ENCLOSURE 4

MONTICELLO NUCLEAR GENERATING PLANT CALCULATION

CA-05-072

Effect of Reduced Pool Water Levels on Fuel Handling Accident Consequences

This enclosure consists of a copy of the Monticello Nuclear Generating Plant Calculation CA-05-072, "Effect of Reduced Pool Water Levels on Fuel Handling Accident Consequences." This calculation is current as of the date of this letter. Future revisions to this calculation, if any, will be available onsite for staff review.

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CALCULATION COVER SHEET

Title *Effect of Reduced Pool Water Levels on Fuel Handling Accident Consequences* CA- *05* - *072* Add. *0*

PART A – (Not Applicable to Vendor Calcs)

Assigned Personnel

Name (Print)	Signature	Title	Initials

Record of Issues

Rev	Description	Total Sheets	Last Sheet	Preparer	Verifier	Approval	Approval Date

Verification Method(s)

☐ Review ☐ Alternate Calculation ☐ Test ☐ Other

☐ Technical Review (per 4 AWI-05.08.07 (FP-E-MOD-07))

3087 (DOCUMENT CHANGE, HOLD AND COMMENT FORM) incorporated:				
FOR ADMINISTRATIVE USE ONLY	Resp Supv: CNSTP	Assoc Ref: 4 AWI-05.01.25	SR: N	Freq: 0 yrs
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Approved (Signatures available in Master File)

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PART B – (Applicable to Vendor Calculations Only)

Vendor Name *Sargent & Lundy* Vendor Calc No: *2004-09840*

Vendor Approval Date: *03/07/2005*

☒ Form 3345 or QF-0547 attached.

☒ Safety related? If checked, attach DIA or reference here. *SLMON-2005-017*

Reviewed by: *Melissa Limbeck / Kathy Shriver* MLimbeck/K.K. Shriver 3/11/05

Print Name Signature Date

Accepted by: *Al Williams* 3/17/05

Print Name Eng. Supv. Signature Date

Record of Issues

Revision	Description	Total No. of Sheets	Last Sheet Number
0	Initial Calculation	29	23 of 23

PART C – Design Basis Tracking Data (Complete for all Calculations)

10 CFR50.59 Screening or Evaluation No: *N/A*

Associated Reference(s): *AST Phase 1 (FHA) LAR*

Does this calculation:

Supercede another calculation?	Yes ☐	No ☒:	Calc. No(s) Rev.s & Add No(s):
Augment (credited by) another calculation?	Yes ☒	No ☐:	Calc. No(s) Revs & Add No(s): *04-041, Rev 1; 05-081, Rev 0*
Derive inputs from another calculation?	Yes ☐	No ☒:	Calc. No(s) Revs & Add No(s):
Affect the Fire Protection Program (Form 3765)?	Yes (attach Form 3765) ☐	No ☒	

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Affect piping or supports?	Yes (attach Form 3544) ☐	No ☒	

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Does this calculation (Cont'd):

Affect IST Program Valve or Pump Reference Values, and/or Acceptance Criteria? If yes, inform the IST Coordinator and provide with copy of revised calculation.	Yes ☐	No ☒	

List all documents/procedures that are based on this calculation:

Documents/Procedures (include revision): USAR, Rev 21 (Section 14.7.6); AST Phase 1 (FHA) LAR *

List all plant procedures used to ensure inputs/assumptions/outputs are maintained:

Procedures (include revision): USAR, Rev 21 (Section 14.7.6) *

What Systems or components are affected?

System Code(s): (See Form 3805 (DESIGN BASIS INFORMATION SYSTEM (DBIS) CODES FOR SYSTEMS, STRUCTURES AND TOPICS) for available codes)) FPC, RCH

Component ID's (CHAMPS Equip) N/A

DBD Section (if any): B.02.01: Table 1.1; Sections 1, 2, 4

Topic Code: (See Form 3805 for available codes) DBAE

Structure Code: (See Form 3805 for available codes) N/A

Other Comments: See next page.

Approved (Signatures available in Master File)

Future needs (reference EWR024927): Update USAR and DBD relevant sections. Determine procedural controls to ensure consideration and update of this calculation if fuel design or refuel bridge and mast configuration change.

This calculation was completed in accordance with the approved project work plan (DIA Equivalent) S&L Letter # SLMON-2005-017, and P502378.

*This calculation provides the basis for amendment to TS 3.10.C, Spent Fuel Pool Water Level, as part of the AST Phase 1 (FHA) LAR. This calculation also provides the basis for pool water level specifications for the ITS submittal. Procedures referencing required spent fuel pool water level will be based on the TS itself rather than this calculation, and will be revised as part of the TS or ITS implementation process. These procedures include: 0000-J; 9007; 9007-B; 9009; D.2-02; D.2-05.

Approved (Signatures available in Master File)

MONTICELLO NUCLEAR GENERATING PLANT		3345
TITLE:	VENDOR CALCULATION REVIEW CHECKLIST	Revision 3
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Attachment 1

The purpose of the review is to ensure that the vendor calculation or analysis complies with the conditions of the purchase order and is appropriate for its intended use. The purpose of the review is not to serve as an independent verification. Independent verification of the calculation or analysis by the vendor should be evident in the document.

The reviewer should use the criteria below as a guide to assess the overall quality, completeness and usefulness of the calculation or analysis. The reviewer is not required to check the vendor's calculations in detail.

See 4 AWI-05.01.25 (CALCULATION/ANALYSIS CONTROL) for guidance. Place initials by items reviewed.

REVIEW

1. Form 3544 (PIPING AND SUPPORT NUMBERING) completed for calculations affecting piping or supports. N/A
2. Design inputs correspond to those which were transmitted to the vendor.
3. Assumptions are described and reasonable. Basis for assumptions identified.
4. Applicable codes, standards and regulations are identified and met.
5. Applicable construction and operating experience is considered.
6. Applicable structure(s), system(s), and component(s) are listed.
7. Formulas and equations documented and unusual symbols are defined.
8. Acceptance criteria are identified, adequate and satisfied.
9. Results are reasonable compared to inputs.
10. Source documents are referenced.
11. The calculation is appropriate for its intended use.
12. The calculation complies with the terms of the Purchase Order.
13. Inputs, assumptions, outputs, etc. which could affect plant operation are enforced by adequate procedural controls. List any affected procedures.
    Reference EWR024927, Future Needs for CA-05-072.

