**Development of EAL Threshold values from NEE-323-CALC-002**

Due to elevated background radiation levels on these monitors during plant operation (10-12 R/hr), the calculated threshold value was rounded to 5 (minimum serviceable threshold value accounting for scale of monitor) for ease of use by the EAL evaluator, and the "in Mode 5 only" caveat is added to the EAL usage.

The resultant EALs are:

RA2.2 Reading greater than 5 R/hr on ANY of the following radiation monitors (in Mode 5 only):

- NW Drywell Area Hi Range Rad Monitor, RIM-9184A
- South Drywell Area Hi Range Rad Monitor, RIM-9184B

CS1/CG1 Core uncovery is indicated by ANY of the following:

- Drywell Monitor (9184A/B) reading greater than 5.0 R/hr

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|---|---|---|

| | | | |
|---|---|---|---|
| **Title:** | Dose Rate Evaluation of Reactor Vessel Water Levels During Refueling for EAL Thresholds | **Client:** | Duane Arnold Energy Center |
| | | **Project Identifier:** | NEE-323 |

| Item | Cover Sheet Items | Yes | No |
|---|---|---|---|
| 1 | Does this calculation contain any open assumptions, including preliminary information, that require confirmation? (If **YES**, identify the assumptions.) | ☐ | ☒ |
| 2 | Does this calculation serve as an "Alternate Calculation"? (If **YES**, identify the design verified calculation.)<br>**Design Verified Calculation No.** _____ | ☐ | ☒ |
| 3 | Does this calculation supersede an existing Calculation? (If **YES**, identify the design verified calculation.)<br>**Superseded Calculation No.** _____ | ☐ | ☒ |

**Scope of Revision:**
Initial Issue

**Revision Impact on Results:**
Initial Issue

**Study Calculation** ☐ **Final Calculation** ☒

**Safety-Related** ☐ **Non-Safety-Related** ☒

***(Print Name and Sign)***

| | |
|---|---|
| **Originator:** Jay Bhatt | **Date:** **12/12/17** |
| **Design Verifier[1] (Reviewer if NSR):** Caleb Trainor | **Date:** **12/12/17** |
| **Approver:** Aaron Holloway | **Date:** **12/12/17** |

Note 1: For non-safety-related calculation, design verification can be substituted by review.

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|---|---|---|

## CALCULATION REVISION STATUS

| REVISION | DATE | DESCRIPTION |
|---|---|---|
| 00 | **12/12/17** | Initial Issue |

## PAGE REVISION STATUS

| PAGE NO. | REVISION | PAGE NO. | REVISION |
|---|---|---|---|
| All | 00 | | |

## APPENDIX/ATTACHMENT REVISION STATUS

| APPENDIX NO. | NO. OF PAGES | REVISION NO. | ATTACHMENT NO. | NO. OF PAGES | REVISION NO. |
|---|---|---|---|---|---|
| A | 1 | 00 | 1 | 5 | 00 |
| B | 2 | 00 | | | |
| C | 1 | 00 | | | |

## 1.0 Purpose and Scope

The purpose of this calculation is to evaluate dose rates with water at the top of active fuel in the reactor vessel during cold shutdown or refueling operations in order to set Emergency Action Level (EAL) thresholds (RA2, CS1, CG1) per NEI 99-01 [Reference 3.5]. The dose rates are calculated at the locations of the drywell monitors 9184A/B so that dose rate measurements by these devices can be correlated to the water level in the core, upon failure of other water level detection systems. This calculation is nonsafety-related as the results of the calculation do not affect the design basis or safety-related systems structures or components. These results are best estimates based on as-built conditions and provide information to operators with respect to classifying an emergency, therefore no acceptance criteria is required.

## 2.0 Summary of Results and Conclusions

The dose rates just prior to the core being uncovered (i.e. water at the top of the active fuel) are shown in the table below. Note that the results presented below are calculated dose rates and do not account for background radiation or any installed detector check sources.

*Table 1 – Dose Rate at Top of Active Fuel*

| Model Description | Drywell Monitor 9184A Reading (R/hr) | Drywell Monitor 9184B Reading (R/hr) | Drywell Monitor (9184A/B) Range (R/hr) |
|---|---|---|---|
| **Head Off** | 1.81 | 1.68 | 1 to 1E+7 |
| **Head On** | 1.11 | 7.41E-01[1] | 1 to 1E+7 |

[1] This value is off scale low.

## 3.0 References

3.1 "Standard Composition Library," ORNL/NUREG/CSD-2/V1/R6, Volume 3, Section M8, March 2000

3.2 CGDG-SCALE-6.1.2, Rev 00, Commercial Grade Dedication SCALE Version 6.1.2

3.3 CGDG-MCNP6-V1.0, Rev 00, Commercial Grade Dedication MCNP6 Version 1.0

3.4 ANSI/ANS 6.1.1-1977, Neutron and Gamma Flux-To-Dose Conversion Factors

3.5 NEI 99-01, Rev. 6, "Development of Emergency Action Levels for Non-Passive Reactors"

3.6 I.RIM-V115-01, Rev. 10, "Victoreen Model 876A Containment Radiation Monitor Calibration"

3.7 NUREG 1940, "RASCAL 4: Descriptions of Models and Methods"

3.8 CAL-R00-PUP-008, Rev. 03, "Non-LOCA Radiological Consequence Dose with Alternate Source Term"

3.9 RFP 110, Rev. 45, "Refueling Procedure- Reactor Pressure Vessel Disassembly"

3.10 Technical Specifications, Section 1.1

3.11 Technical Specifications, Section 4.2.1

3.12 NUREG 1754, "A New Comparative Analysis of LWR Fuel Designs"

3.13 BECH-M009, Rev. 14, "Equipment Locations Reactor Building Section-GG"

3.14 BECH-C405, Rev. 14, "Reactor Building Floor Plan @ El. 757'-6""

3.15 NG-17-0156, Proprietary Data Transmittal to ENERCON

3.16 BECH-M405, Sh 04, Rev. 24, "Instrument Points and Rack Locations Diagram Plans at Elevs 812'-0" & 833'-6""

3.17 NG-88-0966, "G.E. Fuel Damage Documentation/Dose Rate Calculations"

3.18 C003-029, Rev. 0, "Drywell Cylindrical Shell & Cone"

3.19 VS-01-06, Rev. 4, "Top Head Assembly"

3.20 BECH-C511, Rev. 5, "Reactor Building RPV Ped Dev. Elev. & Sect's"

3.21 BECH-C514, Rev. 1, "Drywell Interior Biological Shield Wall Reinforcing Sections"

3.22 BECH-C-516, Rev. 6, "Drywell Interior Biological Shield Wall Plans El. 816'-3 ¼" to El 779'-1 ½""

3.23 BECH-M405, Sh 02, Rev. 71, "Instrument Points & Lines Diagrams Plan at Elev 757'-6""

3.24 APED-B-31-2816-001, Rev. 5, "Outline Reactor Recirculating Pump"

3.25 FSAR Section 4.3.2.1, and Section 9.1

3.26 CAL-M98-058, Rev. 1, "ADS Accumulator Size Verification"

## 4.0 Assumptions

4.1 The core is homogenized based on the typical 10x10 fuel assembly dimensions, taking into account the fuel rods and space between. Any small variations in fuel parameters will have a negligible effect on containment dose rates. The cladding is modeled as Zircaloy 4 in lieu of ZIRLO; this is acceptable due to the similarity of the materials.

4.2 Any non-fuel hardware, including rod end plugs, is ignored in the active fuel region. This is acceptable since the primary self-shielding occurs in the fuel itself, and there may be some unknown streaming effects through the non-fuel hardware. This homogenization takes into account the presence of water when calculating the isotopic weight fraction and homogenized density. For the case with the reactor vessel head in place, the region between the head and the active fuel region is homogenized based on the actual mass of the upper internals over the entire region. Homogenization of source regions and shields is acceptable due to the insignificant effects on the detector response given the model geometry.

4.3 The composition of the containment structure and components are based on the values in the SCALE standard composition library [Reference 3.1]. These material properties are commonly used in shielding applications, and are acceptable for modelling the structures and components used to determine the best estimate response at the detector locations.

4.4 The minimum period of decay after reactor shutdown before moving fuel is 60 hours [Reference 3.8, Section 4.3.8]. This calculation assumes a decay time of 50 hours to allow EAL thresholds to be determined for reactor vessel conditions that exist prior to the commencement of fuel movement which is representative of the applicable operating modes (cold shutdown, refueling). This decay time is appropriate to produce best estimate results for both the head on and head off configurations.

4.5 The hardware in the upper internals region between the active fuel region, reactor recirculating pumps and reactor vessel head is assumed to be stainless steel type 304. While the actual composition of the hardware may vary slightly, small variations in the material will have a negligible effect on the dose rate response at the detectors.

4.6 It is assumed that the water below the active fuel region is liquid at a constant temperature. Using a density of 0.9982 g/cm$^3$ is common in shielding applications. Any water above this region would be steam with little shielding value.

4.7 The source term is generated shortly after shutdown, therefore, the fuel gamma source term will predominate and the neutron-gamma and hardware activation can be neglected.

4.8 The high range detectors read out in roentgen per hour (R/h) which is a measurement of exposure rate, while the MCNP output is provided in mrem/h which is a measurement of the equivalent dose rate that represents the biological effects of ionizing radiation. It is assumed that 1 R is approximately 1000 mrem. This is acceptable as only the gamma source term is considered.

4.9 The roof of the Reactor Building is modeled as 0.5 inches of stainless steel. This will account for any scattering interactions that may contribute to the response at the detector. The magnitude of the detector response due to scattering off of the roof will be small due to the geometry and amount of shielding in the model, and is therefore acceptable.

4.10 Automatic Depressurization System Accumulators 1R003A/B/C located on the 775'-11 ½" elevation are not included in the model. The size of the accumulators are 200 gallons [Reference 3.26]. This is relatively small compared to the geometry of the model, and the corresponding scatter interactions will not have a significant impact on the detector response.

## 5.0 Design Inputs

### 5.1 Fuel Assembly Parameters

The following fuel assembly parameters are used to homogenize the core in the MCNP model. They are based on typical fuel assembly values for 10x10 fuel.

