

10 CFR 50.90

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U. S. Nuclear Regulatory Commission
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Washington, DC 20555-0001

Three Mile Island Nuclear Station, Unit 1
Facility Operating License No. DPR-50
NRC Docket No. 50-289

Subject: Technical Specification Change Request No. 337 – Reactor Building Emergency Sump pH Control System Buffer Change

In accordance with 10 CFR 50.90, "Application for amendment of license or construction permit," AmerGen Energy Company, LLC (AmerGen) proposes changes to Appendix A, Technical Specifications (TS), of the Three Mile Island Nuclear Station, Unit 1 (TMI Unit 1) Facility Operating License. Enclosure 1 contains AmerGen's description and assessment of the change. Enclosure 2 contains the proposed TS changes.

The proposed change would revise TMI Unit 1 Technical Specification 3.3.1.3, "Reactor Building Spray System and Reactor Building Emergency Core Cooling System." The current capability to add sodium hydroxide (NaOH) to the Reactor Building spray system as a buffer during the initial phase of a loss-of-coolant accident will be replaced with trisodium phosphate dodecahydrate (TSP) stored in baskets located inside the Reactor Building containment. Related changes to Technical Specifications 3.3.2.1 and 4.1, and the Bases are also proposed.

As part of this license amendment request, AmerGen proposes to modify the current UFSAR licensing basis methodology for calculating the iodine removal coefficients for the Reactor Building spray system to be consistent with NUREG-0800, Standard Review Plan 6.5.2.

The proposed amendment has been reviewed by the TMI Unit 1 Plant Operations Review Committee and approved by the Nuclear Safety Review Board in accordance with the requirements of the AmerGen Quality Assurance Program.

Using the standards in 10 CFR 50.92, AmerGen has concluded that these proposed changes do not constitute a significant hazards consideration, as described in the enclosed analysis performed in accordance with 10 CFR 50.91(a)(1). Pursuant to 10 CFR 50.91(b)(1), a copy of this Technical Specification Change Request is provided to the designated official of the Commonwealth of Pennsylvania, Bureau of Radiation Protection, as well as the chief executives of the township and county in which the facility is located.

ADD
NRR

We request approval of the proposed change by December 1, 2007, with the amendment being implemented within 30 days of issuance. This will allow an orderly implementation of these changes following approval in accordance with the December 31, 2007 containment emergency sump modification compliance requirements specified in NRC Generic Letter 2004-02.

Regulatory commitments established by this submittal are identified in Enclosure 3. If you have any questions or require additional information, please contact Mr. David Distel at (610) 765-5517.

I declare under penalty of perjury that the foregoing is true and correct. Executed on the 29th day of June, 2007.

Respectfully,



Pamela B. Cowan
Director - Licensing and Regulatory Affairs
AmerGen Energy Company, LLC

- Enclosures:
- 1) TMI Unit 1 Technical Specification Change Request No. 337 - Reactor Building Emergency Sump pH Control System Buffer Change Description and Assessment
 - 2) TMI Unit 1 Technical Specification Change Request No. 337 - Markup of Proposed Technical Specification and Bases Page Changes
 - 3) List of Commitments

cc: S. J. Collins, Administrator, USNRC Region I
D. M. Kern, USNRC Senior Resident Inspector, TMI Unit 1
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of Environmental Protection
Chairman, Board of County Commissioners of Dauphin County, PA
Chairman, Board of Supervisors of Londonderry Township, Dauphin County, PA
TMI Unit 1 File No. 07029

ENCLOSURE 1

TMI Unit 1 Technical Specification Change Request No. 337

Reactor Building Emergency Sump pH Control System Buffer Change

Description and Assessment

**Subject: Reactor Building Emergency Sump pH Control System Buffer Change – TS
Sections 3.3.1.3, 3.3.2.1, and 4.1**

- 1.0 DESCRIPTION
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ATTACHMENTS:

- Attachment 1: AmerGen/Exelon Calculation C-1101-153-E410-036, Revision 0,
"Reactor Building Spray pH Prior to the Start of Recirculation Spray"
- Attachment 2: AmerGen/Exelon Calculation C-1101-153-E410-040, Revision 0,
"Reactor Building Sump Post-LOCA pH and TSP Quantity"
- Attachment 3: AmerGen/Exelon Calculation C-1101-900-E000-087, Revision 2,
"Post-LOCA EAB, LPZ, TSC, and CR Doses Using AST and RG 1.183
Requirements" (Electronic CD)

ENCLOSURE 1
DESCRIPTION AND ASSESSMENT

1.0 Description

In accordance with 10 CFR 50.90, "Application for amendment of license or construction permit," AmerGen Energy Company, LLC (AmerGen) is requesting an amendment to Facility Operating License No. DPR-50 for Three Mile Island Nuclear Station, Unit 1 (TMI Unit 1). The proposed change would revise TMI Unit 1 Technical Specification (TS) 3.3.1.3, "Reactor Building Spray System and Reactor Building Emergency Core Cooling System." The current capability to add sodium hydroxide (NaOH) to the Reactor Building spray system as a buffer during the initial phase of a loss-of-coolant accident (LOCA) will be replaced with trisodium phosphate dodecahydrate (TSP) stored in baskets located inside the Reactor Building containment. As part of the modification, the sodium hydroxide addition tank will be isolated from the Reactor Building spray system, but will physically remain in place.

The reason for this change is to minimize the potential for exacerbating sump screen blockage under post-LOCA conditions. As a result of AmerGen's efforts to address Generic Safety Issue 191 (Assessment of Debris Accumulation on PWR Sump Performance) for TMI Unit 1, concerns have been identified relating to potential adverse chemical interactions between NaOH and certain insulation materials used in the TMI Unit 1 containment. Related changes to Technical Specifications 3.3.2.1 and 4.1, and the Bases are also proposed.

AmerGen requests that the following changed replacement pages be inserted into the existing Technical Specifications:

Revised TMI Unit 1 TS Pages: 3-22, 3-23, 3-24, 4-2b, 4-7, 4-10, and 4-10c.

2.0 Proposed Change

The proposed amendment changes the method of pH control for the water in the Reactor Building emergency sump after a postulated LOCA. This change deletes the specification for sodium hydroxide (NaOH) spray addition and adds a specification for the use of trisodium phosphate dodecahydrate (TSP) as the chemical for pH control. In addition, to support the buffer change, the Updated Final Safety Analysis Report (UFSAR) methodology for calculating the iodine removal coefficients for the Reactor Building spray system is modified to be consistent with NUREG-0800, Standard Review Plan 6.5.2.

- 2.1 Revise TMI Unit 1 TS 3.3.1.3, Reactor Building Spray System and Reactor Building Emergency Cooling System, (page 3-22) to delete the sodium hydroxide tank requirements and insert TSP requirements:

OLD TS 3.3.1.3

- b. *The sodium hydroxide (NaOH) tank shall be maintained at 8 ft. ± 6 inches lower than the BWST level as measured by the BWST/NaOH tank differential pressure indicator. The NaOH tank concentration shall be 10.0 ± .5 weight percent (%). Specification 3.3.2.1 applies.*
- c. *All manual valves in the discharge lines of the NaOH tank shall be locked open. Specification 3.3.2.1 applies.*

NEW

3.3.1.3.b *The Reactor Building emergency sump pH control system shall be maintained with ≥ 18,815 lbs and ≤ 28,840 lbs of trisodium phosphate dodecahydrate (TSP). Specification 3.3.2.1 applies.*

- 2.2 Revise TMI Unit 1 TS Section 3.3.2.1 to delete the reference to the NaOH tank on page 3-23, and to read as follows:

"If the CFT boron concentration is outside of limits, or if the TSP baskets contain amounts of TSP outside the limits specified in 3.3.1.3.b, restore the system to operable status within 72 hours. If the system is not restored to meet the requirements of Specification 3.3.1 within 72 hours, the reactor shall be placed in a HOT SHUTDOWN condition within six hours."

- 2.3 Revise TMI Unit 1 TS Table 4.1-1 (page 4-7), item 40, for the BWST/NAOH Differential Pressure Indicator, and item 41, for the Sodium Hydroxide Tank Level Indicator, to delete these line items from the table. Revise Table 4.1-3 (page 4-10), item 10, for the Sodium Hydroxide concentration, to delete this line item from the table.

- 2.4 Revise TMI Unit 1 TS Table 4.1-5 (page 4-10c), System Surveillance Requirements, to add surveillance testing for the TSP buffer and to read as follows:

NEW

<u>Item</u>	<u>Test</u>	<u>Frequency</u>
2. Reactor Building Emergency Sump pH Control System	a. Verify the TSP baskets contain ≥ 18,815 lbs and ≤ 28,840 lbs of TSP.	R
	b. Verify that a sample from the TSP baskets provides adequate pH adjustment of borated water	R

- 2.5 Bases Changes:

The Bases Section 3.3 will be revised to delete discussion of NaOH addition and add the following discussion:

The Reactor Building emergency sump pH control system ensures a sump pH between 7.3 and 8.0 during the recirculation phase of a postulated LOCA. A minimum pH level of 7.3 is required to reduce the potential for chloride induced stress corrosion cracking of austenitic stainless steel and assure the retention of elemental iodine in the recirculating fluid. A maximum pH value of 8.0 minimizes the formation of precipitates that may migrate to the emergency sump and minimizes post-LOCA hydrogen generation. Trisodium phosphate dodecahydrate is used because of the high humidity that may be present in the Reactor Building during normal operation. This form is less likely to absorb large amounts of water from the atmosphere.

All TSP baskets are located outside of the secondary shield wall in the Reactor Building basement (El. 281'-0"). Therefore, the baskets are protected from the effects of credible internal missiles inside the shield wall. The designated TSP basket locations ensure that the baskets are not impacted by the effect of potential LOCA jet impingement forces and pipe whip.

The Bases Section 3.3 (TS page 3-24) will also be revised to state that the iodine removal function of the Reactor Building spray system requires one spray pump and TSP in baskets located in the Reactor Building basement. In addition, Bases Section 4.1 (TS page 4-2b) will be revised to add information related to surveillance testing for the TSP in the baskets.

2.6 Licensing Basis Methodology Change

As part of the proposed buffer change, the UFSAR methodology for calculating the iodine removal coefficients for the Reactor Building spray system is modified to be consistent with NUREG-0800, Standard Review Plan 6.5.2, Revision 4 (March 2007), "Containment Spray as A Fission Product Cleanup System." This methodology is recommended in Regulatory Guide 1.183 (Reference 2), which is applicable to TMI Unit 1 for accident analysis using alternative radiological source terms.

3.0 Background

Under LOCA conditions, a buffering agent must be added to the Reactor Building sump recirculation water to increase the sump solution pH to between 7.3 and 8.0. Buffering agent addition is required to reduce re-evolution of iodine fission products from the sump solution to the containment atmosphere as iodine gas. Thus, pH adjustment is primarily a control measure for offsite and control room doses. Increasing the coolant pH also reduces the corrosion rates of materials in the containment, most notably metal structural members and components. Traditionally, both sodium hydroxide (NaOH) and trisodium phosphate dodecahydrate (TSP) have been used as buffering agents at many plants. NaOH is stored in liquid form in a tank and is fed into the containment spray system post-LOCA. In plant designs that use TSP, the TSP is stored in baskets that become submerged within the containment sump pool (as the post-LOCA water level rises) and release the buffering agent by dissolution.

The present method of buffering the sump water at TMI Unit 1 is through the addition of NaOH to the Reactor Building (RB) spray system. The NaOH solution is stored in the sodium hydroxide tank (BS-T-2) located outside the RB. The tank is isolated from the RB spray system piping by two normally closed motor-operated valves BS-V-2A and 2B. The valves

open on receipt of an engineered safeguards actuation signal, and the NaOH mixes with Borated Water Storage Tank (BWST) injection supply water. The RB spray solution mixes with the spilled reactor coolant from the LOCA and the buffered water makes its way to the emergency sump where it is available for recirculation. In the current design, the buffered water has a pH of at least 8.0 prior to initiating recirculation. However, NRC Standard Review Plan (SRP) 6.5.2, Revision 4 permits the spraying of a boric acid solution during the initial injection phase when the spray solution is being drawn from the borated water storage tank (BWST). The SRP also states that the pH of the spray solution should be adjusted to at least 7.0 by the onset of recirculation.

This TS change will allow the use of TSP, a highly water-soluble basic chemical, to buffer the acidic spray/reactor coolant mixture in the RB emergency sump. This method uses plain boric acid as the spray solution during the post-LOCA injection phase. Other than isolating the NaOH tank and associated recirculation pump from the RB spray system, there are no changes in RB spray system operation required by the use of TSP.

TSP is used as a post-LOCA buffering agent at other stations because of its many favorable characteristics. In particular, it dissolves rapidly and the quantity needed to increase the coolant pH above 7.3 is reasonable. It also has corrosion inhibitor properties beyond its ability to moderate pH. For example, carbon steel corrosion is inhibited through the formation of iron phosphate conversion coatings. Also, aluminum corrosion is inhibited. In the dodecahydrate form, TSP has a good storage life and is readily available.

TSP has been successfully used in a wide variety of applications that are relevant to use in a containment spray solution. The proposed amendment to change the method of pH control will improve personnel safety by eliminating the caustic chemical sodium hydroxide from the RB.

Proposed Design

The Reactor Building emergency sump pH control system will be a passive system using 23 stainless steel storage baskets filled with TSP. No active means of Reactor Building emergency sump pH control are required. TMI Unit 1 has determined by analyses the amount of TSP required to adjust the sump pH to a proposed minimum value of 7.3. These analyses considered a range of quantities for the boric acid and TSP.

The minimum pH is produced by the maximum amount of boric acid and the minimum amount of TSP. Conversely, the maximum pH is produced by the minimum amount of boric acid and the maximum amount of TSP. The proposed TS surveillance requirement of $\geq 18,815$ lbs and $\leq 28,840$ lbs of TSP will result in a pH between 7.3 and 8.0 during the long-term recirculation phase. A maximum pH value of 8.0 minimizes the formation of precipitates that may migrate to the emergency sump and minimizes post-LOCA hydrogen generation.

The sump pH baskets will be located outside of the secondary shield wall in the Reactor Building basement (El. 281'-0"), so that they are in the flow path of the RB spray/reactor coolant mixture flowing to the emergency sump. A total of 23 baskets will be installed to assure that adequate TSP is dissolved in the water, given the flow paths and allowable floor space in the Reactor Building. The sides of the baskets will be stainless steel mesh screen to allow the spray/reactor coolant mixture to dissolve the TSP. The baskets are designed to

withstand seismic loads. The TSP chemical is technical grade, granular TSP dodecahydrate, which contains 12 waters of hydration and has the chemical formula of $\text{Na}_3\text{PO}_4 \cdot 12\text{H}_2\text{O}$.

4.0 **Technical Analysis**

The following topics associated with the proposed change are discussed further below:

1. Radiological Consequences
2. Chemical effects
3. Corrosion of containment materials
4. Hydrogen generation
5. Environmental qualification (EQ) of equipment
6. TSP basket design and isolation of sodium hydroxide tank
7. UFSAR accident analysis

4.1 Radiological Consequences

4.1.1 Effect of pH Change

The present method of buffer addition is to add NaOH to the RB spray during the emergency core cooling system (ECCS) injection phase of the LOCA. The NaOH is mixed with water from the BWST prior to being sprayed into the containment atmosphere. The proposed change to replace this method with TSP stored in baskets will reduce the rate of buffer addition during the ECCS injection phase. Initially, the RB spray mixture will consist of plain boric acid solution. The spray pH during the injection phase may be as low as 4.6 as documented in Attachment 1 (Calculation No. C-1101-153-E410-036, Revision 0, "Reactor Building Spray pH Prior to the Start of Recirculation Spray"). As indicated in Standard Review Plan (SRP), Section 6.5.2, "Containment Spray as A Fission Product Cleanup System", fresh sprays (i.e., sprays with no dissolved iodine) are effective at scrubbing elemental iodine and thus a spray additive is unnecessary during the initial injection phase when the spray solution is being drawn from the BWST. As described in the SRP, research has shown that elemental iodine can be scrubbed from the atmosphere with borated water, even at low pH. The SRP provides an equation for calculating a first-order removal coefficient that is not dependent on pH.

However, since long-term use of a plain boric acid spray could increase the potential for elemental iodine re-evolution and long-term stress corrosion during the recirculation phase of the LOCA, the equilibrium sump solution pH must be increased. The current licensing basis for TMI Unit 1 credits the Alternative Source Term (AST) with guidance from Regulatory Guide (RG) 1.183 (Reference 2) for calculating radiological dose consequences post-LOCA. The RG 1.183 guidance indicates that if sump pH is above 7.0, then a licensee does not need to evaluate revolatization of iodines for dose consequences. RG 1.183 also recommends an iodine flashing fraction of 10% as applied to Engineered Safety Feature (ESF) recirculation leakage outside primary containment, unless a lower value can be justified. The TMI Unit 1 AST calculations currently justify a calculated iodine flashing fraction of 5% during ESF recirculation for the first 24 hours following a LOCA and 2% for the remainder of the 30-day accident evaluation; however, these values are pH-dependent (Reference Attachment 3). The supporting analysis indicates that use of these values requires that the sump pH be ≥ 7.3 . The NRC accepted use of the 5% and 2% flashing

fraction values in Reference 3. In the current design, use of NaOH injection results in a calculated pH ≥ 8.0 . With the proposed change to TSP, continued use of the 5% and 2% iodine flashing fractions will require that the long-term sump pH be ≥ 7.3 . The TSP baskets will be designed and located with the objective of ensuring rapid dissolution of the TSP. The baskets will be located on the RB floor (El. 281'-0") around the RB, but outside the secondary shield wall. All baskets will be submerged by the post-LOCA flood inventory. There will be a sufficient quantity of TSP to adjust the pH range to ≥ 7.3 to 8.0, as documented in Attachment 2 (Calculation No. C-1101-153-E410-040, Revision 0, "Reactor Building Sump Post-LOCA pH").

4.1.2 Change to UFSAR Methodology for Spray Removal Coefficient

When applying the AST guidance, the chemical forms of radioiodine released to the containment are assumed to be 95% cesium iodide (particulate form), 4.85 percent elemental iodine, and 0.15 percent organic iodide. As part of the proposed change, AmerGen will use the methodology in SRP Section 6.5.2, Revision 4 for calculation of RB spray removal coefficients. The current TMI Unit 1 spray removal coefficients, which are developed in UFSAR Appendix 14B, "Iodine Removal Capabilities of the TMI-1 Reactor Building Spray System," are based on the methodology in ANSI/ANS-56.5-1979, "American National Standard for PWR and BWR Containment Spray System Design Criteria." Separate spray removal coefficients are developed for elemental, organic and particulate forms of iodine. The ANSI formulation for the elemental spray removal coefficient is directly proportional to the iodine partition coefficient, which is a strong function of the spray pH.

Regulatory Guide 1.183 states that the iodine removal models in SRP Section 6.5.2 are acceptable (ANSI/ANS-56.5 was withdrawn in 1993). The formulation for the elemental iodine spray removal coefficient in SRP Section 6.5.2 is independent of spray pH, and results in a larger removal coefficient than that used in the current design basis. For the particulate iodine, the formulation for spray removal coefficient in SRP Section 6.5.2 is essentially the same as currently described in the UFSAR. The SRP also states that no credit should be taken for the removal of organic iodine, which is consistent with the approach used in the current TMI Unit 1 dose calculations, so an organic iodine removal coefficient is not applied.

Calculation C-1101-900-E000-087, Revision 2, "Post-LOCA EAB, LPZ, TSC, and CR Doses Using AST and RG 1.183 Requirements" (provided in Attachment 3) has been prepared to evaluate the proposed change. This calculation uses the NRC sponsored computer code RADTRAD, version 3.03 (Reference 5) and determines the containment spray elemental and particulate (i.e., aerosol) iodine removal coefficients and the elemental iodine decontamination factor in accordance with SRP 6.5.2. It shows that use of the SRP 6.5.2 methodology results in larger elemental iodine removal coefficients than those calculated using ANS-56.5 methodology. This means the elemental iodine is removed faster from the RB atmosphere and, therefore, for a given elemental iodine decontamination factor, there will be less airborne elemental iodine available for leakage from containment atmosphere, as compared to the current calculation. The reduced minimum RB sump water pH (i.e., 7.3 for the proposed change using TSP versus 8.0 for the current design using NaOH) results in a smaller elemental iodine decontamination factor. A smaller elemental iodine decontamination factor means there will be greater residual airborne elemental iodine activity in the containment building atmosphere at the point in the analysis when credit for

RB spray is cut off, as compared to the current calculation. Revision 2 of the calculation includes an adjustment to the assumed RB sprayed volume that is unrelated to the proposed change discussed in this amendment. The combined effect of these calculation changes results in slightly smaller post-LOCA doses to the control room, the Exclusion Area Boundary (EAB), and the Low Population Zone (LPZ), as compared to the current licensing basis values.

The calculated total effective dose equivalent (TEDE) for the control room, EAB, and LPZ are summarized below for the proposed change. The allowable dose limits from 10 CFR 50.67, "Accident Source Term", and the TMI Unit 1 current licensing basis dose analysis results are also provided. All calculated dose consequence results remain below the acceptance criteria of 10 CFR 50.67 and General Design Criterion (GDC) 19.

Large Break Loss-of Coolant Accident (Maximum Hypothetical Accident) TEDE Dose (Rem)			
	Control Room	EAB	LPZ
Current Licensing Basis TEDE Dose	4.75	24.37	7.72
Reanalyzed TEDE Dose Results	4.74	22.58	7.45
Allowable TEDE Dose Limit	5	25	25

4.2 Chemical Effects

As part of a PWR Owners Group chemical effects resolution effort, Westinghouse has evaluated several compounds as potential replacement buffers that would minimize the potential for chemical precipitate formation following a LOCA (Reference 1). The type of thermal insulation used in the TMI Unit 1 RB is predominantly reflective metallic. The NaOH spray, reacting with significant quantities of aluminum in the RB, has the potential to produce chemical precipitates such as sodium aluminum silicate ($\text{NaAlSi}_3\text{O}_8$) and aluminum oxyhydroxide (AlOOH), especially at higher pH values. The Westinghouse study determined that trisodium phosphate in granular form is a good candidate for replacing NaOH in plants, such as TMI Unit 1, that do not generate calcium silicate debris. TSP inhibits aluminum corrosion, which provides an advantage over the present use of NaOH.

Further evaluation of the effect of the proposed buffer change from NaOH to TSP on the TMI Unit 1 resolution of GSI-191 is being addressed separately by AmerGen. As discussed in Reference 4, TMI will validate that adequate margin exists to bound the impact of

chemical effects once the vendors' tests results to quantify chemical debris effect on head loss have been published.

4.3 Corrosion of Containment Materials

NRC Branch Technical Position MTEB 6-1, "pH for Emergency Coolant Water for PWRs", states that in order to reduce the probability of stress-corrosion cracking of austenitic stainless steel components, the pH of the recirculation fluid should have a minimum pH of 7.0. TSP is presently used as a buffering agent in other U.S. PWRs (e.g., Crystal River-3) to establish a post-LOCA sump pH of > 7.0. The application of TSP at TMI Unit 1 will be similar to that of other plants, establishing sump pH of ≥ 7.3 to 8.0. TSP inhibits aluminum corrosion and corrosion to carbon steel is low (Reference 1).

For the proposed change, the pH of the spray solution during the post-LOCA initial injection phase will be acidic. The TMI Unit 1 coatings for the containment liner and concrete have been evaluated for a spray pH of 4.0 with an exposure time of 7.5 hours. The coatings were determined to be acceptable for the proposed change since the exposure is for short duration, the coatings used exhibit satisfactory resistance to chemical exposure from acids, and the primers are protected by the topcoat, so they are not directly exposed to spray.

4.4 Hydrogen Generation

As stated in UFSAR Section 6.5.3, corrosion of zinc and aluminum are accounted for in the production of hydrogen post-LOCA. However, research has shown that aluminum corrosion from exposure to water at higher pH values generates more hydrogen than water at lower pH values. The production of hydrogen by aluminum corrosion is based on aluminum surface area within the containment and the surface corrosion rate according to the reaction: $2\text{Al} + 3\text{H}_2\text{O} \rightarrow 3\text{H}_2 + \text{Al}_2\text{O}_3$. One pound of aluminum reacts to produce 19.93 scf H_2 . The TSP chemical buffers the RB emergency sump water at a lower pH range than the current NaOH buffer (7.3 to 8.0 for TSP versus 8.0 to 11.0 for NaOH). As such, the post-LOCA hydrogen generation rate will not increase as a result of the proposed change.

4.5 Environmental Qualification (EQ) of Equipment

The EQ Program for TMI Unit 1 meets the requirements of 10 CFR 50.49. All equipment within the scope of this program has been evaluated for compliance with either the Division of Operating Reactors (DOR) Guidelines or 10 CFR 50.49 with guidance from Regulatory Guide 1.89.

In the current design, the RB spray solution is alkaline due to the direct addition of sodium hydroxide to the boric acid solution from the BWST. Equipment in the EQ program is qualified for a chemical spray with a pH range of 8.0 - 11.0. In the proposed design, the spray solution during the injection mode will be acidic, consisting of spray solution from the BWST, only. The EQ components in the RB needed to function after RB spray has initiated were identified and evaluated for the effects of an acidic RB spray. DOR Guidelines allow environmental qualification by analysis. These components were evaluated for an exposure to RB spray with a pH of 4.0 for an initial 7.5 hours. This pH value bounds the minimum pH determined in the calculation provided in Attachment 1. After 7.5 hours, an alkaline spray is assumed, with a long term pH of 7.3 - 8.0. The age sensitive materials (non-metallic parts)

covered under the requirements of 10 CFR 50.49, and the metallic parts of these EQ components (such as metal housings of components) were evaluated for this spray condition. Evaluation was based on utilizing and analyzing available industry and technical research data. This included chemical resistance of materials, effect of aging on materials that will be exposed to spray, and the duration of acidic and alkaline spray. The analysis concluded that all EQ equipment located inside the RB is qualified for the revised RB spray chemical conditions resulting from the proposed change.

4.6 TSP Basket Design and Isolation of Sodium Hydroxide Tank

TSP Basket Design

The TSP baskets will be fabricated with stainless steel framing and wire mesh. Based on the structural analysis, the baskets will not need anchorage to the basement floor to prevent movement or overturning. This will reduce the radiation exposure during installation and will allow for temporary relocation, as needed, during refueling outages without the need to remove anchor bolts. The baskets will be located outside of the secondary shield wall in the RB basement (El. 281'-0"). Therefore, the baskets will be protected from the effects of credible internal missiles generated by failure of reactor coolant piping or control rod drive equipment components that are located inside of the shield wall. The basket locations will be selected such that they are not adversely impacted by the effects of LOCA jet impingement forces and pipe whip.

The proposed installation of TSP baskets will result in a minor decrease in net free volume of the RB. This decrease has been reviewed for effects on the RB peak pressure analysis and the post-LOCA radiological analysis. The proposed change will not affect the calculated post-accident RB peak pressure or the RB pressure profile used for EQ analysis, as reported in UFSAR Appendix 6B. Also, the radiological analysis is unaffected. The volume of steel added by the proposed basket design has been assessed for the effect on maximum RB post-LOCA flood level, and there is no adverse impact.

NaOH Tank Isolation

As discussed above, NaOH tank BS-T-2 will be isolated from the RB spray system. The proposed change will not alter the seismic classification of the RB spray system or the NaOH tank (both Seismic Class I). The existing ESAS signal circuitry and electrical power will be removed from the NaOH tank isolation valves, and at least one manual valve in each supply train will be locked closed providing permanent isolation of the NaOH tank. The existing TS associated with the NaOH tank instruments will no longer be required and are deleted in the proposed change.

Isolation of the tank will remove the NaOH tank liquid inventory (1451 ft³) from the post-accident emergency sump water inventory. This results in a minor reduction in calculated RB post-LOCA flood level. The reduced level has been evaluated for impact on net positive suction head (NPSH) available for the ECCS pumps. Sufficient NPSH margin will remain available.

4.7 UFSAR Accident Analysis

UFSAR Section 14.2.2.3 discusses the large break LOCA analysis and Section 14.2.2.3.4 discusses the consequences of LOCA radioactive releases to the environment. The NRC-sponsored computer code RADTRAD, is used to determine TEDE doses at the EAB, LPZ and in the control room. UFSAR Appendix 14B, "Iodine Removal Capabilities of the TMI-1 Reactor Building Spray System", discusses the RB spray effectiveness in reducing airborne iodine. Appendix 14C, "Evaluation of Accident Dose", discusses radioactive dose analysis and results based on implementation of AST per Regulatory Guide 1.183 and 10 CFR 50.67.

As discussed in Section 4.1 above, the post-LOCA radiological consequences and the methodology for calculating RB spray removal coefficients are revised for the proposed change.

Summary

The proposed change to remove the existing RB emergency sump pH buffer (sodium hydroxide) and replace it with TSP will reduce precipitate formation in the RB post-LOCA, while maintaining an acceptable long-term sump pH range for minimizing radioactivity releases and corrosion of the RB materials. The proposed change to the methodology for calculating RB spray removal coefficients will be consistent with SRP 6.5.2. Evaluation has determined that the proposed change will not have adverse effects on the radiological analysis, hydrogen generation, or the functional capability of Reactor Building systems, structures, and components following a postulated LOCA.

5.0 Regulatory Analysis

5.1 No Significant Hazards Consideration

AmerGen has evaluated whether or not a significant hazards consideration is involved with the proposed amendment by focusing on the three standards set forth in 10 CFR 50.92, "Issuance of amendment," as discussed below:

1. Does the proposed amendment involve a significant increase in the probability or consequences of an accident previously evaluated?

Response: No.

For the proposed change, trisodium phosphate dodecahydrate (TSP) will be used as a buffer for post-accident pH control and will replace the existing buffer. The buffer material and means of storage and delivery are not initiators for previously analyzed accidents. The accident mitigation function of the replacement buffer is the same as the existing buffer. The pH of the water in the emergency sump following a loss of coolant accident (LOCA) will be adjusted with TSP rather than sodium hydroxide (NaOH) to be within a range that will reduce the potential for elemental iodine re-evolution and long-term stress corrosion during the recirculation mode of emergency core cooling system (ECCS) operation. In addition, the replacement buffer will reduce the formation of

precipitates resulting from chemical reactions between the recirculating spray solution and insulating materials in the Reactor Building (RB), thus reducing the potential for ECCS emergency sump intake screen blockage. The proposed sump pH range will not result in an increase in post-LOCA hydrogen generation. The proposed isolation of the sodium hydroxide tank, and the installation of TSP in baskets has been evaluated for impacts on accident effects and the safety functions of required systems, structures, and components (SSCs). The RB emergency sump solution pH profile resulting from the proposed change has been evaluated for impacts on environmental qualification of SSCs. The accident mitigation functions of required SSCs will not be affected by the proposed change.

As a part of the proposed change, the radiological consequences of a postulated LOCA have been reanalyzed using Standard Review Plan (SRP) 6.5.2, "Containment Spray as a Fission Product Cleanup System", and the Alternate Source Term (AST) guidance in Regulatory Guide 1.183. The analysis considered the use of a plain borated water spray during the post-LOCA injection phase and a spray mixture with a minimum pH of 7.3 during the recirculation phase. The results of the reanalysis show that the consequences of the accident are not increased. The calculated doses at the Exclusion Area Boundary, Low Population Zone boundary, and in the Control Room remain within 10 CFR 50.67 AST dose limits.

Therefore, the proposed change does not involve a significant increase in the probability or consequences of an accident previously evaluated.

2. Does the proposed amendment create the possibility of a new or different kind of accident from any accident previously evaluated?

Response: No.