Completed By: KShriver / [illegible] Date: 3-11-2005

3087 (DOCUMENT CHANGE, HOLD AND COMMENT FORM) incorporated:				
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ISSUE SUMMARY
Form SOP-0402-07, Revision 6

DESIGN CONTROL SUMMARY

CLIENT:	Nuclear Management Company	UNIT NO.: 1	Page No.: 1
PROJECT NAME:	Monticello		
PROJECT NO.:	11163-063	☒ NUCLEAR SAFETY- RELATED	
CALC. NO.:	2004-09840	☐ NOT NUCLEAR SAFETY-RELATED	
TITLE:	Effect of Reduced Pool Water Levels on Fuel Handling Accident Consequences		
EQUIPMENT NO.:			

IDENTIFICATION OF PAGES ADDED/REVISED/SUPERSEDED/VOIDED & REVIEW METHOD

Original Calculation (23 pages)

INPUTS/ ASSUMPTIONS
☒ VERIFIED
☐ UNVERIFIED

REVIEW METHOD:	Detailed	REV.	0
STATUS:	Approved	DATE FOR REV.:	3-7-2005
PREPARER	W. J. Johnson	DATE:	3/7/05
REVIEWER	B. J. Andrews	DATE:	3-7-2005
APPROVER	S. R. Raupp	DATE:	3-7-2005

IDENTIFICATION OF PAGES ADDED/REVISED/SUPERSEDED/VOIDED & REVIEW METHOD

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☐ VERIFIED
☐ UNVERIFIED

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IDENTIFICATION OF PAGES ADDED/REVISED/SUPERSEDED/VOIDED & REVIEW METHOD

INPUTS/ ASSUMPTIONS
☐ VERIFIED
☐ UNVERIFIED

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NOTE: PRINT AND SIGN IN THE SIGNATURE AREAS

Sargent & Lundy LLC

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Project	Monticello	Reviewed by	Date
Proj. No	11163-063 Equip. No.	Approved by	Date

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1 PURPOSE AND SCOPE

The purpose of this calculation is to determine the effect of reduced water level in the Refueling Pool (RP) and Spent Fuel Storage Pool (SFSP) on radiological consequences following a Fuel Handling Accident (FHA). The depth of water affects the radiological consequences because credit is taken for removal by the pool water of airborne iodine nuclides, thereby reducing the amount of activity released from the plant and the resulting radiation doses. As described in the Section 14.7.6.1 of the MNGP USAR [Reference 7.5], the limiting FHA is one resulting from the accidental dropping of a fuel assembly into the reactor vessel onto the top of the core. The objective of this calculation is to demonstrate that the current design basis (limiting) FHA is bounding for an FHA that involves the drop of an assembly in the RP (such as on the Reactor Pressure Vessel (RPV) flange) or in the SFSP.

The scope of this calculation involves three separate analyses:

- Effect of Water Level on Iodine Removal. A generic analysis is performed to demonstrate the effect of reduction of pool water level on the amount of iodine activity released from the pool.
- Evaluation of the Drop of an Assembly in the RP. The drop of an assembly in the RP (rather than in the reactor vessel) is evaluated to demonstrate that the consequences are bounded by the current design basis FHA.
- Evaluation of the Drop of an Assembly in the SFSP. The current design basis FHA is a drop of an assembly into the reactor vessel. A drop of an assembly in the SFSP is evaluated to demonstrate that it is bounded by the current design basis FHA.

The current design basis analysis for the FHA uses the assumptions outlined in Regulatory Guide 1.25 (RG 1.25) [Reference 7.1], which includes assumptions concerning removal of iodine by the pool water. An alternative method of analysis for the FHA is outlined in Regulatory Guide 1.183 (RG 1.183) [Reference 7.2], which includes different assumptions concerning removal of iodine by the pool water. Calculation 2004-02104 [Reference 7.7] documents the FHA analysis performed for MNGP using RG 1.183 (AST) methodology. This analysis addresses both sets of assumptions.

2 DESIGN INPUT

2.1 The minimum depth of water in the refueling pool in the fuel movement path is the depth to the cattle chute floor. With a refueling water height at elevation 1026'-2", this depth is 21'-8" and the minimum water depth above the RPV flange is 22'-2". [Reference 7.3, Item 1]

2.2 With a refueling water height at elevation 1026'-2", the minimum depth of water in the reactor pressure vessel above the core during fuel movement is 45'-10". [Reference 7.3, Item 2]

2.3 With a refueling water height at elevation 1026'-2", the minimum depth of water in the SFSP above spent fuel during fuel movement is 21'-9". The minimum depth of water above damaged fuel (dropped bundle) is 21'-4". [Reference 7.3, Item 11]

2.4 Maximum height of fuel assembly above the RPV flange during fuel movement is 3'-2". [Reference 7.3, Item 3]

2.5 Maximum height of a fuel assembly above core during fuel movement is 26'-10". [Reference 7.3, Item 4]

2.6 Maximum height of a fuel assembly in the SFSP above the spent fuel during fuel movement is 2'-10". [Reference 7.3, Item 12]

2.7 The inorganic iodine species fraction for RG 1.25 analysis is 99.75%, and the inorganic iodine species fraction for RG 1.183 analysis is 99.85%. [Reference 7.3, Item 5]

2.8 The pool decontamination factor for inorganic iodine for a pool depth of 23' is 133 for the RG 1.25 analysis and 500 for the RG 1.183 analysis. [Reference 7.3, Item 6]

2.9 The decontamination factor for organic iodine is 1.0 for both the RG 1.25 and RG 1.183 analysis. [Reference 7.3, Item 7]

2.10 The number of fuel rods in the fuel assembly considered in the design basis FHA analysis is 60, based on an 8x8 fuel assembly. [Reference 7.3, Item 8]

2.11 The length of a GE14 BWR/3 fuel assembly is approximately 14.3'. This is the difference between the height of the fuel assembly above the bottom of the SFSP and the height of the bottom of the fuel racks: 185.24"-8.99"-5.19" = 171.06" ≅ 14.3' [Reference 7.3, Item 11]

