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2007-295 BWR Vessel & Internals Project (BWRVIP)

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Attention: John Honcharik

Subject: Project No. 704 – BWRVIP-145NP, BWR Vessel and Internals Project, Evaluation of Susquehanna Unit 2 Top Guide and Core Shroud Material Samples Using RAMA Fluence Methodology

Reference: Letter from William A. Eaton (BWRVIP) to Document Control Desk (NRC), "Project 704 – BWRVIP-145: BWR Vessel and Internals Project, Evaluation of Susquehanna Unit 2 Top Guide and Core Shroud Material Samples Using RAMA Fluence Methodology," dated November 17, 2005.

Enclosed are two (2) copies of the non-proprietary report "BWRVIP-145NP: BWR Vessel and Internals Project, Evaluation of Susquehanna Unit 2 Top Guide and Core Shroud Material Samples Using RAMA Fluence Methodology," EPRI Technical Report 1011694NP, September 2007. This report is being transmitted to the NRC as a means of exchanging information with the NRC for the purpose of supporting generic regulatory improvements related to surveillance programs for monitoring changes in BWR reactor pressure vessel material properties due to neutron irradiation.

This non-proprietary report is identical to BWRVIP-145 proprietary report submitted to the NRC by the letter referenced above except that the proprietary information has been deleted and the letters "NP" appear in the BWRVIP report number.

If you have any questions on this subject please contact Chuck Wirtz (FirstEnergy, BWRVIP Integration Committee Technical Chairman) by telephone at 440.280.7665 or by e-mail at cjwirtz@firstenergycorp.com.

Sincerely,

Rick Libra

Rick Libra
Exelon
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BWRVIP-145NP: BWR Vessel and Internals Project Evaluation of Susquehanna Unit 2 Top Guide and Core Shroud Material Samples Using RAMA Fluence Methodology

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Technical Report

BWRVIP-145NP: BWR Vessel and Internals Project

Evaluation of Susquehanna Unit 2 Top Guide and Shroud Material Samples Using RAMA Fluence Methodology

1011694NP

Final Report, September 2007

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BWRVIP-145NP: BWR Vessel and Internals Project, Evaluation of Susquehanna Unit 2 Top Guide and Shroud Using RAMA Fluence Methodology, EPRI, Palo Alto, CA: 2007. 1011694NP.

REPORT SUMMARY

This report provides a comparison of the fluence predicted by the RAMA Fluence Methodology to the fluence of material samples removed from the core shroud and top guide at the Susquehanna Unit 2 nuclear plant.

Background

The RAMA Fluence Methodology calculates neutron fluence of the BWR pressure vessel internals regions. RAMA has been previously benchmarked at locations near the inner surface of the reactor pressure vessel. Material samples were removed from the core shroud and top guide at the Susquehanna Unit 2 nuclear power plant after eleven cycles of operation. Fast and thermal fluences were determined by a laboratory analysis of the samples. Results of this work were published in EPRI report 1011695. The current report uses these data to further benchmark and validate the use of RAMA to calculate the fluence for the core shroud and top guide locations in a BWR.

Objectives

To benchmark the RAMA Fluence Methodology for the core shroud and top guide locations by comparing calculations to measurements of fluence using material samples removed from Susquehanna Unit 2.

Approach

The primary reactor operating parameters that affect neutron fluence evaluations for BWRs include the reactor power level, core power distribution, core void fraction distribution, and fuel material distribution. Investigators developed an accurate three-dimensional RAMA computer model of the Susquehanna Unit 2 reactor core internals using detailed mechanical design information. They obtained the daily power history of the plant and developed 136 state points for use in the fluence evaluation. For each cycle, they used appropriate fuel assembly models to build the reactor core region of the RAMA fluence model. They used RAMA to calculate the fast nuclide activities and fast fluence at the locations where the material samples were removed and made comparisons of the calculated-to-measured values to assess the accuracy of RAMA.

Results

The calculated-to-measured (C/M) results show reasonably good agreement between the RAMA calculated values and the measured values for the fast nuclide activations.

