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Scientific Analysis/Calculation Error Resolution Document

Complete only applicable items.

QA: QA
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INITIATION

1. Originator: Roger Henning	2. Date: 09/11/2008	3. ERD No. ANL-EBS-MD-000076 ERD 02

4. Document Identifier: ANL-EBS-MD-000076 REV 00 and ACN 01	5. Document Title: Analysis of Mechanisms for Early Waste Package/Drip Shield Failure

6. Description of and Justification for Change (Identify applicable CRs and TBVs):

I. Background Information Summary

CR 12332 was written to identify that in ANL-EBS-MD-000076 (Analysis of Mechanisms for Early Waste Package / Drip Shield Failure), in Section 5.4 of Rev 00 ACN 01 design parameter “03-20” is cited. However, the proper citation should be “03-16”. This is an editorial error having no impact as the proper information was used. The incorrect citation is in the parent document (ANL-EBS-MD-000076 Rev 00) as well as the ACN 01 to that document. A MGT-PRO-004 evaluation of this activity has been completed and this activity is approved.

II Inputs and/or Software

No software controlled under IM-PRO-003, Software Management, was used in this ERD.

III Analysis Results and Conclusions

The inconsistency identified in CR 12332, as well as a result of this analysis (where it was noted that in Table 4-5 for the value of waste package outer corrosion barrier heat treatment, that the ±50°F should be +50°F −0°F) is analyzed herein for potential impact on the parent report as well as on any technical products that use the information from the parent report.

CONCURRENCE

	Printed Name	Signature	Date
7. Checker	Wendy Mitcheltree	Wendy Mitcheltree	9-17-08
8. QCS/QA Reviewer	Brian Mitcheltree		9/17/08

APPROVAL

9. Originator	Roger J. Henning	Roger J. Henning	9/17/08
10. Responsible Manager	Neil Brown / Jerry McNeish	Neil Brown / J McNeish	9/17/08 9/17/08

The following documents were evaluated for impacts:

Document Input Reference System Impact Analysis for:

> DIRS 178765 SNL (Sandia National Laboratories) 2007. Analysis of Mechanisms for Early Waste Package/Drip Shield Failure. ANL-EBS-MD-000076 REV 00. Las Vegas, Nevada: Sandia National Laboratories. ACC: DOC.20070629.0002; DOC.20071003.0015.

(Note: ANL-EBS-MD-000076 REV 00 ACN 01 was not used as a reference, so there is no DIRS number available and no impact can be performed.)

Potentially Impacted Documents

ANL-DS0-NU-000001 Rev. 00 -- Screening Analysis of Criticality Features, Events, and Processes for License Application

ANL-EBS-MD-000005 Rev. 04 -- Stress Corrosion Cracking of Waste Package Outer Barrier and Drip Shield Materials

ANL-WIS-MD-000024 Rev. 01 -- Postclosure Nuclear Safety Design Bases

ANL-WIS-MD-000027 Rev. 00 -- Features, Events, and Processes for the Total System Performance Assessment: Analyses

CAL-DN0-NU-000002 Rev. 00C -- Waste Package Flooding Probability Evaluation

MDL-WIS-PA-000005 Rev. 00 -- Total System Performance Assessment Model/Analysis for the License Application - Volume I, II, and III.

TDR-MGR-MD-000037 Rev. 02 -- Postclosure Modeling and Analyses Design Parameters

TDR-TDIP-ES-000006 Rev. 00 --Total System Performance Assessment Data Input Package for Requirements Analysis for Transportation Aging and Disposal Canister and Related Waste Package Physical Attributes Basis for Performance Assessment

TDR-TDIP-ES-000009 Rev. 00 --Total System Performance Assessment Data Input Package for Requirements Analysis for Doe SNF/HLW and Naval SNF Waste Package Physical Attributes Basis for Performance Assessment

TDR-WIS-PA-000014 Rev. 00 --TSPA Information Package for the Draft SEIS

DOE/EIS-0250F-S1 -- Final Supplemental Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste At Yucca Mountain, Nye County, Nevada - Appendix F

Yucca Mountain Repository License Application. DOE/RW-0573, Rev. 0.

