting is the main corrosion behavior of aluminum. Rates of pitting usually range from 3 μm/yr to 6 μm /yr during the first year. An average over a 10-year period shows the rate of pitting to be 0.8 μm/yr to 1.5 μm/yr. The decreasing rates over time indicate the tendency of older pits to become inactive. This analysis converts weight loss data on aluminum (including weight loss due to pitting) into a corrosion rate for general corrosion (the process by which the entire surface of the metal is attacked uniformly).

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6-2 (Continued)	In the case of three metals, Aluminum Alloy Types 1100 and 6061-T6 (in saline/concentrated waters) and Carbon Steel Type A516, a large amount of corrosion data is available in the literature as the metals are used extensively by many industries. For this analysis, it was decided to use the data from one large comprehensive study since using a full bibliography of values is impractical. The chosen values for aluminum corrosion in saltwater come from an article by Hollingsworth and Hunsicker (1987 [DIRS 150403]), which is a handbook and thus accepted by the scientific and engineering community to be established fact. For Carbon Steel Type A516, the data provided by McCright (1998 [DIRS 114637]) was used since this study was conducted using environmental conditions expected as present in the repository. Additionally, the experiments and analysis were performed at the Lawrence Livermore National Laboratory using sound engineering practices, a well-accepted methodology, and in a thorough and comprehensive manner. Testing and analysis were done to an approved activity plan (Gdowski 1998 [DIRS 118106]) and technical implementation plans (McCright 1998 [DIRS 114637], p. 2.2-11 for more detail). Materials were cleaned in accordance with ASTM Standard G 1-90 [DIRS 103515]. For steels and alloys other than carbon steel and aluminum alloy, literature data were reviewed and pertinent quality information was used in this analysis. Several references were excluded from the analysis for the following reasons: (1) the experimental procedure was not described in the report so the quality of presented material could not be determined, (2) experimental procedure was not described in sufficient detail to discern quality of presented material, (3) experimental procedure or practices were questionable bringing doubt as to the caliber of the data, (4) the experimental conditions (ie, temperature, water chemistry, etc.) were not reported, thus making it difficult to place the data in the proper data set and/or calling to question quality of experimental procedure, and (5) experimental conditions were not applicable to the repository environment (example – boiling acid). The data used in this report came from either handbooks, reports specifically written for the U.S nuclear regulatory commission, or journal articles and published reports that could be qualified through reliability of data source, qualifications of personnel or organizations generating the data, prior use of the data, and/or availability of corroborating data as indicated in Appendix III. This change is associated with CR-6488.
6-39	Removed text for clarification Section 6.5.2 "**Titanium Grade 24**", delete 2nd paragraph, delete: *General Corrosion and Localized Corrosion of the Drip Shield* (BSC 2004 [DIRS 169845]) plots all of the 2.5-year weight-loss data (vapor, aqueous, and water line) for Titanium Grade 7 from DTN: LL030410012251.056 [DIRS 169583] in the CDF shown in Figure 6-21. The corrosion rate from all weight-loss specimens at the 85% percentile of the cumulative distribution function is about 15 nm/yr. This change was self-identified.