2.12 The number of failed fuel rods assumed in the design basis FHA is 125, based on an 8x8 fuel assembly. [Reference 7.3, Item 10]

2.13 The weight of the GE14 BWR/3 fuel assembly dropped in the FHA is 553 lbs. [Reference 7.3, Item 13]

2.14 The weight of the NF-400 refueling mast that is dropped with the fuel assembly is 350 lbs. [Reference 7.3, Item 14]

2.15 The fraction of GE14 BWR/3 fuel assembly weight (not including fuel) that is associated with the fuel cladding is 0.525. [Reference 7.3, Item 15]

2.16 Current MNGP core and refuel loads include GE11 BWR/3 and GE14 BWR/3 fuel. [Reference 7.3, Item 13]

2.17 The equivalent number of full length fuel rods in a GE14 BWR/3 fuel assembly is 87.33. [Reference 7.8, pg 90]

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Project	Monticello	**Reviewed by**	**Date**
Proj. No	11163-063 **Equip. No.**	**Approved by**	**Date**

3 ASSUMPTIONS

3.1 All iodine that is not inorganic is assumed to be organic. The organic species fraction specified in RG 1.25 is 0.25% and the organic species fraction specified in RG 1.183 is 0.15%.

3.2 As specified in RG 1.25 and RG 1.183, the retention of noble gas activity in the pool water is negligible, i.e., the decontamination factor for noble gas activity is 1.

3.3 The method for determining the number of failed fuel rods resulting from the drop of a fuel assembly is based on the assumptions described in MNGP USAR Section 14.7.6 [Reference 7.5] and GESTAR II [Reference 7.6]. These assumptions are summarized in Section 4.2 of this calculation.

4 METHODOLOGY AND ACCEPTANCE CRITERIA

4.1 Effect of Pool Water Depth on Pool Decontamination Factor

Both RG 1.25 and RG 1.183 indicate that for pool water depths less than 23' the decontamination factor will have to be determined on a case-by-case method. The pool water depth is defined as the depth of water above the damaged fuel. RG 1.183 cites as a reference for the methodology Reference 7.4. Inspection of this reference indicates it is the basis for the guidance provided in RG 1.25. Therefore, the methodology used in this calculation to determine the decontamination factor for pool water depths less than 23' is based on Reference 7.4.

The decontamination factor (DF) is defined as the ratio of the initial to final concentrations of species of interest in a bubble of gas that passes through the pool of water. The DF differs for the inorganic and organic species of iodine and must be evaluated separately for each one. For organic iodine the DF is assumed to be 1, i.e., there is no absorption in the pool water. For inorganic species, the DF is defined by the following expression.

$$DF_{Inorg} = \exp\left(\frac{6}{d_b} k_{eff} \frac{H}{v_b}\right) \qquad (1)$$

The parameters in this equation are defined as follows:

d_b = bubble diameter
k_{eff} = mass transfer coefficient
v_b = bubble velocity
H = bubble rise height, or the effective depth of the water in the pool

The bubble diameter is affected by the size of the orifice through which the leak occurs, which will not change as a function of pool depth. Similarly, since the bubble velocity is directly related to bubble volume it is also not expected to be sensitive to small changes in pool depth. The mass transfer coefficient is determined largely by the characteristics of the water, which will also not change with pool depth. Therefore, these three parameters can be held constant, and the equation for the DF can be rewritten as follows.

$$DF_{Inorg} = \exp(CH) \qquad (2)$$

In this expression, C is defined as follows.

$$C=\frac{6}{d_b}k_{eff}\frac{1}{v_b} \qquad (3)$$

If the DF is known for some specific pool water depth, H_0, the DF for any other water depth H_1 can be determined by the following expression.

$$\frac{DF_{Inorg,1}}{DF_{Inorg,0}}=\frac{\exp(CH_1)}{\exp(CH_0)} \qquad (4)$$

To remove the constant (C) from this equation, the natural logarithm of both sides is taken, resulting in the following equation.

$$\ln(DF_{Inorg,1})-\ln(DF_{Inorg,0})=CH_1-CH_0 \qquad (5)$$

From equation (2) above, the following expression for C results from taking the natural logarithm of both sides of the equation.

$$C=\frac{\ln(DF_{inorg,0})}{H_0} \qquad (6)$$

Substituting this definition for C and rearranging results in the following expression.

$$\ln(DF_{Inorg,1})=\frac{H_1}{H_0}\ln(DF_{Inorg,0}) \qquad (7)$$

Using the relationship $a\ln(x)=\ln(x^a)$, this can be rewritten as follows by exponentiating both sides of the equation.

$$DF_{Inorg,1}=(DF_{Inorg,0})^{\frac{H_1}{H_0}} \qquad (8)$$

The overall DF for the pool is a function of both the DF for the iodine species and the species fraction. Since the DF for organic iodine is 1, the pool DF is given by the following expression.

$$DF_{Eff}=\frac{1}{\dfrac{fraction\ inorganic}{DF_{Inorg}}+\dfrac{fraction\ organic}{1}} \qquad (9)$$

It should be noted that the use of the species fractions and DFs from RG 1.25 results in an effective DF of 100, as stated in the regulatory guide. However, using the species fractions and DFs from RG 1.183 results in an effective DF of 286, which is larger than the DF of 200 specified in the regulatory guide. This discrepancy is a deliberate effort by the NRC to reduce the uncertainty in the pool DF. To maintain this margin, the DF calculated using the RG 1.183 species fractions and DF is normalized to a DF of 200 at a pool depth of 23'.

4.2 Effect of Pool Depth on Fuel Failure

The amount of activity released following an FHA is characterized by two parameters. The first is the amount of activity in the void space of a fuel rod, which is commonly called the gap activity and is specified on a nuclide basis as a fraction of the total core inventory. The second parameter is the number of failed fuel rods caused by the accident since it is assumed that all of the gap activity in each failed fuel rod is released. The gap activity is a characteristic of the operation of the reactor and is not affected by pool depth. The number of failed fuel rods, however, is affected by pool depth since the pool depth determines, in part, how far the fuel assembly will fall before the impact that causes the fuel rods to fail.