*Table 2 – Design Input Fuel Assembly Parameters*

| Parameters | Value | Unit | Reference |
| --- | --- | --- | --- |
| **Fuel type** | 10x10 | | 3.25 |
| **# of Assemblies in Core** | 368 | | 3.11 |
| **# Fuel rods per assembly** | 92 | | 3.12 |
| **Pitch** | 0.51 | [in] | 3.12 |
| **Density (% of theoretical)** | 95 | | 3.12 |
| **Fuel pellet OD** | 0.336 | [in] | 3.12 |
| **Fuel rod OD** | 0.395 | [in] | 3.12 |
| **Clad thickness** | 0.026 | [in] | 3.12 |
| **Active length** | 144 | [in] | 3.12 |

### 5.2 Model Dimensions

The following elevations and dimensions are based on the associated drawings or other reference. Some parameters are estimated using drawing scales when exact dimensions are not provided.

*Table 3 – Design Input Dimensions*

| Dimension | ft | in | cm | Reference |
| --- | --- | --- | --- | --- |
| **Pedestal inner radius** | 8 | | 243.84 | 3.20 |
| **Pedestal outer radius** | 12 | | 365.76 | 3.20 |
| **Reactor vessel inner diameter** | | 185.375 | 470.85 | 3.15 |
| **Reactro vessel thickness** | | 5 | 12.70 | 3.15 |
| **Drywell spherical portion radius** | 31.5 | | 960.12 | 3.17 Figure 2 |
| **Concrete around drywell spherical portion(x and y directions radius)** | 36 | 9 | 1120.14 | 3.14 |
| **Drywell cylindrical portion radius** | 17 | | 518.16 | 3.16 |
| | | | | |
| **Drywell liner thickness** | | 0.75 | 1.91 | 3.18 |
| **Concrete around drywell cylindrical portion (x and y directions)** | 22 | 9 | 693.42 | 3.16 |
| **Reactor Building (x and y directions)** | 140 | | 4267.20 | 3.14 |
| **Reactor Building Roof Thickness** | | 0.5 | 1.27 | Assumption 4.9 |
| **Height of active fuel** | | 144 | 365.76 | 3.12 |
| **Vessel Height** | | 704.5 | 1789.43 | 3.15 |

| Dimension | ft | in | cm | Reference |
|---|---|---|---|---|
| **Reactor vessel head thickness** | | 3.9375 | 10.00 | 3.19 |
| **Distance from vessel 0 to bottom of active fuel** | | 200.94 | 510.39 | 3.15, 3.12 |
| **Bio shield inner radius** | 9 | 6.25 | 290.20 | 3.21 |
| **Bio shield outer radius** | 11 | 8.25 | 356.24 | 3.21 |
| **Reactor recirculating pump height** | 17 | 2 | 523.24 | 3.24 |
| **Reactor recirculating pump radius** | 2 | 9 | 83.82 | 3.24 |
| **Detector RE-9184A distance from origin (x plane)** | -4 | | -121.92 | 3.23 [Scaled] |
| **Detector RE-9184A distance from origin (y plane)** | 13.33 | | 406.29 | 3.23 [Scaled] |
| **Detector RE-9184B distance from origin (x plane)** | 6 | | 182.88 | 3.23 [Scaled] |
| **Detector RE-9184B distance from origin (y plane)** | -12 | | -365.76 | 3.23 [Scaled] |
| **Reactor Recirculating Pump IP-201A distance from origin (x plane)** | 12 | | 365.76 | 3.23 [Scaled] |
| **Reactor Recirculating Pump IP-201A distance from origin (y plane)** | 12 | | 365.76 | 3.23 [Scaled] |
| **Reactor Recirculating Pump IP-201B distance from origin (x plane)** | -12 | | -365.76 | 3.23 [Scaled] |
| **Reactor Recirculating Pump IP-201B distance from origin (y plane)** | -12 | | -365.76 | 3.23 [Scaled] |

*Table 4 – Design Input Elevations*[2]

| Dimension: | ft. | in | cm | Reference |
|---|---|---|---|---|
| **Drywell Equator** | 766 | 0.5 | 0.00 | 3.13 |
| **Vessel 0** | 772 | 5.5 | 195.58 | 3.15 |
| **Bottom of pedestal elevation** | 742 | 9 | -709.93 | 3.13 |
| **Top of cylindrical portion of drywell concrete** | 855 | | 2711.45 | 3.13 |
| **Top of Reactor Building** | 897 | 6 | 4006.85 | 3.13 |
| **Detector elevation** | 760 | | -184.15 | 3.17 |
| **Top of pedestal/ bottom of bio shield** | 770 | 10.5 | 147.32 | 3.20 |
| **Top of bio shield** | 816 | 3.25 | 1530.99 | 3.22 |
| **Reactor recirculating pump bottom** | 748 | 8.5 | -528.32 | 3.13 |

[2] All elevations listed in centimeters are relative to the equator of the drywell elevation of 766' 0.5" [Reference 3.13].

## 5.3 Core Isotopic Inventory

Core isotopic activities in Ci/MWt are taken from Reference 3.7 Table 1-1. A table of the input values is shown in Table 5, below. The activities in Ci are determined by multiplying by the rated thermal power of 1912 MWt taken from Reference 3.10.

*Table 5 – Core Source Term*

| Isotope | Ci/MWt | Ci | Isotope | Ci/MWt | Ci |
|---|---|---|---|---|---|
| **Ba-139** | 4.74E+04 | 9.06E+07 | **Rh-105** | 2.81E+04 | 5.37E+07 |
| **Ba-140** | 4.76E+04 | 9.10E+07 | **Ru-103** | 4.34E+04 | 8.30E+07 |
| **Ce-141** | 4.39E+04 | 8.39E+07 | **Ru-105** | 3.06E+04 | 5.85E+07 |
| **Ce-143** | 4.00E+04 | 7.65E+07 | **Ru-106** | 1.55E+04 | 2.96E+07 |
| **Ce-144** | 3.54E+04 | 6.77E+07 | **Sb-127** | 2.39E+03 | 4.57E+06 |
| **Cm-242** | 1.12E+03 | 2.14E+06 | **Sb-129** | 8.68E+03 | 1.66E+07 |
| **Cs-134** | 4.70E+03 | 8.99E+06 | **Sr-89** | 2.41E+04 | 4.61E+07 |
| **Cs-136** | 1.49E+03 | 2.85E+06 | **Sr-90** | 2.39E+03 | 4.57E+06 |
| **Cs-137** | 3.25E+03 | 6.21E+06 | **Sr-91** | 3.01E+04 | 5.76E+07 |
| **I-131** | 2.67E+04 | 5.11E+07 | **Sr-92** | 3.24E+04 | 6.19E+07 |
| **I-132** | 3.88E+04 | 7.42E+07 | **Tc-99m** | 4.37E+04 | 8.36E+07 |
| **I-133** | 5.42E+04 | 1.04E+08 | **Te-127** | 2.36E+03 | 4.51E+06 |
| **I-134** | 5.98E+04 | 1.14E+08 | **Te-127m** | 3.97E+02 | 7.59E+05 |
| **I-135** | 5.18E+04 | 9.90E+07 | **Te-129** | 8.26E+03 | 1.58E+07 |
| **Kr-83m** | 3.05E+03 | 5.83E+06 | **Te-129m** | 1.68E+03 | 3.21E+06 |
| **Kr-85** | 2.78E+02 | 5.32E+05 | **Te-131m** | 5.41E+03 | 1.03E+07 |
| **Kr-85m** | 6.17E+03 | 1.18E+07 | **Te-132** | 3.81E+04 | 7.28E+07 |
| **Kr-87** | 1.23E+04 | 2.35E+07 | **Xe-131m** | 3.65E+02 | 6.98E+05 |
| **Kr-88** | 1.70E+04 | 3.25E+07 | **Xe-133** | 5.43E+04 | 1.04E+08 |
| **La-140** | 4.91E+04 | 9.39E+07 | **Xe-133m** | 1.72E+03 | 3.29E+06 |
| **La-141** | 4.33E+04 | 8.28E+07 | **Xe-135** | 1.42E+04 | 2.72E+07 |
| **La-142** | 4.21E+04 | 8.05E+07 | **Xe-135m** | 1.15E+04 | 2.20E+07 |
| **Mo-99** | 5.30E+04 | 1.01E+08 | **Xe-138** | 4.56E+04 | 8.72E+07 |
| **Nb-95** | 4.50E+04 | 8.60E+07 | **Y-90** | 2.45E+03 | 4.68E+06 |
| **Nd-147** | 1.75E+04 | 3.35E+07 | **Y-91** | 3.17E+04 | 6.06E+07 |
| **Np-239** | 5.69E+05 | 1.09E+09 | **Y-92** | 3.26E+04 | 6.23E+07 |
| **Pr-143** | 3.96E+04 | 7.57E+07 | **Y-93** | 2.52E+04 | 4.82E+07 |
| **Pu-241** | 4.26E+03 | 8.15E+06 | **Zr-95** | 4.44E+04 | 8.49E+07 |
| **Rb-86** | 5.29E+01 | 1.01E+05 | **Zr-97** | 4.23E+04 | 8.09E+07 |

## 5.4 Material Compositions

The following compositions used in the MCNP model are taken or developed from the SCALE standard composition library [Reference 3.1] and are shown in Table 6.

*Table 6 – Scale Standard Compositions used in MCNP Model*

| Material | Isotope | Weight Fraction |
|---|---|---|
| **Zry- 4** | Zr | 0.9823 |
| **(6.56 g/cm$^3$)** | Sn | 0.0145 |
| | Cr | 0.0010 |
| | Fe | 0.0021 |
| | Hf | 0.0001 |
| **$UO_2$** | U-235 | 0.0348 |
| **(10.412 g/cm$^3$)** | U-238 | 0.8466 |
| | O | 0.1186 |
| **Air** | C | 0.0001 |
| **(1.21E-03 g/cm$^3$)** | N | 0.7651 |
| | O | 0.2348 |
| **Water** | H | 0.1111 |
| **(0.9982 g/cm$^3$)** | O | 0.8889 |
| **SS-304** | Fe | 0.6838 |
| **(7.94 g/cm$^3$)** | Cr | 0.1900 |
| | Ni | 0.0950 |
| | Mn | 0.0200 |
| | Si | 0.0100 |
| | C | 0.0008 |
| | P | 0.0004 |
| **Concrete** | O | 0.5320 |
| **(2.30 g/cm$^3$)** | Si | 0.3370 |
| **[KENO Regular** | Ca | 0.0440 |
| **Concrete Standard** | Al | 0.0340 |
| **Mix]** | Na | 0.0290 |
| | Fe | 0.0140 |
| | H | 0.0100 |
| **Carbon Steel** | C | 0.0100 |
| **(7.82 g/cm$^3$)** | Fe | 0.9900 |

5.5 Upper Internals

The following weights are used in the MCNP model for the region between the active fuel and the reactor vessel head [Reference 3.9, Appendix 8.9]:

- The weight of stainless steel for the moisture separator is 83,000 lbs.
- The weight of stainless steel for the steam dryer is 50,000 lbs.