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EPRI Perspective

Previous analyses have been conducted to benchmark the RAMA Fluence Methodology against other benchmark problems as recommended in the U. S. Nuclear Regulatory Guide 1.190. The results of some RAMA Fluence Methodology benchmarks are presented in EPRI reports 1008063 and 1008065.

The evaluation documented in this report is the first comparison to measurements in the core shroud and top guide components using the RAMA Fluence Methodology. Data used in this project are extremely valuable because materials samples from operating reactors are quite rare. Such data provide real-world validation of analytical methods.

Keywords

Fluence
Embrittlement
Boiling water reactor
Vessel and internals
Reactor pressure vessel

ABSTRACT

This document reports the comparison of the RAMA Fluence Methodology to shroud and top guide sample measurements from the Susquehanna Unit 2 reactor. The samples were removed after eleven cycles of operation and were obtained from multiple elevations on the shroud outer surface and on two top guide plates. Comparisons to specific activity measurements for fast activation reactions are included in the comparison evaluation. In addition, comparisons to neutron fluence with energies of >1.0 MeV and >0.1 MeV that are determined from sample measurements are provided. Comparison of the RAMA Fluence Methodology predicted values for the thermal spectrum activation measurements and fluence will be reported in a separate report.

ACKNOWLEDGMENTS

The author wishes to acknowledge EPRI and the Boiling Water Reactor Vessel and Internals Project (BWRVIP) for their support of the RAMA Fluence Methodology project. Special thanks are extended to Robert Carter of EPRI for his guidance, comments, and overall support in completing this document.

Mr. Ken Knoll and Mr. Bruce Swoyer of PPL Susquehanna, LLC are acknowledged for providing the operating history, fuels data and mechanical design data for this evaluation.

Mr. Eric Jones and Mr. Kevin Retzke of TransWare Enterprises Inc. deserve special recognition for their efforts in the performance of the evaluations documented in this report.

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1 INTRODUCTION

This report presents the results of the core shroud and top guide activation and fast fluence evaluation performed for the Susquehanna Unit 2 reactor using the RAMA Fluence Methodology [1]. This evaluation includes the prediction of specific activities for material samples that were removed from the Susquehanna Unit 2 shroud and top guide regions after eleven cycles of irradiation, corresponding to 15.3 effective full power years (EFPY). Activation measurements and fluence predictions were conducted on the material samples by Pacific Northwest National Laboratories (PNNL) [2]. The activation measurements and resulting fluence estimates from the measured activities included reactions that are sensitive to the fast neutron energy spectrum along with reactions that are sensitive to the thermal neutron spectrum. This report provides the comparison of activation and fluence predictions obtained using the RAMA Fluence Methodology for the fast energy spectrum measurements only. The comparison of predicted thermal activation and fluence using the RAMA Fluence Methodology to the thermal activation and fluence measurement values in [2] will be provided in a separate report.

The core shroud samples were taken from the outer shroud surface at three elevations: 20 inches below the shroud head flange, 58 inches below the head flange, and 116 inches below the head flange. The 20 inch elevation samples were obtained at 47.6° and 356.2° azimuths, and are designated in this report as samples S-47-20 and S-356-20, respectively. The 58 inch elevation samples were obtained at 45° and 356.2° azimuths, and are designated in this report as samples S-45-58 and S-356-58, respectively. The 116 inch elevation sample was taken at an azimuth of 356.2°, and is designated in this report as sample S-356-116. An additional shroud sample at the 116 inch elevation at 47.6° azimuth was planned, but was subsequently omitted from the measurement program due to obstruction at that location from jet pump plug supply lines [2].

The top guide samples were taken from two cell locations, one from an interior core location and one near the core periphery. For the interior top guide location, samples were removed from the top and the bottom portion of the top guide beam, and are designated in this report as samples TG-3419-T and TG-3419-B, respectively. In the peripheral top guide cell, only one sample was taken at the bottom of the beam, and is designated in this report as sample TG-3403-B.