The FHA is described in Section 14.7.6 of the Monticello USAR [Reference 7.5]. The method for determining the number of failed rods is taken from GESTAR II [Reference 7.6]. GESTAR II contains a detailed analysis of the drop of a 9x9 fuel assembly (GE11 or GE13). The following assumptions are made in the determination of the total number of failed fuel rods.

1. The fuel assembly is assumed to be dropped from a height of 34', which is based on a drop into the reactor vessel onto the top of the core from the highest point that the fuel assembly can be raised.
2. The refueling mast and grapple head are also assumed to drop and impact the dropped assembly and the assemblies in the core.
3. The entire amount of potential energy, including the energy of the entire assemblage falling to its side from a vertical position, is available for application to the fuel assemblies involved in the accident.
4. None of the energy associated with the dropped fuel assembly is absorbed by the fuel material (uranium dioxide).
5. The dropped fuel assembly is assumed to impact at a small angle from the vertical, subjecting all the fuel rods in the dropped assembly to bending moments. The fuel rods are expected to absorb little energy prior to failing as a result of bending. For this reason, it is assumed that all of the rods in the dropped assembly fail. For the 9x9 assembly, this is a total of 74 fuel rods (seven of the fuel rods are displaced by water rods).

6. One half of the energy is considered to be absorbed by the falling assembly and one half by the four impacted assemblies.

7. The energy available for clad deformation is considered to be proportional to the mass ratio. For the assembly analyzed, the mass ratio is equal to a maximum of 0.510.

8. Each rod that fails is expected to absorb approximately 200 ft-lb before cladding failure, based on uniform 1% plastic deformation of the cladding.

9. Based on the assumptions above and using a fuel assembly weight of 562 pounds and a grapple mast and head weight of 619 pounds, 51 fuel rods will fail in the impacted fuel assemblies.

10. The dropped assembly is assumed to tip over and impact horizontally on the top of the core from a height of one bundle length, approximately 160 inches. This second impact results in the failure of 15 additional fuel rods.

11. Based on items 5, 9 and 10 above, the total number of failed fuel rods for the drop of the 9x9 assembly is 74+51+15 = 140.

As this discussion indicates, the number of failed fuel rods will depend on the height of the drop because the total potential energy of the dropped assembly is the product of the weight and drop height. The assumption of the failure of all of the rods in the dropped fuel assembly is reasonable and conservative for a drop of any significant height. However, the number of fuel rods that fail in the impacted assemblies will be reduced if the drop height is decreased.

4.3 Effect of Pool Depth on Dose Consequences

The general expression for the thyroid dose due to inhalation of iodine released during a FHA is given by the following expression from RG 1.25.

$$D = \frac{F_g \, I \, F \, P \, B \, R(\chi/Q)}{DF_p \, DF_f} \qquad (10)$$

The variables in this expression are defined as follows.

D = thyroid dose (rads)
F_g = fraction of fuel rod iodine inventory in the fuel rod void space, or gap activity fraction
I = core iodine inventory at time of accident (Ci)
F = fraction of core damaged so as to release void space iodine, or failed fuel fraction
P = fuel peaking factor
B = breathing rate (m^3/sec)

DF_p = effective iodine decontamination factor for pool water
DF_f = effective iodine decontamination factor for filters
χ/Q = atmospheric diffusion factor at receptor location (sec/m^3)
R = adult thyroid dose conversion factor for the iodine isotope of interest (rad/Ci)

In this expression the only variable that is a function of pool water depth is DF_p, which is the same as DF_{Eff} defined in equation (9). There is a potential that the pool water depth would also affect the effectiveness of the charcoal filters in the ventilation system, which is incorporated in DF_f. This effect occurs if different filter efficiencies are assumed for the iodine species. Since the relative mix of inorganic and organic iodine in the air above the pool will change as the pool water depth changes, the amount of activity removed by the filter system would also change if the filter efficiencies for inorganic and organic iodine are different. However, as shown in Table 14.7-22 of the USAR [Reference 7.5], only one filter efficiency is used for the exhaust filter so the change in species distribution will not affect iodine removal. For the AST analysis in Reference 7.7, it is assumed that there is no removal of iodine by either the exhaust filters or the control room intake filters. Therefore, DF_f would default to 1 and not be affected by pool water depth.

The only variable affected by the amount of fuel damage that occurs during the drop is F. Therefore, an expression for the dose that results from a drop occurring in a pool with an effective pool depth of H_1 is as follows.

$$D_1 = F_{DF,1} F_{FF,1} D \qquad (11)$$

In this expression, D is the thyroid dose as calculated using equation (10) (assumed to be with a 23' pool water depth), and the other variables are defined as follows.

D_1 = thyroid dose (rads) for a pool depth of H_1
$F_{DF,1}$ = DF adjustment factor $= \dfrac{DF_p}{DF_{Eff,1}}$, where $DF_{Eff,1}$ is determined using equation (9) for a pool water depth of H_1 and DF_p is the effective DF for a pool water depth of 23'
$F_{FF,1}$ = fuel failure adjustment factor $= \dfrac{F_1}{F}$
F_1 = fraction of core damage for a drop in a pool with effective height H_1

As this expression indicates, the thyroid dose will increase with decreasing pool water depth because the DF will become smaller as the pool water depth becomes smaller. Also, as expected, the thyroid dose will be directly proportional to any change in failed fuel fraction. For analyses based on RG 1.183, the results are reported in total effective dose equivalent (TEDE) rather than thyroid dose. The TEDE includes contributions from both noble gases and iodines. Since the pool water depth has no effect on the noble gas activity released, the decrease in TEDE will be even larger than the decrease in thyroid dose because the noble gas contribution to the TEDE is only affected by the fuel failure adjustment factor.

4.4 Acceptance Criteria

There are no acceptance criteria for the decontamination factor as a function of pool water depth.

For the evaluation of the drop of an assembly in the RP or SFSP, the acceptance criterion is that the control room and offsite doses are bounded by the current design basis FHA.