5.6 The drywell (9184 A/B) and torus (9185 A/B) radiation monitor ranges (1 to $10^7$ R/hr) are taken from Reference 3.6.

5.7 ANSI/ANS-1977 Flux to Dose Factors

Flux to dose conversion factors are taken from ANSI/ANS-6.1.1-1977 [Reference 3.4] and are shown in Table 7.

*Table 7 – ANSI/ANS-6.1.1-1977 Flux to Dose Factors*

| MeV | mrem/hr/($\gamma$/cm$^2$/s) | MeV | mrem/hr/($\gamma$/cm$^2$/s) |
|---|---|---|---|
| 0.01 | 3.96E-03 | 0.8 | 1.68E-03 |
| 0.03 | 5.82E-04 | 1 | 1.98E-03 |
| 0.05 | 2.90E-04 | 2.2 | 3.42E-03 |
| 0.07 | 2.58E-04 | 2.6 | 3.82E-03 |

## 6.0 Methodology

The reactor source terms are decayed to 50 hours with ORIGEN-S of the SCALE 6.1 code package, Reference 3.2. The results are used to bin design input isotope specific activities into energy dependent photon bins. These energy specific photon emission bins are used as input for the energy distribution described by the MCNP source definitions.

The MCNP6, Reference 3.3, Monte Carlo transport code is used to determine the dose rates via the flux to dose conversion factors in Table 7, while accounting for shielding and particle transport.

The detailed engineering drawings are converted into MCNP surface and cell cards in the dimensions shown in Table 3 and Table 4. The radiation monitors of interest are modeled as point detectors to determine the expected dose rate for those detectors. The dose rates are calculated for two reactor refueling conditions:

1. With Head – the reactor is modeled with a 3.9375 inch carbon steel plate as indicated in Table 3, which is additional attenuation between the source and detector. The mass of the moisture separator and steam dryer is homogenized between the active fuel region and the vessel head.
2. Without head – the reactor is modeled with air between the active fuel zone and containment.
3. A sensitivity case is run with a mirror surface at the top of the drywell to ensure the modeling of the drywell cap would not significantly affect the response at the detector locations due to scattering.

Variance reduction is accomplished with a geometric importance map that is imposed on the homogenized core. In addition, cell based importance weighting and source biasing (see Section 7.5) are utilized to improve the variance reduction of the simple geometric scheme. A superimposed weight window mesh is utilized where necessary to improve variance. The weight windows are iteratively generated using the MCNP weight windows generator card. All final dose rates presented in this calculation include weight windows variance reduction.

## 7.0 Calculation

### 7.1 Source Terms

The ORIGEN-S input deck, *DAECEAL.inp*, is provided in Appendix C. This input produces a simple case where the isotopic composition from Table 5 is decayed. The isotope is specified in the 73$$ card using the special identifier described in Section F7.6.2 of the ORIGEN-S manual, and the activity in curies is specified in the 74** card. The time steps for the decay are given on the 60** card in hours. Although multiple time steps are calculated, the source term with 50 hours decay time is used in this calculation to model the core shortly after shutdown. The output of the decay is given in terms of photons/s/Energy-Group, which is automatically normalized in the MCNP input. The results of this calculation are summarized below in Table 8. These values are used in the MCNP input source definition.

*Table 8 – Binned Total Core Source Term*

| Energy Group | Energy Boundaries (MeV) | Photons/sec |
|---|---|---|
| 1 | 0.01-0.05 | 2.028E+19 |
| 2 | 0.05-0.1 | 6.572E+18 |
| 3 | 0.1-0.2 | 1.557E+19 |
| 4 | 0.2-0.3 | 9.672E+18 |
| 5 | 0.3-0.4 | 3.582E+18 |
| 6 | 0.4-0.6 | 7.837E+18 |
| 7 | 0.6-0.8 | 1.373E+19 |
| 8 | 0.8-1 | 2.132E+18 |
| 9 | 1-1.33 | 4.942E+17 |
| 10 | 1.33-1.66 | 3.579E+18 |
| 11 | 1.66-2 | 6.576E+16 |
| 12 | 2-2.5 | 7.518E+16 |
| 13 | 2.5-3 | 1.110E+17 |
| 14 | 3-4 | 8.689E+14 |
| 15 | 4-5 | 1.553E+10 |
| 16 | 5-6.5 | 2.568E+08 |
| 17 | 6.5-8 | 3.792E+07 |
| 18 | 8-10 | 8.041E+06 |
| 19 | 10-11 | 4.352E+05 |
| totals | | 8.37E+19 |

## 7.2 MCNP Model Core Homogenization

The source term is given for the entire core, therefore, the self-shielding from the assemblies is an important part of the dose rate response. For simplicity, the core is modeled as a three dimensional cylinder with a uniformly distributed spatial particle distribution. The calculations for determining the mass of fuel, cladding and water for the core and the resulting density are shown below. The inputs are based on the dimensions in Table 2.

$$Assembly\ Width = (Array\ Size - 1) \times pitch + Rod\ OD = (10-1)(0.51in) + 0.395in = 4.985\ in$$

$$Active\ Fuel\ Region\ Area = (Assembly\ Width)^2 \times Number\ of\ Assemblies\ in\ Core = (4.985in)^2 \times 368 = 9144.883\ in^2$$

$$Active\ Fuel\ Equivalent\ Radius = \sqrt{Active\ Fuel\ Region\ Area/_{\pi}} = \sqrt{9144.883\ in^2/_{\pi}} = 53.953\ in$$

$$Rod\ Volume_{UO_2} = \pi(Pellet\ Radius)^2 \times Active\ Length = \pi(0.168\ in)^2(144\ in) = 12.768\ in^3$$

$$Rod\ Mass_{UO_2} = \rho \times V = \left(10.412\frac{g}{cc}\right)(12.7682\ in^3)\left(2.54\frac{cm}{in}\right)^3 = 2178.54\ g$$

$$Assembly\ Mass_{UO_2} = Rod\ Mass \times \frac{Number\ of\ Fuel\ Rods}{Assembly} = (2178.54\ g)(92) = 200.43\ kg$$

$$Clad\ Volume = \pi\left(\frac{OD^2}{4} - \frac{ID^2}{4}\right) \times Active\ Length = (\pi)\left[\frac{(0.395\ in)^2}{4} - \frac{(0.343\ in)^2}{4}\right](144\ in) = 4.34\ in^3$$

$$Rod\ Mass_{Zry-4} = \rho \times V = \left(6.56\ \frac{g}{cc}\right)(4.34\ in^3)\left(2.54\frac{cm}{in}\right)^3 = 466.5\ g$$

$$Assembly\ Mass_{Zry-4} = Rod\ Mass \times \frac{Number\ of\ Fuel\ Rods}{Assembly} = (466.5g)(92) = 42.92\ kg$$

$$\begin{aligned} Assembly\ \ H_2O\ Volume \\ &= [(Assembly\ Width)^2 \\ &- \pi(Rod\ Radius)^2 \times Number\ of\ Fuel\ Rods] \times Active\ Length \\ &= [(4.985\ in)^2 - (\pi)(0.1975\ in)^2(92)](144\ in) = \ 1955\ in^3 \end{aligned}$$

$$Assembly\ Mass_{H_2O} = \rho \times V = \left(0.9982 \frac{g}{cc}\right)\left(\frac{1955}{in^3}\right)\left(2.54 \frac{cm}{in}\right)^3 = 31.98\ kg$$

$$\begin{aligned} Assembly\ Volume &= Active\ Length\ \times (Assembly\ Width)^2 = (144\ in)(4.985\ in)^2 \\ &= 3578.4\ in^3 \end{aligned}$$

$$Density = \frac{Total\ Mass}{Volume} = \frac{1000g/kg(200.43 + 42.92 + 31.98)\ kg}{3578.4\ in^3 \left(2.54 \frac{cm}{in}\right)^3} = 4.70\ g/cc$$

The corresponding isotopic composition for the homogenized active fuel region is calculated based on the compositions in Table 6. An example calculation for the mass fraction of U-235 is included below.

$$\begin{aligned} Mass\ Fraction\ U235 &= \frac{Assembly\ Mass_{UO_2}}{Total\ Mass} \times weight\ fraction\ U235 \\ &= \frac{200.43\ kg}{(200.43 + 42.92 + 31.98)\ kg} \times 0.0348 = 0.0253 \end{aligned}$$

The remaining calculations for the homogenization are done in the worksheet Compositions of the EXCEL workbook DAEAL.xlsx and are shown in Appendix B. The isotopic compositions are calculated with the water level above the top of the fuel. Note that the EXCEL workbook uses additional significant figures.