- LASAR-2.02 -- LA Safety Analysis Report Section 2.2
- LASAR-2.03.06 -- LA Safety Analysis Report Section 2.3.6
- LASAR-2.04 -- LA Safety Analysis Report Section 2.4

There are no open TBVs associated with this document.

All instances of the use of Parameter 03-20 in the parent report are related to discussions of heat treatment, solution annealing or quenching.

Parameter 03-20 ***Materials Contacting the Waste Package*** states:

> After fabrication final cleaning, the waste package shall be prepared for shipment. Materials or objects contacting the waste package outer surfaces during transportation, loading, and emplacement will be evaluated to ensure that any physical degradation and contamination are within allowable limits.

Parameter 03-16 ***Waste Package Annealing*** states:

> (a) After fabrication and before inserting the inner vessel, the waste package outer corrosion barrier shall be solution-annealed and quenched.
> (b) The minimum time for solution annealing will be 20 minutes at 2,050°F (1,121°C) + 50°F (28°C) / −0°F (0°C).
> (c) The waste package outer corrosion barrier shall be quenched at a rate greater than 275°F (153°C) per minute to below 700°F (371°C).
> (d) The annealing-induced oxide film shall be removed by means of electrochemical polishing or grit blasting.
> (e) After solution annealing and quenching, the waste package surface temperature will be kept below 300°C to eliminate postclosure issues (i.e., phase stability), except for short-term exposure (closure-weld).

Parameter 03-16 is the correct parameter in the context of heat treatment, solution annealing and quenching in the parent report.

The parameter 03-20 and solution-annealing were used as a search keyword in the parent document, the ACN 01 and ERD 01 and found to be used incorrectly in many locations in the document. In addition, on the direct input page, it was noted that the “+/- 50 should be “+50 -0. Parameter 03-20 is found in the parent document as well as the ACN, but not in the ERD 01. The corrections in this ERD 02 apply to the parent document as well as ACN 01

The remainder of this ERD consists of revised pages, which correct the condition noted in CR 12332 as well as the incorrect citation of the limits. The description of the change relative to the original Rev00 ACN01 is that where design parameter 03-20 is cited, it should be `parameter 03-16`. None of these changes result in impacts to the analyses or conclusions in ANL-EBS-MD-000076 REV 00 ACN 01 or to any downstream technical products.

IV Impact Evaluation for CR 12332

CR 12332 identified one minor inconsistency found in 10 instances on 7 pages and a single error in Table 4-5 where the value of waste package outer corrosion barrier heat treatment, the ±50°F should be +50°F −0°F) .

Changes to the Document Shown on Images of the Original Document

Copies of the pages showing the corrections are included with this ERD 02. *(See attached pages 4 through 10).* Updated DIRS have been provided as hardcopy markups.