5 CALCULATIONS

5.1 Decontamination Factor Vs. Pool Water Depth

The calculated inorganic and effective DF for various pool water depths are listed in Table 1. The inorganic DF is calculated using equation (8). For example, consider a pool water depth (H_1) of 20'. For the RG 1.25 assumptions, the inorganic DF is given by

$$DF_{Inorg,20ft} = (133)^{\frac{20}{23}} = 70.279.$$

The effective DF is then calculated using equation (9) with the appropriate species fractions. For the RG 1.25 species fractions and a pool water depth of 20', the effective DF is given by:

$$DF_{Eff} = \frac{1}{\frac{0.9975}{70.279}+\frac{0.0025}{1}} = 59.904.$$

The DF adjustment factor for determining the effect of the change in pool water depth on the dose is calculated as defined in Section 4.3. For the RG 1.25 parameters and a pool water depth of 20', the DF adjustment factor is

$$F_{DF,1} = \frac{100}{59.904} = 1.669.$$

Similarly, for the RG 1.183 assumptions, the inorganic DF is calculated for a pool water depth of 20' using equation (8) as

$$DF_{Inorg,20ft} = (500)^{\frac{20}{23}} = 222.295.$$

The calculation of the effective DF is slightly different because it has to be normalized to an effective DF of 200 at 23'. Since the effective DF using a DF of 500 for inorganic iodine is

$$DF_{Eff,RG1.183} = \frac{1}{\frac{0.9985}{500} + \frac{0.0015}{1}} = 285.959,$$

the normalization factor for the effective DF is

$$Normalization\ Factor = \frac{200}{285.959} = 0.6994.$$

Therefore, the calculated effective DF using the RG 1.183 parameters and a pool water depth of 20' is given by:

$$DF_{Eff,20ft} = \frac{0.6994}{\frac{0.9985}{222.295} + \frac{0.0015}{1}} = 116.727.$$

Using the DF adjustment factor as defined in Section 4.3, the RG 1.183 parameters and a pool water depth of 20', the DF adjustment factor is

$$F_{DF,1} = \frac{200}{116.727} = 1.713.$$

5.2 Evaluation of an Assembly Drop in the RP

The current design basis FHA assumes a drop on to the reactor core that results in failure of 125 fuel rods assuming 8x8 fuel assemblies (Design Input (DI) 2.12). The RG 1.183 analysis [Reference 7.7] also assumes failure of 125 fuel rods of 8x8 fuel. Based on the methodology in GESTAR II and since there are 60 fuel rods in the dropped assembly (DI 2.10), the number of fuel rods that are assumed to fail in the fuel assemblies in the core is 65 (125-60) assuming 8x8 fuel assemblies. The drop height of the fuel assembly is 34', and the pool DF used in the analysis is 100, which implies a minimum pool water depth of 23' (see Section 4.2).

For a drop in the RP that does not impact the core, three items change. First, since only one assembly is involved in the drop, the maximum number of fuel rods that can be damaged is limited to the number of fuel rods in the single assembly. Although an 8x8 fuel assembly is assumed in this evaluation to be consistent with the current design basis analysis, this evaluation is applicable to all fuel types in use at MNGP.

The second item that changes is the drop height of the fuel assembly. The maximum height of a fuel assembly above the RPV flange is 3'-2" (DI 2.4). This means that the distance the assembly falls before impact is smaller than the 34' assumed in the design basis analysis by about a factor of 10. Therefore the amount of energy absorbed by the fuel assembly at impact will also be smaller by a factor of 10. However, the fuel assembly is assumed to impact at a small angle to the vertical, subjecting all the fuel rods in the dropped assembly to bending moments. The fuel rods absorb little energy prior to failing as a result of bending. Therefore, all of the fuel rods in the dropped assembly are assumed to fail.

The third item that changes is height of water above the dropped fuel assembly at the point of impact. As indicated in DI 2.1, the highest point in the RP in the path of fuel movement is actually the cattle chute. The minimum depth of water above the cattle chute is 21'-8" (DI 2.1), which is smaller than the 23' assumed in the design basis analysis. Therefore, the DF for the pool will decrease.

To determine the overall effect of these three items, equation (11) is evaluated. The DF adjustment factor is determined by first calculating the inorganic DF for H_1 of 21'-8". Using the RG 1.25 DF, the inorganic DF is given by the following.

$$DF_{Inorg,1} = (133)^{\frac{21'-8"}{23'}} = 100.168$$

The effective DF is then calculated using equation (9) with the RG 1.25 species fractions.

$$DF_{Eff} = \frac{1}{\frac{0.9975}{100.168} + \frac{0.0025}{1}} = 80.268$$

The DF adjustment factor is then calculated as follows.

$$F_{DF,1} = \frac{100}{80.268} = 1.246$$

The fuel failure adjustment factor is simply the ratio of the number of fuel rods that fail following the drop in the RP to the number of fuel rods that fail following the drop in the design basis FHA.

$$F_{FF,1} = \frac{60}{125} = 0.48$$

The thyroid dose due to a drop in the RP relative to the dose due to a design basis FHA, using the RG 1.25 assumptions, is calculated using equation (11).

$$D_{1,RG\,1.25} = (1.246)(0.48)D = 0.598D$$

The analysis using the RG 1.183 assumptions for iodine species fractions and DFs is similar.

$$DF_{Inorg,1} = (500)^{\frac{21'\text{-}8"}{23'}} = 348.745$$

$$DF_{Eff} = \frac{0.6994}{\dfrac{0.9985}{348.745} + \dfrac{0.0015}{1}} = 160.298$$

$$F_{DF,1} = \frac{200}{160.298} = 1.248$$

The fuel failure adjustment factor is the same as the RG 1.25 evaluation. Therefore the thyroid dose due to a drop in the RP relative to the thyroid dose due to a design basis FHA, using the RG 1.183 assumptions, is:

$$D_{1,RG\,1.183} = (1.248)(0.48)D = 0.599D$$

As this evaluation indicates, for both the RG 1.25 and RG 1.183 assumptions, the thyroid doses resulting from a fuel assembly drop in the RP are 40% lower than the thyroid doses resulting from a design basis FHA. This is because the 25% increase in iodine activity released from the pool due to the decrease in pool water depth is offset by the 52% decrease in iodine activity released from the fuel assemblies because of a smaller number of failed fuel rods. For analyses based on RG 1.183 assumptions that are reported in TEDE, such as Reference 7.7, the portion of the TEDE from iodine activity will also decrease by about 40%. Since the noble gas contribution to the TEDE will decrease by 52%, the net effect will be an even larger decrease in the TEDE. Therefore the current design basis FHA, which is a drop of a fuel assembly onto the reactor core, is bounding for a drop of an assembly in the RP.