*Table 9 – Homogenization of Active Fuel Region*

| ZAID Number | Atom | Mass Fraction Active Fuel Region Homogenized |
|---|---|---|
| 92235 | U-235 | 0.0253 |
| 92238 | U-238 | 0.6163 |
| 8016 | O | 0.1896 |
| 40000 | Zr | 0.1531 |
| 50000 | Sn | 0.0023 |
| 24000 | Cr | 0.0002 |
| 26000 | Fe | 0.0003 |
| 72000 | Hf | 0.0000 |
| 1001 | H | 0.0129 |

## 7.3 MCNP Model Upper Internals Homogenization

For the case with the reactor vessel head in place, the steam dryer and moisture separator region are modeled as a discrete cylinder with a uniformly distributed homogenized material to account for the mass of stainless steel between the active fuel height and reactor vessel head. The homogenization accounts for the mass of metal from Section 5.5 (assumed stainless steel type 304 per Assumption 4.5) distributed evenly across the volume between the active fuel height (Z=1071.73 cm) and the head (Z=1985.01 cm).

$$Mass\ Upper\ Internals = (83000\ lb + 50000\ lb)\left(453.59\frac{g}{lb}\right) = 6.033 \times 10^7\ g$$

The mass is divided by the volume of the region between the active fuel height and the reactor vessel head to determine the density.

$$Density\ Upper\ Internals = Mass\ Upper\ Internals \div V$$
$$= 6.033 \times 10^7\ g \div (913.28cm \times (\pi(235.43cm)^2) = 0.379\frac{g}{cc}$$

## 7.4 MCNP Model Geometry

The following MCNP model geometry is based on the containment dimensions summarized in Table 3 and Table 4. The model only focuses on the primary systems and components that provide shielding or reflection from the core to the radiation monitors. These components include the reactor vessel, recirculation pumps, pedestal, biological shield and drywell. VISED plots of the model geometry are provided in Figures 1-3. The MCNP surface cards with the model dimensions (cm) are shown in Figure 4, and the cell cards are shown in Figure 5 for the cases with no reactor vessel head. A VISED plot of the model with the reactor vessel head is shown in Figure 6. Areas that are not of interest are given an importance of zero (white areas) so MCNP will not track particles in locations that will not contribute to the detector response.

*Figure 1 X-Z VISED Plot of Reactor Vessel (No Head)*

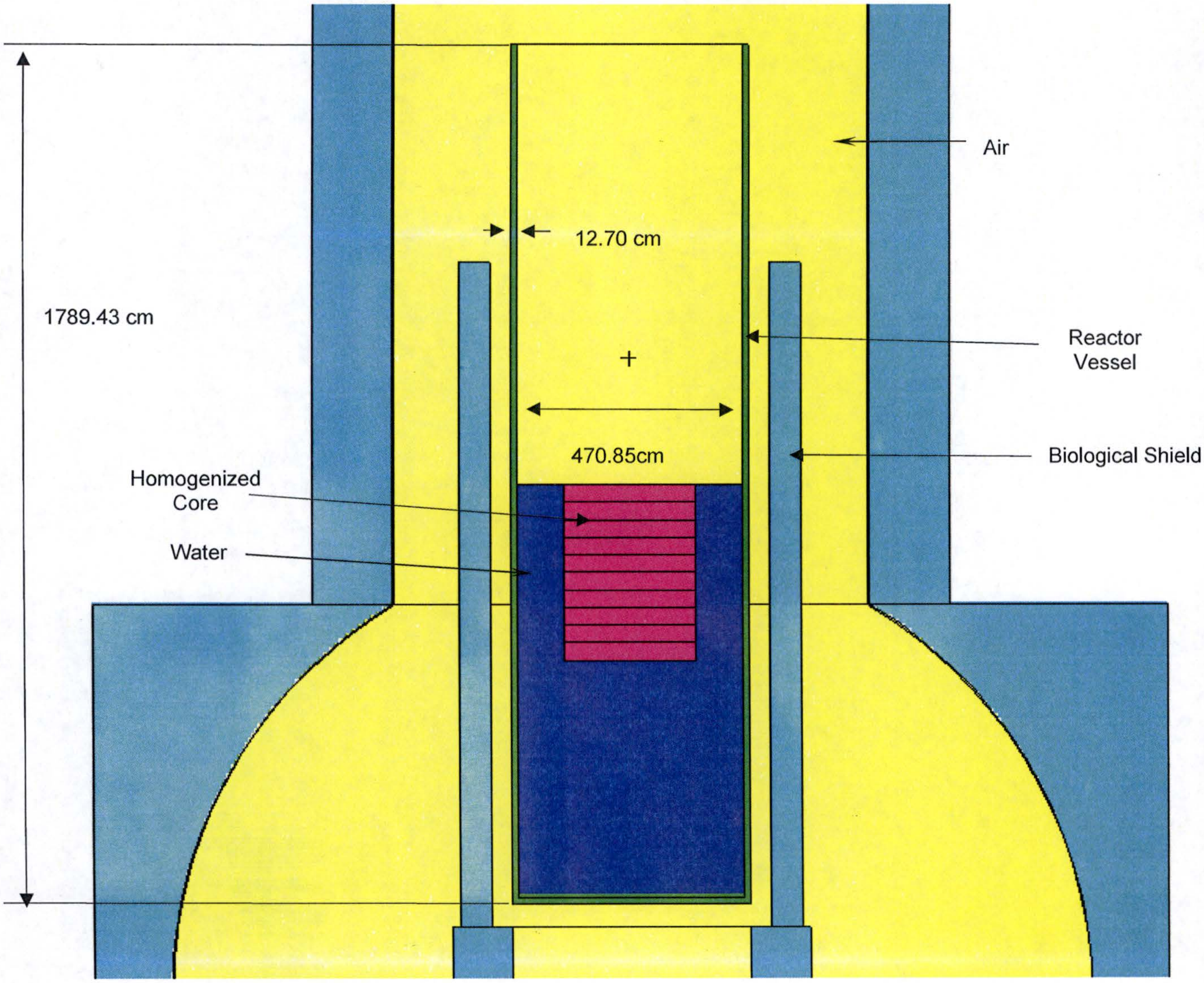
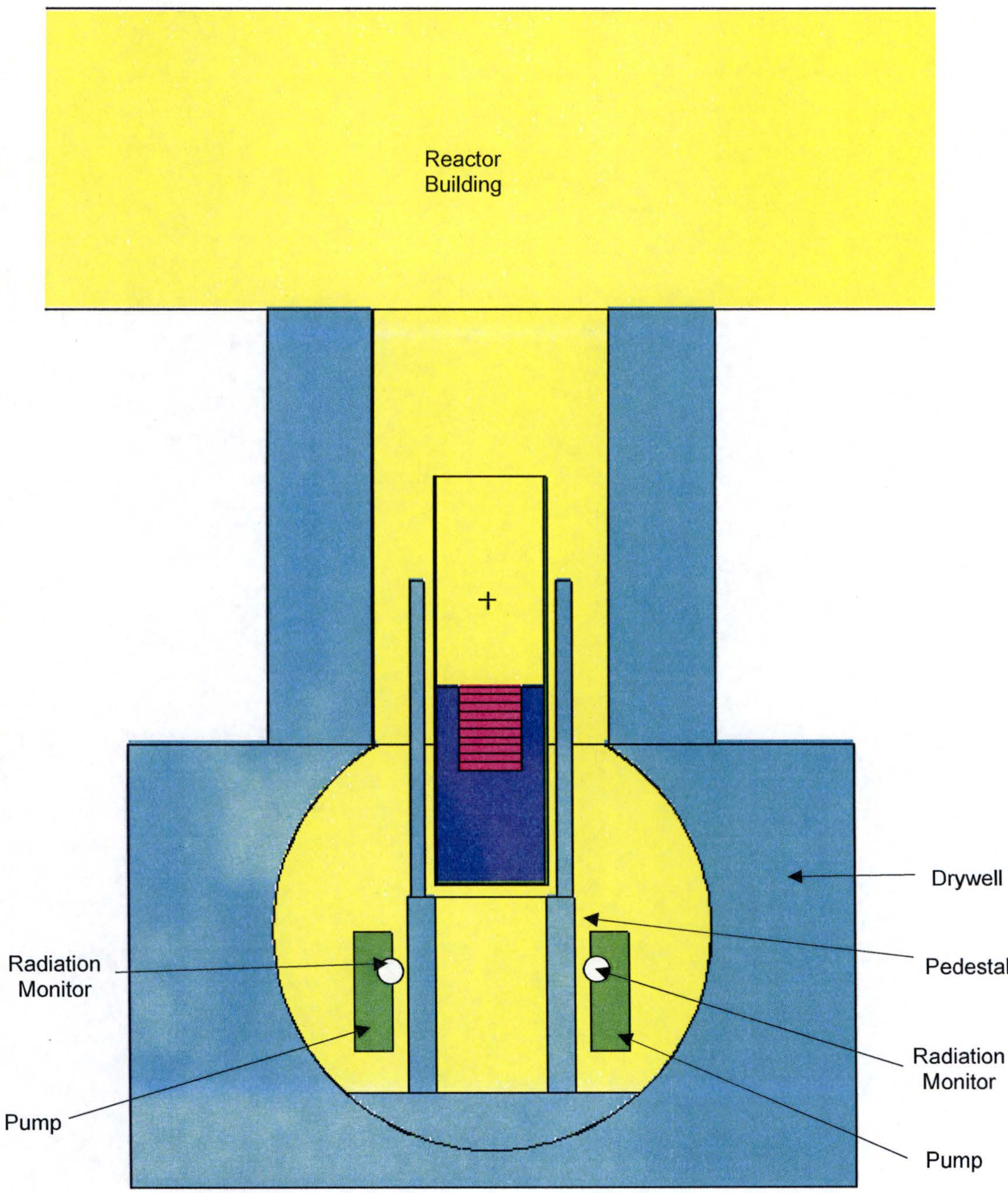
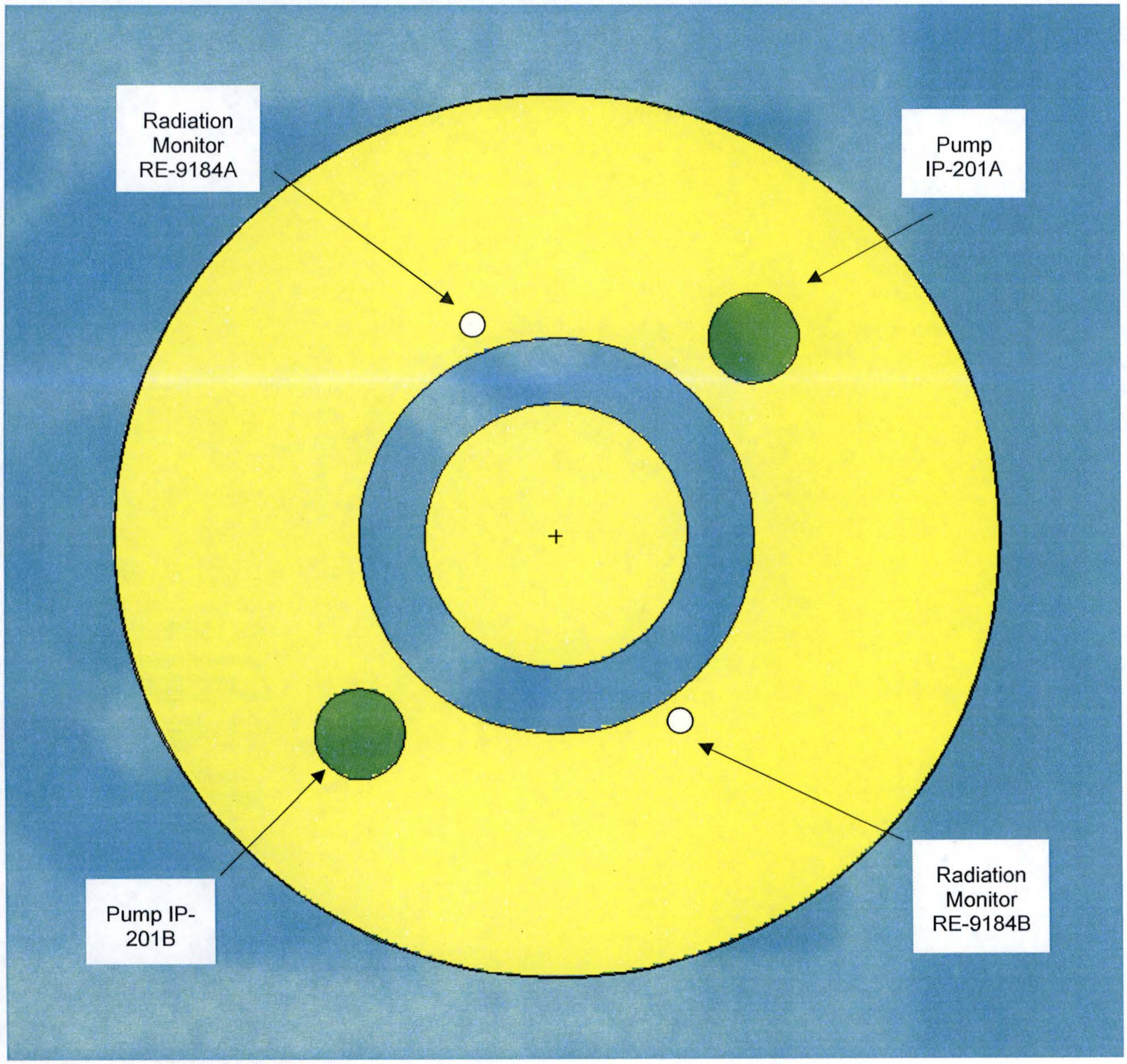