The proposed change will replace the existing spray additive design using sodium hydroxide solution stored in a tank with TSP contained in baskets located on the floor of the RB. The TSP storage and delivery method is passive. The baskets are constructed of stainless steel to resist corrosion and are seismically qualified. The existing sodium hydroxide tank, associated piping, and valves will no longer be used and will be permanently isolated, but their structural integrity will be maintained. The RB spray system will perform the same function and operate in the same manner for the proposed change; however, the sodium hydroxide tank isolation valves will no longer be required to open on an engineered safeguards actuation signal. The accident mitigation function of TSP will be the same as the existing buffer, sodium hydroxide. The TSP will act as a buffering agent to raise the pH of the water in the containment emergency sump to greater than 7.3 for long-term post-LOCA RB spray recirculation. The SSCs required for post-LOCA accident mitigation have been evaluated for the proposed change including the effects of the modified emergency sump solution pH profile. No new accident scenarios, failure mechanisms, or single failures are introduced as a result of the proposed change.

Therefore, the proposed change does not create the possibility of a new or different kind of accident from any accident previously evaluated.

3. Does the proposed amendment involve a significant reduction in a margin of safety?

Response: No.

The proposed change from sodium hydroxide to TSP will not reduce the effectiveness of the post-LOCA pH control buffer. The TSP will buffer the sump water sufficiently to assure that the resulting mixture pH is ≥ 7.3 and ≤ 8.0 . This pH level will be effective in reducing the potential for iodine re-evolution during the recirculation phase of a LOCA, preventing long-term stress corrosion cracking of austenitic stainless steel, and minimizing post-LOCA hydrogen generation. In addition, the use of TSP will reduce the formation of precipitates resulting from chemical reactions between the recirculating spray solution and insulating materials in the RB, thus reducing the potential for ECCS emergency sump intake screen blockage. The proposed use of SRP 6.5.2 guidance, which is an NRC-approved methodology, for post-LOCA dose calculations does not result in a reduction in a margin of safety. The proposed change does not adversely affect the performance of SSCs required for post-LOCA mitigation, and does not affect an operating parameter or setpoint used in the accident analyses to establish a margin of safety. Also, the proposed change does not affect a margin of safety associated with containment functional performance.

Therefore, the proposed change does not involve a significant reduction in any margin of safety.

Based on the above, AmerGen concludes that the proposed amendment to change the Reactor Building emergency sump pH control method from NaOH to TSP, and to revise the related TS, presents no significant hazards consideration under the standards set forth in 10 CFR 50.92(c), and, accordingly, a finding of "no significant hazards consideration" is justified.

5.2 Applicable Regulatory Requirements/Criteria

Design Criteria

TMI Unit 1 has been designed and constructed taking into consideration the general criteria for nuclear power plant construction permits as listed in proposed Atomic Energy Commission General Design Criteria, dated July 1967.

Criterion 11 – "Control Room." The proposed amendment complies with this criterion. Criterion 11 states that the facility shall be provided with a Control Room from which actions to maintain safe operational status of the plant can be controlled. Adequate radiation protection shall be provided to permit access, even under accident conditions, to equipment in the Control Room or other areas as necessary to shut down and maintain safe control of the facility without radiation exposure of personnel in excess of 10CFR20 limits. It shall be possible to shut the reactor down and maintain it in a safe condition if access to the Control Room is lost due to fire or other cause.

Calculated post-accident control room doses for the proposed change are within

10 CFR 50.67 limits, which is applicable to the alternative source term methodology implemented for TMI Unit 1.

Criterion 37 – “Engineered Safety Features Basis for Design.” The proposed amendment complies with this criterion. Criterion 37 states that engineered safety features shall be provided in the facility to back up the safety provided by the core design, the reactor coolant pressure boundary, and their protection systems. As a minimum, such engineered safety features shall be designed to cope with any size reactor coolant pressure boundary break up to and including the circumferential rupture of any pipe in that boundary assuming unobstructed discharge from both ends.

The required capability to control the pH of the post-LOCA emergency sump fluid is maintained. The small reduction in RB post-LOCA cooling water volume due to isolation of the NaOH tank will not affect the design capability of engineered safety features.

Criterion 38 – “Reliability and Testability of Engineered Safety Features.” The proposed amendment complies with this criterion. Criterion 38 states that all engineered safety features shall be designed to provide high functional reliability and ready testability. In determining the suitability of a facility for a proposed site, the degree of reliance upon and acceptance of the inherent and engineered safety afforded by the systems, including engineered safety features, will be influenced by the known and the demonstrated performance capability and reliability of the systems, and by the extent to which the operability of such systems can be tested and inspected where appropriate during the life of the plant.

The proposed pH control system design using TSP is passive and no single failures are assumed. The capability for testing and inspection is provided.

Criterion 41 – “Engineered Safety Features Performance Capability.” The proposed amendment complies with this criterion. Criterion 41 states that engineered safety features, such as emergency core cooling and containment heat removal systems, shall provide sufficient performance capability to accommodate partial loss of installed capacity and still fulfill the required safety function. As a minimum, each engineered safety feature shall provide this required safety function assuming a failure of a single active component.

The proposed pH control system design using TSP is passive, so no new single failures are assumed. In addition, the quantity of TSP in the storage baskets accounts for material densification and all baskets will be submerged by the post-LOCA sump fluid. Therefore, partial loss of installed capacity is not considered a credible failure.

Criterion 42 – “Engineered Safety Features Components Capability.” The proposed amendment complies with this criterion. Criterion 42 states that engineered safety features shall be designed so that the capability of each component and system to perform its required function is not impaired by the effects of a loss of coolant accident.

All TSP baskets will be submerged by the post-LOCA sump fluid, which will promote dissolution of the TSP. The effects of a LOCA will not impair the TSP function.

Criterion 52 – “Containment Heat Removal Systems.” The proposed amendment complies with this criterion. Criterion 52 states that where active heat removal systems are needed under accident conditions to prevent exceeding containment design pressure, at least two systems, preferably of different principles, each with full capacity, shall be provided.

The proposed change to add TSP in baskets, and isolate the NaOH tank, will not affect the RB cooling design function of the RB spray system.

Criterion 70 – “Control of Releases of Radioactivity to the Environment.” The proposed amendment complies with this criterion. Criterion 70 states that the facility design shall include those means necessary to maintain control over the plant radioactive effluents, whether gaseous, liquid, or solid. Appropriate holdup capacity shall be provided for retention of gaseous, liquid, or solid effluent, particularly where unfavorable environmental conditions can be expected to require operational limitations upon the release of radioactivity effluents to the environment. In all cases, the design for radioactivity control shall be justified: (1) on the basis of 10CFR20 requirements for normal operations and for any transient situation that might reasonably be anticipated to occur, and (2) on the basis of 10 CFR 100 dosage level guidelines for potential reactor accidents of exceedingly low probability of occurrence except that reduction of the recommended dosage levels may be required where high population densities or very large cities can be affected by the radioactive effluents.

TMI Unit 1 calculated post-LOCA doses for the proposed change comply with 10 CFR 50.67, “Accident Source Term.”

Regulations

10 CFR 50.36, “Technical Specifications.” The proposed change is consistent with the criteria specified in 10 CFR 50.36(c)(2)(ii) for inclusion of items in TS.

10 CFR 50.44, “Combustible Gas Control for Nuclear Power Reactors.” As discussed in Section 4.4, the proposed change will not result in an increase in post-LOCA hydrogen generation.

10 CFR 50.49, “Environmental Qualification of Electric Equipment Important to Safety for Nuclear Power Plants.” As described in Section 4.5, environmentally qualified components were analyzed and the evaluation concluded that all components analyzed will be capable of performing their safety functions under the short-term and long-term post-accident Reactor Building pH conditions.

10 CFR 50.67, “Accident Source Term.” As described in Section 4.1, with the proposed buffer change from sodium hydroxide to trisodium phosphate, and the proposed change to the UFSAR methodology for calculation of the spray removal coefficient, the post-LOCA offsite radiological consequences at the Exclusion Area Boundary (EAB), the Low Population Zone (LPZ) boundary, and the control room, comply with 10 CFR 50.67.

Other Guidance

Standard Review Plan (SRP) 6.5.2, "Containment Spray as a Fission Product Cleanup System." As described in Section 4.1, the proposed change uses the methodology of SRP 6.5.2 to replace the current UFSAR methodology for calculating the post-LOCA spray removal coefficients.

Summary

AmerGen has determined that the proposed change does not require any exemptions or relief from regulatory requirements and does not affect conformance with any General Design Criteria.

5.3 Precedent

Emergency sump pH control using TSP stored in baskets is presently implemented at a number of operating plants, including Crystal River Unit 3, which is a B&W NSSS plant of the same vintage as TMI Unit 1. Other plants that use TSP include: Palisades, Palo Verde Units 1, 2, and 3, Waterford-3, Arkansas Nuclear One Unit 2, and Millstone Unit 2.

Conclusion

In conclusion, based on the considerations discussed above, (1) there is reasonable assurance that the health and safety of the public will not be endangered by operation in the proposed manner, (2) such activities will be conducted in compliance with the Commission's regulations, and (3) the issuance of the amendment will not be inimical to the common defense and security or to the health and safety of the public.

6.0 Environmental Consideration

A review has determined that the proposed amendment would change a requirement with respect to installation or use of a facility component located within the restricted area, as defined in 10 CFR 20, or would change an inspection or surveillance requirement. However, the proposed amendment does not involve (i) a significant hazards consideration, (ii) a significant change in the types or significant increase in the amounts of any effluent that may be released offsite, or (iii) a significant increase in individual or cumulative occupational radiation exposure. Accordingly, the proposed amendment meets the eligibility criterion for categorical exclusion set forth in 10 CFR 51.22(c)(9). Therefore, pursuant to 10 CFR 51.22(b), no environmental impact statement or environmental assessment need be prepared in connection with the proposed amendment.

7.0 References

1. WCAP 16596-NP, Revision 0, "Evaluation of Alternative Emergency Core Cooling Buffering Agents," July 2006.
2. Regulatory Guide 1.183, Alternative Radiological Source Terms for Evaluating Design Basis Accidents at Nuclear Power Reactors, July 2000.

3. TMI Unit 1 License Amendment No. 235, Engineered Safety Feature (ESF) Systems Leakage Outside Containment, dated September 19, 2001.
4. Letter from P. B. Cowan (Exelon Generation Company, LLC and AmerGen Energy Company, LLC) to U. S. Nuclear Regulatory Commission, Exelon/AmerGen Response to NRC Generic Letter 2004-02, "Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized-Water Reactors," dated September 1, 2005.
5. "RADTRAD, A Simplified Model for RADionuclide Transport and Removal And Dose Estimation," S&L Computer Program Number 03.7.720-3.03, Version 3.03.
6. NUREG-0800, Standard Review Plan 6.5.2, Revision 4 (March 2007), "Containment Spray as A Fission Product Cleanup System."

Attachment 1

AmerGen/Exelon Calculation C-1101-153-E410-036, Revision 0,
"Reactor Building Spray pH Prior to the Start of Recirculation Spray"

Design Analysis (Major Revision)		Last Page No. ° Att. B pg. 4	
Analysis No.: ¹ C-1101-153-E410-036		Revision: ² 0	
Title: ³ Reactor Building Spray pH Prior to the Start of Recirculation Spray			
EC/ECR No.: ⁴ 07-00174		Revision: ⁵ 0	
Station(s): ⁷	TMI	Component(s): ¹⁴	
Unit No.: ⁸	1	N/A	
Discipline: ⁹	TEDM		
Descrip. Code/Keyword: ¹⁰	spray, pH, TSP		
Safety/QA Class: ¹¹	Q, SAFETY RELATED		
System Code: ¹²	210, 214		
Structure: ¹³	Reactor Building		
CONTROLLED DOCUMENT REFERENCES ¹⁵			
Document No.:	From/To	Document No.:	From/To
TMI Unit 1 Technical Specifications, Section 3.3, Amendment 227	From	TMI-Unit 1 FSAR, Table 6.2-1, Update 18	From
Calc. C-1101-823-5450-001, TMI-1 LBLOCA EQ Temperature Profile Using the GOTHIC Computer Code, Rev. 9	From		
Is this Design Analysis Safeguards Information? ¹⁶ Yes <input type="checkbox"/> No <input checked="" type="checkbox"/> If yes, see SY-AA-101-106			
Does this Design Analysis contain Unverified Assumptions? ¹⁷ Yes <input type="checkbox"/> No <input checked="" type="checkbox"/> If yes, AT/AR#:			
This Design Analysis SUPERCEDES: ¹⁸ C-1101-210-5340-005, Rev. 0 and C-1101-210-5340-007, Rev. 1 in part.			
Note: The remainder of these calculations will be superseded by the original revision of C-1101-153-E410-040, being issued in conjunction with this calculation, per ECR 07-00174. The approval of ECR 07-00174, and its associated calculations, will supersede C-1101-210-5340-005, revision 0, and C-1101-210-5340-007, Revision 1, in their entirety.			
Description of Revision (list affected pages for partials): ¹⁹ TMI-1 is changing the buffering chemical for the post-LOCA reactor building sump water from sodium hydroxide (NaOH) to trisodium phosphate dodecahydrate (TSP) via ECR 07-00174. This modification will result in a change in the reactor building spray pH prior to recirculation spray.			
This original (Revision 0) calculation indicates the range of pH in the reactor building prior to recirculation spray is limited to 4.6 pH minimum. It is recommended in the calculation that a conservative estimate of 4 pH be utilized where low pH is a limiting factor and pH 5.5 where high pH is a limiting factor, to provide reasonable margin.			
Preparer: ²⁰	Robert A. Nelson (S&L)	<i>Robert Nelson</i>	6/9/07
	Print Name	Sign Name	Date
Method of Review: ²¹	Detailed Review X	Alternate Calculations (attached) <input type="checkbox"/>	Testing <input type="checkbox"/>
Reviewer: ²²	Jeri C. Penrose (S&L)	<i>Jeri C Penrose</i>	6/10/07
	Print Name	Sign Name	Date
Review Notes: ²³	Independent review <input checked="" type="checkbox"/>	Peer review <input type="checkbox"/>	
(For External Analyses Only)			
External Approver: ²⁴	M. W. IDELL (S&L)	<i>M. W. Idell</i>	6/11/07
	Print Name	Sign Name	Date
Exelon Reviewer: ²⁵	W. E. Rapisarda	<i>Wendy Rapisarda</i>	6/11/07
	Print Name	Sign Name	Date
Independent 3 rd Party Review Req'd? ²⁶ Yes <input type="checkbox"/> No <input checked="" type="checkbox"/>			
Exelon Approver: ²⁷	P. A. Bennett	<i>P. A. Bennett</i>	2/11/07
	Print Name	Sign Name	Date

**Owners Acceptance Review Checklist for External
Design Analysis**

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Revision 6
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Design Analysis No. C-1101-153-E410-036 Rev. 0

	Yes	No	N/A
1. Do assumptions have sufficient rationale?	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
2. Are assumptions compatible with the way the plant is operated and with the licensing basis?	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
3. Do the design inputs have sufficient rationale?	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
4. Are design inputs correct and reasonable?	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
5. Are design inputs compatible with the way the plant is operated and with the licensing basis?	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
6. Are engineering Judgments clearly documented and justified?	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
7. Are Engineering Judgments compatible with the way the plant is operated and with the licensing basis?	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
8. Do the results and conclusions satisfy the purpose and objective of the design analysis?	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
9. Are the results and conclusions compatible with the way the plant is operated and with the licensing basis?	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
10. Does the design analysis include the applicable design basis documentation?	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
11. Have any limitations on the use of the results been identified and transmitted to the appropriate organizations?	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
12. Are there any unverified assumptions?	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
13. Do all unverified assumptions have a tracking and closure mechanism in place?	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
14. Have all affected design analyses been documented on the Affected Documents List (ADL) for the associated Configuration Change.	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
15. Do the sources of inputs and analyses methodology used meet current technical requirements and regulatory commitments? (If the input sources or analysis methodology are based on an out-of-date methodology or code, additional reconciliation may be required if the site has since committed to a more recent code)	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
16. Have vendor supporting technical documents and references (including GE DRFs) been reviewed when necessary?	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Exelon Reviewer: Windy Rapsonda Date: 06/11/07

TITLE Reactor Building Spray pH Prior to the Start of Recirculation Spray

REV	SUMMARY OF CHANGE	APPROVAL	DATE
0	Initial Issue	OAR: W. Rapnanda Mgr: A. Bennett	06/11/07 06/11/07

CALCULATION SHEET

AmerGen

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Attachment A, US Borax Inc., Optibor Product Profile, PP1-AB12-646-US

Attachment B, Cover and pages 8-10 from NUREG/CR-6875, Boric Acid Corrosion of Light Water Reactor Pressure Vessel Materials, July 2005

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1. PURPOSE:

TMI-1 is changing the buffering chemical for the post-LOCA reactor building sump water from sodium hydroxide (NaOH) to trisodium phosphate dodecahydrate (TSP) via ECR 07-00174 [Ref. 4.5].

Historically, when NaOH was utilized as a chemical buffer, it was mixed with a borated water solution from the Borated Water Storage Tank (BWST) upstream of the reactor building spray headers. This spray would be injected into the Reactor Building via the spray headers, prior to recirculation. Limits on the contained water volume, NaOH concentration, and Boron concentration, were established in Technical Specification 3.3 [Ref. 4.1] to ensure a pH value between 8.0 and 11.0 in the solution spray within containment after a Design Basis Accident (DBA).

Utilizing TSP as a buffering chemical prohibits the introduction of the chemical buffer prior to reactor building spray. The TSP is located in baskets on the reactor building floor (elevation 281'). As the sprayed borated water solution from the BWST accumulates in the reactor building, prior to start of recirculation, the TSP buffer will dissolve and begin mixing. Prior to dissolution and mixing of the TSP, the spray will consist of the borated water solution from the BWST. Following the start of recirculation spray, and continual mixing, the pH of the reactor building spray will be the same as the pH of the water in the reactor building sump.

This calculation is a determination of the anticipated range of the Reactor Building spray pH prior to recirculation.

2. INPUTS:

The specific inputs used for this calculation is summarized in this section.

- | | | | |
|-----|----------------------------------|-----------|-----------------------------|
| 2.1 | Minimum BWST boron concentration | 2,500 ppm | [Ref. 4.1, Section 3.3.1.1] |
| 2.2 | Maximum BWST boron concentration | 2,800 ppm | [Ref. 4.2, Table 6.2-1] |

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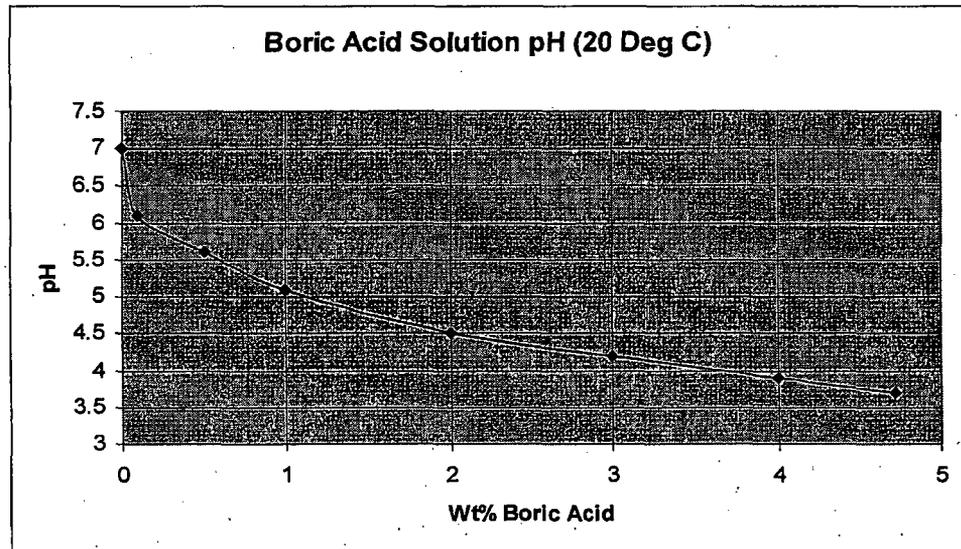
Subject: Reactor Building Spray pH Prior to the Start of Recirculation Spray	Calculation No. C-1101-153-E410-036	Rev. No. 0	System Nos. 210	Sheet 6 of 19
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2.3 Boric Acid Solution

[Ref. 4.3]

Concentration vs. pH	
% H ₃ BO ₃ by weight of solution	pH at 20 °C (68 °F)
0.1	6.1
0.5	5.6
1	5.1
2	4.5
3	4.2
4	3.9
4.72	3.7

(saturated)



2.4 Molecular weight of boron 10.811 g/g-mole [Ref. 4.4]

2.5 Molecular weight of boric acid (H₃BO₃) 61.833 g/g-mole [Ref. 4.4]

2.7 Maximum Containment temperature 138 °C (280 °F) [Ref. 4.7, Sheet 25, Figure 3]

2.8 Minimum BWST temperature 4.4 °C (40 °F) [Ref. 4.1]

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3. ASSUMPTIONS:

- 3.1 The maximum in the containment is 138 °C (280 °F) [Ref. 4.7, Sheet 25, Figure 3]. It is assumed that the spray fluid temperature is in equilibrium with the containment temperature.
- 3.2 The pH of boric acid solutions increases very slightly, ~0.1 pH unit between ~30 and ~95 °C (86 and 203 °F), with increasing temperatures [Ref. 4.6, pg 9-10, Figure 9.a]. It is assumed that this trend continues for the range of temperatures of interest ~4.4 to 138 °C (40 to 280 °F).
- 3.3 For the purposes of this calculation it is assumed that (a) the pH of boric acid solutions at various concentrations that was provided by a major boric acid supplier (US Borax, Inc.) [Ref. 4.3] are accurate and (b) interpolation between the data points is sufficiently accurate for the concentration range of interest (i.e., the difference between different interpolation methods, such as logarithmic and polynomial, is small compared to other potential variations including the range of concentrations in the BWST).

4. REFERENCES:

- 4.1 TMI Unit 1 Technical Specifications, Section 3.3
- 4.2 TMI-Unit 1 FSAR, Update 18
- 4.3 US Borax Inc., Optibor Product Profile, PP1-AB12-646-US (see Attachment A)
- 4.4 CRC Handbook of Chemistry and Physics, 78th Ed.
- 4.5 AmerGen ECR No. 07-00174, RB Buffer Replacement Modification (NaOH to TSP)
- 4.6 NUREG/CR-6875, Boric Acid Corrosion of Light Water Reactor Pressure Vessel Materials, July 2005 (see Attachment B)
- 4.7 Calc. C-1101-823-5450-001, TMI-1 LBLOCA EQ Temperature Profile Using the GOTHIC Computer Code, Rev. 9

5. COMPUTER PROGRAMS:

None.

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6. METHOD OF ANALYSIS:

The method for performing this calculation is to use the design basis range of boron concentrations in the BWST to determine the pH of the boric acid solution. This will involve the following steps:

1. Calculate the conversion between ppm boron and wt% boric acid.
2. Calculate the boric acid concentrations associated with the upper and lower boron concentrations in the BWST.
3. Determine the pH of the boric acid solutions associated with the upper and lower boron concentrations in the BWST based on published data of the concentration and temperature dependence of the pH of boric acid solution.

7. NUMERICAL ANALYSIS:

1. Calculate the conversion between ppm boron and wt% boric acid.

$$wt\% \text{ boric acid} = X \text{ ppm boron} \times \left(\frac{100 \text{ wt}\%}{1,000,000 \text{ ppm}} \right) \times \left(\frac{61.833 \text{ g / mole boric acid}}{10.811 \text{ g / mole boron}} \right)$$

or

$$wt\% \text{ boric acid} = \frac{X \text{ ppm boron}}{1749 \text{ ppm boron}}$$

2. Convert BWST boron concentrations in ppm to wt% boric acid.

- a. Upper concentration limit

$$\frac{2,800 \text{ ppm Boron}}{1,749 \text{ ppm Boron}} = 1.60 \text{ wt}\% \text{ Boric Acid}$$

- b. Lower concentration limit

$$\frac{2,500 \text{ ppm Boron}}{1,749 \text{ ppm Boron}} = 1.43 \text{ wt}\% \text{ Boric Acid}$$

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3. Estimate the pH of the boric acid solutions at 20°C (68 °F):

The boric acid concentration in BWST is between 1 and 2 wt%. Estimate the pH at the intermediate concentrations using a Lagrange Interpolation polynomial for 3 points. The Lagrange Interpolation polynomial is based on the following boric acid concentration and pH values from Section 2.3:

% H ₃ BO ₃ by weight of solution	pH at 20 °C (68 °F)
1	5.1
2	4.5
3	4.2

$$\text{pH} = 6.0 - 1.05 \times \text{wt}\% + 0.15 \times \text{wt}\%^2$$

- a. Upper concentration limit (minimum pH)

$$\text{pH} = 6.0 - 1.05 \times 1.60 + 0.15 \times 1.60^2 = 4.70$$

- b. Lower concentration limit (maximum pH)

$$\text{pH} = 6.0 - 1.05 \times 1.43 + 0.15 \times 1.43^2 = 4.81$$

4. Estimate the pH of the boric acid solutions at lower and higher temperatures.

The maximum temperature inside the reactor building following LOCA is 138 °C (280 °F) [See Input 2.7 and Assumption 3.1]. The minimum BWST temperature is 4.4 °C (40 °F) [See Input 2.8].

Based on information provided in NUREG/CR-6875 (Figure 9.a) the pH of boric acid solutions are not change significantly with changes in temperature. This figure is a plot of the pH of a room temperature saturated boric acid solution between ~ 30 °C and ~95 °C (86 and 203 °F). It shows that the pH is increases by ~ 0.1 over the ~65 °C (~30 °C and ~95 °C) range for an air purged solution. Other sections of this report suggest that this trend is consistent for higher temperatures (e.g., Figure 44) indicated that the corrosion rate of steel decreases as the temperature increases from ~ 100 to ~ 250 °C (212 and 480 °F).

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AmerGen

Subject: Reactor Building Spray pH Prior to the Start of Recirculation Spray	Calculation No. C-1101-153-E410-036	Rev. No. 0	System Nos. 210	Sheet 10 of 19
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To conservatively account for temperature variations, the pH will be reduced by 0.1 for the lower temperature (4.4 °C) and the pH will be increased by 0.2 for the higher temperature (138 °C).

- a. Upper concentration limit (minimum pH) and low temperature

$$\text{pH} = 4.70 - 0.1 = 4.6$$

- b. Upper concentration limit (minimum pH) and high temperature

$$\text{pH} = 4.70 + 0.2 = 4.9$$

- c. Lower concentration limit (maximum pH) and low temperature

$$\text{pH} = 4.81 - 0.1 = 4.7$$

- d. Lower concentration limit (maximum pH) and high temperature

$$\text{pH} = 4.81 + 0.2 = 5.0$$

8. RESULTS:

The pH of the Containment Building spray prior to recirculation spray will be the pH of the water from the BWST. The pH of the water in the BWST depends on the boric acid concentration in the water.

The design basis range of the BWST boron and boric acid concentration is:

Boron Concentration (ppm)	Boric Acid Concentration (wt%)	pH at 20 °C (68 °F)	pH at 4.4 °C (40 °F)	pH at 138 °C (280 °F)
2,500	1.43	4.81	4.7	5.0
2,800	1.60	4.70	4.6	4.9

At higher temperatures (during the first several hours following the LOCA), the pH may be slightly greater (i.e., closer to neutral).

CALCULATION SHEET

AmerGen

Subject: Reactor Building Spray pH Prior to the Start of Recirculation Spray	Calculation No. C-1101-153-E410-036	Rev. No. 0	System Nos. 210	Sheet 11 of 19
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9. CONCLUSIONS:

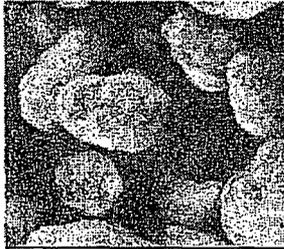
The pH of the Containment Building Spray prior to Recirculation Spray will be between 4.6 and 5.0.

For analyses where a low pH is a limiting factor (e.g., Equipment Qualification) a pH of 4 should be used to provide a reasonable margin. For analyses where a high pH is a limiting factor (e.g., Chemical Effects) a pH of 5.5 should be used to provide a reasonable margin.

10. ATTACHMENTS:

Attachment A, US Borax Inc., Optibor Product Profile, PP1-AB12-646-US.
(4 pages)

Attachment B, Cover and pages 8-10 from NUREG/CR-6875, Boric Acid Corrosion of Light Water Reactor Pressure Vessel Materials, July 2005 (4 pages)



20 MULE TEAM

Optibor®

Boric Acids

Product Profile

H₃BO₃
Orthoboric Acid
CAS/TCNA Number 10043-35-3

Technical Grade:
Granular and Powder

National Formulary (NF):
Granular and Powder

Special Quality (SQ):
Granular

Optibor Boric Acids are a pure, multifunctional source of boric oxide (B₂O₃). Apart from borax pentahydrate, they are the most widely used industrial borate.

Optibor Boric Acids (H₃BO₃) are theoretically composed of boric oxide and water. Crystalline in composition, white in appearance, they can be used as granules or as a powder. Both forms are stable under normal conditions, free-flowing, and easily handled by means of air or mechanical conveying. In solution, they are mildly acidic.

Glass Type	Thermal Expansion	Melting Temperature	Melting Rate	Glass Viscosity	Surface Tension	Chemical Resistance
Textile Fiber Glass (E Glass)		✓	✓	✓	✓	
Borosilicate Glass	✓	✓	✓	✓	✓	✓
Glazes and Enamels	✓	✓	✓	✓	✓	✓

Applications and Benefits

Glass and glass fiber

B₂O₃ is both a flux and a network former; it assists the melt and influences the final product properties. In fiber glass, for example, it reduces melting temperatures and helps the fiberizing process. Generally, B₂O₃ lowers viscosity, controls thermal expansion, inhibits devitrification, increases durability and chemical resistance, and reduces susceptibility to mechanical or thermal shock.

Optibor Boric Acids may be used in combination with a sodium borate (borax pentahydrate or anhydrous borax) in order to adjust the sodium to boron ratio in glasses which require low sodium levels. This is important in borosilicate glass where B₂O₃ provides essential fluxing properties at low sodium and high alumina levels.

Frits, glazes, and enamels

For the glassy surfaces of ceramics and enamels boric oxide acts as both network former and flux. It initiates glass formation (at low temperatures), ensures 'thermal fit' between glaze and body, reduces viscosity and surface tension, increases refractive index, enhances strength, durability and scratch resistance, and facilitates lead-free formulations. High boron frits mature rapidly, improve the speed at which smooth, even glaze surfaces develop, and provide good bases for coloring oxides.

Optibor Boric Acids are used as the B₂O₃ source in the formulation of fast fire frits for tiles because of their requirement for low sodium levels.

Flame retardancy

Incorporated into cellulose materials, borates change the oxidation reactions and promote the formation of 'char', thereby inhibiting combustion. Optibor Boric Acids, alone or in combination with borax, are particularly effective in reducing the flammability of cellulose insulation, wood composites, and the cotton batting used in mattresses.



Optibor Product Profile

Metallurgy

Optibor Boric Acids prevent the oxidation of metal surfaces in welding, brazing, or soldering. They are also used as a source of boron for strengthening metal alloys and steel.

Corrosion inhibition

Optibor Boric Acids are incorporated in many aqueous and non-aqueous systems requiring corrosion inhibition, lubrication or thermal oxidative stabilization. *Optibor* Boric Acids find use in the manufacture of lubricants, brake fluids, metalworking fluids, water treatment chemicals, and fuel additives.

Adhesives

As part of the starch adhesive formulation for corrugated paper and paperboard, and as a peptizing agent in the manufacture of casein-based and dextrin-based adhesives, *Optibor* Boric Acids greatly improve the tack and green strength of the adhesive by crosslinking conjugated hydroxyl groups.