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6-39	Removed figure. Delete Figure 6-21 " Titanium Grade 7 Weight-Loss Corrosion Rates after 2.5 Years", and the source from page 6-39. This change was self-identified.
6-39	Added text for clarification (Correct DIRS as appropriate) Section 6.5.2 "**Titanium Grade 24**", 3rd paragraph, change: The corrosion rates of Titanium Grades 2 (Titanium with no Pd) and 5 (Ti-6Al-4V with no Pd) in hydrochloric acid solutions, a very aggressive test media for titanium alloys, are shown in Figure 6-22 along with those of Titanium Grades 7, 16, and 24. The addition of 0.04 to 0.08 wt % of Pd to Titanium Grades 2 and 5 (to produce Titanium Grades 16 and 24) significantly improves the corrosion resistance of the alloy as demonstrated in Figure 6-22. From Figure 6-22, it can be seen that the corrosion rate of Titanium Grade 24 is about five times higher than that of Titanium Grade 7 in 3% boiling HCl. On this basis, a conservative estimate of the corrosion rate of Titanium Grade 24 in less aggressive repository environments would be a corrosion rate five times higher than that of Titanium Grade 7. To The corrosion rates of Titanium Grades 2 (Titanium with no Pd) and 5 (Ti-6Al-4V with no Pd) in hydrochloric acid solutions, a very aggressive test medium for titanium alloys, are shown in Figure 6-21 along with those of Titanium Grades 7 (0.12 – 0.25 wt% Pd), 16, and 24. The addition of 0.04 to 0.08 wt % of Pd to Titanium Grades 2 and 5 (to produce Titanium Grades 16 and 24) significantly improves the corrosion resistance of the alloy as demonstrated in Figure 6-21. Handbook data (Schutz and Thomas 1987 [DIRS 144302], Table 7, p. 679) indicate that the corrosion rate of Titanium Grade 5 is approximately four times that of Titanium Grade 7 in boiling 25% HNO_3 (a much more aggressive corrosion environment than the repository environment). Since the purpose of Pd alloying of titanium is to help maintain the passivity of a titanium alloy (see BSC 2005 [DIRS 174995], Section 6.2.7), the general corrosion rate of Titanium Grade 24 (i.e., the palladium containing analog of Titanium Grade 5), should be lower than that of Titanium Grade 5. Therefore, the general corrosion rate for Titanium Grade 24 can be conservatively estimated to be 5 times that of Titanium Grade 7. Figure 6-21, shows that the corrosion rate of Titanium Grade 24 is about five times higher than that of Titanium Grade 7 in 3% boiling HCl, further validating the use of Titanium Grade 7 corrosion rates with an applied multiplier of 5. On this basis, a conservative estimate of the corrosion rate of Titanium Grade 24 in less aggressive repository repository environments would be five times higher than that measured for Titanium Grade 7. This change was identified in NRC Summary Letter from Audit BSC-BQAP-05-07

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6-40	Change figure number. Figure 6-22. Corrosion Rates of Titanium Grades 2, 5, 7, 16, and 24 in Boiling HCl Change to read: Figure 6-21. Corrosion Rates of Titanium Grades 2, 5, 7, 16, and 24 in Boiling HCl This change was self-identified.
6-40	Editorial correction. Figure 6-22 "Corrosion Rates of Titanium Grades 2, 5, 7, 16, and 24 in Boiling HCl", change footnote: Source: BSC 2004 [DIRS 169847] (Figure 10). To Source: BSC 2004 [DIRS 169847], Figure 10. This change was self-identified
6-40	Text added for clarification. Section 6.5.2 "Titanium Grade 24", page 6-40, insert the following text after the figure to read: *General Corrosion and Localized Corrosion of the Drip Shield* (BSC 2004 [DIRS 169845]) plots all of the 2.5-year weight-loss data (vapor, aqueous, and water line) for Titanium Grade 7 from DTN: LL030410012251.056 [DIRS 169583] in the CDF shown in Figure 6-22. The corrosion rate from all weight-loss specimens at the 85% percentile of the cumulative distribution function is about 15 nm/yr. Note: This text is moved from page 6-39 to page 6-40 without any change to the content. This change was self-identified.
6-40	Add figure. Insert Figure 6-22 entitled "Titanium Grade 7 Weight-Loss Corrosion Rates after 2.5 Years" and add a footnote to the figure to read: Source: BSC 2004 [DIRS 169845], Figure 26. Note: This figure is moved from page 6-39 to page 6-40. The only change to the figure is the figure number. The figure number changed from Figure 6-21 to Figure 6-22. This change was self-identified.