*Figure 2 Vised Plot of Drywell and Reactor Building*[3]




[3] Radiation monitors are not on the same plane shown above. They are included for visualization purposes only. The VISED Plot was rotated around the Z axis until the Recirculating Pumps were visible.

*Figure 3 X-Y Vised Plot of Detectors and Reactor Recirculating Pumps at Elevation 760'-0"* [4]




[4] Detectors are included for visualization purposes only.

*Figure 4 MCNP Model Surface Cards*[5]

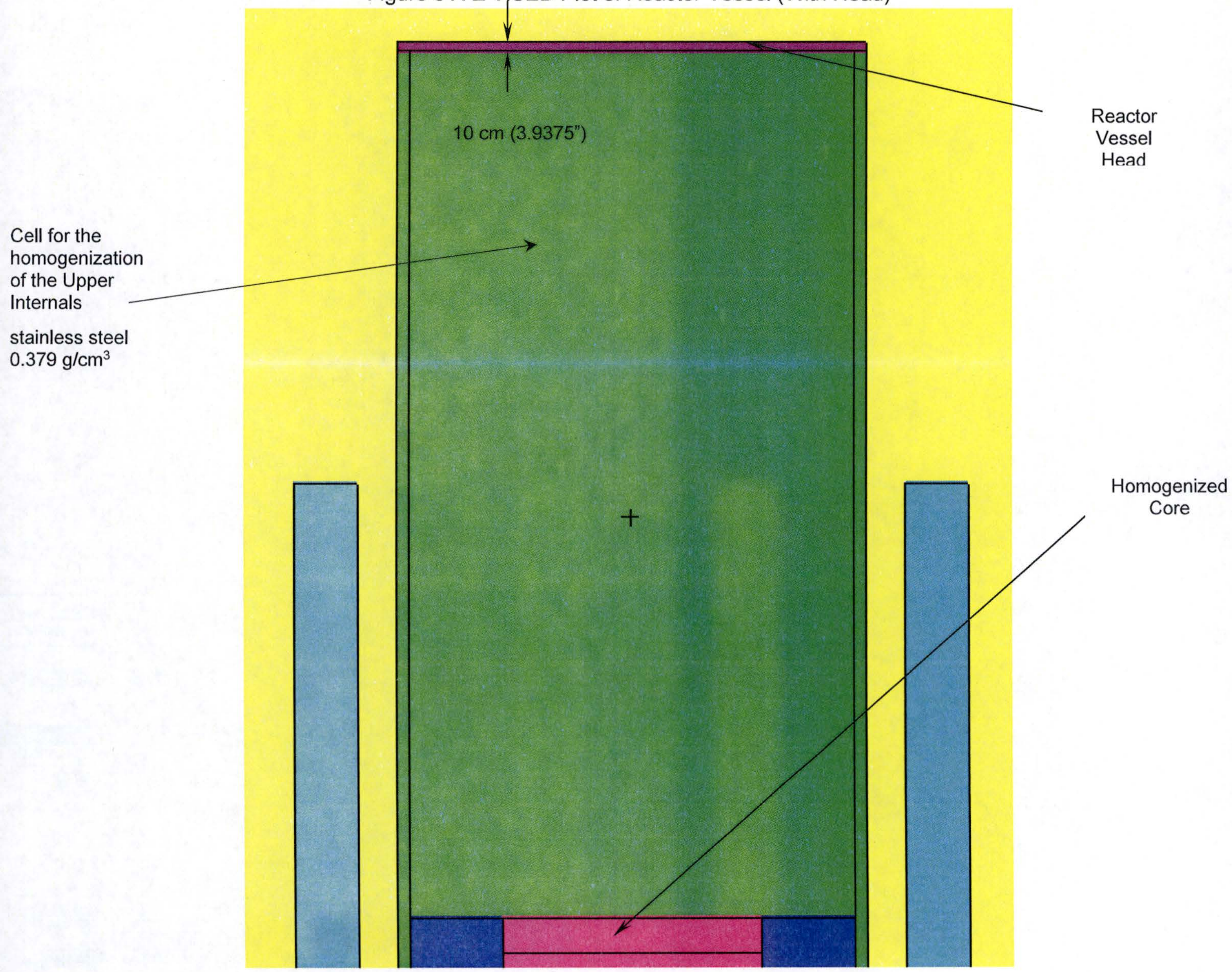
```
c surfaces
1 rcc 0 0 705.97 0 0 365.76 137.045                            $ Active Fuel Region
2 rcc 0 0 208.28 0 0 1776.73 235.43                            $ Reactor Pressure Vessel Inner Surface
3 rcc 0 0 195.58 0 0 1789.43 248.13                            $ Reactor Pressure Vessel Outer Surface
4 rpp -1120.14 1120.14 -1120.14 1120.14 -1120.14 821.86        $ Concrete Spher port drywell outer
5 so 960.12                                                    $ Spher portion of drywell outer surface
6 so 958.21                                                    $ Spher portion of drywell liner surface
7 pz -709.93                                                   $ Bottom of Pedestal Elevation
8 rcc 0 0 -709.93 0 0 857.25 243.84                            $ Pedestal Inner Surface
9 rcc 0 0 -709.93 0 0 857.25 365.76                            $ Pedestal Outer Surface
81 rcc 0 0 147.32 0 0 1383.67 290.20                           $ Bio Shield Inner Surface
91 rcc 0 0 147.32 0 0 1383.67 356.24                           $ Bio Shield Outer Surface
82 rcc 365.76 365.76 -528.32 0 0 523.24 83.82                  $ Recirc Pump IP-201A
92 rcc -365.76 -365.76 -528.32 0 0 523.24 83.82                $ Recirc Pump IP-201B
10 pz 195.58                                                   $ Vessel 0
11 pz 821.86                                                   $ Transition Spherical to Cylindrical
12 rcc 0 0 821.86 0 0 1889.59 518.16                           $ cylin port drywell concrete surface
13 rcc 0 0 821.86 0 0 1889.59 516.25                           $ cylin port drywell liner surface
14 rpp -693.42 693.42 -693.42 693.42 821.86 2711.45            $ Concrete cylin port drywell outer
15 pz 1071.73                                                  $ Water Elevation Surface
16 pz 1985.01                                                  $ Top of RPV (head level)
17 rpp -4267.2 4267.2 -4267.2 4267.2 2711.45 4006.85           $ Reactor building above drywell
18 rpp -4267.2 4267.2 -4267.2 4267.2 4006.85 4008.12           $ Reactor building roof
19 pz 147.32                                                   $ Top of Ped Elevation/Bottom Bio Shield
20 pz 1530.99                                                  $ Top of Ped Elevation/Bottom Bio Shield
28 rcc 0 0 1985.01 0 0 10.00 248.13                            $ Reactor Head
101 pz 742.546
102 pz 779.122
103 pz 815.698
104 pz 852.274
105 pz 888.85
106 pz 925.246
107 pz 962.002
108 pz 998.578
109 pz 1035.154
110 pz 1071.73
```

[5] The surface card for the MCNP model without the reactor vessel head does not have surface 28.