Personal care products

NF grade *Optibor* Boric Acid finds applications in cosmetics, toiletries and pharmaceuticals. It is used in conjunction with sodium borates for pH buffering, and as a crosslinking agent to emulsify waxes and other paraffins.

Nuclear energy

Being a highly effective absorber of thermal neutrons, the boron-10 isotope is essential to the safety and control systems of nuclear power stations. *Optibor* SQ Boric Acid is made for the nuclear industry, and can be isotopically enriched to increase the available proportion of boron-10.

Chemical reactions

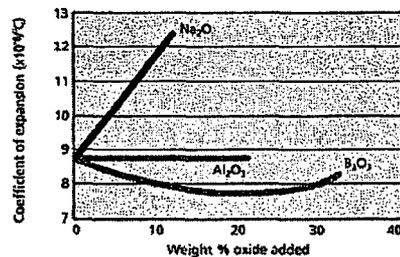
In the manufacturing of nylon intermediates, *Optibor* Boric Acids catalyzes the oxidation of hydrocarbons and increases the yield of alcohols by forming esters that prevent further oxidation of hydroxyl groups to ketones and carboxylic acids.

They are also used in preparing various important industrial products such as boron halides, borohydride, fluoborates, metallic borates, borate esters, and boron containing ceramics.

Some other applications

- | | |
|-------------------------------------|--------------------------|
| Dye stabilization | Paints |
| Electroplating | Sand-casting (magnesium) |
| Electrolytic capacitors | Textile finishing |
| Leather processing
and finishing | |

Effect of B_2O_3 on glass expansion



Reduction in linear coefficient of expansion in glass when silica is replaced proportionately by boric acid. This facilitates "thermal fit" in ceramic glazes and heat resistance in borosilicate glass. From *Glass* by Horst Scholze 1991

Optibor Product Profile

Chemical and Physical Properties

When heated above 100°C (212°F) in the open, *Optibor Boric Acids* gradually lose water first changing to metaboric acid, HBO₂, of which three monotropic forms exist. These have melting points respectively of 176°C (348.8°F), 201°C (393.8°F), and 236°C (456.8°F). Dehydration stops at the composition HBO₂ unless the time of heating is extended or the temperature raised above 150°C (302°F). On continued heating and at higher temperatures all water is removed leaving the anhydrous oxide, B₂O₃, the crystalline form of which melts at 450°C (842°F). The *amorphous* form has no definite melting point, softening at about 325°C (617°F) and becoming fully fluid at about 500°C (932°F).

Stability

Optibor Boric acids are a stable crystalline product that does not change chemically under normal storage conditions. Wide fluctuations in temperature and humidity can cause recrystallisation at particle contact points, resulting in caking. Care should therefore be taken to avoid such fluctuations during storage of the product. Also, it is, of course, essential to maintain the integrity of the packaging.

Characteristics

Molecular Weight	61.83
Specific Gravity	1.51
Melting point	171°C (340°F)
Heat of Solution (absorbed) @18°C	164.19 J/kg (157 BTU/lb)

Solubility in water

Temp °C (°F)	Boric acid % by weight in saturated solution
0 (32)	2.52
5 (42)	2.98
10 (50)	3.49
20 (68)	4.72
25 (77)	5.46
30 (86)	6.23
35 (95)	7.12
40 (104)	8.08
45 (113)	9.12
50 (122)	10.27
55 (131)	11.55
60 (140)	12.97
65 (149)	14.42
70 (158)	15.75
80 (176)	19.10
85 (185)	21.01
90 (194)	23.27
95 (203)	25.22
100 (212)	27.53
103.3 (217.9)*	29.27

*Boiling point of solution

Optibor Product Profile

Solubility in other solvents

Organic Solvent	Temp °C (°F)	Boric acid % by weight in saturated solution
Glycerol (98.5%)	20 (68)	19.90
Glycerol (86.5%)	20 (68)	21.10
Ethylene glycol	25 (77)	13.60
Diethylene glycol	25 (77)	13.60
Ethyl acetate	25 (77)	1.50
Acetone	25 (77)	0.60
Glacial acetic acid	30 (86)	6.30
Methanol	25 (77)	22.66
Ethanol	25 (77)	11.96
1-Propanol	25 (77)	7.34
2-Methyl-1-propanol	25 (77)	5.32
3-Methyl-1-butanol	25 (77)	4.36

Hydrogen ion concentration

Aqueous solutions of *Optibor* Boric Acids are mildly acidic, the pH decreasing with increasing concentration.

%H ₃ BO ₃ by weight of solution	pH @ 20°C (68°F)
0.1	6.1
0.5	5.6
1.0	5.1
2.0	4.5
3.0	4.2
4.0	3.9
4.72 (saturated)	3.7

Notice:

Before using these products, please read the Product Specifications, the Safety Data Sheets and any other applicable product literature.

The descriptions of potential uses for these products are provided only by way of example. The products are not intended or recommended for any unlawful or prohibited use including, without limitation, any use that would constitute infringement of any applicable patents. Nor is it intended or recommended that the products be used for any described purposes without verification by the user of the products' safety and efficacy for such purposes, as well as ensuring compliance with all applicable laws, regulations and registration requirements. Suggestions for use of these products are based on data believed to be reliable. The seller shall have no liability resulting from misuse of the products and provides no guarantee, whether expressed or implied, as to the results obtained if the products are not used in accordance with directions or safe practices. The buyer assumes all responsibility, including any injury or damage, resulting from misuse of the product, whether used alone or in combination with other materials. THE SELLER MAKES NO EXPRESS OR IMPLIED WARRANTIES OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE. THE SELLER SHALL HAVE NO LIABILITY FOR CONSEQUENTIAL DAMAGES.

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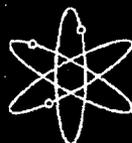
www.borax.com

PP-1481-646/01
2 of 4

NUREG/CR-6875
ANL-04/08



Boric Acid Corrosion of Light Water Reactor Pressure Vessel Materials



Argonne National Laboratory



**U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Washington, DC 20555-0001**



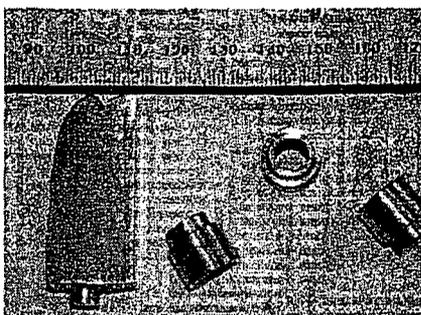


Figure 6.
Ring samples fabricated from the Type 308 SMA
weld overlay.

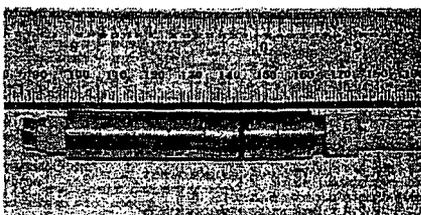


Figure 7.
Assembled set of ring samples of A533-Gr-B
low-alloy steel and Type 308-SS SMA weld
overlay for corrosion/wastage tests.

2.2 Test Environments

The various test environments simulate the postulated conditions in the RPV head/nozzle crevice. The environment in the crevice between the RPV head and the Alloy 600 penetration above the J-groove weld (see Fig. 3) depends on what the leak rate is, and whether the nozzle/head annulus is plugged or open. The following three environmental conditions have been investigated in the present study: (i) low-temperature ($\approx 95^{\circ}\text{C}$) saturated boric acid solution deaerated and aerated; (ii) high-temperature, high-pressure aqueous environment with a range of boric acid solution concentrations; and (iii) high-temperature ($150\text{--}300^{\circ}\text{C}$) boric acid powder at atmospheric pressure with and without addition of water.

2.2.1 Low-Temperature Saturated Boric Acid Solutions

Near the end of the overall progression of damage, high leak rates through the CRDM cracks provide sufficient cooling of the metal surfaces to allow liquid boric acid solutions to form in the crevice. These solutions will become concentrated in boric acid through boiling and more reactive by infusion of oxygen available directly from the ambient atmosphere.

The solubility of boric acid^{6,7} at temperatures up to 100°C (212°F) is shown in Fig. 8. The solubility increases by a factor of ≈ 8 when temperature is increased from room temperature (RT) to 100°C .

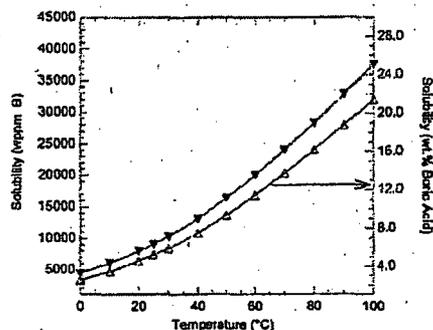


Figure 8.
Solubility of boric acid (wppm B or wt% boric acid) in water vs. temperature (Ref. 6,7).

Figures 9a-d show the measured pH of aerated and deaerated solutions of boric acid at temperatures up to 100°C. The RT-saturated boric acid solution was prepared by adding more than the required amount of boric acid to ultra-high pure (UHP) water at RT and storing it for a few days. The temperature was measured using a three-digit Omega-digital K-type thermometer which was calibrated. The boiling point for the saturated boric acid solution was measured to be ~103°C, but the experiments were conducted at 97.5°C. The 100°C-saturated solution was prepared by adding boric acid to UHP water at 100°C until excess boric acid crystals (or agglomerated powder) were presented in the solution. Boric acid solutions saturated at any other temperature between 25 and 100°C were obtained by cooling the 100°C-saturated solution. The solutions were purged with N₂ plus 1% H₂ gas for deaerated condition and were open to air environment for the aerated condition. The exact concentration of DO, measured by CHEMets ampoules, in the deaerated and aerated solutions was <5 and ~30 ppb, respectively. The DO measurement was made by inserting a glass tip into the solution, opening the tip quickly at temperature to suck the solution, and closing the tip with a rubber cap. The test glass was air cooled to room temperature and DO measured by CHEMets capsules.

The pH of RT-saturated solution of boric acid is plotted as a function of temperature in Fig. 9a. The measured pH of both aerated and deaerated solutions show little or no change with temperature at 25-100°C. The pH of boric acid solutions that were saturated at temperature is plotted as a function of temperature in Fig. 9b and boron concentration in Fig. 9c; the pH decreased with increasing temperature or boron concentration. The pH and solubility of boric acid (wppm B) in water are plotted as a function of inverse temperature in Fig. 9d to gain an understanding of the solution enthalpy for the boric acid in the water and formation energy for the ionization, i.e., $2\text{H}_2\text{O} + \text{B}(\text{OH})_3 = [\text{H}_3\text{O}]^+ + [\text{B}(\text{OH})_4]^-$. The results indicate that the $[\text{B}(\text{OH})_4]^-$ ion is stable in the temperature range 25-100°C, and boric acid may be treated to be totally ionized in solutions that are saturated at test temperature.

Another scenario can also create low-temperature saturated solutions of boric acid. Slow leakage into an open crevice or annulus leaves deposits of boric acid in the crevice and also on top of RPV head surfaces (Fig. 4). The annulus between the nozzle and head is then plugged by deposits and/or corrosion products. In the absence of moisture, these deposits will be relatively dry and a layer of molten HBO₂ and solid B₂O₃ will form next to the hot metal surface. Later moisture may be introduced to this pile of deposits either due to unplugging of

the nozzle/head annulus or leakage from the CRDM nozzle flange or continued leakage through the crack. The heat of evaporation will provide cooling and, if the rate at which moisture is added to the pile of deposits is equal to the rate at which moisture evaporates, a concentrated solution of boric acid will form under the pile; the solution temperature may be as high as 150 or 170°C.

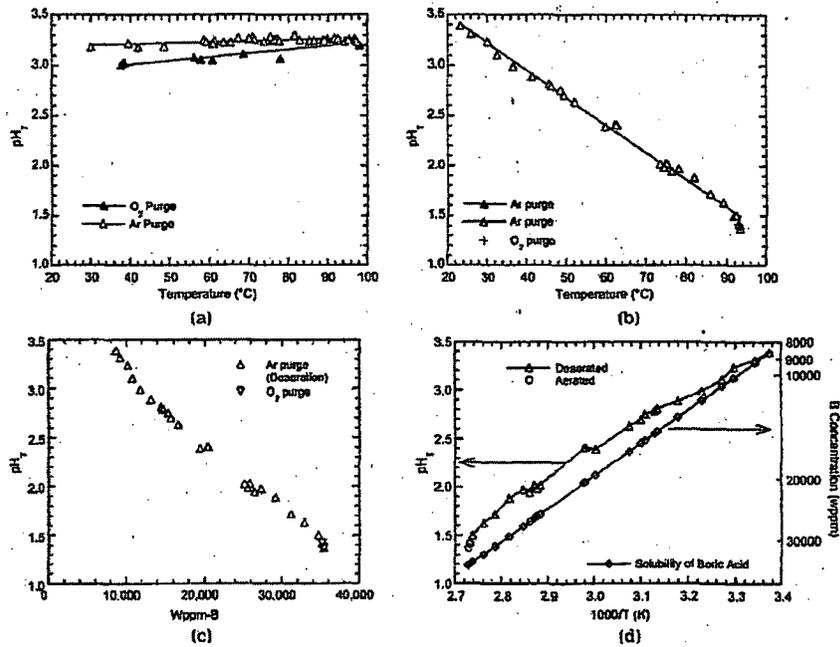


Figure 9. Plots of pH_T vs. temperature in the oxygen and argon gas environments (a) for the RT-saturated solution and (b) the boric acid saturated at T; (c) pH_T vs. wppm B for temperature between RT and 100°C; and (d) pH_T and wppm B vs. inverse temperature.

2.2.2 High-Temperature High-Pressure PWR Environments

Initially, extremely low leak rates result in complete flashing of the coolant to steam. Under this condition, two scenarios are possible based on whether the nozzle/head annulus is plugged by deposits and/or corrosion products or is open to the atmosphere. A plugged nozzle/head annulus will result in a high-temperature, high-pressure aqueous environment in the annulus, i.e., on the OD of the CRDM nozzle. The PWR environment used in the present study consisted of 1000 ppm B, 2 ppm Li, <10 ppb dissolved oxygen (DO), and ≈2 ppm (≈23 cc/kg) dissolved hydrogen. However, depending on how long after the leak that the crevice gets plugged, the concentrations of B and Li in the solution may be significantly greater than the typical values in the PWR environment. Continued leakage into an open crevice will cause a buildup of boric acid deposits in the crevice.

Attachment 2

AmerGen/Exelon Calculation C-1101-153-E410-040, Revision 0,
"Reactor Building Sump Post-LOCA pH and TSP Quantity"

Design Analysis (Major Revision)		Last Page No. 75	
Analysis No.: ¹ C-1101-153-E410-040		Revision: ² 0	
Title: ³ RB Sump Post-LOCA pH and TSP Quantity			
EC/ECR No.: ⁴ 07-00174		Revision: ⁵ 0	
Station(s): ⁷ TMI	Component(s): ¹⁴		
Unit No.: ⁸ 1			
Discipline: ⁹ TEDM			
Descrip. Code/Keyword: ¹⁰ TSP, Sump pH			
Safety/QA Class: ¹¹ Safety Related			
System Code: ¹² 214			
Structure: ¹³ Reactor Building			
CONTROLLED DOCUMENT REFERENCES ¹⁵			
Document No.:	From/To	Document No.:	From/To
TMI Unit 1 UFSAR	From	C-1101-211-E610-060	From
TMI Technical Specification	From	C-1101-212-5450-040	From
SDBD-T1-211	From	C-1101-212-E610-069	From
SDBD-T1-212	From	C-1101-220-E610-054	From
SDBD-T1-213	From	C-1101-823-5450-001	From
C-1101-202-E620-415	From	C-1101-900-E610-070	From
C-1101-210-E610-010	From	Drawing 1E-153-02-011 sht 2	From
Is this Design Analysis Safeguards Information? ¹⁶ Yes <input type="checkbox"/> No <input checked="" type="checkbox"/> If yes, see SY-AA-101-106			
Does this Design Analysis contain Unverified Assumptions? ¹⁷ Yes <input type="checkbox"/> No <input checked="" type="checkbox"/> If yes, AT/AR#:			
This Design Analysis SUPERCEDES: ¹⁸ C-1101-900-E610-070, C-1101-210-E741-012 C-1101-210-5340-005, C-1101-210-5340-007 in their entirety.			
Description of Revision (list affected pages for partials): ¹⁹ TMI-1 is changing the buffering chemical for the post-LOCA reactor building sump water from sodium hydroxide (NaOH) to trisodium phosphate dodecahydrate (TSP) via ECR 07-00174. This modification will result in a change in the reactor building sump pH. <small>WR 06/26/07</small> This Revision 4 calculation indicates the range of pH in the reactor building sump limited to pH 7.3 to pH 8.0. It also indicates the amount of TSP required to achieve this pH range and the required storage volume.			
Preparer: ²⁰	Jeri C. Penrose (S&L) <small>Print Name</small>	<i>Jeri C. Penrose</i> <small>Sign Name</small>	6/26/07 <small>Date</small>
Method of Review: ²¹	Detailed Review <input checked="" type="checkbox"/> Alternate Calculations (attached) <input type="checkbox"/> Testing <input type="checkbox"/>		
Reviewer: ²²	Robert A. Nelson (S&L) <small>Print Name</small>	<i>Robert A. Nelson</i> <small>Sign Name</small>	6/26/07 <small>Date</small>
Review Notes: ²³	Independent review <input checked="" type="checkbox"/> Peer review <input type="checkbox"/>		
<small>(For External Analyses Only)</small>			
External Approver: ²⁴	W.F. Bartling (S&L) <small>Print Name</small>	<i>W.F. Bartling</i> <small>Sign Name</small>	6/26/07 <small>Date</small>
Exelon Reviewer: ²⁵	<i>W.E. Rapinarda</i> <small>Print Name</small>	<i>Wendy Rapinarda</i> <small>Sign Name</small>	6/26/07 <small>Date</small>
Independent 3rd Party Review Req'd? ²⁶	Yes <input type="checkbox"/> No <input checked="" type="checkbox"/>		
Exelon Approver: ²⁷	<i>P.A. Bennett</i> <small>Print Name</small>	<i>P.A. Bennett</i> <small>Sign Name</small>	6/26/07 <small>Date</small>

**Owners Acceptance Review Checklist for
External Design Analysis**

CC-AA-309
Revision 6
Page 17 of 17

Page 1a followed by page 1b

Design Analysis No. C-1101-153-E410-040 **Rev.** 0

	Yes	No	N/A
1. Do assumptions have sufficient rationale?	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
2. Are assumptions compatible with the way the plant is operated and with the licensing basis?	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
3. Do the design inputs have sufficient rationale?	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
4. Are design inputs correct and reasonable?	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
5. Are design inputs compatible with the way the plant is operated and with the licensing basis?	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
6. Are engineering Judgments clearly documented and justified?	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
7. Are Engineering Judgments compatible with the way the plant is operated and with the licensing basis?	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
8. Do the results and conclusions satisfy the purpose and objective of the design analysis?	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
9. Are the results and conclusions compatible with the way the plant is operated and with the licensing basis?	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
10. Does the design analysis include the applicable design basis documentation?	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
11. Have any limitations on the use of the results been identified and transmitted to the appropriate organizations?	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
12. Are there any unverified assumptions?	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
13. Do all unverified assumptions have a tracking and closure mechanism in place?	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
14. Have all affected design analyses been documented on the Affected Documents List (ADL) for the associated Configuration Change.	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
15. Do the sources of inputs and analyses methodology used meet current technical requirements and regulatory commitments? (If the input sources or analysis methodology are based on an out-of-date methodology or code, additional reconciliation may be required if the site has since committed to a more recent code)	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
16. Have vendor supporting technical documents and references (including GE DRFs) been reviewed when necessary?	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Exelon Reviewer:

Wendy Rapraada
Print/Sign

Date:

6/26/07

AmerGen

Calc. No. C-1101-153-E410-040

Sheet 1b

TITLE RB Sump Post-LOCA pH and TSP Quantity

	SUMMARY OF CHANGE	APPROVAL	DATE
0	Initial Issue	WRaprauda AB SA	6/26/07 6/26/07

Subject: RB Sump Post-LOCA pH and TSP Quantity	Calculation No. C-1101-153-E410-040	Rev. No. 0	System Nos. 214	Sheet 2 of 75
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4. REFERENCES:	10
5. COMPUTER PROGRAMS:	12
6. METHOD OF ANALYSIS:	13
7. NUMERIC ANALYSIS:	15
8. RESULTS:	29
9. CONCLUSION:	31
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Attachment B – Spreadsheets (including formulae)	35
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Attachment D – Benchmarks of FORTRAN Programs	53
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Subject: RB Sump Post-LOCA pH and TSP Quantity	Calculation No. C-1101-153-E410-040	Rev. No. 0	System Nos. 214	Sheet 3 of 75
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1.0 PURPOSE

Following a design basis accident, the contents of the Reactor Coolant System (RCS), the Borated Water Storage Tank (BWST), the Core Flood Tanks (CFT), and the Makeup Tank (MUT) mix in the Reactor Building. These waters are borated and generally have an acidic pH. To maintain the pH of the mixture within the required limits, sodium hydroxide has been injected into water pumped from the BWST to raise the pH of borated water collecting in the RB sump.

ECR TM 07-00174 replaces the sodium hydroxide (NaOH) buffer with trisodium phosphate (TSP) buffer. The TSP will be stored in baskets in containment and will dissolve to raise the pH of the borated water mixture.

This calculation determines the minimum required amount of TSP which will raise the pH to a minimum level of 7.3 and the maximum allowable amount of TSP which will limit the sump pH to a maximum level of 8.0.

Subject:	Calculation No.	Rev. No.	System Nos.	Sheet
RB Sump Post-LOCA pH and TSP Quantity	C-1101-153-E410-040	0	214	4 of 75

2.0 INPUTS

- 2.1 The minimum injected BWST volume is 40,684 ft³ (304,344 gal) per calculation C-1101-212-5450-040 (Reference 4.29). The minimum mass of water for this volume is conservatively determined by the maximum BWST temperature of 120° F (SDBD-T1-212 Reference 4.19). The corresponding minimum mass is calculated at 2,510,738 lb in calculation C-1101-210-E610-010 (Reference 4.25) using a specific volume of 0.016204 ft³/lb from the ASME steam tables (Reference 4.7).
- 2.2 The maximum injected BWST volume is 47,983 ft³ (358,936 gal) per calculation C-1101-212-E610-069 (Reference 4.31). This volume is based on an initial tank level of 59.0 ft and a final tank level of 1.354 ft. The initial 59.0-ft tank level is the high level alarm of 58.0 ft plus 1.0 ft instrumentation uncertainty; and it coincides with the bottom of the overflow pipe. The final level is at the bottom of the 24-inch outlet nozzle (2'-4" centerline level). The maximum mass of water for this volume is conservatively determined by the minimum BWST temperature of 40° F required by TMI Tech Spec, Section 3.3.1.1.a (Reference 4.17).
- 2.3 The minimum BWST boron content is 2500 ppm as B as required by the Tech Spec (Reference 4.17). The maximum BWST boron concentration is 2800 ppm as B per the UFSAR (Reference 4.16). The maximum boron content limit of 2800 ppm as B is based on a maximum 2750 ppm measured plus 50 ppm sampling error to prevent boric acid precipitation in the core per calculation C-1101-220-E610-054 (Reference 4.32) and description in the Decay Heat Removal System Design Basis (Reference 4.19).
- 2.4 Reactor coolant (RC) is contained in the reactor, two steam generators (OTSG), pressurizer, four RC pumps, and interconnecting piping. The RC volumes of these components and RC temperatures are listed in the UFSAR (Reference 4.16).

Component RC volumes are as follows:

- Reactor 4058 ft³
- OTSG (ea) 2030 ft³
- Pressurizer 800 ft³
- RC pumps (ea) 56 ft³
- Piping:
 - Reactor inlet 1102 ft³
 - Reactor outlet 979 ft³
 - Pressurizer 20 ft³
 - Pressurizer spray 2 ft³

The Pressurizer contains both RC and steam, and the listed volumes are for RC only. The normal steam volume is 702 ft³ and is in addition to the normal RC volume.

The reactor coolant temperatures are as follows:

- Reactor inlet 554° F
- Reactor outlet 604° F
- Pressurizer 648° F

- 2.5 The normal RC pressure is 2155 psig measured at the reactor outlet pipe per the UFSAR (Reference 4.16).
- 2.6 The boric acid content of RC varies during the fuel cycle and from cycle to cycle. A bounding maximum boric acid content is conservatively taken as 2800 ppm as B based on the BWST maximum boric acid level. This boron content will not be exceeded provided the power rate (2568 MWt) does not increase and the

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cycle duration (2 years) does not increase (See Assumption 3.4). It also conservatively exceeds the refueling boron limit. The minimum RC boron content is 0 ppm as B (Ref. not required).

- 2.7 The two Core Flood Tanks (CFT) contain a volume of $940 \pm 30 \text{ ft}^3$ each. [Tech Spec 3.3.1.2.a] (Reference 4.17). Therefore the maximum CFT volume is 1940 ft^3 and the minimum CFT volume is 1820 ft^3 .
- 2.8 The CFT normal operating temperature is 90° F per UFSAR Table 6.1-1 (Reference 4.16)
- 2.9 The CFT boric acid content is required to be a minimum of 2270 ppm as B by the Tech Spec [TS 3.3.1.2.b] (Reference 4.17). The maximum CFT boric acid content is limited to 2850 by the Operating Procedure chemistry requirements (Reference 4.20).
- 2.10 The volume of the Makeup Tank is calculated to be 574 ft^3 in calculation C-1101-211-E610-060 (Reference 4.27).
- 2.11 The Makeup Tank normal operating temperature is 120° F [SDBD-T1-211] (Reference 4.18)
- 2.12 The Makeup Tank system (MUT) mirrors the RC system and has the same chemistry. The maximum boric acid content is 2800 ppm as B consistent with Input 2.6. The minimum boric acid is 0 ppm as B.
- 2.13 The bounding maximum RB sump temperature is 280° F based on the EQ temperature profile in the Gothic LB LOCA calculation C-1101-823-5450-001 (Reference 4.33). A bounding minimum RB sump temperature of 40° F is used based on the minimum BWST temperature of 40° F consistent with Input 2.2.
- 2.14 The Reactor Building containment has an inside diameter of 130 ft and a free volume of $2.126 \times 10^6 \text{ ft}^3$ per UFSAR (Reference 4.16).
- 2.15 Radiation Doses

The specific gamma and beta doses inside containment were not calculated at TMI-1. LOCA radiation conditions were developed based on bounding requirements of DOR Guidelines and NUREG-0588. As a result, radiation doses for equipment qualification are not affected by reload core inventory changes.

The UFSAR (Reference 4.17) establishes radiation service conditions applicable to equipment in the containment vapor space and applicable to equipment submerged in the containment sump fluid. The total gamma dose radiation service condition inside containment is $2 \times 10^7 \text{ Rad}$. The total beta dose radiation service condition inside containment is $2 \times 10^6 \text{ Rad}$. Because beta radiation is non-penetrating, one-half this value or $1 \times 10^6 \text{ Rad}$ will be used for surface exposures to account for self-shielding. These doses are 6-month integrated doses and are conservative for a 30-day exposure in this calculation.

2.16 Electrical Cable Insulation

The total volume of chlorine-bearing electrical cable insulation in containment is 146.5 ft^3 of hypalon per GPUN memo E550-98-055 (Reference 4.36). A copy of this memo was not available, but it is used as input in approved calculation C-1101-900-E610-070 (Reference 4.35) for calculation of hydrochloric acid generation by radiolysis in containment. Calculation C-1101-900-E610-070 is being superseded by this calculation, but the input remains valid.

- 2.17 The core inventory of iodine and cesium is determined in Calculation C-1101-202-E620-415 (Reference 4.24). End-of-Cycle (EOC) conditions produce higher overall iodine and cesium concentrations and were used as bounding in this calculation. The mass of each isotope is tabulated in Tables 1 and 2 in Attachment 1.

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- 2.18 The density of water as a function of temperature is abstracted from the ASME Steam Tables (tabulated in Reference 4.3, p. A-6) and is presented below. These densities are used for linear interpolation in the program TSP.

Temperature °F	Density, ρ_{H_2O} lbm/ft ³	Temperature °F	Density, ρ_{H_2O} lbm/ft ³	Temperature °F	Density, ρ_{H_2O} lbm/ft ³
32	62.414	120	61.713	210	59.862
40	62.426	130	61.550	212	59.812
50	62.410	140	61.376	220	59.613
60	62.371	150	61.188	240	59.081
70	62.305	160	60.994	260	58.517
80	62.220	170	60.787	280	57.924
90	62.116	180	60.569	300	57.307
100	61.996	190	60.343	350	55.586
110	61.862	200	60.107	400	53.648

- 2.19 The molecular weights of species used in this calculation are given below. For the compounds, the molecular weight is the sum of the molecular weights of the individual elements in their respective quantities.

Species	Molecular Weight	Reference
Boron, B	10.81	Ref. 4.1, front cover
Water, H ₂ O	18.02	Ref. 4.1, front cover
Boric Acid, H ₃ BO ₃	61.83	Ref. 4.1, front cover
Technical-grade TSP, Na ₃ PO ₄ ·12H ₂ O·½NaOH	390.12*	Ref. 4.1, front cover

*Consistent with ICL Product Data Sheet provided in Reference 4.38.

- 2.20 The ionic activity product of water, K_w , is as follows (Reference 4.4):

$$pK_w = -\log(K_w) = \frac{4470.99}{T} - 6.0875 + 0.01706 \cdot T$$

where: T = temperature, degrees K

- 2.21 The molal equilibrium quotients for boric acid, $Q_{1,1}$, $Q_{2,1}$, $Q_{3,1}$, and $Q_{4,2}$, are as follows (Reference 4.5):

$$\log(Q_{1,1}) = \frac{1573.21}{T} + 28.6059 + 0.012078 \cdot T - 13.2258 \cdot \log(T) + (0.3250 - 0.00033 \cdot T) \cdot I - 0.0912 \cdot I^{3/2}$$

$$\log(Q_{2,1}) = \frac{2756.1}{T} - 18.966 + 5.835 \cdot \log(T)$$

$$\log(Q_{3,1}) = \frac{3339.5}{T} - 8.084 + 1.497 \cdot \log(T)$$

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$$\log(Q_{4,2}) = \frac{12,820}{T} - 134.56 + 42.105 \cdot \log(T)$$

where: $Q_{x,y}$ = molal equilibrium quotient (see Section 7.7)
 T = Temperature, deg K
 I = Ionic strength

- 2.22 The approximate effective ionic radii of H^+ and OH^- in aqueous solutions at 25°C are presented below (Reference 4.1, Table 5-2, p. 5-5). Ionic radii of other species are not required because activity coefficients are determined for only H^+ , OH^- , $H_2PO_4^-$, HPO_4^{2-} , and PO_4^{3-} in this calculation.

Species	Effective Ionic Radius, Å (Å)
H^+	9.0
OH^-	3.5
$H_2PO_4^-$	4.0
HPO_4^{2-}	4.0
PO_4^{3-}	4.0

- 2.23 The constants A and B for the Extended Debye-Hückel equation are taken from Table 5-3 of Reference 4.1 (p. 5-6) and are given below.