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6-40	Editorial change. Section **6.5.2** "**Titanium Grade 24**", page 6-40, 1st paragraph, 2nd line, change: (Figure 6-1, based on data collected in all test environments) To (Figure 6-22, based on data collected in all test environments) This change was self-identified
8-4	Added reference (Correct DIRS as appropriate) Section **8.1 "DOCUMENTS CITED",** add reference with DIRS number 170028, add: 170028 BSC 2004. *Dike/Drift Interactions*. MDL-MGR-GS-000005 REV 01. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20041124.0002; DOC.20050622.0002. This change was self-identified.
8-4	Added reference (Correct DIRS as appropriate) Section **8.1 "DOCUMENTS CITED",** add reference with DIRS number 174995, add: 174995 BSC 2005. *Screening of Features, Events, and Processes in Drip Shield and Waste Package Degradation*. ANL-EBS-PA-000002 REV 05. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20050817.0003. This change was self-identified.
8-4	Added reference (Correct DIRS as appropriate) Section **8.1 "DOCUMENTS CITED",** add reference with DIRS number 174583, add: 174583 BSC 2005. *In-Package Chemistry Abstraction*. ANL-EBS-MD-000037 REV 04. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20050714.0003; DOC.20051130.0007. This change was self-identified.

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8-4	Added reference (Correct DIRS as appropriate) Section **8.1 "DOCUMENTS CITED",** add reference with DIRS number 175083, add: 175083 BSC 2005. *Engineered Barrier System: Physical and Chemical Environment*. ANL-EBS-MD-000033 REV 05. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20050829.0008. This change was self-identified.
8-9	Added reference (Correct DIRS as appropriate) Section **8.1 "DOCUMENTS CITED",** add reference with DIRS number 144302, add: 144302 Schutz, R.W. and Thomas, D.E. 1987. "Corrosion of Titanium and Titanium Alloys." *In Corrosion*, Volume 13, Pages 669-706 of *Metals Handbook*. 9th Edition. Metals Park, Ohio: ASM International. TIC: 209807. This change was self-identified.

ACKNOWLEDGEMENTS

This analysis report was developed through the contributions of the following individuals, listed in alphabetical order:

- Sara Arthur, AREVA. Author Section 4.1.3.5 of REV 00. Lead author of REV 01
- Patricia Bernot, BSC. Originator and lead author on REV 00. Co-author of REV 01
- Kevin Mon, Framatome. Co-author Section 6.5 of REV 01
- Kaveh Zarrabi, BSC. Author Sections 4.1.3.6 and 6.1.6 of REV 00.

The developed statistical parameters and ECDFs for aqueous degradation rates affecting waste package materials degradation will encompass various aqueous parameters such as temperature (up to 100°C), water type (i.e., fresh versus saline), and pH. This report investigates the corrosion of materials between pH 4 to 10. This range is supported by *In-Package Chemistry Abstraction* (BSC 2005 [DIRS 174583] Sections 6.9 and 8.2), which indicates that the in-package pH will be between the range of 4.5 and 8.5. *Dike/Drift Interactions* (BSC 2004 [DIRS 170028] Section 8.2.4), and *Engineered Barrier System: Physical and Chemical Environment* (BSC 2005 [DIRS 175083] Sections 6.9 and 8.2) extend the pH range to 4 to 10. The pH value resulting from water interacting with a basalt block after an igneous intrusion is between 7.6 and 9.9 (BSC 2004 [DIRS 170028]). Although *Engineered Barrier System: Physical and Chemical Environment* (BSC 2005 [DIRS 175083]) predicts possible pH values above 10 and below 4, these cases are of short duration and under unusual circumstances. Additionally, *In-Package Chemistry Abstraction* (BSC 2005 [DIRS 174583]) shows that, though it has an effect on the chemistry, the incoming water composition is not the primary parameter controlling in-package pH values, rather the degradation of the waste package materials themselves. Corrosion rates of materials at pH extremes (below 4 and above 10) are not included in this analysis since this is a special condition for which materials commonly display different corrosion behaviors and a full analysis is not justified because of the rarity of these cases.