*Figure 5 MCNP Model Cell Cards (No Head)*

```
c cells
101 1 -4.49 -1 -101                  imp:p=256        $ Active Fuel Region
102 1 -4.49 -1 101 -102              imp:p=128        $ Active Fuel Region
103 1 -4.49 -1 102 -103              imp:p=64         $ Active Fuel Region
104 1 -4.49 -1 103 -104              imp:p=32         $ Active Fuel Region
105 1 -4.49 -1 104 -105              imp:p=16         $ Active Fuel Region
106 1 -4.49 -1 105 -106              imp:p=8          $ Active Fuel Region
107 1 -4.49 -1 106 -107              imp:p=4          $ Active Fuel Region
108 1 -4.49 -1 107 -108              imp:p=3          $ Active Fuel Region
109 1 -4.49 -1 108 -109              imp:p=2          $ Active Fuel Region
110 1 -4.49 -1 109 -110              imp:p=1          $ Active Fuel Region
2 2 -0.9982 1 -2 -15                 imp:p=256        $ Water Region
3 3 -1.21E-03 15 -2                  imp:p=256        $ Air Region inside vessel
4 4 -7.94 2 -3 -16                   imp:p=256        $ RPV Shell
7 5 -2.3 5 -4                        imp:p=256        $ Concrete Surrounding RPV spherical
8 5 -2.3 -14 12                      imp:p=256        $ Concrete Surrounding RPV cylindrical
9 5 -2.3 -9 8 7 -19                  imp:p=256        $ Pedestal
91 5 -2.3 -91 81 19 -20              imp:p=256        $ Bio Shield
10 5 -2.3 -6 -7                      imp:p=256        $ Concrete at bottom of pedestal
11 3 -1.21E-03 -8                    imp:p=256        $ Inside Pedestal Air
12 3 -1.21E-03 -6 7 -11 9 3
        #18 #19 #91                  imp:p=256        $ Inside Spherical portion Air
13 3 -1.21E-03 -13 3 #91             imp:p=256        $ Inside Cylindrical portion Air
14 3 -1.21E-03 -17                   imp:p=256        $ Reactor Building above drywell Air
15 4 -7.94 2 -18                     imp:p=256        $ Reactor Build Roof Stainless Steel
16 4 -7.94 6 -5 -11                  imp:p=256        $ Containment Liner Spherical portion
17 4 -7.94 13 -12                    imp:p=256        $ Containment Liner Cylin portion
18 4 -7.94 -82                       imp:p=256        $ Recirc Pump IP-201A
19 4 -7.94 -92                       imp:p=256        $ Recirc Pump IP-201B
999 0 1 #2 #3 #4 #7 #8 #9 #10 #11 #12 #13 #14
             #15 #16 #17 #18 #19 #91       imp:p=0          $ Problem Boundary
```

Figure 6 X-Z VISED Plot of Reactor Vessel (With Head)




## 7.5 MCNP Source Definition

The core source term is modeled as uniformly distributed throughout the homogenized core, and has an energy spectra based on the decayed core inventory (Section 7.1). Only the gamma source term is taken into account for this evaluation. The source term is generated shortly after shutdown, therefore, the fuel gamma source term will predominate, and the neutron-gamma and hardware activation source terms can be neglected (Assumption 4.7). The source is defined on the MCNP sdef card using distributions to define the particle location and energy. The radius of the core is defined with the rad parameter, which automatically creates a uniform distribution based on a cylindrical geometry. The ext and axs parameters define the direction and distance of the cylinder axis. These parameters combined define the core where the particles can be born. The erg parameter defines the energy spectrum of source particles, and is based on the results of the ORIGEN-S calculation discussed previously. This distribution is a histogram of energies represented by activities. These are automatically normalized by MCNP to create a probability distribution. The total activity is preserved in the tally multiplier. The MCNP source definition cards are shown below in Figure 7. The sb card is a source biasing card, which in this case biases the particle generation to the lower end of the core. This is a variance reduction technique to improve the statistical certainty in the results.

*Figure 7 MCNP Source Definition Cards*

```
sdef rad=d1 ext=d2 axs=0 0 1 erg=d8                                    ←Source Definition Card
                                                                             -Radius = d1
                                                                             -Extent = d2
                                                                             -Axis = +Z
                                                                             -Energy = d8
si1 137.045                                                            ←Core Radius Distribution
si2 h 0 742.546 779.122 815.698 852.274 888.85 925.246 962.002         ←Core Axial Distribution
       998.578 1035.154 1071.73
sp2 0 1 1 1 1 1 1 1 1 1 1                                              ←Actual Uniform Distribution
sb2 0 1 1 0.1 0.1 0.1 0.01 0.01 0.01 0.001 0.001                       ←Biased to Bot Distribution
c  Fuel Gamma Spectra
si8  h 1.000e-002 5.000e-002 1.000e-001 2.000e-001 3.000e-001 4.000e-001   ←Source Energy Groups
     6.000e-001 8.000e-001 1.000e+000 1.330e+000 1.660e+000 2.000e+000
     2.500e+000 3.000e+000 4.000e+000 5.000e+000 6.500e+000 8.000e+000
     1.000e+001 1.100e+001
sp8     0.00E+00 2.028E+19 6.572E+18 1.557E+19 9.672E+18 3.582E+18 7.837E+18 ←Source Emission on
                                                                                Energy Basis
       1.373E+19 2.132E+18 4.942E+17 3.579E+18 6.576E+16 7.518E+16 1.110E+17
       8.689E+14 1.553E+10 2.568E+08 3.792E+07 8.041E+06 4.352E+05
```

## 7.6 MCNP Tally Specification

The tallies used in this evaluation are point detectors placed at approximate locations of radiation monitors RE-9184A, and RE-9184B. Point detectors are chosen because they use quasi-deterministic dose calculations that will provide better results than surface or cell based tallies that require the particles to enter those regions. The inputs to this card are the coordinates of the dose points followed by an exclusion zone to reduce variance, as well as a multiplier card, which represents the total core activity in photons/sec. The tally cards are shown in Figure 8.

*Figure 8 MCNP Tally Cards*

```
f5c RE-9184A, and 9184B                                  ←Tally Comment Card
f5:p -121.92  406.29 -184.15 20                          ←Tally 5 (point detector)
182.88   -365.76 -184.15 20                              x      y      z     exclusion
fm5 8.370E+19                                            ← Tally Multiplier
                                                           (Total Activity)
```

In addition, the flux is multiplied by ANSI/ANS flux-dose conversion factors [Reference 3.4]. This is specified in MCNP using the de/df cards. These are shown in Figure 9.

*Figure 9 ANSI/ANS-6.1.1-1977 Gamma Flux to Dose Conversion Factors*

```
c -----------------------------------------------------------------
c ANSI/ANS-6.1.1-1977
c Gamma Flux to Dose Conversion Factors
c (mrem/hr)/(photons/cm2-s)
c -----------------------------------------------------------------
de0  .01 .03 .05 .07 .10 .15 .20 .25 .30 .35 .40                    ←Energy Bins for Flux
     .45 .50 .55 .60 .65 .70 .80 1. 1.4 1.8 2.2                      to Dose Conversion
     2.6 2.8 3.25 3.75 4.25 4.75 5. 5.25 5.75 6.25
     6.75 7.5 9. 11.
df0  3.96E-03   5.82E-04   2.90E-04   2.58E-04   2.83E-04   3.79E-04   ←Energy Dependent
     5.01E-04   6.31E-04   7.59E-04   8.78E-04   9.85E-04   1.08E-03     Flux Multipliers
     1.17E-03   1.27E-03   1.36E-03   1.44E-03   1.52E-03   1.68E-03
     1.98E-03   2.51E-03   2.99E-03   3.42E-03   3.82E-03   4.01E-03
     4.41E-03   4.83E-03   5.23E-03   5.60E-03   5.80E-03   6.01E-03
     6.37E-03   6.74E-03   7.11E-03   7.66E-03   8.77E-03   1.03E-02
```

## 7.7 MCNP Material Cards

The MCNP material cards are provided in Figure 9. These are based on the compositions described in Table 6 or calculated in Section 7.2.

*Figure 10 MCNP Material Cards*

```
m1     92235      -0.0253            $ Homogenized Active Fuel Region
       92238      -0.6163
       8016       -0.1896
       40000      -0.1531
       50000      -0.0023
       24000      -0.0002
       26000      -0.0003
       1001       -0.0129
m2     1001 2 8016 1                 $ Water
m3     6012 -0.000126                $ Air
       7014 -0.76508
       8016 -0.234793
m4     6000 -0.0008                  $ SS 304
       14000 -0.01
       15031 -0.00045
       24000 -0.19
       25055 -0.02
       26000 -0.68375
       28000 -0.095
m5     26000 -0.014                  $ Reg-Concrete
       1001 -0.01
       13027 -0.034
       20000 -0.044
       8016 -0.532
       14000 -0.337
       11023 -0.029
m6     6012 -0.01                     $ Carbon Steel
       26056 -0.99
```

### 7.8 Results

The dose rates are provided in Table 10 for the water level at the top of the fuel assemblies. The dose rate is slightly above the detectable response of 1 R/h (1E+03 mrem/h) for the no head configuration, and below the detectable response for the configuration with the reactor vessel head in place for one of the detectors. The sensitivity case shows that there is no significant impact due to reflection from the drywell cap.

*Table 10 – Dose Rate Response (mrem/h)*

| Configuration | Dose Rate 1 RE-9184A | fsd[6] | Dose Rate 2 RE-9184B | fsd | Tally File |
|---|---|---|---|---|---|
| No Head | 1.81E+03 | 10.81% | 1.68E+03 | 7.31% | d0ndm |
| With Head | 1.11E+03 | 10.16% | 7.41E+02 | 8.24% | d0hgm |
| With Head (Sensitivity Case) | 1.07E+03 | 15.27% | 7.67E+02 | 15.51% | d0rdm |

## 8.0 Computer Software

This calculation uses ORIGEN-S of the SCALE Version 6.1.2 code package [Reference 3.2] and MCNP Version 6.1.0 [Reference 3.3] in accordance with CSP 3.09.

[6] Fraction standard deviation.