Temperature		Unit Volume of Water		Temperature		Unit Volume of Water	
°C	°F	A	B	°C	°F	A	B
0	32	0.4918	0.3248	55	131	0.5432	0.3358
5	41	0.4952	0.3256	60	140	0.5494	0.3371
10	50	0.4989	0.3264	65	149	0.5558	0.3384
15	59	0.5028	0.3273	70	158	0.5625	0.3397
20	68	0.5070	0.3282	75	167	0.5695	0.3411
25	77	0.5115	0.3291	80	176	0.5767	0.3426
30	86	0.5161	0.3301	85	185	0.5842	0.3440
35	95	0.5211	0.3312	90	194	0.5920	0.3456
40	104	0.5262	0.3323	95	203	0.6001	0.3471
45	113	0.5317	0.3334	100	212	0.6086	0.3488
50	122	0.5373	0.3346				

- 2.24 Mass attenuation coefficients for gamma and beta radiation in air and in Hypalon are taken from NUREG-1081 (Reference 4.9). As described in NUREG-1081, the gamma coefficients are based on the average gamma radiation energy from post-accident fission products of 1.0 MeV and the beta coefficients are based on the maximum beta radiation energy from post-accident fission products of 0.55 MeV.

Mass attenuation coefficients for air are:

$$\mu_{\gamma}/\rho = 0.0636 \text{ cm}^2/\text{g} \text{ for } 1 \text{ MeV gamma radiation}$$

$$\mu_{\beta}/\rho = 33.6 \text{ cm}^2/\text{g} \text{ for maximum beta radiation of } 0.55 \text{ MeV}$$

where: μ = linear attenuation coefficient, cm^{-1}
 ρ = density of air, gram/cm^3

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Mass absorption coefficients for Hypalon electrical cable jacketing (which has carbon as the major ingredient) are:

$$\mu_{\gamma}/\rho = 0.0637 \text{ cm}^2/\text{g} \text{ for } 1 \text{ MeV gamma radiation}$$

$$\mu_{\beta}/\rho = 33.6 \text{ cm}^2/\text{g} \text{ for maximum beta radiation of } 0.55 \text{ MeV}$$

where: μ = linear absorption coefficient, cm^{-1}
 ρ = density of hypalon, gram/cm^3

The density of Hypalon is $1.55 \text{ g}/\text{cm}^3$ per NUREG-1081.

- 2.25 The TSP baskets provided as part of ECR TM 07-00174 are as shown in Drawing 1E-153-02-011 (Reference 4.40). Each basket provides a storage chamber $3'-0" \times 3'-0" \times 3'-0"$ high. The uppermost $2\text{-}\frac{1}{2}"$ is visually obscured by a $2\text{-}\frac{1}{2}"$ square tubular rim, so the usable (visible) storage height is $2\text{-}9\frac{1}{2}"$. Deducting the space occupied by the four $2\text{-}\frac{1}{2}" \times 2\text{-}\frac{1}{2}"$ corner posts and the double $2\text{-}\frac{1}{2}" \times 2\text{-}\frac{1}{2}"$ horizontal brace on each side, each basket contains a net maximum volume of 24.51 ft^3 to the bottom of the top rim. A total of 23 baskets are provided.
- 2.26 The bulk density of granular TSP dodecahydrate is 51 lb per ft^3 as reported by the manufacturer ICL Performance Products (Reference 4.41).

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3.0 ASSUMPTIONS

- 3.1 All species in the containment sump solution are assumed to be in equilibrium. Therefore, the results for the amount of TSP required are based on a steady state analysis.
- 3.2 The density of pure water is used for all solutions analyzed herein. This is considered acceptable and within the accuracy of this calculation as the containment sump solutions analyzed are dilute.
- 3.3 Electrical cable is represented by a single cable construction consistent with the NRC model used in NUREG-1081 (Reference 4.9) and NUREG/CR-5950 (Reference 4.12). The cable is a 0.89-inch diameter single-conductor cable with a 158 mil insulation/jacket thickness. The jacket thickness is 72 mil. The jacket material is Hypalon (chlorine-bearing) and the insulation material is ethylene propylene rubber (EPR) or other non-chlorine bearing material. All cable is assumed to be routed in cable tray because of the large quantity used in this calculation.
- 3.4 The maximum RC boron content varies from fuel cycle to fuel cycle. A bounding value was selected (Input 2.6) assuming the power rate (2568 MWt) does not increase and the cycle duration (2 years) does not increase.

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4.0 REFERENCES

- 4.1 Dean, J. A., Editor, Lange's Handbook of Chemistry, 11th Edition, McGraw-Hill Book Company, New York, NY, 1973. ISBN 0-07-016190-9
- 4.2 Pavlyuk, L. A. and P. A. Kryukov, "Spectrophotometric Determination of the First and Second Ionization Constants of Phosphoric Acid from 25 to 175°C," Institute of Inorganic Chemistry, Novosibirsk, USSR, 1978.
- 4.3 Crane Technical Paper No. 410, "Flow of Fluids through Valves, Fittings, and Pipe," 25th Printing, Stamford, CT, 1991.
- 4.4 Faust, S. D. and O. M. Aly, Chemistry of Natural Waters, Ann Arbor Science Publishers, Inc., 1981.
- 4.5 Mesmer, R. E., C. F. Baes, Jr., and F. H. Sweeton, "Acidity Measurements at Elevated Temperatures. VI. Boric Acid Equilibria," Inorganic Chemistry, Volume 11, Number 3, pp. 537-543, 1972.
- 4.6 Grenthe, I. and Wanner, H, "TBD-2: Guidelines for the Extrapolation to Zero Ionic Strength", AEN-NEA, Issy-lès-Moulineaux, France, (2000)
- 4.7 ASME Steam Tables, 4th Edition, The American Society of Mechanical Engineers, New York, NY, 1979.
- 4.8 NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants", Section 6.5.2, Revision 4
- 4.9 NUREG-1081, Post-Accident Gas Generation from Radiolysis of Organic Materials", published September 1984.
- 4.10 NUREG-1465, "Accident Source Terms for Light-Water Nuclear Power Plants," February 1995.
- 4.11 NUREG/CR-5732 (ORNL/TM-11861), Revision 3, "Iodine Chemical Forms in LWR Severe Accidents," April 1992.
- 4.12 NUREG/CR-5950, "Iodine Evolution and pH Control," December 1992.
- 4.13 U.S. Nuclear Regulatory Commission Regulatory Guide 1.183, Revision 0, "Alternative Radiological Source Terms for Evaluating Design Basis Accidents at Nuclear Power Reactors", dated July 2000
- 4.14 GE Document APED-5398-A, "Summary of Fission Product Yields for U-235, U-238, Pu-239, and Pu-241 at Thermal, Fission Spectrum and 14 MeV Neutron Energies"
- 4.15 Radiological Health Handbook, U.S. Department of Health, Education, and Welfare, Public Health Service, Compiled and Edited by the Bureau of Radiological Health and the Training Institute Environmental Control Administration, Revised Edition, 1970
- 4.16 TMI Unit 1 USFAR
- 4.17 Three Mile Island Technical Specification
- 4.18 SDBD-T1-211, Rev 4, "System Design Basis Document for Makeup and Purification (#211)"
- 4.19 SDBD-T1-212, Rev 4, "System Design Basis Document for Decay Heat Removal System (#212)"

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- 4.20 SDBD-T1-213, Rev 4, "System Design Basis Document for Core Flood System (#213)"
- 4.21 SDBD-T1-214, Rev 4, "System Design Basis Document for Reactor Building Spray System (#214)"
- 4.22 SDBD-T1-220, Rev 4, "System Design Basis Document for Reactor Coolant System (#220)"
- 4.23 C-1101-153-5310-022 Rev 5A, "TMI Unit 1 Reactor Building Maximum Flood Level"
- 4.24 C-1101-202-E620-415 Rev 3, "TMI-1 Isotopic Core Inventory"
- 4.25 C-1101-210-E610-010 Rev 4, "Reactor Building Minimum Level During Recirculation Following LBLOCA"
- 4.26 C-1101-210-E741-012 Rev 1, "Estimated Reactor Building Sump pH Following a LOCA" MHA
- 4.27 C-1101-211-E610-060 Rev 0, "Makeup Tank Volume"
- 4.28 C-1101-212-5360-028 Rev 0, "Water Level Limit in BWST During a OTSG Tube Rupture" "
- 4.29 C-1101-212-5450-040 Rev 2, "BWST Minimum Usable Volume"
- 4.30 C-1101-212-E510-057 Rev 0, "TMI BWST Level Loop Accuracy"
- 4.31 C-1101-212-E610-069 Rev 0, "BWST Maximum Usable Volume"
- 4.32 C-1101-220-E610-054 Rev 1, "Boron Concentration Following a Large Break LOCA"
- 4.33 C-1101-823-5450-001 Rev 9, "TMI-1 LBLOCA EQ Temp Profile Using the GOTHIC Computer Code"
- 4.34 C-1101-900-E000-087, Rev 2, "Post-LOCA EAB, LPZ, TSC, and CR Doses Using AST and RG 1.183 Requirements"
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- 4.36 GPUN Memo E550-98-055, M.G. Acosta to A. Irani "Response to ETTS No. 12256, Chloride Bearing Cables in Reactor Building TMI-1"
- 4.37 C-1101-901-5360-007 Rev 9A, "TMI-1 Hydrogen Generation Inside Containment"
- 4.38 Trisodium Phosphate Crystalline (TSPc) Product Data Sheet, ICL Performance Products LP
- 4.39 Computer Programs
 - 4.39.1 Microsoft Excel 97 SR-2, S&L Program No. 03.2.081-1.0, dated 04/28/1999.
 - 4.39.2 Lahey/Fujitsu FORTRAN 95 – LF95 Version 5.70c, S&L Program No. 03.5.044-5.7c, dated 01/07/2003.
 - 4.39.3 Mathcad 11.2, S&L Program No. 03.7.548-11.2, dated 6/28/2004
- 4.40 Drawing 1E-153-02-011, Sht 2, Rev 0, "Reactor Building/TSP Basket Location and Fabrication"
- 4.41 E-mail from Robert Allison (ICL) to Stephen Eichfeld (S&L), Subject: TSPc bulk density, dated 5/2/200 (included in Attachment F)

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5.0 COMPUTER PROGRAMS

The FORTRAN 95 computer language is utilized to write the computer program TSP. The source code is compiled using the Lahey/Fujitsu FORTRAN 95 compiler, Version 5.7c. The computer program TSP was validated using Mathcad 11.2.

All spreadsheets developed for this calculation are created using Microsoft Excel 97 SR-2. The validation of the spreadsheets is implicit in their detailed review.

These programs were run under the Windows XP Professional Version 2002, SP1 operating system on S&L PC No. ZD2480.

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6.0 METHOD OF ANALYSIS

6.1 Summary

This calculation determines the amount of TSP required to neutralize borated waters in the Reactor Building (RB) containment following a LOCA design basis accident. A required minimum amount of TSP is determined which will raise the pH to a required lower limit over the post-LOCA range of conditions. A limiting maximum amount of TSP is determined which will not exceed a required upper pH limit over the post-LOCA range of conditions.

Following a design basis accident, borated waters from the Reactor Coolant System (RCS), the Borated Water Storage Tanks (BWST), the Core Flood Tanks (CFT), and the Makeup Tank (MUT) mix in the Reactor Building. Failure of the core releases iodine and cesium to containment which form hydriodic acid, cesium hydroxide, and cesium iodide in the sump solution. In addition, nitric acid is contributed to the mixture from radiolysis of air and water and hydrochloric acid is contributed from radiolysis of chlorine-bearing electrical cable insulation. TSP stored in baskets in containment dissolves and contributes trisodium phosphate plus water of hydration and sodium hydroxide impurities to the mixture.

Equilibrium chemistry is computed as a function of TSP addition and as a function of temperature to determine the resulting pH of the combined solution. The required amount of TSP is found by iteratively solving for the amount of TSP necessary to achieve the acceptance criteria pH. These evaluations were based on a steady state analysis of equilibrium conditions for each condition.

6.2 Analytical Methods

Calculation of equilibrium conditions considers the following:

- Borated water mass
- Nitric acid addition
- Hydrochloric acid addition
- Iodine release from core inventory
- Cesium release from core inventory
- Boron speciation
- TSP speciation
- Water dissociation

The total amount of water and boric acid is determined from a mass balance of the RCS, BWST, CFT, and MUT volumes added to containment. Two bounding conditions were determined: the minimum water mass and minimum boric acid content and the maximum water mass and maximum boric acid content. The minimum water mass was determined using the minimum volume and maximum specific volume, while the maximum water mass was determined using the maximum volume and minimum specific volume. The concentration of boric acid for each condition was determined by mass balance.

The generation of nitric acid (HNO_3) is determined following the methodology of NUREG/CR-5950 (Reference 4.12). This method calculates HNO_3 as a function of gamma and beta radiation doses and as a function of the water mass.

The generation of hydrochloric acid (HCl) is determined following the methodology of NUREG-1081 (Reference 4.9) and NUREG/CR-5950 (Reference 4.12). This method calculates HCl as a function of gamma and beta radiation doses and as a function of the mass of chlorine-bearing insulation/jacketing.

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Iodine and cesium are released when the core fails. The fractions of iodine and cesium in the core inventory that are released to containment are determined as discussed in Regulatory Guide 1.183 (Reference 4.13).

In the resulting solutions, boric acid dissociates to form equilibrium amounts of various borate species. Trisodium phosphate also dissociates to form equilibrium amounts of various phosphate species. The speciation of each is a function of equilibrium constants, temperature, ionic strength and pH. Water also dissociates to form H⁺ and OH⁻ as a function of dissociation constant, temperature, and ionic strength.

The overall equilibrium conditions are computed for the mixture and the pH is determined from the equilibrium hydrogen ion concentration. The TSP requirements are found iteratively.

6.3 Acceptance Criteria

1. A minimum sump pH of 7.3 is required to prevent iodine evolution from the sump. This pH value is specified in the Tech Spec (Reference 4.17) and has been updated as a part of ECR TM 07-00174.
2. A maximum sump pH of 8.0 is required to limit chemical effects of materials dissolved in containment which can subsequently collect on the sump strainers. This is a consideration for evaluation of chemical effects as part of GSI-191.

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7.0 NUMERICAL ANALYSIS

7.1 Summary

This analysis determines the mass of trisodium phosphate dodecahydrate (TSP) required to raise the pH of the borated water in the containment sump to within a design range of 7.3 to 8.0 for post-LOCA conditions.

A parametric analysis was performed to determine the required TSP mass as a function of the quantity of borated water in the sump, the boron concentration in the sump, the sump water temperature, and the desired equilibrium pH value. The analysis is performed using equilibrium equations derived in this calculation which were iteratively solved with a computer algorithm, TSP, which has been developed specifically for this purpose.

The detailed analysis is described in subsequent sections.

The pH resulting from dissolution of TSP in borated water was evaluated to determine the minimum amount of TSP required to raise the post-LOCA pH in the containment sump to a minimum of 7.3 and the maximum amount of TSP required to limit the pH to 8.0. This analysis included computation of:

- Borated water mass
- Nitric acid addition from radiolysis
- Hydrochloric acid addition from radiolysis
- Iodine addition from core inventory
- Cesium addition from core inventory
- Boron speciation
- TSP speciation
- Water dissociation
- Equilibrium conditions and pH

The analysis is performed for both the maximum and the minimum quantities of borated water in the sump with corresponding maximum and minimum boron concentrations. The analysis is repeated for equilibrium pH values ranging from 7.0 to 8.5 for sump temperatures between 40°F and 280°F. This pH range encompasses the design range and shows the pH sensitivity to TSP addition.

The equilibrium conditions for the resulting solution were determined as a function of TSP addition and as a function of temperature. These evaluations were based on a steady state analysis of equilibrium conditions for each condition.

7.2 Borated Water

The amounts of borated water and boric acid concentrations are determined as follows.

The minimum boric acid mass and boric acid concentration are determined by the following data (Inputs 2.1 through 2.12). The minimum mass of borated water is **3,148,801 lb** and the boric acid concentration is **2073 ppm** as B based on the total mass of boric acid of 6528 lb as B.

Minimum Volume	Maximum Temperature	Specific Volume	Minimum Mass	Minimum Boric acid
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	<u>ft³</u>	<u>deg F</u>	<u>ft³/lb</u>	<u>lb</u>	<u>ppm as B</u>	<u>lb</u>
BWST	40648	120	0.016204	2508516	2500	6271
Reactor Coolant:						
Reactor	4058	579	0.022609	179486	0	0
OTSG (2)	4060	579	0.022609	179575	0	0
Pressurizer	800	648	0.026552	30130	0	0
RC pumps (4)	224	579	0.022609	9908	0	0
RC piping - inlet	1102	554	0.021692	50802	0	0
RC piping - outlet	979	604	0.023818	41103	0	0
Pressurizer piping	20	648	0.026552	753	0	0
Pressurizer spray piping	2	648	0.026552	75	0	0
Core Flood Tank	1820	90	0.016102	113029	2270	257
Makeup Tank	574	120	0.016204	35423	0	0
TOTALS				3148801.		6528

The maximum boric acid mass and boric acid concentration are determined by the following data (Inputs 2.1 through 2.12). The maximum mass of borated water is **3,643,118 lb** and the boric acid concentration is **2802 ppm as B** based on the total mass of boric acid of 10207 lb as B.

	<u>Minimum Volume</u> <u>ft³</u>	<u>Maximum Temperature</u> <u>deg F</u>	<u>Specific Volume</u> <u>ft³/lb</u>	<u>Minimum Mass</u> <u>lb</u>	<u>Minimum Boric acid</u> <u>ppm as B</u>	<u>lb</u>
BWST	47983	40	0.016019	2995380	2800	8387
Reactor Coolant:						
Reactor	4058	579	0.022609	179486	2800	503
OTSG (2)	4060	579	0.022609	179575	2800	503
Pressurizer	800	648	0.026552	30130	2800	84
RC pumps (4)	224	579	0.022609	9908	2800	28
RC piping - inlet	1102	554	0.021692	50802	2800	142
RC piping - outlet	979	604	0.023818	41103	2800	115
Pressurizer piping	20	648	0.026552	753	2800	2
Pressurizer spray piping	2	648	0.026552	75	2800	0
Core Flood Tank	1940	90	0.016102	120482	2850	343
Makeup Tank	574	120	0.016204	35423	2800	99
TOTALS				3643118		10207

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Nitric acid (HNO_3) is formed by irradiation of air and water in the containment sump. Per Section 2.2.4 of NUREG/CR-5950 (Ref. 4.12), the generation rate of HNO_3 , G, is 0.007 molecules HNO_3 per 100 eV absorbed in the sump. This generation rate converts to 7.3×10^{-6} g-mole/liter per MegaRad as follows:

$$G = \frac{0.007 \text{ molecule}}{100 \text{ eV}} * \frac{\text{mole}}{6.022 \times 10^{23} \text{ molecule}} * \frac{6.241 \times 10^{11} \text{ eV}}{\text{erg}} * \frac{100 \times 10^6 \text{ erg}}{\text{MegaRad g}} * \frac{1000 \text{ g}}{\text{kg}}$$

$$G = 7.3 \times 10^{-6} \text{ g-mole/kg per MegaRad}$$

The 30-day total integrated dose (TID) of radiation in the containment sump is:

$$\begin{aligned} \text{30-day gamma TID} &= 0.2 \times 10^8 \text{ rad} \\ \text{30-day beta TID} &= \frac{1.0 \times 10^8 \text{ rad}}{1.2 \times 10^8 \text{ rad total}} \end{aligned}$$

Although beta radiation has a limited penetration, the beta dose is conservatively applied to the entire mass of water. This accounts for any mixing or spray that could expose waters to beta radiation.

The concentration of HNO_3 in the sump after 30 days is:

$$[\text{HNO}_3] = G * \text{TID} = 8.71 \times 10^{-4} \text{ g-mole per kg water}$$

Because the formation of HNO_3 is dependent on the amount of water that is irradiated, the total mass of HNO_3 is directly proportional to the mass of water. Consequently, the resulting concentration of HNO_3 in the sump after 30 days will be constant and not vary with the mass of water.

For the minimum and maximum amounts of boric acid added to the sump calculated in Section 7.2, the corresponding amounts of HNO_3 added to the sump are 173 lb and 200 lb, respectively.

TSP dodecahydrate contains water of hydration which is released when the TSP dissolves. A small amount of HNO_3 will also be formed from TSP water of hydration and is 3.04×10^{-5} lb HNO_3 per pound of TSP.

7.4 Hydrochloric Acid from Radiolysis

Hydrochloric acid (HCl) is formed by radiolysis of chloride-bearing electrical cable insulation in containment. Hydrochloric acid production was computed using the methodology described in NUREG/CR-5950 (Ref. 4.12) and NUREG-1081 (Ref. 4.9).

There are many sizes of electrical cable in containment ranging from small control cable to large power cable. A cable inventory by size and by weight was not readily available, so a typical cable size is utilized in this calculation as representative of the total combination of cables. A single electrical cable size and construction description from NUREG/CR-5950, Appendix B was used as a representative size for this calculation.

The NUREG/CR-5950 electrical cable description was based on the model developed by the NRC in NUREG-1081. This model utilized a single-conductor power cable with an OD of 2.2608 cm (0.89 in) and with an EPR insulation layer and a Hypalon jacket. The conductor diameter is 1.4580 cm (0.574 inches) and the insulation O.D./jacket I.D. is 1.8948 cm (0.746 inches). These dimensions result in a total insulation/jacket thickness of 0.4014 cm (158 mils). Of this total insulation and jacket thickness, the outer portion that is Hypalon is 72 mil thick.

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The outside cable diameter and jacket thickness used in this calculation are:

- Outside cable diameter, D_o , = 2.2608 cm = 0.89 in
- Jacket thickness, y , = 0.183 cm = 0.072 in

Hydrochloric acid generation in chlorine-bearing material in the cable is determined based on the following equation from Appendix B of NUREG/CR-5950 (Ref. 4.12):

$$R = G * \phi * S * A$$

where: R = HCl production rate

G = radiolysis yield

ϕ = radiation energy flux on the cable jacket

S = cable jacket surface area

A = absorption fraction of energy flux in the cable jacket

The values for each of these parameters used in this calculation are determined in the following paragraphs.

Radiolysis yield, G

Per NUREG/CR-5950 (Ref. 4.12) the G value for Hypalon is 2.115 molecules HCl per 100 eV (in a vacuum). This corresponds to 3.512×10^{-20} g-mole HCl/MeV:

$$G = \frac{2.115 \text{ molecule}}{100 \text{ eV}} * \frac{\text{mole}}{6.022 \times 10^{23} \text{ molecule}} * \frac{1 \times 10^6 \text{ eV}}{\text{MeV}}$$

$$G = 3.512 \times 10^{-20} \text{ g-mole HCl/MeV}$$

Radiation flux at the surface of the cable jacket, ϕ

The exposure of the cable jacket to radiation energy is represented by the energy flux applied to the cable surface (ϕ). The term ϕ is derived in NUREG-1081 (Ref. 4.9) from the radiation source term (energy release per unit volume of containment), diminished by attenuation in air between the source and the cable surface.

In this calculation, input data was available in the form of Total Integrated Dose (TID) instead of the radiation source term. Consequently, an energy flux in containment is determined from the radiation dose (TID) and the mass attenuation coefficient in air.

The TID calculations used as input are conservatively treated as an infinite cloud. For an infinite cloud, the energy absorbed equals the energy emitted so the volumetric energy emission is related to TID by:

$$\frac{E}{V} = \text{TID} * \rho_{\text{air}}$$

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The energy flux at the cable surface is determined by integrating the air-attenuated radiation over the distance from the cable.

The flux at the cable surface is determined in NUREG-1081 to be:

$$\phi = \frac{E}{V} * \frac{1 - e^{(-\mu * r)}}{\mu} = \text{TID} * \rho_{\text{air}} * \frac{1 - e^{(-\mu_{\text{air}} * r)}}{\mu_{\text{air}}}$$

where: ϕ = cumulative radiation flux at cable surface (for 30 days)
TID = 30-day total integrated dose in air
 ρ_{air} = density of air
 μ_{air} = linear attenuation coefficient for air
 r = distance from surface

The linear attenuation coefficient μ for air is determined from the mass attenuation coefficient μ/ρ as discussed in NUREG-1081 (Ref. 4.9):

μ/ρ = constant, k ,

or $\mu = k \rho$

Consistent with treatment as an infinite cloud, the distance r is infinite and the term $e^{(-\mu r)}$ reduces to zero.

Substituting,

$$\phi = \text{TID} * \rho_{\text{air}} * \frac{1 - e^{(-\mu * r)}}{\mu} = \text{TID} * \rho_{\text{air}} * \frac{1 - 0}{k * \rho_{\text{air}}}$$

The air density terms cancel leaving:

$$\phi = \frac{\text{TID}}{k}$$

where: ϕ = cumulative radiation flux at cable surface (30-day)
TID = 30-day total integrated dose
 k = mass attenuation coefficient for air

The TID for gamma radiation and beta radiation are as follows (Input 2.15):

30-day gamma (γ) TID = 2.0×10^7 Rad
30-day beta (β) TID = 1.0×10^8 Rad (includes 50% reduction for self-shielding)

Mass attenuation coefficients for air per NUREG-1081 are:

$\mu_{\gamma}/\rho = 0.0636 \text{ cm}^2/\text{g}$ for 1 MeV gamma radiation (k_{γ})
 $\mu_{\beta}/\rho = 33.6 \text{ cm}^2/\text{g}$ for maximum beta radiation of 0.55 MeV (k_{β})

This leads to a gamma surface flux of:

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$$\phi_{\gamma} = \frac{2.0 \times 10^7 \text{ Rad}}{0.0636 \text{ cm}^2/\text{gram}} * \frac{100 \text{ erg}}{\text{gram Rad}} * \frac{6.2415 \times 10^5 \text{ MeV}}{\text{erg}} = 1.9627 \times 10^{16} \text{ MeV per cm}^2$$

and a beta surface flux of:

$$\phi_{\beta} = \frac{1.0 \times 10^8 \text{ Rad}}{33.6 \text{ cm}^2/\text{gram}} * \frac{100 \text{ erg}}{\text{gram Rad}} * \frac{6.2415 \times 10^5 \text{ MeV}}{\text{erg}} = 1.8576 \times 10^{14} \text{ MeV per cm}^2$$

Surface area of cable jacket, S

The amount of cable insulation in containment subject to radiolysis at TMI is 146.5 ft³ of hypalon (Input 2.16). The insulation is considered to be composed of an ethylene propylene rubber (EPR) insulator with a hypalon jacket based on typical electrical cable construction in NUREG/CR-5950. Hypalon is the portion of insulation which releases HCl during radiolysis.

Using the cable construction and dimensions as described in NUREG/CR-5950, the Hypalon jacket has an outside diameter of 0.89 in and a thickness of 72 mil while the EPR insulation has an outside diameter of 0.746 in and a thickness of 86 mil. The combined jacket and insulation has a thickness of 158 mil.

The density of Hypalon is given in NUREG-1081 as 1.55 g/cm³. This results in a mass of 14,176 lb of Hypalon jacket.

The jacket surface area is determined from the jacket volume and cross-sectional area. The jacket volume is 146.5 ft³ (4148418 cm³). The jacket cross-sectional area based on the 0.89 in (2.2608 cm) OD and 0.746 in (1.8948 cm) ID is 1.19455 cm².

The jacket surface area is:

$$S = \pi D * \text{Length} = \pi D * \frac{\text{Volume}}{\text{jacket x-sectional area}}$$

$$S = \pi * 2.2608 \text{ cm} * \frac{4,148,418 \text{ cm}^3}{1.19455 \text{ cm}^2} = 24,665,500 \text{ cm}^2$$

Hypalon absorption coefficient, A

The absorption fraction of the energy is calculated as follows per Section 4.2 of NUREG-1081 (Ref. 4.9):

$$A = 1 - e^{-\mu y}$$

where: A = fraction of radiation energy absorbed by cable jacket

μ = linear absorption coefficient of cable jacket

y = thickness of cable jacket

Linear absorption coefficients for Hypalon are determined as discussed in NUREG-1081 (Ref. 4.9) using the following mass absorption coefficients:

$$\mu_{\gamma}/\rho = 0.0637 \text{ cm}^2/\text{g} \text{ for gamma radiation in carbon material (e.g. Hypalon)}$$

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$$\mu_p/\rho = 33.6 \text{ cm}^2/\text{g} \text{ for beta radiation}$$

The density of Hypalon is given in NUREG-1081 as 1.55 g/cm^3

This results in the following gamma radiation and beta radiation linear absorption coefficients for Hypalon:

$$\mu_\gamma = 0.0637 \text{ cm}^2/\text{g} \times 1.55 \text{ g/cm}^3 = 0.0987 \text{ cm}^{-1}$$

$$\mu_\beta = 33.6 \text{ cm}^2/\text{g} \times 1.55 \text{ g/cm}^3 = 52.08 \text{ cm}^{-1}$$

Using the jacket thickness of 0.183 cm as determined from cable construction, the absorption coefficient for gamma radiation in hypalon is:

$$A_\gamma = 1 - e^{-\mu_\gamma y} = 1 - e^{-(0.0987 \times 0.183)} = 0.0179$$

And the absorption coefficient for beta radiation in hypalon is:

$$A_\beta = 1 - e^{-\mu_\beta y} = 1 - e^{-(52.08 \times 0.183)} = 0.9999$$

Resulting HCl production rate

These values are substituted in the preceding HCl generation equation:

$$R = G * \phi * S * A$$

The following results are calculated:

HCl production from gamma radiation = 304 g-mole

HCl production from beta radiation = 161 g-mole

Total HCl production = 465 g-mole

7.5 Hydriodic Acid from Core Inventory

Hydriodic acid is formed by the post-LOCA release of elemental iodine (I) and hydrogen iodide (HI) from the reactor core and its absorption in the containment sump water.

Per Regulatory Guide 1.183, Table 2 (Ref. 4.13), 5% of the iodine core inventory is released into containment during the Gap Release Phase and an additional 35% of the iodine core inventory is released into containment during the Early In-Vessel (EIV) Phase. This occurs during the first 1.8 hours of the LOCA. The Gap Release Phase has an onset of 30 seconds and a duration of 30 minutes and is followed by the EIV Phase with a duration of 78 minutes per Table 4 of Regulatory Guide 1.183 (Ref. 4.13). No further iodine is released after the EIV phase, so the total release is the sum of the Gap Release Phase and the EIV Phase

The reactor core inventory of iodine, the Gap Release Phase iodine release, and the EIV Phase iodine release and the total iodine release are determined in Table 1, Core Iodine Inventory Determination, from the activities of iodine radionuclides listed in Input 2.17.

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Per Section 3.5 of Regulatory Guide 1.183 (Ref. 4.13), 95% of the iodine released from the RCS is in the form of cesium iodide, 4.85% is in the form of elemental iodine, and 0.15% is in the form of organic iodide. Section 3.5 of NUREG-1465 (Ref. 4.10) and Section 4.2 of NUREG/CR-5732 (Ref. 4.11) indicate that at least 95% of the iodine entering containment from the RCS is in the form of cesium iodide with no more than 5% as I plus HI. For this calculation, it will be conservatively assumed that the combined I plus HI is the maximum 5% in order to maximize the acid contribution from iodine to the containment sump. The amount of iodine release that forms HI is 3.76 g-mole.

As shown in Table 1 (Attachment A), the core iodine inventory released in containment during the LOCA is 75.22 g-mole. The amount of iodine release that forms cesium iodide is 71.46 g-mole. This compound is a soluble salt and dissolves in the sump to form cesium ions and iodide ions. These ions contribute to the ionic strength of the sump solution. Because activity coefficients of chemical species are functions of ionic strength, cesium iodide influences chemical equilibria. Consequently, cesium iodide is included in the computation of solution ionic strength.

Considering the above, the amount of iodine used in this calculation is **75.22 g-mole** released in containment.

7.6 Cesium Hydroxide from Core Inventory

Cesium hydroxide is formed by the release of cesium from the reactor core and its absorption in the suppression chamber water.