In addition to extreme pH values, values for other conditions were also not included. One of these includes cases where there was extensive biofouling on the test specimen. The corrosion of materials due to biofouling is much different than corrosion of materials exposed to groundwater. Because this report deals only with corrosion due to contact of metals with water, excluding cases where biofouling occurred is justified. Other values rejected for use in this report were those containing the influence of localized corrosion (as indicated in Section 6.1.2) and values that were outliers. The exception to this is for aluminum. Pitting is the main corrosion behavior of aluminum. Rates of pitting usually range from 3 µm/yr to 6 µm/yr during the first year. An average over a 10-year period shows the rate of pitting to be 0.8 µm/yr to 1.5 µm/yr. The decreasing rates over time indicate the tendency of older pits to become inactive. This analysis converts weight loss data on aluminum (including weight loss due to pitting) into a corrosion rate for general corrosion (the process by which the entire surface of the metal is attacked uniformly).

In the case of three metals, Aluminum Alloy Types 1100 and 6061-T6 (in saline/concentrated waters) and Carbon Steel Type A516, a large amount of corrosion data is available in the literature as the metals are used extensively by many industries. For this analysis, it was decided to use the data from one large comprehensive study since using a full bibliography of values is impractical. The chosen values for aluminum corrosion in saltwater come from an article by Hollingsworth and Hunsicker (1987 [DIRS 150403]), which is a handbook and thus accepted by the scientific and engineering community as established fact. For Carbon Steel Type A516, the data provided by McCright (1998 [DIRS 114637]) was used since this study was conducted using environmental conditions expected to be present in the repository. Additionally, the experiments and analysis were performed at the Lawrence Livermore National Laboratory using sound engineering practices, a well-accepted methodology, and in a thorough and comprehensive manner. Testing and analysis were done to an approved activity plan (Gdowski

1998 [DIRS 118106]) and technical implementation plans (McCright 1998 [DIRS 114637], p. 2.2-11 for more detail). Materials were cleaned in accordance with ASTM Standard G 1-90 [DIRS 103515].

For steels and alloys other than carbon steel and aluminum alloy, literature data were reviewed and pertinent quality information was used in this analysis. Several references were excluded from the analysis for the following reasons: (1) the experimental procedure was not described in the report so the quality of presented material could not be determined, (2) experimental procedure was not described in sufficient detail to discern quality of presented material, (3) experimental procedure or practices were questionable bringing doubt as to the caliber of the data, (4) the experimental conditions (ie, temperature, water chemistry, etc.) were not reported, thus making it difficult to place the data in the proper data set and/or calling to question quality of experimental procedure, and (5) experimental conditions were not applicable to the repository environment (example – boiling acid). The data used in this report came from either handbooks, reports specifically written for the U.S nuclear regulatory commission, or journal articles and published reports that could be qualified through reliability of data source, qualifications of personnel or organizations generating the data, prior use of the data, and/or availability of corroborating data as indicated in Appendix III.

The output from this analysis is to be used in corrosion analysis to determine likelihood of corrosion scenarios and most likely corrosion rates for waste package materials to be used in corrosion studies.

The output from this analysis will support the determination of the probability of criticality for DOE SNF codisposal waste packages. Outputs can also be used for corrosion analyses to determine realistic (most probable) values of corrosion for various materials in waste packages.

6.1 TYPES OF CORROSION

The purpose of this report is not to describe the performance of engineered barriers for the TSPA-LA. Instead, the analysis provides simple statistics on aqueous corrosion rates of steels and alloys. In the EQ6 cases used to characterize corrosion of DOE waste packages, the rate is represented as a general corrosion over the entire surface of the material. For example, localized corrosion weight loss rates for aluminum are converted to general corrosion rates in μm/yr for use in EQ6 calculations (BSC 2001 [DIRS 157640]; BSC 2002 [DIRS 158828]). Since the purpose of this analysis is to support EQ6 reaction path calculations and analyses, it will also focus on general corrosion rates. However, for some materials (such as aluminum), the primary corrosion behavior is a form of localized corrosion called pitting. In addition, galvanic coupling of materials in proximity to each other can have a strong effect on the rates of corrosion. Therefore, some data from specimens exhibiting localized or galvanic corrosion weight loss have been converted to general corrosion rates in μm/yr and included in the rates presented in Section 6.2. This section presents a short overview of these corrosion types.