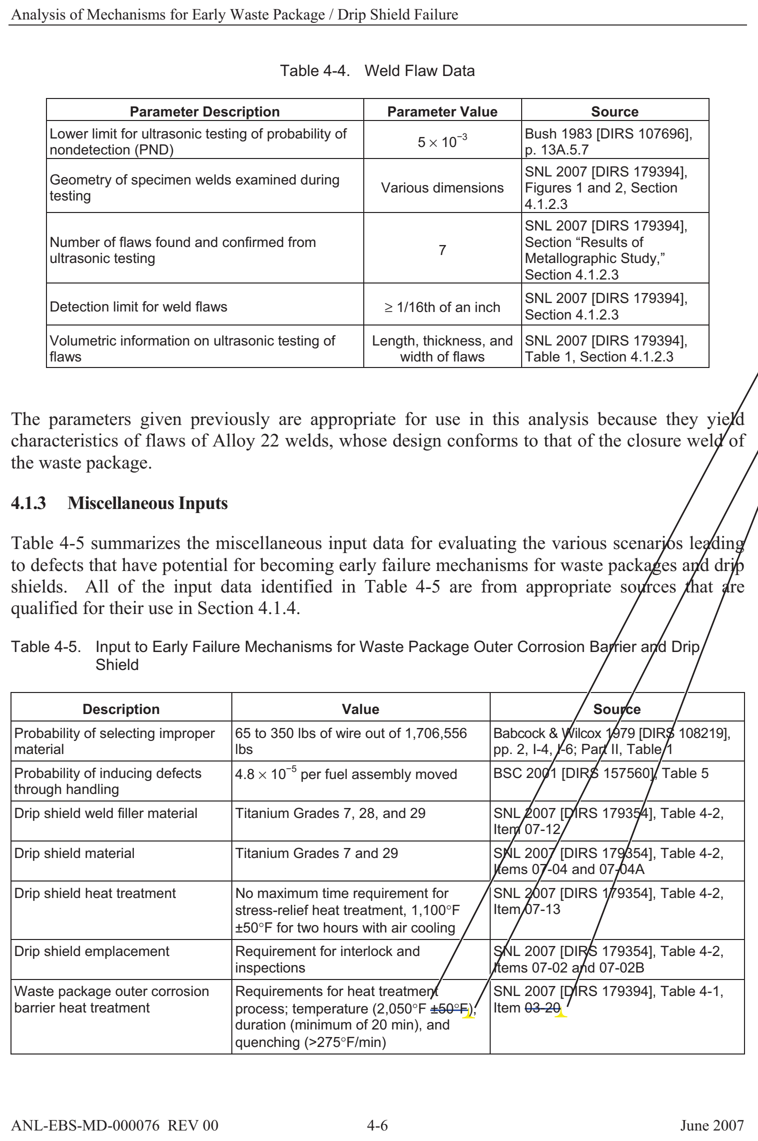

Table 4-4. Weld Flaw Data

Parameter Description	Parameter Value	Source
Lower limit for ultrasonic testing of probability of nondetection (PND)	5×10^{-3}	Bush 1983 [DIRS 107696], p. 13A.5.7
Geometry of specimen welds examined during testing	Various dimensions	SNL 2007 [DIRS 179394], Figures 1 and 2, Section 4.1.2.3
Number of flaws found and confirmed from ultrasonic testing	7	SNL 2007 [DIRS 179394], Section "Results of Metallographic Study," Section 4.1.2.3
Detection limit for weld flaws	≥ 1/16th of an inch	SNL 2007 [DIRS 179394], Section 4.1.2.3
Volumetric information on ultrasonic testing of flaws	Length, thickness, and width of flaws	SNL 2007 [DIRS 179394], Table 1, Section 4.1.2.3

The parameters given previously are appropriate for use in this analysis because they yield characteristics of flaws of Alloy 22 welds, whose design conforms to that of the closure weld of the waste package.

4.1.3 Miscellaneous Inputs

Table 4-5 summarizes the miscellaneous input data for evaluating the various scenarios leading to defects that have potential for becoming early failure mechanisms for waste packages and drip shields. All of the input data identified in Table 4-5 are from appropriate sources that are qualified for their use in Section 4.1.4.

Table 4-5. Input to Early Failure Mechanisms for Waste Package Outer Corrosion Barrier and Drip Shield

Description	Value	Source
Probability of selecting improper material	65 to 350 lbs of wire out of 1,706,556 lbs	Babcock & Wilcox 1979 [DIRS 108219], pp. 2, I-4, I-6; Part II, Table 1
Probability of inducing defects through handling	4.8×10^{-5} per fuel assembly moved	BSC 2001 [DIRS 157560], Table 5
Drip shield weld filler material	Titanium Grades 7, 28, and 29	SNL 2007 [DIRS 179354], Table 4-2, Item 07-12
Drip shield material	Titanium Grades 7 and 29	SNL 2007 [DIRS 179354], Table 4-2, Items 07-04 and 07-04A
Drip shield heat treatment	No maximum time requirement for stress-relief heat treatment, 1,100°F ±50°F for two hours with air cooling	SNL 2007 [DIRS 179354], Table 4-2, Item 07-13
Drip shield emplacement	Requirement for interlock and inspections	SNL 2007 [DIRS 179354], Table 4-2, Items 07-02 and 07-02B
Waste package outer corrosion barrier heat treatment	Requirements for heat treatment process; temperature (2,050°F ~~±50°F~~); duration (minimum of 20 min), and quenching (>275°F/min)	SNL 2007 [DIRS 179394], Table 4-1, Item ~~03-20~~

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The rationale for this assumption is that there is uncertainty associated with any probability value, whether explicitly specified or not, and the lognormal distribution is one possible representation for distributions that cannot be negative. In addition, assigning a lognormal attribute to nonspecified uncertainty distributions makes them consistent with HEPs, which are represented by lognormal distributions (Swain and Guttmann 1983 [DIRS 139383], pp. 2-18 and 2-19).