Per Regulatory Guide 1.183, Table 1 (Ref. 4.13), 5% of the cesium core inventory is released into containment during the Gap Release Phase and an additional 25% of the cesium core inventory is released into containment during the Early In-Vessel (EIV) Phase. This occurs during the first 1.8 hours of the LOCA. The Gap Release Phase has an onset of 30 seconds and a duration of 30 minutes and is followed by the EIV phase with a duration of 78 minutes per Table 4 of Regulatory Guide 1.183 (Ref. 4.13).

The reactor core inventory of cesium, the Gap Phase cesium release, and the EIV Phase cesium release are determined in Table 2 (Attachment A), Core Cesium Inventory Determination, from the activities of cesium radionuclides listed in Input 2.17.

As shown in Table 2 (Attachment A), the core cesium inventory released in containment during the LOCA is a total of 677.98 g-mole.

Cesium released in the form of cesium iodide does not contribute to formation of cesium hydroxide. The quantity of cesium iodide is 71.46 g-mole (95% of the molar quantity of iodine released) consistent with the determination of hydriodic acid production (see Section 7.5). The amount of cesium as cesium iodide is subtracted from the cesium release to obtain the quantity of cesium hydroxide in the post-LOCA suppression chamber water. The cesium release that forms cesium hydroxide is 606.52 g-mole.

Cesium iodide is a soluble salt and dissolves in the sump to form cesium ions and iodide ions. These ions contribute to the ionic strength of the sump solution. Because activity coefficients of chemical species are functions of ionic strength, cesium iodide influences chemical equilibria. Consequently, cesium iodide is included in the computation of solution ionic strength.

Considering the above, the amount of cesium used in this calculation is **677.98 g-mole** released in containment.

7.7 Boron Speciation

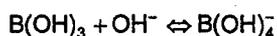
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Specific values of pH, sump temperature, borated water quantity, and boron concentration are considered in this analysis. Based on the borated water quantity and the boron concentration, the total quantity of boric acid in gram-moles per liter, as boron, is calculated.

Based on the total quantity of boron and the temperature-dependent molal equilibrium quotients reported by Mesmer et al. (Ref. 4.5), the equilibrium concentrations of the boron species are determined. The boron species considered in the containment sump solution are $B(OH)_3$ (boric acid, H_3BO_3), $B(OH)_4^-$, $B_2(OH)_7^-$, $B_3(OH)_{10}^-$, and $B_4(OH)_{14}^{2-}$. Reference 4.5 presents two dissociation schemes wherein the only difference is that Scheme I contains the $B_4(OH)_{14}^{2-}$ species and Scheme II contains the $B_5(OH)_{18}^{3-}$ species instead. However, the contributions of the $B_4(OH)_{14}^{2-}$ species and the $B_5(OH)_{18}^{3-}$ species are minimal and are so similar that replacement of one by the other has no significant effect on the formation of quotients of the other species (Ref. 4.5). Therefore, Scheme I with the $B_4(OH)_{14}^{2-}$ species was selected for convenience.

The dissociation equilibrium equations and their molal equilibrium quotients are as follows (Reference 4.5). The species, $B_x(OH)_{3x+y}^y$, are defined by (x,y).

Species (1,1):



$$Q_{1,1} = \frac{[B(OH)_4^-]}{[B(OH)_3] \cdot [OH^-]}$$

$$\log(Q_{1,1}) = \frac{1573.21}{T} + 28.6059 + 0.012078 \cdot T - 13.2258 \cdot \log(T) + (0.3250 - 0.00033 \cdot T) \cdot I - 0.0912 \cdot I^{3/2}$$

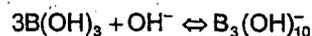
Species (2,1):



$$Q_{2,1} = \frac{[B_2(OH)_7^-]}{[B(OH)_3]^2 \cdot [OH^-]}$$

$$\log(Q_{2,1}) = \frac{2756.1}{T} - 18.966 + 5.835 \cdot \log(T)$$

Species (3,1):



$$Q_{3,1} = \frac{[B_3(OH)_{10}^-]}{[B(OH)_3]^3 \cdot [OH^-]}$$

$$\log(Q_{3,1}) = \frac{3339.5}{T} - 8.084 + 1.497 \cdot \log(T)$$

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Species (4,2):



$$Q_{4,2} = \frac{[\text{B}_4(\text{OH})_{14}^{2-}]}{[\text{B(OH)}_3]^4 \cdot [\text{OH}^-]^2}$$

$$\log(Q_{4,2}) = \frac{12,820}{T} - 134.56 + 42.105 \cdot \log(T)$$

where

[X] concentration of species X [gram-moles/liter]

T solution temperature [K]

$Q_{x,y}$ molal equilibrium quotient

I ionic strength of the solution, defined as follows (Ref. 4.1, p. 5-3):

$$I = 0.5(c_1z_1^2 + c_2z_2^2 + \dots + c_nz_n^2)$$

c_i molarity of species i [gram-moles/liter]

z_i ionic charge of species i

It should be noted that individual activity coefficients are not used to define the molal equilibrium quotients for the boron species since the quotients already account for the individual activity coefficients (Ref. 4.5).

The equilibrium quotient $Q_{1,1}$ for B(OH)_4 includes terms using ionic strength I. Although Q is based on ionic strength derived from molal concentrations, the ionic strength used in this calculation is based on molar solutions. In dilute solutions molality and molarity are approximately equal. This calculation involves only dilute solutions, so molality and molarity are used interchangeably.

To determine the concentrations of all boron species, the total B(OH)_3 concentration is iterated until the total boron concentration is the same when calculated in both of the following manners.

$$[\text{B}] = \frac{m_B}{\text{MW}_B \cdot V_{\text{H}_2\text{O}}}$$

$$[\text{B}] = [\text{B(OH)}_3] + [\text{B(OH)}_4^-] + 2 \cdot [\text{B}_2(\text{OH})_7^-] + 3 \cdot [\text{B}_3(\text{OH})_{10}^-] + 4 \cdot [\text{B}_4(\text{OH})_{14}^{2-}]$$

where

[X] concentration of species X [gram-moles/liter]

m_B mass of boron in containment sump [grams]

$$m_B = m_{\text{H}_2\text{O},1} \cdot \text{ppm}_B / 10^6$$

MW_B molecular weight of boron

$V_{\text{H}_2\text{O}}$ total volume of water in containment sump [liters]

7.8 TSP Phosphate Speciation

Technical grade TSP dodecahydrate, $\text{Na}_3\text{PO}_4 \cdot 12\text{H}_2\text{O} \cdot \frac{1}{4}\text{NaOH}$, is used to raise the pH of borated water in containment. The amount required is iteratively varied to achieve a specified pH.

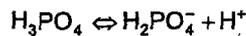
In aqueous solution, the TSP dissociates into phosphoric acid, negatively charged phosphate ions and positively charged sodium ions. Based on the quantity of TSP and the temperature-dependent dissociation

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constants of phosphoric acid reported by Palviyuk et al. (Ref. 4.2), the equilibrium quantities of the dissociation products of phosphoric acid are determined. These products are H_3PO_4 , $H_2PO_4^-$, HPO_4^{2-} , and PO_4^{3-} .

The dissociation equilibrium equations and their dissociation constants are given as follows (Ref. 4.2).

Dissociation Constant K_1 :



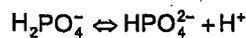
$$K_1 = \frac{\gamma_{H_2PO_4^-} [H_2PO_4^-] \cdot \gamma_{H^+} [H^+]}{\gamma_{H_3PO_4} [H_3PO_4]}$$

where K_1 is defined by (Ref. 4.2):

$$pK_1 = -\log(K_1) = \frac{583.01}{T} - 2.715 + 0.009801 \cdot T$$

Note that the activity of a non-ionic species such as H_3PO_4 in dilute solutions is the same as the molar concentration; thus, the activity coefficient, γ , is unity.

Dissociation Constant K_2 :



$$K_2 = \frac{\gamma_{HPO_4^{2-}} [HPO_4^{2-}] \cdot \gamma_{H^+} [H^+]}{\gamma_{H_2PO_4^-} [H_2PO_4^-]}$$

where K_2 is defined by (Ref. 4.2):

$$pK_2 = -\log(K_2) = \frac{1272.7}{T} - 1.154 + 0.01368 \cdot T$$

Dissociation Constant K_3 :



$$K_3 = \frac{\gamma_{PO_4^{3-}} [PO_4^{3-}] \cdot \gamma_{H^+} [H^+]}{\gamma_{HPO_4^{2-}} [HPO_4^{2-}]}$$

where K_3 is defined by (Ref. 4.1, p. 5-15):

$$pK_3 = -\log(K_3) = 12.36$$

where

[X] concentration of species X [gram-moles/liter]
T solution temperature [K]

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K_i dissociation product constant
 γ_i individual activity coefficient for a species

Since phosphoric acid is a triprotic acid, the concentration of H_3PO_4 can be determined in terms of the three dissociation constants (K_1 , K_2 , K_3) and the total mass of TSP in the containment sump. Once the concentration of H_3PO_4 is known, the concentrations of the other species can be determined. The concentration of TSP in the sump is given by:

$$[TSP] = \frac{m_{TSP}}{MW_{TSP} \cdot V_{H_2O}}$$

$$[TSP] = [H_3PO_4] + [H_2PO_4^-] + [HPO_4^{2-}] + [PO_4^{3-}]$$

Realizing that $[H_2PO_4^-]$ is dependent on $[H_3PO_4]$, that $[HPO_4^{2-}]$ is dependent on $[H_2PO_4^-]$ and that $[PO_4^{3-}]$ is dependent on $[HPO_4^{2-}]$ leads to the following:

$$[TSP] = [H_3PO_4] \cdot \left\{ 1 + \frac{K_1}{\gamma_{H_2PO_4^-} \cdot \gamma_{H^+} \cdot [H^+]} + \frac{K_1 \cdot K_2}{\gamma_{HPO_4^{2-}} \cdot (\gamma_{H^+} \cdot [H^+])^2} + \frac{K_1 \cdot K_2 \cdot K_3}{\gamma_{PO_4^{3-}} \cdot (\gamma_{H^+} \cdot [H^+])^3} \right\}$$

where: $[X]$ concentration of species X [gram-moles/liter]
 m_{TSP} mass of TSP in containment sump [grams]
 MW_{TSP} molecular weight of TSP
 V_{H_2O} total volume of water in containment sump [liters]

Thus, given a mass of TSP and a desired pH, the H_3PO_4 concentration can be determined.

7.9 Water Dissociation

Based on the desired equilibrium pH and the temperature-dependent ionic activity product constant of water, K_w , the equilibrium concentrations of OH^- and H^+ ions in water are determined using the following equations.

$$K_w = \gamma_{H^+} [H^+] \cdot \gamma_{OH^-} [OH^-]$$

where

$$\gamma_{H^+} [H^+] = 10^{-pH}$$

and the ionic activity product constant of water, K_w , is calculated as follows (Ref. 4.4).

$$pK_w = -\log(K_w) = \frac{4470.99}{T} - 6.0875 + 0.01706 \cdot T$$

where

T solution temperature [K]
 γ_i individual activity coefficient for a species

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The individual activity coefficients, γ_i , are estimated using the extended form of the Debye-Hückel theory (Ref. 4.1, p. 5-3):

$$-\log(\gamma_i) = \frac{A \cdot z_i^2 \cdot I^{0.5}}{1 + (B \cdot a_i \cdot I^{0.5})}$$

where

- A temperature dependent constant of the Debye-Hückel equation
- B temperature dependent constant of the Debye-Hückel equation
- z_i ionic charge of species i
- a_i effective ionic radius of species i
- I ionic strength of solution defined as follows (Ref. 4.1, p. 5-3):
 $I = 0.5(C_1 z_1^2 + C_2 z_2^2 + \dots + C_n z_n^2)$

The Debye-Hückel constant "A" is a function of temperature and density; and the Debye-Hückel constant "B" is a function of temperature and water dielectric constant which is itself a function of temperature. Readily available tabulations of the Debye-Hückel constants lie in the temperature range of 32° F to 212° F to cover typical water conditions from freezing to boiling at atmospheric pressure. The functions are well behaved (as shown in a plot of temperature vs. constants included in Attachment F) and the curve fit of the existing data shows excellent agreement with an R2 of 0.99999. Extrapolation from 212° F to the maximum sump temperature of 280° F is reasonable given the excellent data trend.

The effective ionic radii, a_i , used in this analysis were taken at a temperature of 25° C (77° F). The effect of temperature on the approximate ionic radii, and thus on the individual activity coefficients, is considered negligible.

Debye-Huckel constants A and B are recognized to be temperature dependant, but the ionic radius " a_i " is not treated as temperature dependant in the literature. No reference could be found for values of "a" at temperatures other than 25 degrees C. The tabulation of ionic radii used in this calculation were listed at 25 degrees C following conventional practice and are applicable to other temperatures. It is thought that any temperature dependence of the Debye Huckel product $B \cdot a_i$ is lumped in the term B. Therefore the effect of temperature on the approximate ionic radii is considered to be negligible.

7.10 TSP

When TSP dodecahydrate ($\text{Na}_3\text{PO}_4 \cdot 12\text{H}_2\text{O} \cdot \frac{1}{4}\text{NaOH}$) dissolves in the containment sump, it dissociates to form phosphate ions and sodium ions. TSP also contributes additional water to the sump from its water of hydration.

Sodium contributed to the sump from TSP is determined by:

$$[\text{Na}] = \frac{(3 + 0.25) \cdot m_{\text{TSP}}}{\text{MW}_{\text{TSP}} \cdot V_{\text{H}_2\text{O}}}$$

TSP is available as anhydrous trisodium phosphate (i.e., no water of hydration) and as trisodium phosphate dodecahydrate (12 moles of water of hydration). The amount of hydration can vary, and at least one chemical vendor reports the product as a decahydrate (10 moles of water of hydration) based on chemical assays. For this calculation, the fully hydrated TSP dodecahydrate is used.

The mass of water added by TSP is:

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$$m_{H_2O} = \frac{m_{NaTB} \cdot N \cdot MW_{H_2O}}{MW_{NaTB}}$$

where N = the number of moles of water of hydration in the TSP formula

Using the fully hydrated form of TSP (trisodium phosphate dodecahydrate), N = 12.

This water is added to the mass of water initially present in the sump.

7.11. Determination of Equilibrium Conditions

Equilibrium conditions are determined for the mixture of borated water, nitric acid, hydrochloric acid, hydriodic acid, cesium hydroxide, cesium iodide, and TSP. Equilibrium amounts of each chemical species in solution are simultaneously solved as described in preceding sections.

At equilibrium, the concentration of negatively charged species (anions) must equal the concentration of positively charged species (cations) for electroneutrality.

The sum of negative charges is determined from the concentrations of the anions $B(OH)_4^-$, $B_2(OH)_7^-$, $B_3(OH)_{10}^-$, $B_4(OH)_{14}^{2-}$, OH^- , Cl^- , NO_3^- , I^- , $H_2PO_4^-$, HPO_4^{2-} and PO_4^{3-} . The species $B_4(OH)_{14}^{2-}$ and HPO_4^{2-} have charges of negative 2 and PO_4^{3-} has a charge of negative 3, so contributions to the sum of negative charges from these ions are adjusted accordingly.

$$\begin{aligned} \text{Neg Charge} = & [B(OH)_4^-] + [B_2(OH)_7^-] + [B_3(OH)_{10}^-] + 2 \cdot [B_4(OH)_{14}^{2-}] \\ & + [OH^-] + [Cl^-] + [NO_3^-] + [I^-] + [H_2PO_4^-] + 2 \cdot [HPO_4^{2-}] + 3 \cdot [PO_4^{3-}] \end{aligned}$$

The sum of positive charges is determined from the concentrations of H^+ , Na^+ , and Cs^+ .

$$\text{Pos Charge} = [H^+] + [Na^+] + [Cs^+]$$

7.12. Determination of pH

The equilibrium concentrations of borate, phosphate, and hydroxyl anions are functions of pH and temperature. For a given temperature, the pH is iteratively adjusted until electroneutrality is achieved. Electroneutrality is verified when the ratio of positive to negative charges is unity.

The pH resulting from addition of a fixed amount of TSP is determined from the H^+ concentration after electroneutrality is achieved. By definition, pH is:

$$pH = -\log(\gamma_H \cdot [H^+])$$

where: γ_H = activity coefficient for the species H^+

The mass of TSP required to achieve a selected pH is determined by iteratively varying the mass of TSP until the selected pH is achieved.

The computer program TSP-R is used to iteratively solve the simultaneous equilibrium, mass balance, and charge balance equations. This program is capable of determining either the pH resulting from a specified mass of TSP or the mass of TSP required for a specified pH.

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8.0 RESULTS

8.1 Mass of TSP Required for Containment Sump pH Control

The parametric analysis performed in this calculation determines the mass of TSP required for post-LOCA containment sump pH control.

The results of iterative computations are provided in the following tables.

Required Minimum Mass of TSP (lb)

Temperature °F	Maximum Boron and Borated Water 3,643,118 lb water in sump 2802 ppm B (net sump concentration)			
	pH=7.2	pH=7.3	pH=7.4	pH=7.5
40	15431	18815	22710	27096
100	15396	18793	22699	27100
150	14286	17674	21661	26256
200	12322	15496	19357	23954
250	9922	12640	16069	20312
280	8474	10838	13879	17731

Required Maximum Mass of TSP (lb)

Temperature °F	Minimum Boron and Borated Water 3,148,801 lb water in sump 2073 ppm B (net sump concentration)		
	pH=7.9	pH=8.0	pH=8.1
40	24993	28840	32933
100	26467	30674	35240
150	27895	32766	38133
200	27955	33388	39455
250	26130	31810	38253
280	24176	29810	36283

The lower limit for the required TSP mass is the maximum required TSP mass (over the range of temperatures) at the low pH limit (pH = 7.3) for the maximum boron concentration and borated water mass. The lower limit TSP mass requirement of 18,815 lb ensures that the post-LOCA containment sump pH will be at least 7.3, regardless of sump temperature.

Similarly, the upper limit for the required TSP mass is the minimum required TSP mass (over the range of temperatures) at the high pH limit (pH = 8.0) for the minimum boron concentration and borated water mass. The upper limit TSP mass requirement of 28,840 lb ensures that the post-LOCA containment sump pH will not be greater than 8.0, regardless of sump temperature.

- 8.2 Based on the above results, a mass of TSP within the range of **18,815 to 28,840 lb** would maintain the post-LOCA containment sump pH value within the range of 7.3 to 8.0 for both the maximum and minimum quantities of boron and borated water at all sump temperatures. TSP requirements for other pH limits are included in the analysis to indicate the sensitivity of these results.

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This range of required TSP mass is applicable provided the following post-LOCA containment sump conditions are met:

- boron concentration between 2073 ppm and 2802 ppm
- temperature between 40°F and 280°F
- borated water mass between 3,148,801 lbm and 3,643,118 lbm

8.3 Each TSP basket has a usable storage capacity of 24.51 ft³ (Input 2.25). At the bulk density of 51 lb/ft³ (Input 2.26), each basket can contain up to 1250 lb TSP. Installation of 23 baskets (see Input 2.25) is required and will store a total of 28,750 lb when filled to the bottom of the upper rim. This is a filled depth of 33.5 inches. The minimum 18,815 lb TSP will fill the baskets to a depth of 22 inches.

8.4 Because TSP will be provided in the fully hydrated dodecahydrate form, the volume will not expand during storage. Some TSP compaction or dehydration may occur during storage which will decrease the required volume.

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9.0 CONCLUSION

- 9.1 A minimum of 18,815 lb fully-hydrated TSP (dodecahydrate) is required to meet the acceptance criteria of a sump pH of 7.3 minimum. This conclusion applies to the full range of expected sump conditions and temperatures.
- 9.2 A maximum of 28,840 lb fully-hydrated TSP (dodecahydrate) is required to meet the acceptance criteria of a sump pH of 8.0 maximum. This conclusion applies to the full range of expected sump conditions and temperatures.
- 9.3 A total of 23 TSP baskets will contain the required amount of TSP. The baskets have a capacity of 28750 lb TSP when filled to a depth of 33.5 inches (bottom of upper rim). The minimum 18815 lb TSP will fill the baskets to a depth of approximately 22 inches. Because TSP will be provided in the fully hydrated dodecahydrate form, the volume will not expand during storage. Some TSP compaction or dehydration may occur during storage which will decrease the required volume.
- 9.4 The sump pH will be 7.3 to 8.0 using TSP as the buffer.

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Attachment A

Iodine and Cesium Released from Core Inventory

Table 1 – Iodine Core Inventory33

Table 2 – Cesium Core Inventory34

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Table A-1 – Iodine Core Inventory

Neutron Mass	1.008665 amu	(Ref. 1)	Core Inventory Fraction Released in Containment for Halogens
1 Curie	3.70E+10 dis/sec	(Ref. 1)	Gap Release Phase
Avogadro's Number	6.022137E+23 atoms/mole	(Ref. 2)	Early In-Vessel Phase
Fuel Assemblies per Core		(Ref. 3)	Fraction as Csl
			0.05 (Ref. 4, Tbl 2)
			0.35 (Ref. 4, Tbl 2)
			0.95 (ref. 4)

Isotope	Atomic Mass (Ref. 1) [amu]	Half Life (Ref. 2)	t _{1/2} units	Half Life [sec]	Specific Activity [Ci/gm]	BOC Core Inventory (Ref 3) [gm/core]	EOC Core Inventory (Ref 3) [gm/core]	Gap Release [mole]	EIV Release [mole]	Total Release [mole]
I-127	126.904470	stable			stable	2.82E+03	5.24E+03	2.06E+00	1.47E+01	1.68E+01
I-128	127.905838	25.00	m	1,500	5.88E+07	6.00E-03	1.46E-02	5.71E-06	4.00E-05	4.57E-05
I-129	128.904987	1.57E+07	a	4.95E+14	1.77E-04	9.98E+03	1.81E+04	7.02E+00	4.91E+01	5.62E+01
I-130	129.906676	12.36	h	44,496	1.95E+06	5.32E-01	1.24E+00	4.77E-04	3.34E-03	3.82E-03
I-130M	129.906676	9.0	m	540	1.61E+08	2.54E-03	5.95E-03	2.29E-06	1.60E-05	1.83E-05
I-131	130.906127	8.020	d	692,928	1.24E+05	5.33E+02	5.49E+02	2.10E-01	1.47E+00	1.68E+00
I-132	131.907981	2.28	h	8,208	1.04E+07	9.35E+00	9.52E+00	3.61E-03	2.53E-02	2.89E-02
I-133	132.907750	20.8	h	74,880	1.13E+06	1.26E+02	1.23E+02	4.63E-02	3.24E-01	3.70E-01
I-133M	132.907750	9	s	9	9.43E+09	3.97E-04	4.34E-04	1.63E-07	1.14E-06	1.31E-06
I-134	133.909850	52.6	m	3,156	2.67E+07	5.93E+00	5.77E+00	2.15E-03	1.51E-02	1.72E-02
I-134M	133.909850	3.7	m	222	3.79E+08	3.31E-02	3.80E-02	1.42E-05	9.93E-05	1.14E-04
I-135	134.910020	6.57	h	23,652	3.54E+08	3.78E+01	3.73E+01	1.38E-02	9.68E-02	1.11E-01
I-136	135.914740	1.39	m	83	9.95E+08	6.40E-02	6.24E-02	2.30E-05	1.61E-04	1.84E-04
I-136M	135.914740	47	s	47	1.77E+09	2.16E-02	2.06E-02	7.58E-06	5.30E-05	6.06E-05
I-137 ⁽¹⁾	136.923405	24.5	s	24.5	3.36E+09	1.95E-02	1.83E-02	6.68E-06	4.68E-05	5.35E-05
I-138 ⁽¹⁾	137.932070	6.5	s	6.5	1.26E+10	2.58E-03	2.39E-03	8.66E-07	6.06E-06	6.93E-06
I-139 ⁽¹⁾	138.940735	2.30	s	2.30	3.53E+10	4.38E-04	4.00E-04	1.44E-07	1.01E-06	1.15E-06
I-140 ⁽¹⁾	139.949400	0.86	s	0.86	9.37E+10	4.60E-05	4.09E-05	1.46E-08	1.02E-07	1.17E-07
I-141 ⁽¹⁾	140.958065	0.45	s	0.45	1.78E+11	3.39E-06	3.10E-06	1.10E-09	7.70E-09	8.80E-09
I-142 ⁽¹⁾	141.966730	0.2	s	0.2	3.97E+11	1.97E-07	2.05E-07	7.22E-11	5.05E-10	5.78E-10
I-143 ⁽¹⁾	142.975395			n/a		1.98E-08	2.21E-08	7.73E-12	5.41E-11	6.18E-11
I-144 ⁽¹⁾	143.984060			n/a		6.06E-10	7.12E-10	2.47E-13	1.73E-12	1.98E-12
I-145 ⁽¹⁾	144.992725			n/a		0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Totals (g-mole)								9.36E+00	6.58E+01	7.52E+01
Fraction as Csl Totals (g-mole)								8.89E+00	6.25E+01	7.15E+01
Fraction as HI Totals⁽²⁾ (g-mole)								4.68E-01	3.29E+00	3.76E+00

Notes

- 1) Atomic mass not given for these isotopes in Reference 1; therefore, a multiple of the neutron mass is added to the atomic mass of I-136M.
- 2) Fraction as HI conservatively includes organic iodides

References

1. Radiological Health Handbook, 1970.
2. Chart of the Nuclides, 15th Edition.
3. TMI Calculation C-1101-202-E620-415, Rev 3 - Table 5
4. Reg Guide 1.183.

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Table A-2 – Cesium Core Inventory

Neutron Mass 1.008665 amu (Ref. 1)
 1 Curie 3.70E+10 dis/sec (Ref. 1)
 Avogadro's Number 6.022137E+23 atoms/mole (Ref. 2)

Core Inventory Fraction Released in Containment for Alkalis
 Gap Release Phase 0.05 (Ref. 4, Tbl 2)
 Early In-Vessel Phase 0.25 (Ref. 4, Tbl 2)
 Fraction Iodine as CsI 0.95 (Ref. 4)

Isotope	Atomic Mass (Ref. 1) [amu]	Half Life (Ref. 2)	t _{1/2} units	Half Life [sec]	Specific Activity [Ci/gm]	BOC Core Inventory (Ref 3) [gm/core]	EOC Core Inventory (Ref 3) [gm/core]	Gap Release [mole]	EIV Release [mole]	Total Release [mole]
CS-132	131.906393	6.48	d	559,872	1.53E+05	5.040E-02	1.12E-01	4.25E-05	2.12E-04	2.55E-04
CS-133	132.905355			stable		8.870E+04	1.17E+05	4.40E+01	2.20E+02	2.64E+02
CS-134	133.906823	2.065	a	65,121,840	1.29E+03	5.950E+03	1.26E+04	4.70E+00	2.35E+01	2.82E+01
CS-134M	133.906823	2.90	h	10,440	8.07E+08	2.030E-01	4.49E-01	1.68E-04	8.38E-04	1.01E-03
CS-135	134.905770	2.30E+06	a	7.25E+13	1.15E-03	2.760E+04	4.92E+04	1.82E+01	9.12E+01	1.09E+02
CS-135M	134.905770	53	m	3,180	2.63E+07	2.600E-02	7.09E-02	2.63E-05	1.31E-04	1.58E-04
CS-136	135.907340	13.16	d	1,137,024	7.30E+04	2.930E+01	6.15E+01	2.26E-02	1.13E-01	1.36E-01
CS-137	136.906770	30.07	a	9.48E+08	8.69E+01	7.160E+04	1.26E+05	4.60E+01	2.30E+02	2.76E+02
CS-138	137.910800	32.2	m	1,932	4.23E+07	3.200E+00	3.04E+00	1.10E-03	5.51E-03	6.61E-03
CS-138M	137.910800	2.9	m	174	4.70E+08	1.210E-02	1.26E-02	4.57E-06	2.28E-05	2.74E-05
CS-139	138.912900	9.3	m	558	1.46E+08	8.910E-01	8.47E-01	3.05E-04	1.52E-03	1.83E-03
CS-140	139.917110	1.08	m	64	1.27E+09	9.160E-02	8.69E-02	3.11E-05	1.55E-04	1.86E-04
CS-141 ⁽¹⁾	140.925775	24.9	s	24.9	3.22E+09	2.730E-02	2.55E-02	9.05E-06	4.52E-05	5.43E-05
CS-142 ⁽¹⁾	141.934440	1.8	s	1.8	4.42E+10	1.170E-03	1.07E-03	3.77E-07	1.88E-06	2.26E-06
CS-143 ⁽¹⁾	142.943105	1.78	s	1.78	4.43E+10	6.070E-04	5.34E-04	1.87E-07	9.34E-07	1.12E-06
CS-144 ⁽¹⁾	143.951770	1.01	s	1.01	7.76E+10	9.160E-05	8.90E-05	3.09E-08	1.55E-07	1.85E-07
CS-145 ⁽¹⁾	144.960435	0.59	s	0.59	1.32E+11	1.240E-05	1.22E-05	4.21E-09	2.10E-08	2.52E-08
CS-146 ⁽¹⁾	145.969100	0.322	s	0.322	2.40E+11	5.740E-07	5.93E-07	2.03E-10	1.02E-09	1.22E-09
CS-147 ⁽¹⁾	146.977765	0.227	s	0.227	3.38E+11	2.420E-07	2.73E-07	9.29E-11	4.64E-10	5.57E-10
CS-148 ⁽¹⁾	147.986430	0.15	s	0.15	5.08E+11	5.290E-09	6.25E-09	2.11E-12	1.06E-11	1.27E-11
CS-149 ⁽¹⁾	148.995095			n/a		0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
CS-150 ⁽¹⁾	150.003760			n/a		2.95E-12	3.61E-12	1.20E-15	6.02E-15	7.22E-15
						Totals (g-mole)	1.130E+02	5.850E+02	6.780E+02	6.780E+02
						Fraction as CsI Totals (g-mole)	8.893E+00	6.253E+01	7.146E+01	7.146E+01
						Fraction as CsOH Totals (g-mole)	1.041E+02	5.025E+02	6.065E+02	6.065E+02

Notes

1) Atomic mass not given for these isotopes in Reference 1; therefore, a multiple of the neutron mass is added to the atomic mass of CS-140.

References

1. Radiological Health Handbook, 1970.
2. Chart of the Nuclides, 15th Edition.
3. TMI Calculation C-1101-202-E620-415, Rev 3 - Table 5
4. Reg Guide 1.183.