6.1.1 General Corrosion

General corrosion describes the process by which the entire surface of the metal is attacked uniformly.

6.1.2 Localized Corrosion

Localized corrosion of passive metals includes various phenomena such as pitting, crevice corrosion, intergranular attack, and stress corrosion cracking.

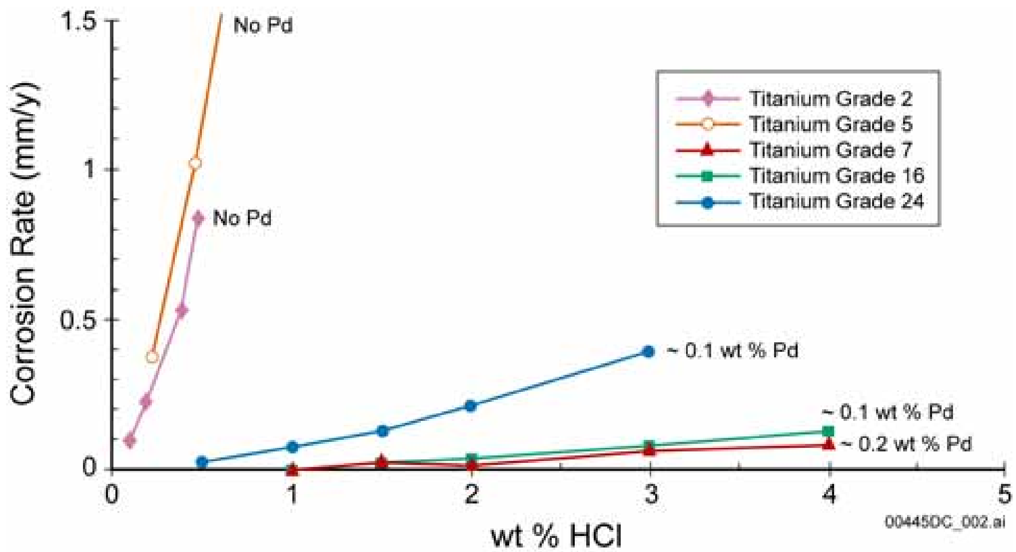
Crevice corrosion is a form of localized corrosion that can occur within crevices or shielded surfaces in which a solution can stagnate. Crevices can form from 1) the geometry of a structure (riveted plates, threaded joints, etc.), 2) Contact of the metal with nonmetallic solids (plastics, rubber, or glass associated with rivets, bolts, gaskets, welds, etc.), and 3) Deposits of sand, dirt, or corrosion products, or microbial growths on the metal surface (Shreir et al. 1998 [DIRS 100891], Section 1.6; Sedriks 1996 [DIRS 164036], Section 5). This corrosion can range from small pits to extensive corrosion over the whole surface.

6.5.2 Titanium Grade 24

Titanium Grade 24, an alloy with ~ 6 wt % Al, 4 wt % V, and ~ 0.04 to 0.08 wt % Pd, is used as the structural material in the design of the drip shield. An experimentally obtained corrosion rate for Titanium Grade 24 under repository conditions is not available at this time. However, the comparative corrosion behavior of Titanium Grade 24 can be estimated based on available data for other titanium alloys.

The corrosion rates of Titanium Grades 2 (Titanium with no Pd) and 5 (Ti-6Al-4V with no Pd) in hydrochloric acid solutions, a very aggressive test medium for titanium alloys, are shown in Figure 6-21 along with those of Titanium Grades 7 (0.12 – 0.25 wt% Pd), 16, and 24. The addition of 0.04 to 0.08 wt % of Pd to Titanium Grades 2 and 5 (to produce Titanium Grades 16 and 24) significantly improves the corrosion resistance of the alloy as demonstrated in Figure 6-21. Handbook data (Schutz and Thomas 1987 [DIRS 144302], Table 7, p. 679) indicate that the corrosion rate of Titanium Grade 5 is approximately four times that of Titanium Grade 7 in boiling 25% HNO_3 (a much more aggressive corrosion environment than the repository environment). Since the purpose of Pd alloying of titanium is to help maintain the passivity of a titanium alloy (see BSC 2005 [DIRS 174995], Section 6.2.7), the general corrosion rate of Titanium Grade 24 (i.e., the palladium containing analog of Titanium Grade 5), should be lower than that of Titanium Grade 5. Therefore, the general corrosion rate for Titanium Grade 24 can be conservatively estimated to be 5 times that of Titanium Grade 7.