The specification of an error factor range between 3 and 15 is a reasonable value that is consistent with the range of HEPs. This spread in error factor values allows the uncertainty distribution for the associated probability a range that is on the order of 10 to 100 (Equation 2).

This assumption is used in Sections 5.7, 6.3.3, 6.3.4, 6.3.5, and 6.4.2 and does not require confirmation.

5.4 CRITICAL PHASE OF THE WASTE PACKAGE OUTER CORROSION BARRIER HEAT TREATMENT

It is assumed that the critical portion of the heat treatment process for the waste package outer corrosion barrier is the final phase of the operation that is the time-sensitive solution annealing of the outer corrosion barrier.

The rationale for this assumption is that strict time constraints are imposed on the solution-annealing phase of the waste package outer corrosion barrier heat treatment to prevent the development of undesirable phases in the outer corrosion barrier material during cool-down (SNL 2007 [DIRS 179394], Table 4-1, Item ~~03-20)~~. The purpose of the heat treatment is to produce a uniform phase in the outer corrosion barrier material and then avoid an undesirable phase transition during cooling (SNL 2007 [DIRS 179394], Section 4.1.2.2). In addition, the heat treatment will be applied to the outer corrosion barrier as a complete unit with the exception of the closure lid. The overall outer corrosion barrier fabrication is to be performed in a controlled manner (SNL 2007 [DIRS 179394], Table 4-1, Item 03-16). Performance constraints on the operation prior to the solution-annealing phase are less stringent than those pertaining to the solution-annealing phase, permitting potential process faults or failures to be more readily identified and corrected, minimizing the likelihood of nondetection of such events.

This assumption is used in Sections 6.3.3 and 6.3.4 and does not require confirmation since additional phases of the operation can be modeled, if identified as important as a mechanism contributing to early failures.

5.5 MONITORS FOR WASTE PACKAGE OUTER CORROSION BARRIER FABRICATION PROCESSES

It is assumed that the fabrication processes for the waste package outer corrosion barrier will be monitored with appropriate systems (e.g., timers, thermocouples) equipped with recording capability and alarms that serve as surrogates for operational monitoring processes.

The rationale for this assumption is that, firstly, recording capability is a normal part of operations performed under quality assurance procedures to provide the necessary documentation records. This capability applies to all fabrication processes. Secondly, in the

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event of process malfunctions or failures, it is anticipated that operational monitoring systems will be available to alert the operator to take remedial action. For example, strict time constraints are placed on certain phases of the fabrication process, e.g., the solution annealing phase of the waste package outer corrosion barrier heat treatment, to prevent the development of undesirable phases in the outer corrosion barrier material during cool-down (SNL 2007 [DIRS 179394], Table 4-1, Item ~~03-20~~). Imposing limits on the minimum outer corrosion barrier temperature allowable to begin the quench process implies that the outer corrosion barrier must be transferred to the quench facility within a prescribed time period. Exceeding the prescribed transfer period could result in an inadequate heat treatment process. A monitoring system would alert the operator to take remedial action, minimizing the likelihood that a process malfunction is undetected. For this analysis, some type of alarm system serves as a surrogate for such a monitoring system.

This assumption, which is used in Sections 6.3.3 and 6.3.5, requires confirmation that will be accomplished when the fabrication procedures are finalized.

5.6 QUENCHING OF WASTE PACKAGE OUTER CORROSION BARRIER

It is assumed that the waste package outer corrosion barrier quench operation will be performed with the outer corrosion barrier in an inverted axial position.

The rationale for this assumption is that an inverted position with the open end down provides the best arrangement for maintaining a relatively uniform through-wall metal temperature distribution during the rapid cool-down (SNL 2007 [DIRS 179394], Table 4-1, Item ~~03-20~~) since both inside and outside surfaces are quenched simultaneously. This arrangement is amenable to pool and/or spray quenching methods. Performing the quenching process with the outer corrosion barrier inverted also prevents any excess water from accumulating in the outer corrosion barrier.

This assumption is used in Section 6.3.3 and requires confirmation that it will be accomplished when the fabrication procedures are finalized.