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Attachment B

Excel Spreadsheets (including formulae)

Table 1 – Iodine Core Inventory	36
Table 2 – Cesium Core Inventory	37

Neurotic Mean
1 Date
Participant Number
Post Assessment per Ct

1.02886
2702020000
6.8221378-423

(Ph. 1)
(Ph. 1)
(Ph. 2)
(Ph. 2)

Core Inventory Function B
Gap Release Phase
Early Release Phase
Patches as Ct

0.08
0.08
0.08

(Ph. A, T9 2)
(Ph. A, T9 2)
(Ph. A)

Temp	Attend Mean (Ph. 1) Item	Heat Life (Ph. 2)	Temp	Heat Life Item	Specs Activity (Ph. 1)	BOC Core Inventory (Ph. 2)	BOC Core Inventory (Ph. 2)	Core Release (Ph. 2)	EV Release (Ph. 2)	Total Release (Ph. 2)
1.117	121.8041	10.00	10.00							
1.118	121.8041	10.00	10.00							
1.119	121.8041	10.00	10.00							
1.120	121.8041	10.00	10.00							
1.121	121.8041	10.00	10.00							
1.122	121.8041	10.00	10.00							
1.123	121.8041	10.00	10.00							
1.124	121.8041	10.00	10.00							
1.125	121.8041	10.00	10.00							
1.126	121.8041	10.00	10.00							
1.127	121.8041	10.00	10.00							
1.128	121.8041	10.00	10.00							
1.129	121.8041	10.00	10.00							
1.130	121.8041	10.00	10.00							
1.131	121.8041	10.00	10.00							
1.132	121.8041	10.00	10.00							
1.133	121.8041	10.00	10.00							
1.134	121.8041	10.00	10.00							
1.135	121.8041	10.00	10.00							
1.136	121.8041	10.00	10.00							
1.137	121.8041	10.00	10.00							
1.138	121.8041	10.00	10.00							
1.139	121.8041	10.00	10.00							
1.140	121.8041	10.00	10.00							
1.141	121.8041	10.00	10.00							
1.142	121.8041	10.00	10.00							
1.143	121.8041	10.00	10.00							
1.144	121.8041	10.00	10.00							
1.145	121.8041	10.00	10.00							
1.146	121.8041	10.00	10.00							
1.147	121.8041	10.00	10.00							
1.148	121.8041	10.00	10.00							
1.149	121.8041	10.00	10.00							
1.150	121.8041	10.00	10.00							
1.151	121.8041	10.00	10.00							
1.152	121.8041	10.00	10.00							
1.153	121.8041	10.00	10.00							
1.154	121.8041	10.00	10.00							
1.155	121.8041	10.00	10.00							
1.156	121.8041	10.00	10.00							
1.157	121.8041	10.00	10.00							
1.158	121.8041	10.00	10.00							
1.159	121.8041	10.00	10.00							
1.160	121.8041	10.00	10.00							
1.161	121.8041	10.00	10.00							
1.162	121.8041	10.00	10.00							
1.163	121.8041	10.00	10.00							
1.164	121.8041	10.00	10.00							
1.165	121.8041	10.00	10.00							
1.166	121.8041	10.00	10.00							
1.167	121.8041	10.00	10.00							
1.168	121.8041	10.00	10.00							
1.169	121.8041	10.00	10.00							
1.170	121.8041	10.00	10.00							
1.171	121.8041	10.00	10.00							
1.172	121.8041	10.00	10.00							
1.173	121.8041	10.00	10.00							
1.174	121.8041	10.00	10.00							
1.175	121.8041	10.00	10.00							
1.176	121.8041	10.00	10.00							
1.177	121.8041	10.00	10.00							
1.178	121.8041	10.00	10.00							
1.179	121.8041	10.00	10.00							
1.180	121.8041	10.00	10.00							
1.181	121.8041	10.00	10.00							
1.182	121.8041	10.00	10.00							
1.183	121.8041	10.00	10.00							
1.184	121.8041	10.00	10.00							
1.185	121.8041	10.00	10.00							
1.186	121.8041	10.00	10.00							
1.187	121.8041	10.00	10.00							
1.188	121.8041	10.00	10.00							
1.189	121.8041	10.00	10.00							
1.190	121.8041	10.00	10.00							
1.191	121.8041	10.00	10.00							
1.192	121.8041	10.00	10.00							
1.193	121.8041	10.00	10.00							
1.194	121.8041	10.00	10.00							
1.195	121.8041	10.00	10.00							
1.196	121.8041	10.00	10.00							
1.197	121.8041	10.00	10.00							
1.198	121.8041	10.00	10.00							
1.199	121.8041	10.00	10.00							
1.200	121.8041	10.00	10.00							

1) Add/00 means not gte
2) Patches in 10 count
References
1. Psychological Health
2. Chain of the Headline
3. The Continuum of
4. Reg Guide 7.183

Human Name
1 Cash
Assignment Number

1.028888
3700000000
8.0221370-23

ssu
Gates
stomach

(Ref. 1)
(Ref. 1)
(Ref. 2)

Core Inventory Position
Gap Release Phase
Liquidity Release
Position Index as of

0.00
0.00
0.00

(Ref. A, TR 2)
(Ref. A, TR 2)
(Ref. A)

Invoice	Account Name (Ref. 1) Item	Half Life (Ref. 2)	Reg. 1912	Half Life Item	Specific Activity (Item)	EOC Core Inventory (Ref. 3) Item	EOC Core Inventory (Ref. 2) Item	Gap Release (Item)	EV Release (Item)	Total Release (Item)
CS-13	131-02333	0.44	a	02333	02333	02333	02333	02333	02333	02333
CS-14	131-02334	0.44	a	02334	02334	02334	02334	02334	02334	02334
CS-15	131-02335	0.44	a	02335	02335	02335	02335	02335	02335	02335
CS-16	131-02336	0.44	a	02336	02336	02336	02336	02336	02336	02336
CS-17	131-02337	0.44	a	02337	02337	02337	02337	02337	02337	02337
CS-18	131-02338	0.44	a	02338	02338	02338	02338	02338	02338	02338
CS-19	131-02339	0.44	a	02339	02339	02339	02339	02339	02339	02339
CS-20	131-02340	0.44	a	02340	02340	02340	02340	02340	02340	02340
CS-21	131-02341	0.44	a	02341	02341	02341	02341	02341	02341	02341
CS-22	131-02342	0.44	a	02342	02342	02342	02342	02342	02342	02342
CS-23	131-02343	0.44	a	02343	02343	02343	02343	02343	02343	02343
CS-24	131-02344	0.44	a	02344	02344	02344	02344	02344	02344	02344
CS-25	131-02345	0.44	a	02345	02345	02345	02345	02345	02345	02345
CS-26	131-02346	0.44	a	02346	02346	02346	02346	02346	02346	02346
CS-27	131-02347	0.44	a	02347	02347	02347	02347	02347	02347	02347
CS-28	131-02348	0.44	a	02348	02348	02348	02348	02348	02348	02348
CS-29	131-02349	0.44	a	02349	02349	02349	02349	02349	02349	02349
CS-30	131-02350	0.44	a	02350	02350	02350	02350	02350	02350	02350
CS-31	131-02351	0.44	a	02351	02351	02351	02351	02351	02351	02351
CS-32	131-02352	0.44	a	02352	02352	02352	02352	02352	02352	02352
CS-33	131-02353	0.44	a	02353	02353	02353	02353	02353	02353	02353
CS-34	131-02354	0.44	a	02354	02354	02354	02354	02354	02354	02354
CS-35	131-02355	0.44	a	02355	02355	02355	02355	02355	02355	02355
CS-36	131-02356	0.44	a	02356	02356	02356	02356	02356	02356	02356
CS-37	131-02357	0.44	a	02357	02357	02357	02357	02357	02357	02357
CS-38	131-02358	0.44	a	02358	02358	02358	02358	02358	02358	02358
CS-39	131-02359	0.44	a	02359	02359	02359	02359	02359	02359	02359
CS-40	131-02360	0.44	a	02360	02360	02360	02360	02360	02360	02360
CS-41	131-02361	0.44	a	02361	02361	02361	02361	02361	02361	02361
CS-42	131-02362	0.44	a	02362	02362	02362	02362	02362	02362	02362
CS-43	131-02363	0.44	a	02363	02363	02363	02363	02363	02363	02363
CS-44	131-02364	0.44	a	02364	02364	02364	02364	02364	02364	02364
CS-45	131-02365	0.44	a	02365	02365	02365	02365	02365	02365	02365
CS-46	131-02366	0.44	a	02366	02366	02366	02366	02366	02366	02366
CS-47	131-02367	0.44	a	02367	02367	02367	02367	02367	02367	02367
CS-48	131-02368	0.44	a	02368	02368	02368	02368	02368	02368	02368
CS-49	131-02369	0.44	a	02369	02369	02369	02369	02369	02369	02369
CS-50	131-02370	0.44	a	02370	02370	02370	02370	02370	02370	02370
CS-51	131-02371	0.44	a	02371	02371	02371	02371	02371	02371	02371
CS-52	131-02372	0.44	a	02372	02372	02372	02372	02372	02372	02372
CS-53	131-02373	0.44	a	02373	02373	02373	02373	02373	02373	02373
CS-54	131-02374	0.44	a	02374	02374	02374	02374	02374	02374	02374
CS-55	131-02375	0.44	a	02375	02375	02375	02375	02375	02375	02375
CS-56	131-02376	0.44	a	02376	02376	02376	02376	02376	02376	02376
CS-57	131-02377	0.44	a	02377	02377	02377	02377	02377	02377	02377
CS-58	131-02378	0.44	a	02378	02378	02378	02378	02378	02378	02378
CS-59	131-02379	0.44	a	02379	02379	02379	02379	02379	02379	02379
CS-60	131-02380	0.44	a	02380	02380	02380	02380	02380	02380	02380
CS-61	131-02381	0.44	a	02381	02381	02381	02381	02381	02381	02381
CS-62	131-02382	0.44	a	02382	02382	02382	02382	02382	02382	02382
CS-63	131-02383	0.44	a	02383	02383	02383	02383	02383	02383	02383
CS-64	131-02384	0.44	a	02384	02384	02384	02384	02384	02384	02384
CS-65	131-02385	0.44	a	02385	02385	02385	02385	02385	02385	02385
CS-66	131-02386	0.44	a	02386	02386	02386	02386	02386	02386	02386
CS-67	131-02387	0.44	a	02387	02387	02387	02387	02387	02387	02387
CS-68	131-02388	0.44	a	02388	02388	02388	02388	02388	02388	02388
CS-69	131-02389	0.44	a	02389	02389	02389	02389	02389	02389	02389
CS-70	131-02390	0.44	a	02390	02390	02390	02390	02390	02390	02390
CS-71	131-02391	0.44	a	02391	02391	02391	02391	02391	02391	02391
CS-72	131-02392	0.44	a	02392	02392	02392	02392	02392	02392	02392
CS-73	131-02393	0.44	a	02393	02393	02393	02393	02393	02393	02393
CS-74	131-02394	0.44	a	02394	02394	02394	02394	02394	02394	02394
CS-75	131-02395	0.44	a	02395	02395	02395	02395	02395	02395	02395
CS-76	131-02396	0.44	a	02396	02396	02396	02396	02396	02396	02396
CS-77	131-02397	0.44	a	02397	02397	02397	02397	02397	02397	02397
CS-78	131-02398	0.44	a	02398	02398	02398	02398	02398	02398	02398
CS-79	131-02399	0.44	a	02399	02399	02399	02399	02399	02399	02399
CS-80	131-02400	0.44	a	02400	02400	02400	02400	02400	02400	02400

Notes
1. Amount shown not gr
References
1. Reference Health
2. Chart of the Month
3. The Collection C-1
4. Reg Guide 1.165

Subject: RB Sump Post-LOCA pH and TSP Quantity	Calculation No. C-1101-153-E410-040	Rev. No. 0	System Nos. 214	Sheet 38 of 75
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Attachment C
FORTTRAN Program Listings

This attachment contains the FORTRAN code used to compile the TSP-R.exe program.

File Name	Description	Page
tsp.for	File contains the code for determination of pH/mass of TSP	39 - 45
openf.for	Sub-routine for user supplied input and output file names	46-47
rhoh2ofcn.for	Sub-routine determines the density of water via linear interpolation	48
faint.for	Sub-routine determines the Debye-Hückel constant 'A' via linear interpolation	49
fbint.for	Sub-routine determines the Debye-Hückel constant 'B' via linear interpolation	50

To compile TSP-R.exe, the following programs are used: tsp.for, openf.for, rhoh2ofcn.for, faint.for and fbint.for.

This attachment also includes instructions for creating the input file required for TSP-R.exe. The instructions are included after the FORTRAN code (pages 51 – 52).

Subject:	Calculation No.	Rev. No.	System Nos.	Sheet
RB Sump Post-LOCA pH and TSP Quantity	C-1101-153-E410-040	0	214	39 of 75

Tsp.for

C CONTAINMENT SUMP pH CONTROL USING TRISODIUM PHOSPHATE
C -----

```
IMPLICIT REAL *8 (A-H,O-Z)
REAL *8 MWB,MWTSP,NA,LQB11,LQB11I,LQB21,LQB31,LQB42
REAL *8 IST,IS,PPMB,PPMTSP,LGH,LGOH,LGP
REAL *8 MWH3BO3,MWH2O,NHYDRATE,NNAOH,MH2OADD
REAL *8 IODINE
INTEGER *4 OPTN1,OPTN2,OPTN3,OPTN4,OPTN5
CHARACTER *60 TITLE

CALL OPENF

READ(8,100)TITLE
READ(8,*)PH,TF,A,B
READ(8,*)OPTN1,OPTN2,OPTN3,OPTN4,OPTN5
READ(8,*)TMH2OI,ROH2O,PKH2O,MH2OADD
READ(8,*)TMB,PPMB,LQB11I,LQB21,LQB31,LQB42
READ(8,*)TMTSP,MWTSP,NHYDRATE,NNAOH,PKP1,PKP2,PKP3
READ(8,*)GMI,GMCS,GMCL,TID

MWB = 10.81
MWH3BO3 = 61.83
MWH2O = 18.02
aH = 9.0
aOH = 3.5
aHxPOx = 4.0

IF (OPTN4.EQ.0) GOTO 5
A = FAINT(TF)
B = FBINT(TF)

5 IF (OPTN1.EQ.0) GOTO 10
T = (TF-32)/1.8+273.15
PKH2O = 4470.99/T-6.0875+0.01706*T
PKP1 = 583.01/T-2.715+0.009801*T
PKP2 = 1272.7/T-1.154+0.01368*T
PKP3 = 12.36
LQB11I = 1573.21/T+28.6059+0.012078*T-13.2258*DLOG10(T)
LQB21 = 2756.1/T-18.966+5.835*DLOG10(T)
LQB31 = 3339.5/T-8.084+1.497*DLOG10(T)
LQB42 = 12820/T-134.56+42.105*DLOG10(T)
ROH2O = RHOH2OFCN(TF)

10 IF (OPTN2.EQ.0) GOTO 50

20 IF (OPTN3.EQ.0) TMB = TMH2OI*PPMB/10**6
IF (OPTN3.EQ.1) PPMB = 10**6*TMB/TMH2OI
PPMTSP = 10**6*TMTSP/(TMH2OI+TMTSP)
PPMH3BO3 = PPMB*MWH3BO3/MWB
```

Subject:	Calculation No.	Rev. No.	System Nos.	Sheet
RB Sump Post-LOCA pH and TSP Quantity	C-1101-153-E410-040	0	214	40 of 75

TMH3BO3 = TMH2OI*PPMH3BO3/10**6
TMH2O = TMH2OI+TMTSP*(NHYDRATE*MWH2O/MWTSP)-TMH3BO3+MH2OADD
TLH2O = (TMH2O/ROH2O)*(12**3)*(2.54**3)/1000

GMPLI=GMI/TLH2O
GMPLCS=GMCS/TLH2O
GMPLCL=GMCL/TLH2O
GMPLNO3=(7.3E-06)*TID/1.0E06

PKOH = PKH2O-PH
PHT = 7.0
LQB11 = LQB11I
IST = 0.01
GOTO 40

30 PH = PHT
PHT = PHT+(CBEP+CBEB)
PKOH = PKH2O-PHT
IF (OPTN1.EQ.0) GOTO 40
IST = IS
IS = (BOH4+B2OH7+B3OH10+4*B4OH14+H2PO4+4*HPO4+9*PO4+NA+H+OH) / 2
IS = IS + 0.5*(GMPLI+GMPLCS+GMPLCL+GMPLNO3)

LQB11 = LQB11I+(0.325-0.00033*T)*IS-0.0912*IS**1.5
LGOH = -A*IS**0.5/(1+B*aOH*IS**0.5)
PKOH = PKH2O-(PH-LGOH)

40. GMPLB = TMB*453.59/(MWB*TLH2O)
H3BO3 = 0.95*GMPLB
GOTO 44

42 H3BO3 = H3BO3*(GMPLB/TGMPLB)

44 RB11 = 10**(LQB11-PKOH)
RB21 = 10**(LQB21-PKOH)
RB31 = 10**(LQB31-PKOH)
RB42 = 10**(LQB42-2*PKOH)
BOH4 = H3BO3*RB11
B2OH7 = H3BO3**2*RB21
B3OH10 = H3BO3**3*RB31
B4OH14 = H3BO3**4*RB42
TGMPLB = H3BO3+BOH4+2*B2OH7+3*B3OH10+4*B4OH14

ERR = ABS((TGMPLB-GMPLB)/GMPLB)
IF (ERR.GT.0.000001) GOTO 42

LGH = -A*IS**0.5/(1+B*aH*IS**0.5)
H = 10**(-PHT-LGH)
OH = 10**(-PKOH)
CBEB = H-(OH+BOH4+B2OH7+B3OH10+2*B4OH14)

GMPLTSP = TMTSP*453.59/(MWTSP*TLH2O)
LGP = -A*IS**0.5/(1+B*aHxPOx*IS**0.5)
RP1 = 10**(PHT-PKP1-LGP)

Subject:	Calculation No.	Rev. No.	System Nos.	Sheet
RB Sump Post-LOCA pH and TSP Quantity	C-1101-153-E410-040	0	214	41 of 75

RP2 = 10**(PHT-PKP2-3*LGP)
RP3 = 10**(PHT-PKP3-5*LGP)
NA = (3+NNAOH)*GMPLTSP
H3PO4 = GMPLTSP/(1+RP1+RP1*RP2+RP1*RP2*RP3)
H2PO4 = H3PO4*RP1
HPO4 = H2PO4*RP2
PO4 = HPO4*RP3

CBEP = NA-(H2PO4+2*HPO4+3*PO4)
CBEP=CBEP-GMPLI+GMPLCS-GMPLCL-GMPLNO3

ERR = ABS((CBEB+CBEP)*2/(CBEB-CBEP))
IF (ERR.GT.0.000001) GOTO 30
ERR = ABS((IS-IST)*2/(IS+IST))
IF (ERR.GT.0.000001) GOTO 30
GOTO 90

50 TLH2O = (TMH2OI/ROH2O)*(12**3)*(2.54**3)/1000
IF (OPTN3.EQ.0) TMB = TMH2OI*(PPMB/10**6)
IF (OPTN3.EQ.1) PPMB = 10**6*TMB/TMH2OI
PPMH3BO3 = PPMB*MWH3BO3/MWB
TMH3BO3 = TMH2OI*PPMH3BO3/10**6
TMTSP = TMB
PKOH = PKH2O-PH
LQB11 = LQB11I
IST = 0.01
GOTO 70

60 TMH2O = TMH2OI+TMTSP*(NHYDRATE*MWH2O/MWTSP)-TMH3BO3+MH2OADD
TLH2O = (TMH2O/ROH2O)*(12**3)*(2.54**3)/1000

GMPLI=GMI/TLH2O
GMPLCS=GMCS/TLH2O
GMPLCL=GMCL/TLH2O
GMPLNO3=(7.3E-06)*TID/1.0E06

TMTSP = TMTSP*ABS(CBEB/CBEP)
IF (OPTN1.EQ.0) GOTO 70
IST = IS
IS = (BOH4+B2OH7+B3OH10+4*B4OH14+H2PO4+4*HPO4+9*PO4+NA+H+OH)/2
IS = IS + 0.5*(GMPLI+GMPLCS+GMPLCL+GMPLNO3)

LQB11 = LQB11I+(0.325-0.00033*T)*IS-0.0912*IS**1.5
LGOH = -A*IS**0.5/(1+B*aOH*IS**0.5)
PKOH = PKH2O-(PH-LGOH)

70 GMPLB = TMB*453.59/(MWB*TLH2O)
H3BO3 = 0.95*GMPLB
GOTO 74

72 H3BO3 = H3BO3*(GMPLB/TGMPLB)

74 RB11 = 10**(LQB11-PKOH)

Subject:	Calculation No.	Rev. No.	System Nos.	Sheet
RB Sump Post-LOCA pH and TSP Quantity	C-1101-153-E410-040	0	214	42 of 75

```
RB21 = 10**(LQB21-PKOH)
RB31 = 10**(LQB31-PKOH)
RB42 = 10**(LQB42-2*PKOH)
BOH4 = H3BO3*RB11
B2OH7 = H3BO3**2*RB21
B3OH10 = H3BO3**3*RB31
B4OH14 = H3BO3**4*RB42
TGMPLB = H3BO3+BOH4+2*B2OH7+3*B3OH10+4*B4OH14
```

```
ERR = ABS((TGMPLB-GMPLB)/GMPLB)
IF (ERR.GT.0.000001) GOTO 72
```

```
LGH = -A*IS**0.5/(1+B*aH*IS**0.5)
H = 10**(-PH-LGH)
OH = 10**(-PKOH)
CBEB = H-(OH+BOH4+B2OH7+B3OH10+2*B4OH14)
```

```
GMPLTSP = TMTSP*453.59/(MWTSP*TLH2O)
LGP = -A*IS**0.5/(1+B*aHxPOx*IS**0.5)
RP1 = 10**(PH-PKP1-LGP)
RP2 = 10**(PH-PKP2-3*LGP)
RP3 = 10**(PH-PKP3-5*LGP)
NA = (3+NNAOH)*GMPLTSP
H3PO4 = GMPLTSP/(1+RP1+RP1*RP2+RP1*RP2*RP3)
H2PO4 = H3PO4*RP1
HPO4 = H2PO4*RP2
PO4 = HPO4*RP3
```

```
CBEP = NA-(H2PO4+2*HPO4+3*PO4)
CBEP=CBEP-GMPLI+GMPLCS-GMPLCL-GMPLNO3
```

```
ERR = ABS((CBEB+CBEP)*2/(CBEB-CBEP))
IF (ERR.GT.0.000001) GOTO 60
ERR = ABS((IS-IST)*2/(IS+IST))
IF (ERR.GT.0.000001) GOTO 60
```

```
PPMTSP = 10**6*TMTSP/(TMH2OI+TMTSP)
GOTO 90
```

```
90 WRITE(10,100) TITLE
```

```
WRITE(10,*)'-----'
&-----'
```

```
IF (OPTN1.EQ.0)
&WRITE(10,*)'Option 1 = 0 (pK values are entered)'
IF (OPTN1.EQ.1)
&WRITE(10,*)'Option 1 = 1 (pK values are calculated)'
IF (OPTN2.EQ.0)
&WRITE(10,*)'Option 2 = 0 (quantity of TSP is calculated)'
IF (OPTN2.EQ.1)
&WRITE(10,*)'Option 2 = 1 (equilibrium pH is calculated)'
IF (OPTN3.EQ.0)
&WRITE(10,*)'Option 3 = 0 (input boron quantity is in PPM)'
IF (OPTN3.EQ.1)
&WRITE(10,*)'Option 3 = 1 (input boron quantity is in lbm)'
```

Subject:	Calculation No.	Rev. No.	System Nos.	Sheet
RB Sump Post-LOCA pH and TSP Quantity	C-1101-153-E410-040	0	214	43 of 75

```
IF (OPTN4.EQ.0)
&WRITE(10,*)'Option 4 = 0 (Debye-Hückel constants are entered)'
IF (OPTN4.EQ.1)
&WRITE(10,*)'Option 4 = 1 (Debye-Hückel constants are calculated)'
IF (OPTN5.EQ.0)
&WRITE(10,*)'Option 5 = 0 (Formatted results)'
IF (OPTN5.EQ.1)
&WRITE(10,*)'Option 5 = 1 (Unformatted results)'  
IF (OPTN5.EQ.0) THEN
  
WRITE(10,*)'-----'
&-----'
WRITE(10,102)'Temperature, °F =',TF
WRITE(10,105)'A (constant of activity) =',A
WRITE(10,105)'B (constant of activity) =',B
WRITE(10,106)'Solution ionic strength =',IS
WRITE(10,*)'-----'
&-----'
WRITE(10,102)'Initial mass of borated water, lbm =',TMH2OI
WRITE(10,102)'Final mass of pure water, lbm =',TMH2O
WRITE(10,104)'Density of water, lb/ft³ =',ROH2O
WRITE(10,106)'pK (water) =',PKH2O
WRITE(10,106)'pK (OH) =',PKOH
WRITE(10,108)'Log (gamma OH) =',LGOH
WRITE(10,102)'Equilibrium pH =',PH
WRITE(10,108)'Log (gamma H) =',LGH
WRITE(10,*)'-----'
&-----'
WRITE(10,102)'Total mass of Boron, lbm =',TMB
WRITE(10,101)'PPM of Boron =',PPMB
WRITE(10,103)'MW of Boron =',MWB
WRITE(10,102)'Total mass of Boric acid, lbm =',TMH3BO3
WRITE(10,101)'PPM of Boric acid =',PPMH3BO3
WRITE(10,106)'Log Q1,1 (Boric acid) =',LQB11
WRITE(10,106)'Log Q2,1 (Boric acid) =',LQB21
WRITE(10,106)'Log Q3,1 (Boric acid) =',LQB31
WRITE(10,106)'Log Q4,2 (Boric acid) =',LQB42
WRITE(10,108)'H3BO3 =',H3BO3
WRITE(10,108)'B(OH)4 =',BOH4
WRITE(10,108)'B2(OH)7 =',B2OH7
WRITE(10,108)'B3(OH)10 =',B3OH10
WRITE(10,108)'B4(OH)14 =',B4OH14
WRITE(10,107)'CBEB =',CBEB
WRITE(10,*)'-----'
&-----'
WRITE(10,102)'Total mass of TSP, lbm =',TMTSP
WRITE(10,101)'PPM of TSP =',PPMTSP
WRITE(10,103)'MW of TSP =',MWTSP
WRITE(10,101)'# of Hydrates (X), Na3PO4*XH2O*YNaOH =',NHYDRATE
WRITE(10,104)'# of NaOH (Y), Na3PO4*XH2O*YNaOH =',NNAOH
WRITE(10,106)'Log (gamma H2PO4) =',LGP
WRITE(10,106)'Log (gamma HPO4) =',LGP
WRITE(10,106)'pK1 (Phosphoric acid) =',PKP1
```

Subject:	Calculation No.	Rev. No.	System Nos.	Sheet
RB Sump Post-LOCA pH and TSP Quantity	C-1101-153-E410-040	0	214	44 of 75

```

WRITE (10,106) 'pK2 (Phosphoric acid)          =' , PKP2
WRITE (10,103) 'pK3 (Phosphoric acid)          =' , PKP3
WRITE (10,108) 'H3PO4                          =' , H3PO4
WRITE (10,108) 'H2PO4                          =' , H2PO4
WRITE (10,108) 'HPO4                           =' , HPO4
WRITE (10,108) 'PO4                            =' , PO4
WRITE (10,108) 'NA                             =' , NA
WRITE (10,107) 'CBEP                           =' , CBEP
WRITE (10,*) '-----'
&-----'
WRITE (10,108) '[I]                            =' , GMPLI
WRITE (10,108) '[Cs]                          =' , GMPLCS
WRITE (10,108) '[Cl]                          =' , GMPLCL
WRITE (10,108) '[NO3]                         =' , GMPLNO3
WRITE (10,*) '-----'
&-----'
WRITE (10,107) 'Charge balance error           =' , ERR
WRITE (10,*) '-----'
&-----'

ELSE IF (OPTN5.EQ.1) THEN

WRITE (10,*) '-----'
&-----'
WRITE (10,*) 'Temperature, °F                 =' , TF
WRITE (10,*) 'A (constant of activity)         =' , A
WRITE (10,*) 'B (constant of activity)         =' , B
WRITE (10,*) 'Solution ionic strength          =' , IS
WRITE (10,*) '-----'
&-----'
WRITE (10,*) 'Initial mass of borated water, lbm =' , TMH2OI
WRITE (10,*) 'Final mass of pure water, lbm    =' , TMH2O
WRITE (10,*) 'Density of water, lb/ft³         =' , ROH2O
WRITE (10,*) 'pK (water)                      =' , PKH2O
WRITE (10,*) 'pK (OH)                        =' , PKOH
WRITE (10,*) 'Log (gamma OH)                  =' , LGOH
WRITE (10,*) 'Equilibrium pH                   =' , PH
WRITE (10,*) 'Log (gamma H)                   =' , LGH
WRITE (10,*) '-----'
&-----'
WRITE (10,*) 'Total mass of Boron, lbm                =' , TMB
WRITE (10,*) 'PPM of Boron                       =' , PPMB
WRITE (10,*) 'MW of Boron                          =' , MWB
WRITE (10,*) 'Total mass of Boric acid, lbm      =' , TMH3BO3
WRITE (10,*) 'PPM of Boric acid                   =' , PPMH3BO3
WRITE (10,*) 'Log Q1,1 (Boric acid)                   =' , LQB11
WRITE (10,*) 'Log Q2,1 (Boric acid)                   =' , LQB21
WRITE (10,*) 'Log Q3,1 (Boric acid)                   =' , LQB31
WRITE (10,*) 'Log Q4,2 (Boric acid)                   =' , LQB42
WRITE (10,*) 'H3BO3                               =' , H3BO3
WRITE (10,*) 'B(OH)4                               =' , BOH4
WRITE (10,*) 'B2(OH)7                               =' , B2OH7
WRITE (10,*) 'B3(OH)10                              =' , B3OH10
WRITE (10,*) 'B4(OH)14                              =' , B4OH14

```

Subject:	Calculation No.	Rev. No.	System Nos.	Sheet
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```
WRITE (10,*) 'CBEB'                                =', CBEB
WRITE (10,*) '-----'
&-----'
WRITE (10,*) 'Total mass of TSP, lbm'              =', TMTSP
WRITE (10,*) 'PPM of TSP'                          =', PPMTSP
WRITE (10,*) 'MW of TSP'                          =', MWTSP
WRITE (10,*) '# of Hydrates(X), Na3PO4*XH2O*YNaOH =', NHYDRATE
WRITE (10,*) '# of NaOH(Y), Na3PO4*XH2O*YNaOH     =', NNAOH
WRITE (10,*) 'Log (gamma H2PO4)'                  =', LGP
WRITE (10,*) 'Log (gamma HPO4)'                   =', LGP
WRITE (10,*) 'pK1 (Phosphoric acid)'              =', PKP1
WRITE (10,*) 'pK2 (Phosphoric acid)'              =', PKP2
WRITE (10,*) 'pK3 (Phosphoric acid)'              =', PKP3
WRITE (10,*) 'H3PO4'                              =', H3PO4
WRITE (10,*) 'H2PO4'                              =', H2PO4
WRITE (10,*) 'HPO4'                               =', HPO4
WRITE (10,*) 'PO4'                                =', PO4
WRITE (10,*) 'NA'                                 =', NA
WRITE (10,*) 'CBEP'                               =', CBEP
WRITE (10,*) '-----'
&-----'
WRITE (10,*) '[I]'                                =', GMPLI
WRITE (10,*) '[Cs]'                              =', GMPLCS
WRITE (10,*) '[Cl]'                              =', GMPLCL
WRITE (10,*) '[NO3]'                             =', GMPLNO3
WRITE (10,*) '-----'
&-----'
WRITE (10,*) 'Charge balance error'                =', ERR
WRITE (10,*) '-----'
&-----'
```

END IF

```
100 FORMAT (A60)
101 FORMAT (A38, F16.0)
102 FORMAT (A38, F16.1)
103 FORMAT (A38, F16.2)
104 FORMAT (A38, F16.3)
105 FORMAT (A38, F16.4)
106 FORMAT (A38, F16.6)
107 FORMAT (A38, ES16.8E2)
108 FORMAT (A38, ES16.6E2)
```

END

Subject: RB Sump Post-LOCA pH and TSP Quantity	Calculation No. C-1101-153-E410-040	Rev. No. 0	System Nos. 214	Sheet 46 of 75
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Open. for