As these results indicate, there is still considerable margin between the thyroid dose calculated for the design basis event and the thyroid dose that results from a drop in the RP. This implies that the water level could be even lower than the current design and result in thyroid doses that are still bounded by the design basis FHA. The minimum water level is that water level that produces a DF adjustment factor that is the inverse of the fuel failure adjustment factor so that the product of the two adjustment factors is 1. For the drop in the RP, the limiting DF adjustment factor is given by the following expression.

$$F_{DF,\max} = \frac{1}{0.48} = 2.08$$

Inspection of Table 1 indicates that, for the RG 1.25 analysis, the minimum height of water above the dropped assembly is 19' since it is the minimum height of water that results in a DF adjustment factor less than 2.08. Table 1 indicates that for the RG 1.183 assumptions the DF adjustment factor for 19' is 2.112, which is slightly larger than the maximum estimated value. However, the 19' value is still considered applicable to RG 1.183 analyses because the portion of the TEDE from noble gas will be reduced by about 52% and the total TEDE will be less than the TEDE calculated for the design basis FHA.

The depth of water used in this analysis is 21'-8", which is 2'-8" deeper than the minimum value of 19'. This implies that the minimum elevation of the refueling water level can be reduced from 1026'-2" to 1023'-6" without exceeding the design basis FHA.

5.3 Evaluation of an Assembly Drop in the SFSP

The drop of a fuel assembly in the SFSP is similar to the design basis accident in that it is the drop of a single fuel assembly onto other fuel assemblies. There are two major differences between the drop in the SFSP and the design basis analysis. The first is that the depth of water above the fuel in the SFSP is considerably less than the depth of the water above the core, which will result in less removal of iodine by the pool water. The second is that the drop height of the fuel assembly is shorter in the SFSP than in the reactor. This results in less energy in the dropped fuel assembly and therefore fewer failed rods. Current MNGP core and refuel loads consist of GE11 BWR/3 and GE14 BWR/3 fuel (DI 2.16). The GE14 BWR/3 fuel assembly, which is a 10x10 assembly containing partial length fuel rods that contains the equivalent to 87.33 full length fuel rods (DI 2.17), is the heaviest of the two assemblies. The GE14 BWR/3 assembly is therefore used in this analysis because it generates more energy and results in more damage than the GE11 BWR/3 fuel assembly. Note that the number of damaged fuel rods assuming GE14 BWR/3 fuel can be converted to an equivalent number of damaged fuel rods for 8x8 fuel assemblies by multiplying by the ratio of the number of fuel rods per assembly (60/87.33).

The effect of the smaller pool water depth is evaluated by calculating the DF adjustment factor as described in Section 4.1. As indicated in DI 2.3, the minimum depth of water above a damaged fuel assembly is 21'-4". Using the RG 1.25 species fractions and DFs, the DF adjustment factor is calculated as follows.

$$DF_{Inorg,1} = (133)^{\frac{21'\text{-}4"}{23'}} = 93.315$$

$$DF_{Eff} = \frac{1}{\frac{0.9975}{93.315} + \frac{0.0025}{1}} = 75.817$$

$$F_{DF,1,RG1.25} = \frac{100}{75.817} = 1.319$$

Similarly, the evaluation of the DF adjustment factor using the RG 1.183 assumptions is as follows.

$$DF_{Inorg,1} = (500)^{\frac{21'-4"}{23'}} = 318.708$$

$$DF_{Eff} = \frac{0.6994}{\frac{0.9985}{318.708} + \frac{0.0015}{1}} = 150.962$$

$$F_{DF,1,RG1.183} = \frac{200}{150.962} = 1.325$$

Estimation of the number of failed fuel rods is done by balancing the energy of the dropped assemblage against the energy required to fail a fuel rod. The weight of the dropped assemblage is the sum of the weight of the fuel assembly (553 lbs, DI 2.13) and the weight of the NF-400 refueling mast (350 lbs, DI 2.14). The drop height of the fuel assembly in the pool is the maximum height of a fuel assembly above the spent fuel during fuel movement. From DI 2.6, this height is 2'-10". Therefore, the potential energy to be dissipated by the first impact is

$$(553\ lbs + 350\ lbs)(2'-10") = 2558\ ft-lbs.$$

One half of the energy is considered to be absorbed by the falling assembly and one half by the impacted assemblies. In addition, the energy available for clad deformation is considered to be proportional to the mass fraction of cladding in the fuel assembly, which is 0.525 (DI 2.15). Therefore, the energy absorbed by the cladding in the impacted fuel assemblies is

$$(2558\ ft-lbs)(0.5)(0.525) = 672\ ft-lbs.$$

Each rod that fails is expected to absorb approximately 200 ft-lbs before cladding failure. Therefore, the number of rods that fail in the impacted assemblies following the initial impact is

$$\frac{672\ ft-lbs}{200\ ft-lbs} = 3.36\ rods.$$

The dropped assembly is assumed to impact at a small angle from vertical, subjecting all the fuel rods in the dropped assembly to bending moments. The fuel rods are expected to absorb little energy prior to failure as a result of bending. For this reason, it is assumed that all the rods in the dropped assembly fail (87.33 fuel rods, DI 2.17). The total number of failed fuel rods on initial impact is

$$87.33\ \textit{rods dropped assembly} + 3.36\ \textit{rods impacted assemblies} = 90.69\ \textit{rods}.$$

The assembly is assumed to tip over and impact horizontally on the top of the fuel racks from a height of one bundle length, approximately 14.3' (DI 2.11). The energy available for this second impact is calculated by assuming a linear weight distribution in the assembly with a point load at the top of the assembly to represent the fuel grapple weight.