5.7 PROBABILITY FOR MECHANICAL MALFUNCTIONING OF LIFTING AND MOVING EQUIPMENT

It is assumed that a value of 3×10^{-3} per event is an upper bound for the median probability of having a mechanical malfunction of moving equipment such as cranes and trolleys.

The rationale for this bounding assumption is that equipment malfunctions that could cause a failure of the heat treatment processes are much less severe but more likely than major failures for equipment. Data for major equipment failures (e.g., load drops) that cause damage to the objects being handled were used to develop the probability of damage to fuel assemblies due to equipment failure. This probability was estimated as 1.9×10^{-5} per event (BSC 2001 [DIRS 157560], Table 4). The probability of heavy load drops at reactor power facilities has been estimated as approximately 5.6×10^{-5} per event (Lloyd 2003 [DIRS 174757], Section 3.7.1). The equipment malfunctions that could cause a failure of the heat-treatment processes are much less severe but more likely. These malfunctions could be caused by such

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then be welded circumferentially to complete the vessel, whose overall length is approximately 5.7 m (SNL 2007 [DIRS 179394], Table 4-3). After being inspected and undergoing the threshold flaw testing, the lower lid would be welded in place. The lids, basically large discs, are fabricated separately of the same alloy material as the body of the vessels. The lid thicknesses are 25.4 mm and 50.8 mm, respectively, for the outer corrosion barrier and inner vessel (SNL 2007 [DIRS 179394], Table 4-3). The lower lid welds will also be subjected to detailed NDE (SNL 2007 [DIRS 179394], Table 4-1, Item 03-17). The outer corrosion barrier and its lids are solution-annealed (SNL 2007 [DIRS 179394], Table 4-1, Item ~~03-20~~) to preserve their corrosion properties. The inner vessel does not require a heat treatment, since it serves primarily as a support structure. Following heat treatment of the outer corrosion barrier and machining of the weld preparations, the inner vessel is placed within the outer corrosion barrier. The lids are shipped along with the assembled waste package.

The dimensions of the completed vessels will be confirmed to ensure that the inner liner can be inserted into the outer corrosion barrier without interactions. Here, dimensions and ovality are important. The inner liner will then be inserted into the outer corrosion barrier and the completed unit packaged for transport to the repository. The waste package pieces will contain impressed inventory numbers so that each package can be followed through subsequent handling. The empty waste packages will be received and inspected at the repository and placed into temporary storage. When needed, the empty waste packages will be moved to the appropriate building where the TAD or defense high-level waste canister will be inserted in the vertical position. After waste insertion and placement of a Stainless Steel Type 316 spread ring, the inner lid will be welded in place. Following nondestructive inspection, the outer lid will be welded in place. This weld will undergo residual stress mitigation by means of low-plasticity burnishing, followed by detailed NDE (SNL 2007 [DIRS 179394], Table 4-1, Item 03-21). The loaded waste packages will then be rotated vertically and readied for movement by the fuel transporter into the repository position established for that package. The transporter is remotely operated and places the waste package and its pallet in the required position using location sensors.

6.2.2 Drip Shield Fabrication and Handling Processes

Conceptually the drip shield looks like an inverted "U" or mailbox. The overall dimensions of the drip shield, about 2.4 meters across and about 5.8 meters in length including the overlap section, have been developed and documented. These dimensions can be found in *Total System Performance Assessment Data Input Package for Requirements Analysis for EBS In-Drift Configuration* (SNL 2007 [DIRS 179354], Table 4-2, Item 07-01). The processes for the fabrication and handling of the drip shield have conceptually been developed. The exact processes will be dependent on the approach of the vendor to meeting the specifications of the YMP. The requirements and specifications for the drip shield can be found in *Total System Performance Assessment Data Input Package for Requirements Analysis for EBS In-Drift Configuration* (SNL 2007 [DIRS 179354], Table 4-2).