Figure 6-21 shows that the corrosion rate of Titanium Grade 24 is about five times higher than that of Titanium Grade 7 in 3% boiling HCl, further validating the use of Titanium Grade 7 corrosion rates with an applied multiplier of 5. On this basis, a conservative estimate of the corrosion rate of Titanium Grade 24 in less aggressive repository environments would be five times higher than that measured for Titanium Grade 7.

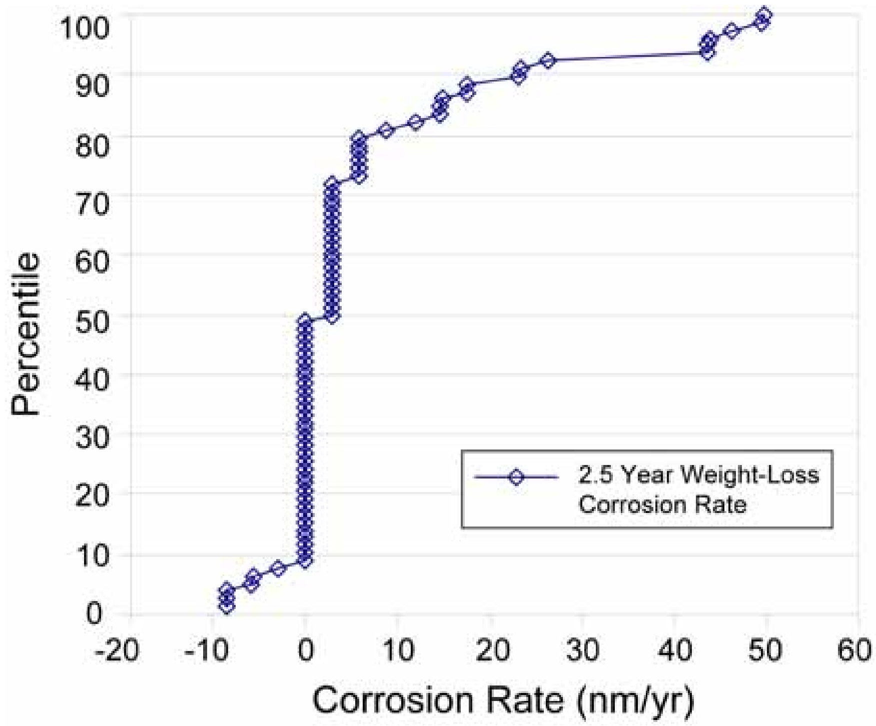


Source: BSC 2004 [DIRS 169847], Figure 10.

NOTE: This figure shows the significant improvement in corrosion resistance due to addition of palladium.

Figure 6-21. Corrosion Rates of Titanium Grades 2, 5, 7, 16, and 24 in Boiling HCl

General Corrosion and Localized Corrosion of the Drip Shield (BSC 2004 [DIRS 169845]) plots all of the 2.5-year weight-loss data (vapor, aqueous, and water line) for Titanium Grade 7 from DTN: LL030410012251.056 [DIRS 169583] in the CDF shown in Figure 6-22. The corrosion rate from all weight-loss specimens at the 85% percentile of the cumulative distribution function is about 15 nm/yr.



Source: BSC 2004 [DIRS 169845], Figure 26.

Figure 6-22. Titanium Grade 7 Weight-Loss Corrosion Rates after 2.5 Years

A corrosion allowance of 1 mm per exposed surface is accounted for in the drip shield design (BSC 2004 [DIRS 169220]). The 85th percentile on the cumulative distribution curve (Figure 6-22, based on data collected in all test environments) for the general corrosion rate of Titanium Grade 7 is about 15 nm/yr. Therefore, the estimated corrosion rate of Titanium Grade 24 at the 85th percentile is estimated to be a factor of five greater or about 75 nm/yr. Over a 10,000-year period, this corrosion rate results in a metal loss of about 0.75 mm per exposed surface.