$$(350\ lb)(14.3') + \frac{1}{2}(553\ lb)(14.3') = 8960\ ft-lbs$$

As before, the energy is considered to be absorbed equally by the falling assembly and the impacted assemblies. The fraction available for clad deformation of 0.525. Therefore, the energy absorbed by the clad in the impacted fuel assemblies from the second impact is

$$(8960\ ft-lbs)(0.5)(0.525) = 2352\ ft-lbs,$$

and the number of failed fuel rods in the impacted assemblies is

$$\frac{2352\ ft-lbs}{200\ ft-lbs} = 11.76\ rods.$$

Since all of the rods in the dropped assembly are assumed to fail on initial impact, there are no additional failed rods in the dropped assembly on the second impact. The total number of failed rods is therefore

$$90.69\ \textit{rods initial impact} + 11.76\ \textit{rods second impact} = 102.45\ \textit{rods}.$$

This is the number of fuel rods that fail in the GE14 BWR/3 fuel assembly. To convert this to the equivalent number of rods in an 8x8 assembly, the following expression is used.

$$102.45\ rods\ \frac{60\ \textit{rods in}\ 8x8}{87.33\ \textit{rods in}\ GE14} = 71\ rods.$$

Using this number of failed rods, the failed fuel adjustment factor is calculated as follows.

$$F_{FF,1}=\frac{71}{125}=0.568$$

The impact on the thyroid dose due to a drop in the SFSP relative to the thyroid dose due to a design basis FHA is evaluated using equation (11).

$$D_{1,RG1.25}=(1.319)(0.568)D=0.749D$$

$$D_{1,RG1.183}=(1.325)(0.568)D=0.753D$$

As this evaluation indicates, for both the RG 1.25 and RG 1.183 assumptions, the thyroid doses resulting from a fuel assembly drop in the SFSP are 25% lower than the thyroid doses resulting from a design basis FHA. This is because the more than 30% increase in iodine activity released due to the decrease in pool water depth is offset by the 40% decrease in iodine activity released from the fuel assemblies because of a smaller number of failed fuel rods. For analyses based on RG 1.183 assumptions that are reported in TEDE, such as Reference 7.7, the portion of the TEDE from iodine activity will also decrease by about 25%. Since the noble gas contribution to the TEDE decreases by 40%, the net effect will be an even larger decrease in the TEDE. Therefore the current design basis FHA, which is a drop of a fuel assembly onto the reactor core, is bounding for a drop of an assembly in the SFSP.

As these results indicate, there is still considerable margin between the thyroid dose calculated for the design basis event and the thyroid dose that results from a drop in the SFSP. This implies that the water level could be even lower than the current design and result in thyroid doses that are still bounded by the design basis FHA. The minimum water level is that water level that produces a DF adjustment factor that is the inverse of the fuel failure adjustment factor so that the product of the two adjustment factors is 1. For the drop in the RP, the limiting DF adjustment factor is given by the following expression.

$$F_{DF,max}=\frac{1}{0.568}=1.761$$

Inspection of Table 1 indicates that, for both the RG 1.25 and RG 1.183 analysis, the minimum height of water above the dropped assembly is 20' since it is the minimum height of water that results in a DF adjustment factor less than 1.761.

The depth of water used in this analysis is 21'-4", which is 1'-4" deeper than the minimum value of 20'. This implies that the minimum elevation of the refueling water level can be reduced from 1026'-2" to 1024'-10" without exceeding the design basis FHA.

6 RESULTS

A generic analysis of the change in pool DF as a function of pool water depth is summarized in Table 1 and Figure 1.

An evaluation of the drop of a GE14 BWR/3 fuel assembly in the RP and the SFSP was performed. Since MNGP current core and refuel loads include only GE11 BWR/3 and GE14 BWR/3 fuel, and since the GE14 BWR/3 fuel is heavier and therefore will cause more damage, this evaluation is bounding for both types of fuel. The results of this evaluation are summarized below.

Parameter Evaluated		Drop in the RP	Drop in the SFSP
Fraction of the Current Design Basis FHA Dose for a Refueling Water Elevation of 1026'-2"	RG 1.25	0.598	0.749
	RG 1.183	0.599	0.753
Minimum Elevation of the Refueling Water that Bounds the Design Basis FHA		1023'-6"	1024'-10"

These results indicate that the design basis FHA, which involves a drop of a fuel assembly onto the reactor core, is bounding for a drop in the RP and the SFSP. This is because the increase in iodine activity released from the pool due to lower water height is offset by a smaller number of failed rods, which reduces the iodine activity available for release. For doses reported as TEDE rather than thyroid dose, the decrease will be even larger because the noble gas contribution to the TEDE will decrease more than the iodine contribution.

7 REFERENCES

7.1 Regulatory Guide 1.25, "Assumptions Used for Evaluating the Potential Radiological Consequences of a Fuel Handling Accident in the Fuel Handling and Storage Facility for Boiling and Pressurized Water Reactors," USNRC, March 23, 1972

7.2 Regulatory Guide 1.183, "Alternative Radiological Source Terms for Evaluating Design Basis Accidents at Nuclear Power Reactors," USNRC, July 2000

7.3 NMC DIT No. 18933, "Alternate Source Term Implementation/Improved Tech Specs," for MNGP dated 02/09/05

7.4 G. Burley, "Evaluation of Fission Product Release and Transport," Staff Technical Paper, USNRC, 1971

7.5 Monticello Updated Safety Analysis Report, Rev. 21

7.6 GNF Licensing Topical Report NEDE-24011-P-A-14-US, "General Electric Standard Application for Reactor Fuel (Supplement for United States)," June 2000 (Referred to as GESTAR II)