The fabrication process begins with the procurement of the plates and structural support beams that form the drip shield. The body of the drip shield and the connector plate are constructed of Titanium Grade 7 (R52400), an alpha-phase titanium alloy with approximately 0.15 wt % palladium added to increase corrosion resistance (SAE 1993 [DIRS 119579], Reactive and

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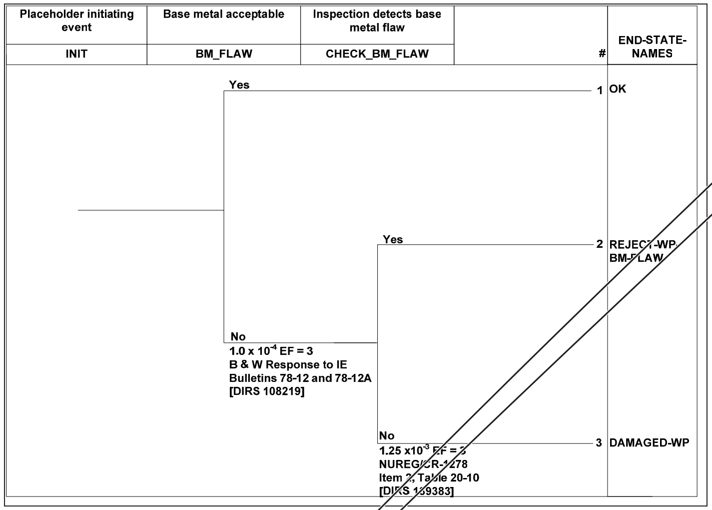

Figure 6-9. Event Tree for Evaluating Improper Base Metal Selection for Waste Package Outer Corrosion Barrier

6.3.3 Improper Heat-Treatment Implementation for Waste Package Outer Corrosion Barrier

Heat treatment of the outer corrosion barrier of the waste package can be controlled by any suitable method of heating and cooling, provided the required heating and cooling rates, metal temperature uniformity, and temperature control are maintained (SNL 2007 [DIRS 179394], Table 4-1, Item ~~03-20).~~ Such controls are assumed to be integrated into the heat treatment facility independent of the objects being processed (Assumption 5.10, Section 5). The heat treatment, however, must provide for heating of the entire outer corrosion barrier with the exception of the closure lid as a single application. Quenching in a water bath to achieve the minimum quenching rate for the outer corrosion barrier (SNL 2007 [DIRS 179394], Table 4-1, Item ~~03-20)~~ is evaluated in this report. Auxiliary instrumentation associated with the heat treatment of the outer corrosion barrier uses calibrated thermocouples in contact with the material while protecting them from direct contact with water. These thermocouples monitor the operation and provide a record of the heat treatment and solution annealing process. Such records are maintained for the quality assurance documentation and can be inspected as a check that the annealing process followed the procedures correctly. The solution-annealing operation following the heat treatment is a time-sensitive operation, and particular attention must be paid to this part of the process in order to achieve proper annealing. The final machining of the inner diameter of the outer corrosion barrier, if required, and of the final closure weld area will be performed after the solution-annealing process is complete.

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The outer corrosion barrier is to be furnace-heated at a temperature of 2,050°F + 50°F/–0°F for a minimum of 20 minutes (no maximum specified) and then quenched. Cooling will be achieved by immersion in water or spray quenching with water. The cooling rate for the entire outer corrosion barrier will be greater than 275°F/min from soak temperature to less than 700°F (SNL 2007 [DIRS 179394], Table 4-1, Item ~~03-20~~ and Section 4.1.2.2) to avoid a phase transition during cooling. The quench delay (time from removal from furnace to start of quench) needs to be sufficiently limited to assure that the quench initiation starts at 2,020°F or higher. Since it is expected that the outer corrosion barrier will be quenched in an inverted position (Assumption 5.6, Section 5), a snorkel must be installed on the interior of the outer corrosion barrier to permit the interior to fill rapidly if immersion quenching is selected. The quench rate is specified to be greater than 275°F/min, and, based on a rate that is on the order of 300°F/min, the quenching operation will require approximately four minutes to complete. Thus, it is reasonable that the makeup water system must operate for at least six minutes to be at capacity when needed. It is assumed that this last phase of the heat treatment of the waste package outer corrosion barrier (i.e., removal from the furnace and quenching) is the critical part of the process (Assumption 5.4, Section 5), and the analysis of the heat treatment process focuses on this phase. It is expected that the outer corrosion barrier will be moved into the heat treatment facility and then to the quench chamber by a crane, since this type of handling equipment is the most suitable for such large and non-compact objects as the outer corrosion barrier.