## 9.0 Impact Assessment

This calculation is based on "realistic" assumptions for the purpose of declaring EALs, rather than typical conservative "bounding" type design basis analyses. The calculation results are intended to provide order of magnitude dose rates to assist Operations and Emergency Response personnel in determination of core uncovery in accordance with NEI 99-01 Rev. 6.

```
Origen output:
07/26/2017  04:19 PM            82,114 DAECEAL.OUT

MCNP output:

 Directory of \No head\
08/16/2017  09:13 AM             327,680 d0nao

 Directory of \With Head\
08/16/2017  10:01 AM           1,269,760 d0hgo

 Directory of \sensitivity\
08/16/2017  03:54 AM             286,720 d0rdo
```

| Material | Isotope | Weight Fraction | Reference |
|---|---|---|---|
| **Zry- 4** | Zr | 0.9823 | [1] |
| (6.56 g/cm$^3$) | Sn | 0.0145 | |
| | Cr | 0.001 | |
| | Fe | 0.0021 | |
| | Hf | 0.0001 | |
| **$UO_2$** | U-235 | 0.0348 | [1] |
| | U-238 | 0.8466 | |
| | O | 0.1186 | |
| **Air** | C | 0.0001 | [1] |
| (1.21E-03 g/cm$^3$) | N | 0.7651 | |
| | O | 0.2348 | |
| **Water** | H | 0.1111 | [1] |
| (0.9982 g/cm$^3$) | O | 0.8889 | |
| **SS-304** | Fe | 0.6838 | [1] |
| (7.94 g/cm$^3$) | Cr | 0.19 | |
| | Ni | 0.095 | |
| | Mn | 0.02 | |
| | Si | 0.01 | |
| | C | 0.0008 | |
| | P | 0.0004 | |
| **Concrete** | O | 0.532 | [1] |
| (2.30 g/cm$^3$) | Si | 0.337 | |
| | Ca | 0.044 | |
| | Al | 0.034 | |
| | Na | 0.029 | |
| | Fe | 0.014 | |
| | H | 0.01 | |
| **Carbon Steel** | C | 0.01 | [1] |
| (7.82 g/cm$^3$) | Fe | 0.99 | |

| Material | Mass (KG) |
|---|---|
| **$UO_2$** | 200.4 |
| **Zry- 4** | 42.92 |
| **Water** | 31.98 |

| ZAID Number | Atom | Mass Fraction Active Fuel Region Homogenized |
|---|---|---|
| 92235 | U-235 | 0.0253 |
| 92238 | U-238 | 0.6163 |
| 8016 | O | 0.1896 |
| 40000 | Zr | 0.1531 |
| 50000 | Sn | 0.0023 |
| 24000 | Cr | 0.0002 |
| 26000 | Fe | 0.0003 |
| 72000 | Hf | 0.0000 |
| 1001 | H | 0.0129 |
| | | 1.0000 |

| Row | Material | Isotope | Weight Fraction | Reference | Material | Mass (KG) | ZAID Number | Atom | Mass Fraction Active Fuel Region Homogenized |
|---|---|---|---|---|---|---|---|---|---|
| 3 | **Zry- 4** | Zr | 0.9823 | [1] | **$UO_2$** | 200.42 | 92235 | U-235 | =(H3/SUM(H3:H5))*D8 |
| 4 | (6.56 $g/cm^3$) | Sn | 0.0145 | | **Zry- 4** | 42.92 | 92238 | U-238 | =(H3/SUM(H3:H5))*D9 |
| 5 | | Cr | 0.001 | | **Water** | 31.98 | 8016 | O | =((H3/(SUM(H3:H5)))*D10)+((H5/(SUM(H3:H5))))*D15 |
| 6 | | Fe | 0.0021 | | | | 40000 | Zr | =($H$4/SUM($H$3:$H$5))*D3 |
| 7 | | Hf | 0.0001 | | | | 50000 | Sn | =($H$4/SUM($H$3:$H$5))*D4 |
| 8 | **$UO_2$** | U-235 | 0.0348 | [1] | | | 24000 | Cr | =($H$4/SUM($H$3:$H$5))*D5 |
| 9 | | U-238 | 0.8466 | | | | 26000 | Fe | =($H$4/SUM($H$3:$H$5))*D6 |
| 10 | | O | 0.1186 | | | | 72000 | Hf | =($H$4/SUM($H$3:$H$5))*D7 |
| 11 | **Air** | C | 0.0001 | [1] | | | 1001 | H | =(H5/SUM(H3:H5))*D14 |
| 12 | (1.21E-03 $g/cm^3$) | N | 0.7651 | | | | | | =SUM(L3:L11) |
| 13 | | O | 0.2348 | | | | | | |
| 14 | **Water** | H | 0.1111 | [1] | | | | | |
| 15 | (0.9982 $g/cm^3$) | O | 0.8889 | | | | | | |
| 16 | **SS-304** | Fe | 0.6838 | [1] | | | | | |
| 17 | (7.94 $g/cm^3$) | Cr | 0.19 | | | | | | |
| 18 | | Ni | 0.095 | | | | | | |
| 19 | | Mn | 0.02 | | | | | | |
| 20 | | Si | 0.01 | | | | | | |
| 21 | | C | 0.0008 | | | | | | |
| 22 | | P | 0.0004 | | | | | | |
| 23 | **Concrete** | O | 0.532 | [1] | | | | | |
| 24 | (2.30 $g/cm^3$) | Si | 0.337 | | | | | | |
| 25 | | Ca | 0.044 | | | | | | |
| 26 | | Al | 0.034 | | | | | | |
| 27 | | Na | 0.029 | | | | | | |
| 28 | | Fe | 0.014 | | | | | | |
| 29 | | H | 0.01 | | | | | | |
| 30 | **Carbon Steel** | C | 0.01 | [1] | | | | | |
| 31 | (7.82 $g/cm^3$) | Fe | 0.99 | | | | | | |

```
=origens
0$$ a11 71 e t
BWR Source Term DAEC EAL Analysis
3$$  21 1 1 a4 27 a16 4 a33 19 e t
35$$ 0 t
54$$ a8 0 a11 2 e
56$$ 0 6 a6 1 a10 0 a13 63 3 3 0 2 0 e
57** 0  a3 1-16 e
95$$ 0 t
DAECEAL
Ci Source Terms
60** 0 24 40 50 60 70
61** 5r1-8 1+6 1+4
65$$
'GRAM-ATOMS   GRAMS    CURIES     WATTS-ALL  WATTS-GAMMA
     3Z      0  1  0     1 0 0     1 0 0          3Z          6Z
     3Z      1  1  1     1 0 1     1 1 1          3Z          6Z
     3Z      1  1  1     1 1 1     1 1 1          3Z          6Z
81$$ 2 0 26 1 e
82$$ f2
83** 1.10E+07 1.00E+07 8.00E+06 6.50E+06 5.00E+06 4.00E+06 3.00E+06
     2.50E+06 2.00E+06 1.66E+06 1.33E+06 1.00E+06 8.00E+05 6.00E+05
     4.00E+05 3.00E+05 2.00E+05 1.00E+05 5.00E+04 1.00E+04 e
84** 2.00E+07 6.43E+06 3.00E+06 1.85E+06 1.40E+06 9.00E+05 4.00E+05
     1.00E+05 1.70E+04 3.00E+03 5.50E+02 1.00E+02 3.00E+01 1.00E+01
     3.05E+00 1.77E+00 1.30E+00 1.13E+00 1.00E+00 8.00E-01 4.00E-01
     3.25E-01 2.25E-01 1.00E-01 5.00E-02 3.00E-02 1.00E-02 1.00E-05 e
73$$ 561390 561400 581410 581430 581440 962420 551340 551360
    551370 531310 531320 531330 531340 531350 360831 360850
    360851 360870 360880 571400 571410 571420 420990 410950
    601470 932390 591430 942410 370860 451050 441030 441050
    441060 511270 511290 380890 380900 380910 380920 430991
    521270 521271 521290 521291 521311 521320 541311 541330
    541331 541350 541351 541380 390900 390910 390920 390930
    400950 400970
74** 9.06E+07 9.10E+07 8.39E+07 7.65E+07 6.77E+07 2.14E+06 8.99E+06
    2.85E+06 6.21E+06 5.11E+07 7.42E+07 1.04E+08 1.14E+08 9.90E+07
    5.83E+06 5.32E+05 1.18E+07 2.35E+07 3.25E+07 9.39E+07 8.28E+07
    8.05E+07 1.01E+08 8.60E+07 3.35E+07 1.09E+09 7.57E+07 8.15E+06
    1.01E+05 5.37E+07 8.30E+07 5.85E+07 2.96E+07 4.57E+07 1.66E+07
    4.61E+07 4.57E+06 5.76E+07 6.19E+07 8.36E+07 4.51E+06 7.59E+05
    1.58E+07 3.21E+06 1.03E+07 7.28E+07 6.98E+05 1.04E+08 3.29E+06
    2.72E+07 2.20E+07 8.72E+07 4.68E+07 6.06E+07 6.23E+07 4.82E+07
    8.49E+07 8.09E+07
75$$ 3 3 3 3 3 2 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 2 3 2 3 3 3 3
    3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3
t
56$$ f0 t
end
```

| ENERCON Excellence—Every project. Every day. | Attachment 1 CALCULATION PREPARATION CHECKLIST | CALC NO. | NEE-323-CALC-002 |
|---|---|---|---|
| | | REV. | 0 |

| CHECKLIST ITEMS[1] | YES | NO | N/A |
|---|---|---|---|
| **GENERAL REQUIREMENTS** | | | |
| 1. If the calculation is being performed to a client procedure, is the procedure being used the latest revision? | ☐ | ☐ | ☒ |
| The Calculation is performed in accordance with ENERCON procedures. | | | |
| 2. Are the proper forms being used and are they the latest revision? | ☒ | ☐ | ☐ |
| The Calculation is performed in accordance with ENERCON procedures. | | | |
| 3. Have the appropriate client review forms/checklists been completed? | ☐ | ☐ | ☒ |
| OAR will be performed after calculation submittal | | | |
| 4. Are all pages properly identified with a calculation number, calculation revision and page number consistent with the requirements of the client's procedure? | ☒ | ☐ | ☐ |
| | | | |
| 5. Is all information legible and reproducible? | ☒ | ☐ | ☐ |
| | | | |
| 6. Is the calculation presented in a logical and orderly manner? | ☒ | ☐ | ☐ |
| | | | |
| 7. Is there an existing calculation that should be revised or voided? | ☐ | ☒ | ☐ |
| There is no existing calculation that should be revised or voided. | | | |
| 8. Is it possible to alter an existing calculation instead of preparing a new calculation for this situation? | ☐ | ☒ | ☐ |
| No existing calculation would be applicable. | | | |
| 9. If an existing calculation is being used for design inputs, are the key design inputs, assumptions and engineering judgments used in that calculation valid and do they apply to the calculation revision being performed. | ☐ | ☐ | ☒ |
| No existing calculation is used for design inputs | | | |
| 10. Is the format of the calculation consistent with applicable procedures and expectations? | ☒ | ☐ | ☐ |
| | | | |
| 11. Were design input/output documents properly updated to reference this calculation? | ☐ | ☐ | ☒ |
| There are no design output documents. | | | |
| 12. Can the calculation logic, methodology and presentation be properly understood without referring back to the originator for clarification? | ☒ | ☐ | ☐ |
| | | | |
| **OBJECTIVE AND SCOPE** | | | |
| 13. Does the calculation provide a clear concise statement of the problem and objective of the calculation? | ☒ | ☐ | ☐ |
| | | | |
| 14. Does the calculation provide a clear statement of quality classification? | ☒ | ☐ | ☐ |
| | | | |
| 15. Is the reason for performing and the end use of the calculation understood? | ☒ | ☐ | ☐ |
| | | | |
| 16. Does the calculation provide the basis for information found in the plant's license basis? | ☐ | ☒ | ☐ |
| This does not provide basis for license basis | | | |
| 17. If so, is this documented in the calculation? | ☐ | ☐ | ☒ |