Figure 6-23 and Table 6-18 present simple statistical information on the corrosion of Titanium Grade 24 (based on Titanium Grade 7 data from Table 4-31 multiplied by 5 to account for the increased corrosion of Titanium Grade 24 over that of Titanium Grade 7). The information presented below is only for aqueous corrosion, as vapor (or atmospheric) corrosion is not within the scope of this document. Figure 6-23 shows that a corrosion rate of 0.075 µm/yr (75 nm/yr) corresponds to the 92nd percentile for the ECDF for corrosion rates in SAW solutions. Over a 10,000-year period, this corrosion rate results in a metal loss of about 0.75 mm per exposed surface.

169847 BSC (Bechtel SAIC Company) 2004. *Hydrogen-Induced Cracking of the Drip Shield.* ANL-EBS-MD-000006 REV 02. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20040909.0004.

167621 BSC 2004. *In-Package Chemistry Abstraction*. ANL-EBS-MD-000037, Rev. 03. Las Vegas, Nevada: Bechtel SAIC Company.

168361 BSC 2004. *Q-List*. 000-30R-MGR0-00500-000-000 REV 00. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20040721.0007.

171583 BSC 2004. *Technical Work Plan For: Regulatory Integration Modeling and Analysis of the Waste Form and Waste Package*. TWP-WIS-MD-000009, REV 00, ICN 01. Las Vegas, Nevada: Becehtel SAIC Company. ACC: DOC.20040910.0001.

170028 BSC 2004. *Dike/Drift Interactions*. MDL-MGR-GS-000005 REV 01. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20041124.0002; DOC.20050622.0002.

174995 BSC 2005. *Screening of Features, Events, and Processes in Drip Shield and Waste Package Degradation*. ANL-EBS-PA-000002 REV 05. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20050817.0003.

174583 BSC 2005. *In-Package Chemistry Abstraction*. ANL-EBS-MD-000037 REV 04. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20050714.0003; DOC.20051130.0007.

175083 BSC 2005. *Engineered Barrier System: Physical and Chemical Environment*. ANL-EBS-MD-000033 REV 05. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20050829.0008.

159368 Butler, F.E. 1963. *Corrosion Studies on 304 Stainless Steel Containing One Percent Boron-10*. RFP-307. Washington, D.C.: U.S. Atomic Energy Commission. TIC: 252108.

166275 Canori, G.F. and Leitner, M.M. 2003. *Project Requirements Document.* TER-MGR-MD-000001 REV 02. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20031222.0006.

159369 Cole, H.S. 1976. *Corrosion of Stainless Steel Type 304 Alloyed with Boron or Gadolinium by Plant Process Solutions Containing* HNO_3 *and HF*. ICP-1097. Idaho Falls, Idaho: Idaho National Engineering Laboratory. TIC: 252106.

100362 CRWMS M&O 1998. "Waste Form Degradation, Radionuclide Mobilization, and Transport Through the Engineered Barrier System." Chapter 6 of *Total System Performance Assessment-Viability Assessment (TSPA-VA) Analyses Technical Basis Document.* B00000000-01717-4301-00006 REV 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19981008.0006.

127351 CRWMS M&O 1999. *EQ6 Calculation for Chemical Degradation of Shippingport PWR (HEU Oxide) Spent Nuclear Fuel Waste Packages*. CAL-EDC-MD-000002 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19991220.0322.

160320 D'Agostino, R.B. and Stephens, M.A., eds. 1986. *Goodness-Of-Fit Techniques*. Statistics, Textbooks and Monographs Volume 68. New York, New York: Marcel Dekker. TIC: 253256.