```
SUBROUTINE OPENF()  
C  
C   subroutine to open files  
C  
C   INTEGER INPUT, OUTPUT  
C   DATA INPUT/8/  
C   DATA OUTPUT/10/  
C  
C   CHARACTER*60 IFNAME,OFNAME  
C   CHARACTER    RESP  
C   LOGICAL      EXISTS  
C   INTEGER      ICODE  
C   CHARACTER*256 ERR_MSG  
C  
10 PRINT *, 'Enter input file name: '  
   READ(*,'(A)') IFNAME  
   IF (IFNAME .EQ. ' ') GO TO 10  
   NRE=1  
   INQUIRE(FILE=IFNAME,EXIST=EXISTS)  
   IF (EXISTS) THEN  
     OPEN (INPUT,FILE=IFNAME,STATUS='OLD',IOSTAT=ICODE,ERR=50)  
   ELSE  
     PRINT*,'File does not exist!'  
     GO TO 10  
   END IF  
C  
20 WRITE(*,*) 'Enter output file name: '  
   READ(*,'(A)') OFNAME  
   IF (OFNAME .EQ. ' ') GO TO 20  
   NRE=2  
   INQUIRE(FILE=OFNAME,EXIST=EXISTS)  
   IF (EXISTS) THEN  
     PRINT *, 'File already exist. Overwrite? Y or N: '  
     READ(*,'(A)') RESP  
     IF (RESP.EQ.'Y' .OR. RESP.EQ.'y') THEN  
       OPEN (OUTPUT,FILE=OFNAME,STATUS='UNKNOWN')  
     ELSE  
       GO TO 20  
     END IF  
   ELSE  
     OPEN (OUTPUT,FILE=OFNAME,STATUS='NEW',IOSTAT=ICODE,ERR=50)  
   END IF  
C  
C   RETURN  
C  
50 CALL IOSTAT_MSG(ICODE,ERR_MSG)  
   PRINT*,'File open error!'  
   PRINT*,'Error Code : ',ICODE  
   PRINT*,'Error Msg : ',ERR_MSG  
   IF (NRE.EQ.1) THEN
```

AmerGen

CALCULATION SHEET

Subject: RB Sump Post-LOCA pH and TSP Quantity	Calculation No. C-1101-153-E410-040	Rev. No. 0	System Nos. 214	Sheet 47 of 75
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```
GO TO 10  
ELSE  
GO TO 20  
END IF  
C  
END
```

Subject: RB Sump Post-LOCA pH and TSP Quantity	Calculation No. C-1101-153-E410-040	Rev. No. 0	System Nos. 214	Sheet 48 of 75
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rhoH2Ofcn.for

```
double precision function rhoH2Ofcn(tfx)
c
c   Calculate Density of Water
c
c   implicit double precision (a-h,o-z)
c
c   double precision tf(27), rho(27)
c
c   data tf/
1   32., 40., 50., 60., 70., 80., 90., 100., 110., 120.,
2   130., 140., 150., 160., 170., 180., 190., 200., 210., 212.,
3   220., 240., 260., 280., 300., 350., 400./
c   data rho/
1   62.414, 62.426, 62.410, 62.371, 62.305, 62.220, 62.116, 61.996,
2   61.862, 61.713, 61.550, 61.376, 61.188, 60.994, 60.787, 60.569,
3   60.343, 60.107, 59.862, 59.812, 59.613, 59.081, 58.517, 57.924,
4   57.307, 55.586, 53.648/
c
c   if (tfx.lt.tf(1)) rhoH2Ofcn = rho(1)
c   do 10 i=2,27
c     if (tfx.ge.tf(i-1) .and. tfx.le.tf(i)) then
c       rhoH2Ofcn=rho(i-1)+
c       &(tfx-tf(i-1))*(rho(i)-rho(i-1))/(tf(i)-tf(i-1))
c     end if
10  continue
c   if (tfx.gt.tf(27)) rhoH2Ofcn = rho(27)
c
c   return
c
c   end
```

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faint.for

double precision function faint(tfx)

c

Calculate Debye-Hückel Coefficient A

c

implicit double precision (a-h,o-z)

c

double precision tf(21), fa(21)

c

data tf/

1 32., 41., 50., 59., 68., 77., 86., 95., 104., 113.,
2 122., 131., 140., 149., 158., 167., 176., 185., 194., 203.,
3 212./

data fa/

1 0.4918, 0.4952, 0.4989, 0.5028, 0.5070, 0.5115, 0.5161, 0.5211,
2 0.5262, 0.5317, 0.5373, 0.5432, 0.5494, 0.5558, 0.5625, 0.5695,
3 0.5767, 0.5842, 0.5920, 0.6001, 0.6086/

c

if (tfx.lt.tf(1)) faint = fa(1)

do 10 i=2,21

if (tfx.ge.tf(i-1) .and. tfx.le.tf(i)) then

faint=fa(i-1)+

&(tfx-tf(i-1))*(fa(i)-fa(i-1))/(tf(i)-tf(i-1))

end if

10 continue

if (tfx.gt.tf(21)) then

faint = (0.00000158486*tfx+0.000260119)*tfx+0.48195

end if

c

return

c

end

Subject: RB Sump Post-LOCA pH and TSP Quantity	Calculation No. C-1101-153-E410-040	Rev. No. 0	System Nos. 214	Sheet 50 of 75
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fbint.for

```
double precision function fbint(tfx)
c
c   Calculate Debye-Hückel Coefficient B
c
c   implicit double precision (a-h,o-z)
c
c   double precision tf(21), fb(21)
c
c   data tf/
1   32., 41., 50., 59., 68., 77., 86., 95., 104., 113.,
2   122., 131., 140., 149., 158., 167., 176., 185., 194., 203.,
3   212./
c   data fb/
1   0.3248, 0.3256, 0.3264, 0.3273, 0.3282, 0.3291, 0.3301, 0.3312,
2   0.3323, 0.3334, 0.3346, 0.3358, 0.3371, 0.3384, 0.3397, 0.3411,
3   0.3426, 0.3440, 0.3456, 0.3471, 0.3488/
c
c   if (tfx.lt.tf(1)) fbint = fb(1)
c   do 10 i=2,21
c     if (tfx.ge.tf(i-1) .and. tfx.le.tf(i)) then
c       fbint=fb(i-1)+
c       &(tfx-tf(i-1))*(fb(i)-fb(i-1))/(tf(i)-tf(i-1))
c     end if
10  continue
c   if (tfx.gt.tf(21)) then
c     fbint = (0.000000271613*tfx+0.0000668289)*tfx+0.322388
c   end if
c
c   return
c
c   end
```

Subject: RB Sump Post-LOCA pH and TSP Quantity	Calculation No. C-1101-153-E410-040	Rev. No. 0	System Nos. 214	Sheet 51 of 75
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TSP-R.exe INPUT DESCRIPTION

Each 'Card' listed below is a separate line of input in the input file.
Each 'Word' on a 'Card' is an input entry on that line. The Words below are all followed by the corresponding variable in the FORTRAN computer code.

Card 1:

TITLE Run title

Card 2:

Word 1 PH Equilibrium pH (set to zero if OPTN2=1)
Word 2 TF Sump temperature, °F
Word 3 A Debye-Hückel constant, A (set to zero if OPTN4=1)
Word 4 B Debye-Hückel constant, B (set to zero if OPTN4=1)

Card 3:

Word 1 OPTN1 Option 1
0 = pK values entered in input deck
1 = pK values calculated
Word 2 OPTN2 Option 2
0 = TSP mass is calculated
1 = equilibrium pH is calculated
Word 3 OPTN3 Option 3
0 = input quantity for boron is in ppm
1 = input quantity for boron is in lbm
Word 4 OPTN4 Option 4
0 = Debye-Hückel constants (A,B) entered in input deck
1 = Debye-Hückel constants (A,B) calculated
Word 5 OPTN5 Option 5
0 = Formatted results
1 = Unformatted results

Card 4:

Word 1 TMH20I initial borated water mass in sump, lbm
Word 2 ROH2O water density, lbm/ft³ (set to zero if OPTN1=1)
Word 3 PKH20 pK water (set to zero if OPTN1=1)
Word 4 MH20ADD Additional non-borated water mass added to total water mass, lbm

Card 5:

Word 1 TMB initial boron mass, lbm (set to zero if OPTN3=0)
Word 2 PPMB initial boron concentration, ppm (set to zero if OPTN3=1)
Word 3 LQB11I log (Q1,1) (set to zero if OPTN1=1)
Word 4 LQB21 log (Q2,1) (set to zero if OPTN1=1)
Word 5 LQB31 log (Q3,1) (set to zero if OPTN1=1)
Word 6 LQB42 log (Q4,2) (set to zero if OPTN1=1)

Subject: RB Sump Post-LOCA pH and TSP Quantity	Calculation No. C-1101-153-E410-040	Rev. No. 0	System Nos. 214	Sheet 52 of 75
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Card 6:

Word 1 TMTSP TSP mass when determining pH, lbn (set to zero if OPTN2=0)
Word 2 MWTSP molecular weight of TSP molecule
Word 3 NHYDRATE Number of hydrates (X) in TSP molecule, $\text{Na}_3\text{PO}_4 \cdot X\text{H}_2\text{O} \cdot Y\text{NaOH}$
Word 4 NNAOH Number of NaOH molecules (Y) in TSP molecule, $\text{Na}_3\text{PO}_4 \cdot X\text{H}_2\text{O} \cdot Y\text{NaOH}$
Word 5 PKP1 pK1 for phosphoric acid (set to zero if OPTN1=1)
Word 6 PKP2 pK2 for phosphoric acid (set to zero if OPTN1=1)
Word 7 PKP3 pK3 for phosphoric acid (set to zero if OPTN1=1)

Card 7:

Word 1 GMI g-moles Iodine added to suppression pool
Word 2 GMCS g-moles Cesium added to suppression pool
Word 3 GMCL g-moles Chloride added to suppression pool
Word 4 POOLTID Suppression pool TID, Rad

Subject: RB Sump Post-LOCA pH and TSP Quantity	Calculation No. C-1101-153-E410-040	Rev. No. 0	System Nos. 214	Sheet 53 of 75
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Attachment D
Mathcad Validation of FORTRAN Program TSP-R

This attachment contains the Mathcad files used to benchmark the FORTRAN program TSP-R as well as the input and output files for the benchmarked FORTRAN runs.

	Page
TSP-R Benchmark Input File (val-test.in).....	54
TSP-R Benchmark Output File (val-test.out).....	55-56
Mathcad Benchmark of TSP-R.....	57-71

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TSP-R Validation Input File

Min pH

7.5, 100, 0, 0

1, 0, 0, 1, 1

3643118, 0, 0, 0

0, 2802, 0, 0, 0, 0

0, 390.12, 12, 0.25, 0, 0, 0

75.22, 677.98, 465, 120000000.

Subject:	Calculation No.	Rev. No.	System Nos.	Sheet
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TSP-R Validation Output

Min pH

Option 1 = 1 (pK values are calculated)
Option 2 = 0 (quantity of TSP is calculated)
Option 3 = 0 (input boron quantity is in PPM).
Option 4 = 1 (Debye-Hückel constants are calculated)
Option 5 = 1 (Unformatted results)

Temperature, °F = 100.0000000000000
A (constant of activity) = 0.5239333245489333
B (constant of activity) = 0.3318111168013679
Solution ionic strength = 7.885496259347409E-02

Initial mass of borated water, lbm = 3643118.000000000
Final mass of pure water, lbm = 3599752.491113404
Density of water, lb/ft³ = 61.99599838256836
pK (water) = 13.59644176324590
pK (OH) = 5.985496521216293
Log (gamma OH) = -0.1109452420296030
Equilibrium pH = 7.500000000000000
Log (gamma H) = -8.002145236355966E-02

Total mass of Boron, lbm = 10208.01663600000
PPM of Boron = 2802.000000000000
MW of Boron = 10.81000041961670
Total mass of Boric acid, lbm = 58386.83282102004
PPM of Boric acid = 16026.61039829620
Log Q1,1 (Boric acid) = 4.469115785953613
Log Q2,1 (Boric acid) = 4.442785580375762
Log Q3,1 (Boric acid) = 6.387948113890130
Log Q4,2 (Boric acid) = 11.62487084571569
H3BO3 = 0.1942850817799009
B(OH)4 = 5.916416222735322E-03
B2(OH)7 = 1.081852288589077E-03
B3(OH)10 = 1.852550075920406E-02
B4(OH)14 = 6.421487200431189E-04
CBEB = -2.680906264918021E-02

Total mass of TSP, lbm = 27100.07930103181
PPM of TSP = 7383.779033150214
MW of TSP = 390.1200000000000
of Hydrates (X), Na3PO4*XH2O*YNaOH = 12.000000000000000
of NaOH (Y), Na3PO4*XH2O*YNaOH = 0.2500000000000000
Log (gamma H2PO4) = -0.1071798789634814
Log (gamma HPO4) = -0.1071798789634814
pK1 (Phosphoric acid) = 2.207469022593649
pK2 (Phosphoric acid) = 7.192725264958558
pK3 (Phosphoric acid) = 12.35999965667725
H3PO4 = 1.452948980353735E-08
H2PO4 = 3.647213786897662E-03
HPO4 = 1.551585072958415E-02

Subject: RB Sump Post-LOCA pH and TSP Quantity	Calculation No. C-1101-153-E410-040	Rev. No. 0	System Nos. 214	Sheet 56 of 75
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PO4 = 7.356569308583342E-07
NA = 6.228239778443303E-02
CBEP = 2.680906113528796E-02

[I] = 4.574877588447088E-05
[Cs] = 4.123471825864606E-04
[Cl] = 2.828128261935517E-04
[NO3] = 8.760000127949752E-04

Charge balance error = 7.712666304611498E-07

Section Input

grammole := 1 gm

Input Values

$T_F := 100 \text{ } ^\circ\text{F}$

$$T_w := \frac{(T_F - 32)}{1.8} + 273.15$$

$T = 310.93 \text{ } \text{K}$

$A_w := 0.5239333245489333$

$B := 0.3318111168013679$

$MH_2O_i := 3643118 \text{ } \text{lb}$

$MH_2O_{add} := 0 \text{ } \text{lb}$

$ppm_B := 2802 \text{ } \text{ppm}$

$N_{hydrate} := 12$

$N_{NaOH} := 0.25$

$MW_{TSP} := 390.12 \frac{\text{gm}}{\text{mol}}$

$MW_B := 10.81 \frac{\text{gm}}{\text{mol}}$

$MW_{BOH_3} := 61.83 \frac{\text{gm}}{\text{mol}}$

$MW_{H_2O} := 18.02 \frac{\text{gm}}{\text{mol}}$

$\rho_w := 61.99599838256836 \frac{\text{lbm}}{\text{ft}^3}$

$I := 7.885496259347409 \times 10^{-2}$

$M_{TSP} := 27100.07930103181 \text{ } \text{lbm}$

$EQ_{BOH_3} := 1.942850817799009 \cdot 10^{-1} \frac{\text{grammole}}{\text{liter}}$

$\text{pH} := 7.500000$

Description

Sump temperature

Sump temperature

Debye-Hückel Constant

Debye-Hückel Constant

Total initial mass of borated water

Additional non-borated water mass added to total water mass

Post-LOCA sump boron concentration

Number of hydrates in TSP molecule

Number of NaOH molecules per TSP molecule

Molecular weight of TSP

Molecular weight of boron

Molecular weight of boric acid

Molecular weight of water

Density of water

(1) Assume a solution ionic strength, I

(2) Assume a TSP mass

(3) Assume $B(OH)_3$ concentration

Equilibrium pH

$a_{iH} := 9.0$ angstroms

Approximate effective ionic radius of H^+ ion in aqueous solution

$a_{iOH} := 3.5$ angstroms

Approximate effective ionic radius of OH^- ion in aqueous solution

$a_{iH_2PO_4} := 4.0$ angstroms

Approximate effective ionic radius of $H_2PO_4^-$ ion in aqueous solution

$a_{iHPO_4} := 4.0$ angstroms

Approximate effective ionic radius of HPO_4^{2-} ion in aqueous solution

$a_{iPO_4} := 4.0$ angstroms

Approximate effective ionic radius of PO_4^{3-} ion in aqueous solution

$GM_I := 75.22$ gram-mole

Moles of Iodine (I^-) from HI

$GM_{Cs} := 677.98$ gram-mole

Moles of Cesium (Cs^+)

$GM_{Cl} := 465$ gram-mole

Moles of Chlorine (Cl^-) from HCl

$TID := 120000000$ rad

Total Integrated Dose

Section II - Calculations

Assumption (1): Assume a solution ionic strength, I.

- The individual activity coefficient, γ_i , is

$$-\log(\gamma_i) := \frac{(A \cdot z_i^2 \cdot I^{0.5})}{1 + (B \cdot a_i \cdot I^{0.5})}$$

or solved for γ_i equivalently,

$$\gamma_i := 10^{-\left[\frac{[A(z_i^2)I^{0.5}]}{1 + (B a_i I^{0.5})} \right]}$$

where z_i is the charge of the ion being evaluated in this equation.

- The activity coefficient of H^+ , γ_H , is:

Given:

$$z_{iH} := 1$$

$$A = 0.5239333$$

$$B = 0.3318111$$

$$I = 0.078855$$

Calculation:

$$\gamma_H := 10^{-\left[\frac{[A(z_{iH}^2)I^{0.5}]}{1 + (B a_{iH} I^{0.5})} \right]}$$

$$\gamma_H = 0.831722686$$

- The activity coefficient of OH^- , γ_{OH} , is:

Given:

$$z_{iOH} := -1$$

$$A = 0.5239333$$

$$B = 0.3318111$$

$$I = 0.078855$$

Calculation:

$$\gamma_{OH} := 10^{-\left[\frac{[A(z_{iOH}^2)I^{0.5}]}{1 + (B a_{iOH} I^{0.5})} \right]}$$

$$\gamma_{OH} = 0.774559452$$

- The activity coefficient of H_3PO_4 , $\gamma_{H_3PO_4}$, is by definition unity since the molecule has no charge.

Given:

$$z_{iH_3PO_4} := 0 \text{ (no charge for a molecule)}$$

Calculation:

$$\gamma_{H_3PO_4} := 1$$

- The activity coefficient of H_2PO_4^- , $\gamma_{\text{H}_2\text{PO}_4^-}$, is:

Given:

$$z_{\text{H}_2\text{PO}_4^-} := -1$$

$$A = 0.5239333$$

$$B = 0.3318111$$

$$I = 0.078855$$

Calculation:

$$\gamma_{\text{H}_2\text{PO}_4^-} := 10 \left[\frac{A (z_{\text{H}_2\text{PO}_4^-})^2 I^{0.5}}{1 + (B a_{\text{H}_2\text{PO}_4^-} I^{0.5})} \right]$$

$$\gamma_{\text{H}_2\text{PO}_4^-} = 0.781304132$$

- The activity coefficient of HPO_4^{2-} , $\gamma_{\text{HPO}_4^{2-}}$, is:

Given:

$$z_{\text{HPO}_4^{2-}} := -2$$

$$A = 0.5239333$$

$$B = 0.3318111$$

$$I = 0.078855$$

Calculation:

$$\gamma_{\text{HPO}_4^{2-}} := 10 \left[\frac{A (z_{\text{HPO}_4^{2-}})^2 I^{0.5}}{1 + (B a_{\text{HPO}_4^{2-}} I^{0.5})} \right]$$

$$\gamma_{\text{HPO}_4^{2-}} = 0.372632289$$

- The activity coefficient of PO_4^{3-} , $\gamma_{\text{PO}_4^{3-}}$, is:

Given:

$$z_{\text{PO}_4^{3-}} := -3$$

$$A = 0.5239333$$

$$B = 0.3318111$$

$$I = 0.078855$$

Calculation:

$$\gamma_{\text{PO}_4^{3-}} := 10 \left[\frac{A (z_{\text{PO}_4^{3-}})^2 I^{0.5}}{1 + (B a_{\text{PO}_4^{3-}} I^{0.5})} \right]$$

$$\gamma_{\text{PO}_4^{3-}} = 0.108487847$$

- The ionic activity product constant of water, K_w , is:

Given:

$$T = 310.9277778 \quad K$$

Calculation:

$$pK_w := \frac{4470.99}{T} - 6.0875 + (0.01706)(T)$$

$$pK_w = 13.5964408$$

$$K_w := 10^{-pK_w}$$

$$K_w = 2.5325567 \times 10^{-14}$$

- The equilibrium quantity of H^+ is:

Given:

$$\gamma_H = 0.8317227$$

$$\gamma_H * [H^+] = 10^{-pH}$$

Calculation:

Solved equivalently for $[H^+]$,

$$EQ_H := \frac{(10)^{-pH}}{\gamma_H}$$

$$EQ_H = 3.8020818 \times 10^{-8}$$

Note that '[H⁺]' is denoted as 'EQ_H' in mathematical form, to represent the equilibrium concentration of the ion.

- The equilibrium quantity of OH^- is:

Given:

$$\gamma_H = 0.8317227$$

$$\gamma_{OH} = 0.7745595$$

$$EQ_H = 3.8020818 \times 10^{-8}$$

$$K_w = 2.5325567 \times 10^{-14}$$

$$\gamma_{OH} * [OH^-] * \gamma_H * [H^+] = K_w$$

Calculation:

Solved equivalently for $[OH^-]$,

$$EQ_{OH} := \frac{K_w}{(EQ_H) \cdot (\gamma_H) \cdot (\gamma_{OH})}$$

$$EQ_{OH} = 1.0339616 \times 10^{-6}$$

Note that '[OH⁻]' is denoted as 'EQ_{OH}' in mathematical form, to represent the concentration of the ion.

Assumption (2): Assume a TSP mass.

- The total mass of Boron in pounds is:

Given:

$$MH2O_i = 3.643118 \times 10^6 \text{ lb}$$

Calculation:

$$M_B := MH2O_i \cdot \frac{ppm_B (ppm)}{10^6 (ppm)}$$

$$M_B = 1.0208017 \times 10^4 \text{ lb}$$

$$M_{BOH3} := M_B \cdot \frac{MW_{BOH3}}{MW_B}$$

$$M_{BOH3} = 5.8386833 \times 10^4$$

- The total final mass of water in pounds is:

Given:

$$MH2O_i = 3.643118 \times 10^6 \text{ lb}$$

$$MH2O_{add} = 0 \text{ lb}$$

$$MW_{TSP} = 390.12$$

$$M_{TSP} = 2.7100079 \times 10^4 \text{ lb}$$

Calculation:

$$MH2O_f := MH2O_i + M_{TSP} \cdot \left[\frac{N_{hydrate} \cdot MW_{H2O} \left(\frac{gm}{mol} \right)}{MW_{TSP} \left(\frac{gm}{mol} \right)} \right] + (-M_{BOH3} + MH2O_{add})$$

$$MH2O_f = 3.5997525 \times 10^6 \text{ lb}$$

- The total final volume of water in liters is:

Given:

$$MH2O_f = 3.5997525 \times 10^6 \text{ lb}$$

$$\rho_w = 61.9959984 \frac{lb}{ft^3}$$

Calculation:

$$VH2O_f := \frac{MH2O_f \text{ lb}}{\rho_w \left(\frac{lb}{ft^3} \right)}$$

$$VH2O_f = 1.6441971 \times 10^6 \text{ liter}$$

- Concentration of Boron in grammoles per liter is:

Given:

$$M_B = 1.0208017 \times 10^4 \text{ lb}$$

$$MW_B = 10.81$$

$$VH2O_f = 1.6441971 \times 10^6 \text{ liter}$$

Calculation:

$$Conc_B := \left(\frac{M_B \cdot lb}{VH2O_f \cdot MW_B} \right) \cdot \left(453.59 \cdot \frac{gm}{lb} \right)$$

$$Conc_B = 0.2605105 \frac{grammole}{liter}$$

- Concentration of Iodine in grammoles per liter is:

Given:

$$VH2O_f = 1.6441971 \times 10^6 \text{ liter}$$

Calculation:

$$\text{Conc}_I := \frac{GM_I \text{ grammole}}{VH2O_f}$$

$$\text{Conc}_I = 4.57487738 \times 10^{-5} \frac{\text{grammole}}{\text{liter}}$$

- Concentration of Chlorine in grammoles per liter is:

Given:

$$VH2O_f = 1.6441971 \times 10^6 \text{ liter}$$

Calculation:

$$\text{Conc}_{Cl} := \frac{GM_{Cl} \text{ grammole}}{VH2O_f}$$

$$\text{Conc}_{Cl} = 2.82812813 \times 10^{-4} \frac{\text{grammole}}{\text{liter}}$$

- Concentration of Cesium in grammoles per liter is:

Given:

$$VH2O_f = 1.6441971 \times 10^6 \text{ liter}$$

Calculation:

$$\text{Conc}_{Cs} := \frac{GM_{Cs} \text{ grammole}}{VH2O_f}$$

$$\text{Conc}_{Cs} = 4.12347163 \times 10^{-4} \frac{\text{grammole}}{\text{liter}}$$

- Concentration of Nitric Acid in grammoles per liter is:

Given:

$$VH2O_f = 1.6441971 \times 10^6 \text{ liter}$$

$$TID = 1.2 \times 10^8 \text{ rad}$$

Calculation:

$$\text{Conc}_{HNO3} := 7.3 \cdot 10^{-6} \frac{\text{grammole}}{\text{liter}} \cdot \frac{TID}{1 \cdot 10^6}$$

$$\text{Conc}_{NO3} := \text{Conc}_{HNO3}$$

$$\text{Conc}_{NO3} = 8.76 \times 10^{-4} \frac{\text{grammole}}{\text{liter}}$$

Note that the units on G [7.3x10⁻⁶ grammole/liter] are actually incorrect [they should be grammole/(liter*MRad)] in the above equation since the radiation unit 'Rad' is not available in Mathcad. Therefore, it is left out of the equation. The correct values are computed, however.

- Concentration of TSP in grammoles per liter is:

Given:

$$V_{H_2O_f} = 1.6441971 \times 10^6 \text{ liter}$$

Calculation:

$$\text{Conc}_{TSP} := \frac{M_{TSP} \cdot (\text{lb}) \cdot 453.59 \cdot \left(\frac{\text{gm}}{\text{lb}}\right)}{V_{H_2O_f} \cdot MW_{TSP}}$$

$$\text{Conc}_{TSP} = 0.0191638 \frac{\text{grammole}}{\text{liter}}$$

- The dissociation constants of phosphoric acid are:

$$T = 310.9277778 \quad K$$

$$pK_1 := \frac{583.01}{T} - 2.715 + (0.009801)(T)$$

$$pK_1 = 2.2074688$$

$$K_1 := 10^{-pK_1}$$

$$K_1 = 6.2019918 \times 10^{-3}$$

$$pK_2 := \frac{1272.7}{T} - 1.154 + (0.01368)(T)$$

$$pK_2 = 7.1927255$$

$$K_2 := 10^{-pK_2}$$

$$K_2 = 6.4161497 \times 10^{-8}$$

$$pK_3 := 12.36$$

$$K_3 := 10^{-pK_3}$$

$$K_3 = 4.3651583 \times 10^{-13}$$

- The equilibrium quantity of phosphoric acid is:

$$EQ_{H_3PO_4} := \frac{\text{Conc}_{TSP} \cdot \left(\frac{\text{liter}}{\text{grammole}}\right)}{1 + \frac{K_1}{\gamma_{H_2PO_4} \gamma_{H^+} EQ_H} + \frac{K_1 \cdot K_2}{\gamma_{HPO_4} (\gamma_{H^+} EQ_H)^2} + \frac{K_1 \cdot K_2 \cdot K_3}{\gamma_{PO_4} (\gamma_{H^+} EQ_H)^3}}$$

$$EQ_{H_3PO_4} = 1.4529489 \times 10^{-8}$$

- The equilibrium quantities of phosphoric acid species are:

Given:

$$\gamma_{\text{H}_3\text{PO}_4} = 1$$

$$\gamma_{\text{H}_2\text{PO}_4} = 0.7813041$$

$$\gamma_{\text{H}} = 0.8317227$$

$$K_1 = 6.2019918 \times 10^{-3}$$

$$EQ_{\text{H}_3\text{PO}_4} = 1.4529489 \times 10^{-8}$$

$$EQ_{\text{H}} = 3.8020818 \times 10^{-8}$$

$$\gamma_{\text{H}_2\text{PO}_4} * [\text{H}_2\text{PO}_4] * \gamma_{\text{H}} * [\text{H}^+] / (\gamma_{\text{H}_3\text{PO}_4} * [\text{H}_3\text{PO}_4]) = K_1$$

Note that '[H₂PO₄]' is denoted as 'EQ_{H₂PO₄}' in mathematical form, to represent the equilibrium concentration of the ion

Given:

$$\gamma_{\text{H}_2\text{PO}_4} = 0.7813041$$

$$\gamma_{\text{HPO}_4} = 0.3726323$$

$$\gamma_{\text{H}} = 0.8317227$$

$$K_2 = 6.4161497 \times 10^{-8}$$

$$EQ_{\text{H}_2\text{PO}_4} = 3.6472153 \times 10^{-3}$$

$$EQ_{\text{H}} = 3.8020818 \times 10^{-8}$$

$$\gamma_{\text{HPO}_4} * [\text{HPO}_4^{2-}] * \gamma_{\text{H}} * [\text{H}^+] / (\gamma_{\text{H}_2\text{PO}_4} * [\text{H}_2\text{PO}_4]) = K_2$$

Note that '[HPO₄²⁻]' is denoted as 'EQ_{HPO₄}' in mathematical form, to represent the equilibrium concentration of the ion

Given:

$$\gamma_{\text{HPO}_4} = 0.3726323$$

$$\gamma_{\text{H}} = 0.8317227$$

$$\gamma_{\text{PO}_4} = 0.1084878$$

$$K_3 = 4.3651583 \times 10^{-13}$$

$$EQ_{\text{H}} = 3.8020818 \times 10^{-8}$$

$$EQ_{\text{HPO}_4} = 0.0155158$$

$$\gamma_{\text{PO}_4} * [\text{PO}_4^{3-}] * \gamma_{\text{H}} * [\text{H}^+] / (\gamma_{\text{HPO}_4} * [\text{HPO}_4^{2-}]) = K_3$$

Note that '[PO₄³⁻]' is denoted as 'EQ_{PO₄}' in mathematical form, to represent the equilibrium

Calculation:

Solved equivalently for [H₂PO₄],

$$EQ_{\text{H}_2\text{PO}_4} := K_1 \cdot \left(\frac{\gamma_{\text{H}_3\text{PO}_4} \cdot EQ_{\text{H}_3\text{PO}_4}}{EQ_{\text{H}} \cdot \gamma_{\text{H}} \cdot \gamma_{\text{H}_2\text{PO}_4}} \right)$$

$$EQ_{\text{H}_2\text{PO}_4} = 3.6472153 \times 10^{-3}$$

Calculation:

Solved equivalently for [HPO₄²⁻],

$$EQ_{\text{HPO}_4} := K_2 \cdot \left(\frac{\gamma_{\text{H}_2\text{PO}_4} \cdot EQ_{\text{H}_2\text{PO}_4}}{EQ_{\text{H}} \cdot \gamma_{\text{H}} \cdot \gamma_{\text{HPO}_4}} \right)$$

$$EQ_{\text{HPO}_4} = 0.0155158$$

Calculation:

Solved equivalently for [PO₄³⁻],

$$EQ_{\text{PO}_4} := K_3 \cdot \left(\frac{\gamma_{\text{HPO}_4} \cdot EQ_{\text{HPO}_4}}{EQ_{\text{H}} \cdot \gamma_{\text{H}} \cdot \gamma_{\text{PO}_4}} \right)$$

$$EQ_{\text{PO}_4} = 7.3565624 \times 10^{-7}$$

concentration of the ion

- The TSP concentration based on the above quantities is:

$$\text{Molality}_{\text{TSP}} := \text{EQ}_{\text{H}_3\text{PO}_4} + \text{EQ}_{\text{H}_2\text{PO}_4} + \text{EQ}_{\text{HPO}_4} + \text{EQ}_{\text{PO}_4}$$

$$\text{Molality}_{\text{TSP}} = 0.0191638$$

$$\text{Error}_{\text{TSP}} := \frac{\left| \text{Molality}_{\text{TSP}} \cdot \left(\frac{\text{grammole}}{\text{liter}} \right) - \text{Conc}_{\text{TSP}} \right|}{\text{Conc}_{\text{TSP}}}$$

$$\text{Error}_{\text{TSP}} = 0$$

- The molal equilibrium quotients of boric acid are:

Given:

$$T = 310.9277778 \text{ K}$$

$$I = 0.078855$$

Calculation:

$$\log Q_{11} := \frac{1573.21}{T} + 28.6059 + 0.012078T - 13.2258 \log(T) + (0.3250 - 0.00033T)I - 0.0912I^{1.5}$$

$$\log Q_{11} = 4.4691148$$

$$Q_{11} := 10^{\log Q_{11}}$$

$$Q_{11} = 2.9452002 \times 10^4$$

$$\log Q_{21} := \frac{2756.1}{T} - 18.966 + 5.835 \cdot \log(T)$$

$$\log Q_{21} = 4.4427847$$

$$Q_{21} := 10^{\log Q_{21}}$$

$$Q_{21} = 2.7719454 \times 10^4$$

$$\log Q_{31} := \frac{3339.5}{T} - 8.084 + 1.497 \cdot \log(T)$$

$$\log Q_{31} = 6.3879476$$

$$Q_{31} := 10^{\log Q_{31}}$$

$$Q_{31} = 2.443136 \times 10^6$$

$$\log Q_{42} := \frac{12820.0}{T} - 134.56 + 42.105 \cdot \log(T)$$

$$\log Q_{42} = 11.6248692$$

$$Q_{42} := 10^{\log Q_{42}}$$

$$Q_{42} = 4.2156949 \times 10^{11}$$

Assumption (3): Assume H_3BO_3 concentration.

$$EQ_{BOH3} = 0.1942851$$

- The equilibrium quantities of boric acid species are:

Given:

$$Q_{11} = 2.9452002 \times 10^4$$

$$EQ_{BOH3} = 0.1942851$$

$$EQ_{OH} = 1.0339616 \times 10^{-6}$$

$$\frac{EQ_{BOH4}}{(EQ_{BOH3})EQ_{OH}} := Q_{11}$$

Given:

$$Q_{21} = 2.7719454 \times 10^4$$

$$EQ_{OH} = 1.0339616 \times 10^{-6}$$

$$EQ_{BOH3} = 0.1942851$$

$$\frac{EQ_{B2OH7}}{(EQ_{BOH3})^2EQ_{OH}} := Q_{21}$$

Given:

$$Q_{31} = 2.443136 \times 10^6$$

$$EQ_{OH} = 1.0339616 \times 10^{-6}$$

$$EQ_{BOH3} = 0.1942851$$

$$\frac{EQ_{B3OH10}}{(EQ_{BOH3})^3EQ_{OH}} := Q_{31}$$

Given:

$$Q_{42} = 4.2156949 \times 10^{11}$$

$$EQ_{OH} = 1.0339616 \times 10^{-6}$$

Calculation:

Solved equivalently for $[B(OH)_4^-]$:

$$EQ_{BOH4} := (Q_{11})(EQ_{BOH3})(EQ_{OH})$$

$$EQ_{BOH4} = 5.9164159 \times 10^{-3}$$

Calculation:

Solved equivalently for $[B_2(OH)_7^-]$:

$$EQ_{B2OH7} := (Q_{21})(EQ_{BOH3})^2(EQ_{OH})$$

$$EQ_{B2OH7} = 1.0818524 \times 10^{-3}$$

Calculation:

Solved equivalently for $[B_3(OH)_{10}^-]$:

$$EQ_{B3OH10} := (Q_{31})(EQ_{BOH3})^3(EQ_{OH})$$

$$EQ_{B3OH10} = 0.0185255$$

Calculation:

Solved equivalently for $[B_4(OH)_{14}^{2-}]$:

$$EQ_{B4OH14} := (Q_{42})(EQ_{BOH3})^4(EQ_{OH})^2$$

$$EQ_{BOH3} = 0.1942851$$

$$\frac{EQ_{B4OH14}}{(EQ_{BOH3})^4 EQ_{OH}^2} := Q_{42}$$

$$EQ_{B4OH14} = 6.4214904 \times 10^{-4}$$

- The Boron concentration based on the above quantities is:

$$\text{Molality}_{\text{Boron}} := EQ_{BOH3} + EQ_{BOH4} + 2EQ_{B2OH7} + 3EQ_{B3OH10} + 4EQ_{B4OH14}$$

$$\text{Molality}_{\text{Boron}} = 0.2605104 \frac{\text{grammole}}{\text{liter}}$$

- The error due to Assumption (4) above is

$$\text{Error}_B := \frac{\left| \text{Molality}_{\text{Boron}} \left(\frac{\text{grammole}}{\text{liter}} \right) - \text{Conc}_B \right|}{\text{Conc}_B}$$

$$\text{Error}_B = 6.3312843 \times 10^{-7}$$

Therefore, Assumption (3) above is verified.