| ENERCON Excellence—Every project. Every day. | Attachment 1 CALCULATION PREPARATION CHECKLIST | CALC NO. | NEE-323-CALC-002 |
|---|---|---|---|
| | | REV. | 0 |

| CHECKLIST ITEMS[1] | YES | NO | N/A |
|---|---|---|---|
| See above | | | |
| 18. Does the calculation provide the basis for information found in the plant's design basis documentation? | ☐ | ☐ | ☒ |
| This does not provide basis for design basis | | | |
| 19. If so, is this documented in the calculation? | ☐ | ☐ | ☒ |
| See above | | | |
| 20. Does the calculation otherwise support information found in the plant's design basis documentation? | ☐ | ☒ | ☐ |
| This does not provide support for information found in design basis documentation | | | |
| 21. If so, is this documented in the calculation? | ☐ | ☐ | ☒ |
| See above | | | |
| 22. Has the appropriate design or license basis documentation been revised, or has the change notice or change request documents being prepared for submittal? | ☐ | ☐ | ☒ |
| See above | | | |
| **DESIGN INPUTS** | | | |
| 23. Are design inputs clearly identified? | ☒ | ☐ | ☐ |
| | | | |
| 24. Are design inputs retrievable or have they been added as attachments? | ☒ | ☐ | ☐ |
| | | | |
| 25. If Attachments are used as design inputs or assumptions are the Attachments traceable and verifiable? | ☒ | ☐ | ☐ |
| | | | |
| 26. Are design inputs clearly distinguished from assumptions? | ☒ | ☐ | ☐ |
| | | | |
| 27. Does the calculation rely on Attachments for design inputs or assumptions? If yes, are the attachments properly referenced in the calculation? | ☒ | ☐ | ☐ |
| The Design Information Transmittal is included as an Attachment is properly referenced in the calculation | | | |
| 28. Are input sources (including industry codes and standards) appropriately selected and are they consistent with the quality classification and objective of the calculation? | ☒ | ☐ | ☐ |
| | | | |
| 29. Are input sources (including industry codes and standards) consistent with the plant's design and license basis? | ☒ | ☐ | ☐ |
| | | | |
| 30. If applicable, do design inputs adequately address actual plant conditions? | ☒ | ☐ | ☐ |
| | | | |
| 31. Are input values reasonable and correctly applied? | ☒ | ☐ | ☐ |
| | | | |
| 32. Are design input sources approved? | ☒ | ☐ | ☐ |
| The Design Information Transmittal contains information from a superseded calculation. | | | |
| 33. Does the calculation reference the latest revision of the design input source? | ☒ | ☐ | ☐ |
| The calculation uses information from a superseded calculation. This information is provided in a Design Information Transmittal. | | | |
| 34. Were all applicable plant operating modes considered? | ☒ | ☐ | ☐ |
| | | | |
| **ASSUMPTIONS** | | | |

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|---|---|---|---|
| | | REV. | 0 |

| CHECKLIST ITEMS[1] | YES | NO | N/A |
|---|---|---|---|
| 35. Are assumptions reasonable/appropriate to the objective? | ☒ | ☐ | ☐ |
| | | | |
| 36. Is adequate justification/basis for all assumptions provided? | ☒ | ☐ | ☐ |
| | | | |
| 37. Are any engineering judgments used? | ☐ | ☒ | ☐ |
| Engineering judgement not used as design input. | | | |
| 38. Are engineering judgments clearly identified as such? | ☐ | ☐ | ☒ |
| Engineering Judgement is not used as a design input. | | | |
| 39. If engineering judgments are utilized as design inputs, are they reasonable and can they be quantified or substantiated by reference to site or industry standards, engineering principles, physical laws or other appropriate criteria? | ☐ | ☐ | ☒ |
| Engineering Judgement is not used as a design input. | | | |
| **METHODOLOGY** | | | |
| 40. Is the methodology used in the calculation described or implied in the plant's licensing basis? | ☐ | ☐ | ☒ |
| The scope of calculation is outside of plant licensing basis | | | |
| 41. If the methodology used differs from that described in the plant's licensing basis, has the appropriate license document change notice been initiated? | ☐ | ☐ | ☒ |
| see above. | | | |
| 42. Is the methodology used consistent with the stated objective? | ☒ | ☐ | ☐ |
| | | | |
| 43. Is the methodology used appropriate when considering the quality classification of the calculation and intended use of the results? | ☒ | ☐ | ☐ |
| | | | |
| **BODY OF CALCULATION** | | | |
| 44. Are equations used in the calculation consistent with recognized engineering practice and the plant's design and license basis? | ☒ | ☐ | ☐ |
| | | | |
| 45. Is there reasonable justification provided for the use of equations not in common use? | ☐ | ☐ | ☒ |
| There are no uncommon equations used in the calculation. | | | |
| 46. Are the mathematical operations performed properly and documented in a logical fashion? | ☒ | ☐ | ☐ |
| | | | |
| 47. Is the math performed correctly? | ☒ | ☐ | ☐ |
| | | | |
| 48. Have adjustment factors, uncertainties and empirical correlations used in the analysis been correctly applied? | ☒ | ☐ | ☐ |
| | | | |
| 49. Has proper consideration been given to results that may be overly sensitive to very small changes in input? | ☒ | ☐ | ☐ |
| | | | |
| **SOFTWARE/COMPUTER CODES** | | | |
| 50. Are computer codes or software languages used in the preparation of the calculation? | ☒ | ☐ | ☐ |
| MCNP and Scale are used | | | |

| ENERCON<br>Excellence—Every project. Every day. | Attachment 1<br>CALCULATION PREPARATION CHECKLIST | CALC NO. | NEE-323-CALC-002 |
|---|---|---|---|
| | | REV. | 0 |

| CHECKLIST ITEMS[1] | | YES | NO | N/A |
|---|---|---|---|---|
| 51. | Have the requirements of CSP 3.09 for use of computer codes or software languages, including verification of accuracy and applicability been met? | ☒ | ☐ | ☐ |
| | | | | |
| 52. | Are the codes properly identified along with source vendor, organization, and revision level? | ☒ | ☐ | ☐ |
| | | | | |
| 53. | Is the computer code applicable for the analysis being performed? | ☒ | ☐ | ☐ |
| | | | | |
| 54. | If applicable, does the computer model adequately consider actual plant conditions? | ☒ | ☐ | ☐ |
| | | | | |
| 55. | Are the inputs to the computer code clearly identified and consistent with the inputs and assumptions documented in the calculation? | ☒ | ☐ | ☐ |
| | | | | |
| 56. | Is the computer output clearly identified? | ☒ | ☐ | ☐ |
| | | | | |
| 57. | Does the computer output clearly identify the appropriate units? | ☒ | ☐ | ☐ |
| | | | | |
| 58. | Are the computer outputs reasonable when compared to the inputs and what was expected? | ☒ | ☐ | ☐ |
| | | | | |
| 59. | Was the computer output reviewed for ERROR or WARNING messages that could invalidate the results? | ☒ | ☐ | ☐ |
| | | | | |
| **RESULTS AND CONCLUSIONS** | | | | |
| 60. | Is adequate acceptance criteria specified? | ☐ | ☐ | ☒ |
| There is no acceptance criteria as discussed in calc. | | | | |
| 61. | Are the stated acceptance criteria consistent with the purpose of the calculation, and intended use? | ☐ | ☐ | ☒ |
| See above | | | | |
| 62. | Are the stated acceptance criteria consistent with the plant's design basis, applicable licensing commitments and industry codes, and standards? | ☐ | ☐ | ☒ |
| See above | | | | |
| 63. | Do the calculation results and conclusions meet the stated acceptance criteria? | ☐ | ☐ | ☒ |
| See above. | | | | |
| 64. | Are the results represented in the proper units with an appropriate tolerance, if applicable? | ☒ | ☐ | ☐ |
| | | | | |
| 65. | Are the calculation results and conclusions reasonable when considered against the stated inputs and objectives? | ☒ | ☐ | ☐ |
| | | | | |
| 66. | Is sufficient conservatism applied to the outputs and conclusions? | ☒ | ☐ | ☐ |
| | | | | |

| CHECKLIST ITEMS[1] | YES | NO | N/A |
|---|---|---|---|
| 67. Do the calculation results and conclusions affect any other calculations? | ☐ | ☒ | ☐ |
| No other calculations are affected by this calculation. | | | |
| 68. If so, have the affected calculations been revised? | ☐ | ☐ | ☒ |
| No other calculations are affected by this calculation. | | | |
| 69. Does the calculation contain any conceptual, unconfirmed or open assumptions requiring later confirmation? | ☐ | ☒ | ☐ |
| There are no open assumptions requiring confirmation later. | | | |
| 70. If so, are they properly identified? | ☐ | ☐ | ☒ |
| There are no open assumptions requiring confirmation later. | | | |
| **DESIGN REVIEW** | | | |
| 71. Have alternate calculation methods been used to verify calculation results? | ☐ | ☒ | ☐ |
| No a Design Review was performed. | | | |

Note:

1. Where required, provide clarification/justification for answers to the questions in the space provided below each question. An explanation is required for any questions answered as "No' or "N/A".

**Originator:** Jay Bhatt

Print Name and Sign

Date