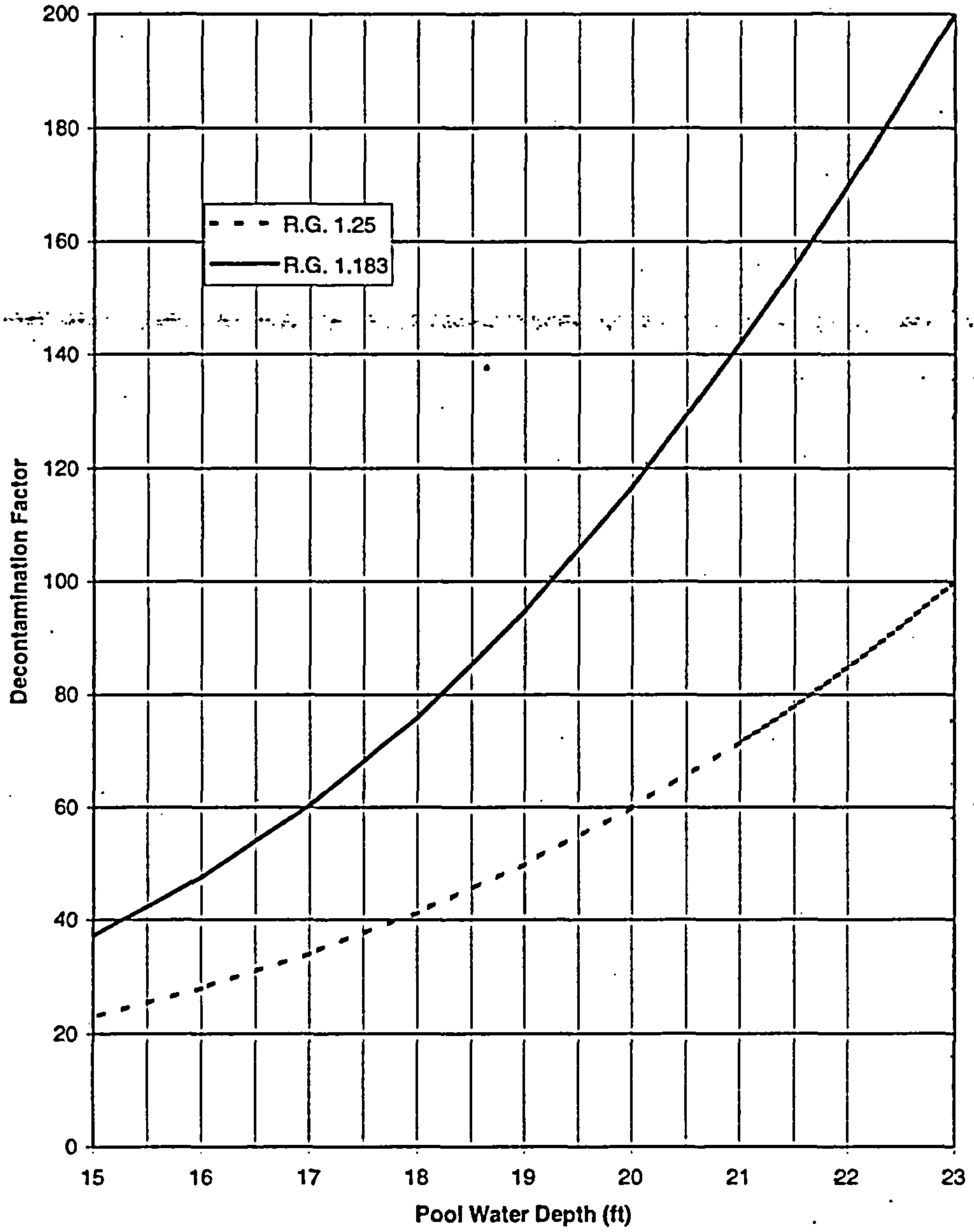
7.7 Calculation 2004-02104, "MNGP AST – FHA Radiological Consequence Analysis," Rev. 0

7.8 GNF Report NEDC-32868P, "GE14 Compliance With Amendment 22 of NEDE-24011-P-A (GESTAR II)," Revision 1, September 2000

Table 1. Decontamination Factor (DF) and DF Adjustment Factor (F_{DF}) for Various Pool Water Depths

Pool Water Depth Ft - In	Reg. Guide 1.25			Reg. Guide 1.183		
	DF			DF		
	Inorganic	Effective	F_{DF}	Inorganic	Effective	F_{DF}
23 - 0	133	100	1	500	200	1
22 - 11	130.66	98.68	1.013	488.87	197.43	1.013
22 - 10	128.37	97.37	1.027	477.98	194.87	1.026
22 - 9	126.11	96.07	1.041	467.34	192.32	1.040
22 - 8	123.90	94.78	1.055	456.94	189.79	1.054
22 - 7	121.72	93.50	1.069	446.76	187.26	1.068
22 - 6	119.59	92.24	1.084	436.81	184.74	1.083
22 - 5	117.49	90.99	1.099	427.09	182.23	1.097
22 - 4	115.42	89.75	1.114	417.58	179.74	1.113
22 - 3	113.40	88.52	1.130	408.28	177.26	1.128
22 - 2	111.40	87.31	1.145	399.19	174.79	1.144
22 - 1	109.45	86.10	1.161	390.30	172.34	1.160
22 - 0	107.53	84.91	1.178	381.61	169.90	1.177
21 - 11	105.64	83.73	1.194	373.12	167.48	1.194
21 - 10	103.78	82.57	1.211	364.81	165.07	1.212
21 - 9	101.96	81.41	1.228	356.69	162.67	1.229
21 - 8	100.17	80.27	1.246	348.74	160.30	1.248
21 - 7	98.41	79.14	1.264	340.98	157.94	1.266
21 - 6	96.68	78.02	1.282	333.39	155.59	1.285
21 - 5	94.98	76.91	1.300	325.97	153.27	1.305
21 - 4	93.31	75.82	1.319	318.71	150.96	1.325
21 - 3	91.68	74.73	1.338	311.61	148.67	1.345
21 - 2	90.07	73.66	1.358	304.67	146.40	1.366
21 - 1	88.48	72.60	1.377	297.89	144.15	1.387
21 - 0	86.93	71.56	1.397	291.26	141.92	1.409
20 - 0	70.28	59.90	1.669	222.30	116.73	1.713
19 - 0	56.82	49.86	2.006	169.66	94.70	2.112
18 - 0	45.94	41.30	2.422	129.49	75.93	2.634
17 - 0	37.14	34.06	2.936	98.83	60.28	3.318
16 - 0	30.02	27.99	3.572	75.43	47.46	4.214
15 - 0	24.27	22.94	4.360	57.57	37.12	5.389

Figure 1. Effective Decontamination Factor as a Function of Pool Water Depth



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