- Na concentration is:

Given:

$$\text{Molality}_{\text{TSP}} = 0.0191638$$

$$N_{\text{NaOH}} = 0.25$$

Calculation:

$$\text{Conc}_{\text{Na}} := (3 + N_{\text{NaOH}}) \cdot \text{Molality}_{\text{TSP}}$$

$$\text{Conc}_{\text{Na}} = 0.0622824 \frac{\text{grammole}}{\text{liter}}$$

- Charge balance error, due to assumption (2) is:

Given:

Concentrations of I^- , Cl^- , Cs^+ , and NO_3^- need to be redefined without units for charge balance.

$$I_{HI} := \text{Conc}_I \frac{\text{liter}}{\text{grammole}} \quad I_{HI} = 4.5748774 \times 10^{-5}$$

$$Cs := \text{Conc}_{Cs} \frac{\text{liter}}{\text{grammole}} \quad Cs = 4.1234716 \times 10^{-4}$$

$$Cl_{HCl} := \text{Conc}_{Cl} \frac{\text{liter}}{\text{grammole}} \quad Cl_{HCl} = 2.8281281 \times 10^{-4}$$

$$NO3_{HNO3} := \text{Conc}_{HNO3} \frac{\text{liter}}{\text{grammole}} \quad NO3_{HNO3} = 8.76 \times 10^{-4}$$

$$\text{Conc}_{\text{Na}} = 0.0622824$$

$$EQ_H = 3.8020818 \times 10^{-8}$$

$$EQ_{OH} = 1.0339616 \times 10^{-6}$$

$$EQ_{H_2PO_4} = 3.6472153 \times 10^{-3}$$

$$EQ_{HPO_4} = 0.0155158$$

$$EQ_{PO_4} = 7.3565624 \times 10^{-7}$$

$$EQ_{BOH_4} = 5.9164159 \times 10^{-3}$$

$$EQ_{B_2OH_7} = 1.0818524 \times 10^{-3}$$

$$EQ_{B_3OH_{10}} = 0.0185255$$

$$EQ_{B_4OH_{14}} = 6.4214904 \times 10^{-4}$$

Calculation:

$$CBEB := EQ_H - EQ_{OH} - EQ_{BOH_4} - EQ_{B_2OH_7} - EQ_{B_3OH_{10}} - 2 \cdot EQ_{B_4OH_{14}}$$

$$CBEB = -0.0268091$$

$$CBEP := Conc_{Na} - EQ_{H_2PO_4} - 2 \cdot EQ_{HPO_4} - 3 \cdot EQ_{PO_4} + Cs - I_{HI} - Cl_{HCl} - NO_3_{HNO_3}$$

$$CBEP = 0.0268091$$

$$CBE := \left[\frac{2 \cdot (CBEB + CBEP)}{(CBEB - CBEP)} \right]$$

$$CBE = 7.9402646 \times 10^{-7}$$

Therefore, Assumption (2) above is verified.

- The ionic strength of the solution is:

$$I_s := \frac{(C_1 \cdot Z_1^2 + C_2 \cdot Z_2^2 + \dots + C_n \cdot Z_n^2)}{2}$$

$$I_s := \frac{\left(Conc_{Na} + EQ_H + EQ_{OH} + EQ_{H_2PO_4} + 2^2 EQ_{HPO_4} + 3^2 EQ_{PO_4} + EQ_{BOH_4} + EQ_{B_2OH_7} \dots \right. \\ \left. + EQ_{B_3OH_{10}} + 2^2 EQ_{B_4OH_{14}} + Cs + I_{HI} + Cl_{HCl} + NO_3_{HNO_3} \right)}{2}$$

$$I_s = 0.078855$$

$$Error_I := \frac{|I_s - I|}{I}$$

$$\text{Error}_1 = 4.1956195 \times 10^{-7}$$

Therefore, Assumption (1) above is verified.

Subject: RB Sump Post-LOCA pH and TSP Quantity	Calculation No. C-1101-153-E410-040	Rev. No. 0	System Nos. 214	Sheet 72 of 75
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Attachment E Reference Materials

1. E-mail from Robert Allison (ICL) to Stephen Eichfeld (S&L), Subject: TSPc bulk density, dated 5/2/200..... 73
2. Debye-Huckel Constants vs. Temperature 75



<Stephen.Eichfeld@exeloncorp.com>

06/11/2007 08:51 AM

To <jeri.c.penrose@sargentlundy.com>

cc <william.f.bartling@sargentlundy.com>, <william.bartling@exeloncorp.com>

bcc

Subject FW: TSPc bulk density

Jeri,

Here is the email from ICL on the density of the bulk TSPc powder, and the latest basket drawing file. The drawing still lacks the total number of baskets, otherwise the drawing is done.

Steve
717-948-8125 (TMI)

-----Original Message-----

From: Robert.Allison@icl-pplp.com [mailto:Robert.Allison@icl-pplp.com]

Sent: Wednesday, May 02, 2007 5:04 PM

To: Eichfeld, Stephen

Subject: TSPc bulk density

Stephen,

According to our records, the sample you received was:

Product Trisodium Phosphate Dodecahydrate
 (TSPC) MED

Accordingly, the bulk density would be:

TSPc powder = 0.82 g/cc, 51
lb/cu.ft.

Should you need any further information please call.

Thanks,
Rob

908 832 0819

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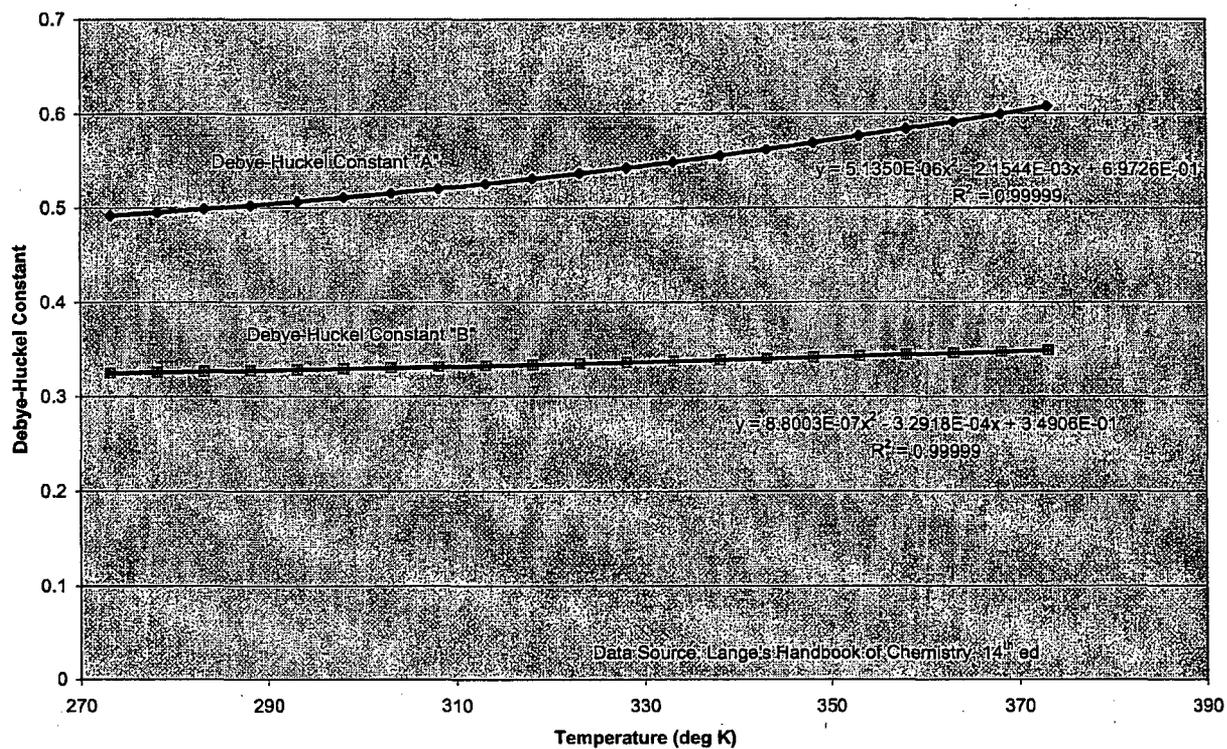
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Thank You.



1E-153-02-011S2a.tif

Debye-Huckel Constants



Attachment 3

AmerGen/Exelon Calculation C-1101-900-E000-087, Revision 2,
"Post-LOCA EAB, LPZ, TSC, and CR Doses Using AST and RG 1.183 Requirements"

(Electronic CD)

ENCLOSURE 2

**TMI Unit 1 Technical Specification Change Request No. 337
Markup of Proposed Technical Specifications and Bases Page Changes**

Revised Technical Specifications & Bases Pages

3-22
3-23
3-24
4-2b
4-7
4-10
4-10c

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3.3 EMERGENCY CORE COOLING, REACTOR BUILDING EMERGENCY COOLING AND REACTOR BUILDING SPRAY SYSTEMS (Contd.)

- b. CFT boron concentration shall not be less than 2,270 ppm boron. Specification 3.3.2.1 applies.
- c. The electrically operated discharge valves from the CFT will be assured open by administrative control and position indication lamps on the engineered safeguards status panel. Respective breakers for these valves shall be open and conspicuously marked. A one hour time clock is provided to open the valve and remove power to the valve. Specification 3.0.1 applies.
- d. DELETED
- e. CFT vent valves CF-V-3A and CF-V-3B shall be closed and the breakers to the CFT vent valve motor operators shall be tagged open, except when adjusting core flood tank level and/or pressure. Specification 3.0.1 applies.

3.3.1.3 Reactor Building Spray System and Reactor Building Emergency Cooling System

The following components must be OPERABLE:

- a. Two reactor building spray pumps and their associated spray nozzles headers and two reactor building emergency cooling fans and associated cooling units (one in each train). Specification 3.0.1 applies.

INSERT
A

- b. The sodium hydroxide (NaOH) tank shall be maintained at 8 ft. +6 inches lower than the BWST level as measured by the BWST/NaOH tank differential pressure indicator. The NaOH tank concentration shall be 10.0 ± 5 weight percent (%). Specification 3.3.2.1 applies.

- c. All manual valves in the discharge lines of the NaOH tank shall be locked open. Specification 3.3.2.1 applies.

3.3.1.4 Cooling Water Systems - Specification 3.0.1 applies.

- a. Two nuclear service closed cycle cooling water pumps must be OPERABLE.
- b. Two nuclear service river water pumps must be OPERABLE.
- c. Two decay heat closed cycle cooling water pumps must be OPERABLE.
- d. Two decay heat river water pumps must be OPERABLE.
- e. Two reactor building emergency cooling river water pumps must be OPERABLE.

3.3.1.5 Engineered Safeguards Valves and Interlocks Associated with the Systems in Specifications 3.3.1.1, 3.3.1.2, 3.3.1.3, 3.3.1.4 are OPERABLE. Specification 3.0.1 applies.

INSERT A - TS PAGE 3-22

The Reactor Building emergency sump pH control system shall be maintained with $\geq 18,815$ lbs and $\leq 28,840$ lbs of trisodium phosphate dodecahydrate (TSP). Specification 3.3.2.1 applies.

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3.3 EMERGENCY CORE COOLING, REACTOR BUILDING EMERGENCY COOLING AND REACTOR BUILDING SPRAY SYSTEMS (Contd.)

3.3.2 Maintenance or testing shall be allowed during reactor operation on any component(s) in the makeup and purification, decay heat, RB emergency cooling water, RB spray, BWST level instrumentation, or cooling water systems which will not remove more than one train of each system from service. Components shall not be removed from service so that the affected system train is inoperable for more than 72 consecutive hours. If the system is not restored to meet the requirements of Specification 3.3.1 within 72 hours, the reactor shall be placed in a HOT SHUTDOWN condition within six hours.*

3.3.2.1 If the CFT boron concentration is outside of limits, or NaOH tank is outside the limits of ~~3.3.1.3.b or any manual valve in the NaOH tank/discharge lines are not locked open~~, restore the system to operable status within 72 hours. If the system is not restored to meet the requirements of Specification 3.3.1 within 72 hours, the reactor shall be placed in a HOT SHUTDOWN condition within six hours.

or if the TSP baskets contain amounts of TSP outside the limits specified in 3.3.1.3.b,

3.3.3 Exceptions to 3.3.2 shall be as follows:

- Both CFTs shall be OPERABLE at all times.
- Both the motor operated valves associated with the CFTs shall be fully open at all times.
- One reactor building cooling fan and associated cooling unit shall be permitted to be out-of-service for seven days.

3.3.4 Prior to initiating maintenance on any of the components, the duplicate (redundant) component shall be verified to be OPERABLE.

* In accordance with AmerGen License Change Application dated February 14, 2001, and any requirements in the associated NRC Safety Evaluation, a portion of the Nuclear Service Water System piping between valves NR-V-3 and NR-V-5 may be removed from service and Nuclear Services River Water flow realigned through a portion of the Secondary Services River Water System piping for up to 14 days. This note is applicable for one time use during TMI Unit 1 Operating Cycle 13.

Bases

The requirements of Specification 3.3.1 assure that, before the reactor can be made critical, adequate engineered safety features are operable. Two engineered safeguards makeup pumps, two decay heat removal pumps and two decay heat removal coolers (along with their respective cooling water systems components) are specified. However, only one of each is necessary to supply emergency coolant to the reactor in the event of a loss-of-coolant accident. Both CFTs are required because a single CFT has insufficient inventory to reflood the core for hot and cold line breaks (Reference 1).

The operability of the borated water storage tank (BWST) as part of the ECCS ensures that a sufficient supply of borated water is available for injection by the ECCS in the event of a LOCA (Reference 2). The limits on BWST minimum volume and boron concentration ensure that 1) sufficient water is available within containment to permit recirculation cooling flow to the core, and 2) the reactor will remain at least one percent subcritical following a Loss-of-Coolant Accident (LOCA).

The contained water volume limit of 350,000 gallons includes an allowance for water not usable because of tank discharge location and sump recirculation switchover setpoint. ~~The limits on contained water volume, NaOH concentration and boron concentration ensure a pH value of~~

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3.3 EMERGENCY CORE COOLING, REACTOR BUILDING EMERGENCY COOLING AND REACTOR BUILDING SPRAY SYSTEMS (Contd.)

Bases (Contd.)

between 8.0 and 11.0 of the solution sprayed within containment after a design basis accident. The minimum pH of 8.0 assures that iodine will remain in solution while the maximum pH of 11.0 minimizes the potential for caustic damage to mechanical systems and components.

Redundant heaters maintain the borated water supply at a temperature greater than 40°F.

Maintaining MUT pressure and level within the limits of Fig 3.3-1 ensures that MUT gas will not be drawn into the pumps for any design basis accident. Preventing gas entrainment of the pumps is not dependent upon operator actions after the event occurs. The plant operating limits (alarms and procedures) will include margins to account for instrument error.

The post-accident reactor building emergency cooling may be accomplished by three emergency cooling units, by two spray systems, or by a combination of one emergency cooling unit and one spray system. The specified requirements assure that the required post-accident components are available.

The iodine removal function of the reactor building spray system requires one spray pump ^{and} sodium hydroxide tank contents and TSP in baskets located in the reactor building basement.

The spray system utilizes common suction lines with the decay heat removal system. If a single train of equipment is removed from either system, the other train must be assured to be operable in each system.

When the reactor is critical, maintenance is allowed per Specification 3.3.2 and 3.3.3 provided requirements in Specification 3.3.4 are met which assure operability of the duplicate components. The specified maintenance times are a maximum. Operability of the specified components shall be based on the satisfactory completion of surveillance and inservice testing and inspection required by Technical Specification 4.2 and 4.5.

The allowable maintenance period of up to 72 hours may be utilized if the operability of equipment redundant to that removed from service is verified based on the results of surveillance and inservice testing and inspection required by Technical Specification 4.2 and 4.5.

In the event that the need for emergency core cooling should occur, operation of one makeup pump, one decay heat removal pump, and both core flood tanks will protect the core. In the event of a reactor coolant system rupture their operation will limit the peak clad temperature to less than 2,200 °F and the metal-water reaction to that representing less than 1 percent of the clad.

Two nuclear service river water pumps and two nuclear service closed cycle cooling pumps are required for normal operation. The normal operating requirements are greater than the emergency requirements following a loss-of-coolant.

REFERENCES

- (1) UFSAR, Section 6.1 - "Emergency Core Cooling System"
- (2) UFSAR, Section 14.2.2.3 - "Large Break LOCA"

INSERT B – TS PAGE 3-24 (Bases for Section 3.3)

The Reactor Building emergency sump pH control system ensures a sump pH between 7.3 and 8.0 during the recirculation phase of a postulated LOCA. A minimum pH level of 7.3 is required to reduce the potential for chloride induced stress corrosion cracking of austenitic stainless steel and assure the retention of elemental iodine in the recirculating fluid. A maximum pH value of 8.0 minimizes the formation of precipitates that may migrate to the emergency sump and minimizes post-LOCA hydrogen generation. Trisodium phosphate dodecahydrate is used because of the high humidity that may be present in the Reactor Building during normal operation. This form is less likely to absorb large amounts of water from the atmosphere.

All TSP baskets are located outside of the secondary shield wall in the Reactor Building basement (El. 281'-0"). Therefore, the baskets are protected from the effects of credible internal missiles inside the shield wall. The designated TSP basket locations ensure that the baskets are not impacted by the effect of potential LOCA jet impingement forces and pipe whip.

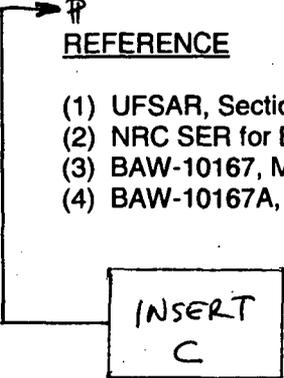
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Bases (Cont'd)

The equipment testing and system sampling frequencies specified in Tables 4.1-2, 4.1-3, and 4.1-5 are considered adequate to maintain the equipment and systems in a safe operational status.

REFERENCE

- (1) UFSAR, Section 7.1.2.3(d) - "Periodic Testing and Reliability"
- (2) NRC SER for BAW-10167A, Supplement 1, December 5, 1988.
- (3) BAW-10167, May 1986.
- (4) BAW-10167A, Supplement 3, February 1998.



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C

INSERT C – TS PAGE 4-2b (Bases for Section 4.1)

Reactor Building Emergency Sump pH Control System

Background

TSP baskets are placed on the floor (281 ft elevation) in the containment building to ensure that iodine, which may be dissolved in the recirculated primary cooling water following a Loss of Coolant Accident (LOCA), remains in solution. Recirculation of the water for core cooling and containment spray provides mixing to achieve a uniform pH. TSP also helps inhibit Stress Corrosion Cracking (SCC) of austenitic stainless steel components in containment during the recirculation phase following an accident.

Fuel that is damaged during a LOCA will release iodine in several chemical forms to the reactor coolant and to the containment atmosphere. A portion of the iodine in the containment atmosphere is washed to the sump by containment sprays. The Borated Water Storage Tank water is borated for reactivity control. This borated water, if left untreated, would cause the sump solution to be acidic. In a low pH (acidic) solution, dissolved iodine will be converted to a volatile form. The volatile iodine will evolve out of solution into the containment atmosphere, significantly increasing the levels of airborne iodine. The increased levels of airborne iodine in containment contribute to the radiological releases and increase the consequences from the accident due to containment atmosphere leakage.

After a LOCA, the components of the safety injection and containment spray systems will be exposed to high temperature borated water. Prolonged exposure to hot untreated sump water combined with stresses imposed on the components can cause SCC. The rate of SCC is a function of stress, oxygen and chloride concentrations, pH, temperature, and alloy composition of the components. High temperatures and low pH, which would be present after a LOCA, tend to promote SCC. This can lead to the failure of necessary safety systems or components.

TSP Quantity

The quantity of TSP placed in containment is designed to adjust the pH of the sump water to be between 7.3 and 8.0 after a LOCA. The hydrated form (dodecahydrate) of TSP is used because of the high humidity in the containment building during normal operation. Since the TSP is hydrated, it is less likely to absorb large amounts of water from the humid atmosphere and will undergo less physical and chemical change than the anhydrous form of TSP. A pH ≥ 7.3 is necessary to prevent significant amounts of iodine released from fuel failures and dissolved in the recirculation water from converting to a volatile form and evolving into the containment atmosphere. Higher levels of airborne iodine in containment may increase the release of radionuclides and the consequences of the accident. A pH ≥ 7.3 is also necessary to prevent SCC of austenitic stainless steel components in containment. SCC increases the probability of failure of components. The pH needs to remain ≤ 8.0 to minimize the formation of precipitates that may migrate to the emergency sump and minimize post-LOCA hydrogen generation. The minimum acceptable amount of TSP is that weight which will ensure a sump solution pH ≥ 7.3 after a LOCA, with the maximum amount of water at the minimum initial pH possible in the containment sump; a maximum acceptable

amount of TSP is that weight which will ensure a sump solution pH of ≤ 8.0 with a minimum amount of water at a maximum initial pH.

The TSP is stored in wire mesh baskets placed inside the containment at the 281 ft elevation. Any quantity of TSP between 18,815 lb and 28,840 lb. will result in a pH in the desired range. If it is discovered that the TSP in the containment building is not within limits, action must be taken to restore the TSP to within limits. The Completion Time of 72 hours is allowed for restoring the TSP within limits, where possible, because 72 hours is the same time allowed for restoration of other ECCS components.

Surveillance Testing

Periodic determination of the mass of TSP in containment must be performed due to the possibility of leaking valves and components in the containment building that could cause dissolution of the TSP during normal operation. A Refueling Frequency is required to determine that $\geq 18,815$ lbs and $\leq 28,840$ lbs are contained in the TSP baskets. This requirement ensures that there is an adequate mass of TSP to adjust the pH of the post LOCA sump solution to a value ≥ 7.3 and ≤ 8.0 . The periodic verification is required every refueling outage. Operating experience has shown this Surveillance Frequency to be acceptable due to the margin in the mass of TSP placed in the containment building.

Periodic testing is performed to ensure the solubility and buffering ability of the TSP after exposure to the containment environment. Satisfactory completion of this test assures that the TSP in the baskets is "active." Adequate solubility is verified by submerging a representative sample, taken via a sample thief or similar instrument, of TSP from one of the baskets in containment in un-agitated borated water heated to a temperature representing post-LOCA conditions; the TSP must completely dissolve within a 4 hour period. The test time of 4 hours is to allow time for the dissolved TSP to naturally diffuse through the un-agitated test solution. Agitation of the test solution during the solubility verification is prohibited, since an adequate standard for the agitation intensity (other than no agitation) cannot be specified. The agitation due to flow and turbulence in the containment sump during recirculation would significantly decrease the time required for the TSP to dissolve. Adequate buffering capability is verified by a measured pH of the sample solution, following the solubility verification, between 7.3 and 8.0. The sample is cooled and thoroughly mixed prior to measuring pH. The quantity of the TSP sample, and quantity and boron concentration of the water are chosen to be representative of post-LOCA conditions. A sampling Frequency of every refueling outage is specified. Operating experience has shown this Surveillance Frequency to be acceptable.

TABLE 4.1-1 (Continued)

<u>CHANNEL DESCRIPTION</u>	<u>CHECK</u>	<u>TEST</u>	<u>CALIBRATE</u>	<u>REMARKS</u>
38. OTSG Full Range Level	W	NA	R	
39. Turbine Overspeed Trip	NA	R	NA	
<i>Deleted</i> 40. BWST/NaOH Differential Pressure Indicator	NA	NA	F	
<i>Deleted</i> 41. Sodium Hydroxide Tank Level Indicator	NA	NA	F	
42. Diesel Generator Protective Relaying	NA	NA	R	
43. 4 KV ES Bus Undervoltage Relays (Diesel Start)				
a. Degraded Grid	NA	M(1)	A	(1) Relay operation will be checked by local test pushbuttons.
b. Loss of Voltage	NA	M(1)	R	(1) Relay operation will be checked by local test pushbuttons.
44. Reactor Coolant Pressure DH Valve Interlock Bistable	S(1)	M	R	(1) When reactor coolant system is pressurized above 300 psig or T_{ave} is greater than 200°F.
45. Loss of Feedwater Reactor Trip	S(1)	S/A(1)	R	(1) When reactor power exceeds 7% power.
46. Turbine Trip/Reactor Trip	S(1)	S/A(1)	F	(1) When reactor power exceeds 45% power.
47. a. Pressurizer Code Safety Valve and PORV Tailpipe Flow Monitors	S(1)	NA	F	(1) When T_{ave} is greater than 525°F.
b. PORV – Acoustic/Flow	NA	M(1)	R	(1) When T_{ave} is greater than 525°F.
48. PORV Setpoints	NA	M(1)	R	(1) Per Specification 3.1.12 excluding valve operation.

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TABLE 4.1-3 Cont'd

<u>Item</u>	<u>Check</u>	<u>Frequency</u>
4. Spent Fuel Pool Water Sample	Boron Concentration greater than or equal to 600 ppmb	Weekly
5. Secondary Coolant	Isotopic analysis for DOSE EQUIVALENT I-131 concentration	At least once per 72 hours when reactor coolant system pressure is greater than 300 psig or T _{av} is greater than 200°F.
6. Deleted		
7. Deleted		
8. Deleted		
9. Deleted		
10. Sodium Hydroxide Tank	Concentration	Semi-Annually and after each makeup.
11. Deleted		
12. Deleted		

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Until the specific activity of the primary coolant system is restored within its limits.

* Sample to be taken after a minimum of 2 EFPD and 20 days of POWER OPERATION have elapsed since the reactor was last subcritical for 48 hours or longer.

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TABLE 4.1-5
SYSTEM SURVEILLANCE REQUIREMENTS

<u>Item</u>	<u>Test</u>	<u>Frequency</u>
1. Core Flood Tank	a. Verify two core flood tanks each contain 940 ± 30 ft ³ borated water.	S
	b. Verify that two core flood tanks each contain 600 ± 25 psig.	S
	c. Verify CF-V-1A&B are fully open.	S
	d. Verify power is removed from CF-V-1A&B and CF-V-3A&B valve operators	M

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D →

INSERT D – TS PAGE 4-10c

- | | | |
|---|--|----------|
| 2. Reactor Building
Emergency Sump
pH Control
System | a. Verify the TSP baskets
contain \geq 18,815 lbs and
\leq 28,840 lbs of TSP. | R |
| | b. Verify that a sample from
the TSP baskets
provides adequate pH
adjustment of borated
water. | R |

ENCLOSURE 3

List of Commitments

SUMMARY OF AMERGEN COMMITMENTS

The following table identifies regulatory commitments made in this document by AmerGen. (Any other actions discussed in the submittal represent intended or planned actions by AmerGen. They are described to the NRC for the NRC's information and are not regulatory commitments.)

COMMITMENT	COMMITTED DATE OR "OUTAGE"	COMMITMENT TYPE	
		ONE-TIME ACTION (Yes/No)	PROGRAMMATIC (Yes/No)
Install TSP buffer modification and isolate NaOH tank BS-T-2.	Within 30 days of approval of the TSP buffer license amendment request.	Yes	No
At least one manual valve in each supply train will be locked closed providing permanent isolation of the NaOH tank.	Within 30 days of approval of the TSP buffer license amendment request.	No	Yes