While fabrication processes for the waste package outer corrosion barrier have not been finalized (Section 5), prototypes have been fabricated that provide collaborative support for the assumptions concerning fabrication processes. In particular, a full-sized Alloy 22 prototype outer corrosion barrier was furnace-heated in an inverted position and subsequently tank-quenched on both sides using two pipes for purging internal gases. Figure C-1 in Appendix C shows the outer corrosion barrier being lowered by a crane into the quench tank. Figure C-2 in Appendix C shows the postannealed outer corrosion barrier with the purge piping still attached.

The probability that the waste package outer corrosion barrier will be subjected to an improper heat treatment, without the error being detected prior to emplacement in the repository, is a combination of human error and process failure probabilities where the HEPs follow lognormal distributions, and the process failure probabilities are point values. It is assumed that process failure probabilities, usually given as point or rate values, can be represented as the mean value of a distribution assumed to be lognormal (Assumption 5.3, Section 5). Error factors were thus assigned to point values to provide a range for uncertainty in the values. Heat treatment of the waste package inner vessel is not evaluated, since no special heat-treatment process is specified for the inner vessel, except that maximum temperatures associated with welding have been specified (BSC 2006 [DIRS 180190], Section 5.5.1.3A); these maximum temperatures are cited in *Total System Performance Assessment Data Input Package for Requirements Analysis for TAD Canister and Related Waste Package Overpack Physical Attributes Basis for Performance Assessment* (SNL 2007 [DIRS 179394], Section 4.1.2.2).

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6.3.4 Improper Heat-Treatment Implementation for Waste Package Outer Corrosion Barrier Lid

Heat treatment of the outer corrosion barrier lid of the waste package can be accomplished by any suitable method of heating and cooling, provided the required heating and cooling rates, metal temperature uniformity, and temperature control are maintained (SNL 2007 [DIRS 179394], Table 4-1, Item ~~03-20~~). Such controls are assumed to be integrated into the heat treatment facility independently of the objects being processed (Assumption 5.10, Section 5). Quenching in a water bath to achieve the minimum quenching rate for the lid (SNL 2007 [DIRS 179394], Table 4-1, Item ~~03-20~~) is evaluated in this report. Auxiliary instrumentation associated with the heat treatment of the outer corrosion barrier lid utilizes calibrated thermocouples in contact with the material while protecting them from direct contact with water. These thermocouples monitor the operation and provide a record of the heat-treatment/solution-annealing process as it evolves. Such records are important for the quality assurance documentation and as a check that the annealing process followed the procedures correctly. The solution-annealing operation following the heat treatment is a critical operation, and particular attention must be paid to this part of the process in order to achieve proper annealing.

The outer corrosion barrier lid is to be furnace heated at a temperature of 2,050°F + 50°F/–0°F for 20 minutes minimum (no maximum specified) and then quenched. Cooling will be achieved by immersion in water or spray quenching with water. The cooling rate for the outer corrosion barrier lid shall be greater than 275°F/min from soak temperature to less than 700°F (SNL 2007 [DIRS 179394], Section 4.1.2.2) to avoid a phase transition during cooling. The quench delay (time from removal from furnace to start of quench) needs to be sufficiently limited to assure that the quench initiation starts at 2020°F or higher. The quench rate is specified to be greater than 275°F/min, and, assuming the rate is on the order of 300°F/min, the quenching operation requires approximately four minutes. Thus, it is reasonable that the makeup water system must operate for at least six minutes to be at capacity when needed. It is assumed that this last phase of the heat treatment of the waste package outer corrosion barrier lid, removal from the furnace and quenching, is the critical part of the process (Assumption 5.4, Section 5), and the analysis of the heat treatment process focuses on this phase. It is expected that the outer corrosion barrier lid will be moved into the heat treatment facility and then to the quench chamber by either a trolley or a crane as these types of handling equipment are common for large objects, where a trolley is analyzed as the preferred method, since the lid is a regular plate.

The probability that the waste package outer corrosion barrier lid will be subjected to an improper heat treatment, without the error being detected prior to emplacement in the repository, is a combination of human error and process failure probabilities, where the HEPs follow lognormal distributions and the process failure probabilities are point values. It is assumed that process failure probabilities, usually given as point or rate values, can be represented as the mean value of a distribution assumed to be lognormal (Assumption 5.3, Section 5). Error factors were thus assigned to point values to provide a range for uncertainty in the values.

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