154395 Danko, J.C. 1987. "Corrosion in the Nuclear Power Industry." In *Corrosion*, Volume 13, Pages 927-984 of Metals Handbook. 9th Edition. Metals Park, Ohio: ASM International. TIC: 209807.

162971 Davison, R.M.; DeBold, T.; and Johnson, M.J. 1987. "Corrosion of Stainless Steels." In *Corrosion*, Volume 13, Pages 547-565 of ASM Handbook. Formerly 9th Edition, *Metals Handbook*. Materials Park, Ohio: ASM International. TIC: 240704.

159371 Satyanarayana Gupta, D.V. 1981. "Corrosion Behavior of 1040 Carbon Steel. I. Effect of pH and Sulfide Ion Concentrations in Aqueous Neutral and Alkaline Solutions at Room Temperature." Corrosion, 37, (11), 611-616. Houston, Texas: National Association of Corrosion Engineers. TIC: 252626.

164921 Sawyer, D.W. and Brown, R.H. 1947. "Resistance of Aluminum Alloys to Fresh Waters." *Corrosion*, *3*, 443-457. Houston, Texas: National Association of Corrosion Engineers. TIC: 252901.

159335 Scarberry, R.C.; Graver, D.L.; and Stephens, C.D. 1967. "Alloying for Corrosion Control, Properties and Benefits of Alloy Materials." *Materials Protection*, *6*, 54-57. Houston, Texas: National Association of Corrosion Engineers. TIC: 251196.

144302 Schutz, R.W. and Thomas, D.E. 1987. "Corrosion of Titanium and Titanium Alloys." *In Corrosion*, Volume 13, Pages 669-706 of *Metals Handbook*. 9th Edition. Metals Park, Ohio: ASM International. TIC: 209807.

164036 Sedriks, A.J. 1996. *Corrosion of Stainless Steels*. 2nd Edition. Corrosion Monograph Series. New York, New York: John Wiley & Sons. TIC: 245121.

164923 Sedriks, A.J. 1982. "Corrosion Resistance of Austenitic Fe-Cr-Ni-Mo Alloys in Marine Environments." *International Metals Reviews*, *27*, (6), 321-353. Metals Park, Ohio: American Society for Metals. TIC: 251201.

164925 Shreir, L.L.; Jarman, R.A.; and Burstein, G.T., eds. 1998. *Corrosion Control*. Volume 2 of *Corrosion*. 3rd Edition. Woburn, Massachusetts: Butterworth-Heinemann. TIC: 244694.

100891 Shreir, L.L.; Jarman, R.A.; and Burstein, G.T., eds. 1998. *Metal/Environment Reactions*. Volume 1 of *Corrosion*. 3rd Edition. Woburn, Massachusetts: Butterworth-Heinemann. TIC: 244694.

159375 Smith, H.D. 1987. *The Influence of Copper on Zircaloy Spent Fuel Cladding Degradation Under a Potential Tuff Repository Condition*. UCRL-15993. Livermore, California: Lawrence Livermore National Laboratory. ACC: MOL.19971016.0036.

102089 Smith, P.K. and Baxter, C.A. 1981. *Fracture During Cooling of Cast Borosilicate Glass Containing Nuclear Wastes.* DP-1602. Aiken, South Carolina: E.I. Du Pont de Nemours & Company, Savannah River Laboratory. TIC: 238536.

103441 Smith, R.J.; Loomis, G.W.; and Deltete, C. P. 1992. *Borated Stainless Steel Application in Spent-Fuel Storage Racks*. TR-100784. Palo Alto, California: Electric Power Research Institute. TIC: 225730.

102088 Smith, T.H. and Ross, W.A. 1975. *Impact Testing of Vitreous Simulated High-Level Waste in Canisters.* BNWL-1903. Richland, Washington: Battelle Pacific Northwest Laboratories. TIC: 238924.

100927 Southwell, C.R.; Bultman, J.D.; and Alexander, A.L. 1976. "Corrosion of Metals in Tropical Environments - Final Report of 16-Year Exposures." *Materials Performance*, *15*, (7), 9-25. Houston, Texas: National Association of Corrosion Engineers. TIC: 224022.