Each sample consisted of several small pieces of metal. As a part of the sample measurement process, PNNL subdivided the material from each sample location into a set of sub-samples. The activity from these sub-samples was measured and compared to the activity of the other sub-samples from the same measurement location as a means of confirming the consistency of the sample material. The top two shroud measurements (i.e., S-47-20 and S-356-20) were found to have unexpectedly large variations (as much as a factor of three) in the activity of the samples, which is likely the result of material intermixing between samples. Attempts to isolate the true material corresponding to the actual measurement locations for these two samples were unsuccessful and PNNL recommended that these samples be excluded from the evaluation of the measurements [2]. Accordingly, these two sample locations are not included in the measurement evaluation described in this report. An additional shroud sample (S-45-58) was also found to have a large variation in sub-sample activities, in fact, one of the sub-samples was not radioactive. The material from this sample had been spilled onto a plastic lid during transfer of the sample from the measuring device to the sample container and was subsequently collected by picking the sample pieces off of the lid with Q-tips. Based upon the assumption that unusually low activity was indicative of contamination with non-radioactive material, only the higher activity sub-samples were included in the measurements reported in [2]. All other samples were found to have reasonably expected variations in sub-sample activities.

The RAMA Fluence Methodology has been developed for the Electric Power Research Institute, Inc. (EPRI) and the Boiling Water Reactor Vessel and Internals Project (BWRVIP) for the purpose of calculating neutron fluence in Boiling Water Reactor (BWR) components. The RAMA Fluence Methodology includes a transport code, model builder codes, a fluence calculator code, an uncertainty methodology, and a nuclear data library. The transport code, fluence calculator, and nuclear data library are the primary software components for calculating the neutron flux and fluence.

Previous analyses have been conducted to benchmark the RAMA Fluence Methodology against other benchmark problems as recommended in the U. S. Nuclear Regulatory Guide 1.190 [3]. The results of the RAMA Fluence Methodology benchmarks are presented in [4]. The RAMA Fluence Methodology has also been used to perform several surveillance capsule activation analyses and a jet pump riser brace pad fluence evaluation. The evaluation documented in this report is the first comparison to measurements in the core shroud and top guide components using the RAMA Fluence Methodology.

2 SUMMARY AND CONCLUSIONS

This section provides a summary of the results of the core shroud and top guide activation and fluence evaluation for Susquehanna Unit 2. Also presented are conclusions that can be drawn from the evaluation results. Detailed tables of all results are presented in Section 5 of this report.

The primary purpose of this evaluation is to compare activation and fluence results calculated by the RAMA Fluence Methodology for Susquehanna Unit 2 core shroud and top guide samples to measurements. Activation results are calculated for two fast reactions for each of the six samples. Fast neutron fluence is predicted for energy >1.0 MeV and energy >0.1 MeV at the sample locations.

2.1 Activation Measurement Comparisons

Table 2-1 summarizes the calculated-to-measured (C/M) results for the six samples evaluated in this report.

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Table 2-1
Average Calculated to Measured (C/M) Activation Results for Susquehanna Unit 2 Core Shroud and Top Guide Samples

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2.2 Fluence Prediction Comparisons

Table 2-2 summarizes the C/M fast fluence values generated from this evaluation for energy >1.0 MeV and energy >0.1 MeV.

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Table 2-2
Average Calculated to Measured (C/M) Neutron Fluence Results for Susquehanna Unit 2 Core Shroud and Top Guide Samples at 15.3 EFPY

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2.3 Observations and Recommendations

Based upon comparison to activation measurements, the RAMA Fluence Methodology is observed to provide conservative estimates of the fast neutron fluence in the shroud and top guide at all measurement locations. No specific guidelines have been established for the acceptable prediction bias and uncertainty for the shroud and top guide components. However, both the shroud and top guide comparisons using the RAMA Fluence Methodology are within the expected comparison accuracy that is prescribed in [3] for reactor pressure vessel neutron fluence evaluations.

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3 DESCRIPTION OF THE REACTOR SYSTEM

This section describes the design inputs for the Susquehanna Unit 2 reactor that were used in the core shroud and top guide activation and fluence evaluation. The basic design inputs include mechanical design drawings, material compositions, and reactor operating history. The design inputs were provided for this project by the utility support staff of PPL Susquehanna [5, 6].

3.1 Reactor System Mechanical Design Inputs

The RAMA Fluence Methodology employs a three-dimensional modeling technique to describe the reactor geometry for the neutron transport calculations. Detailed mechanical design information is needed in order to build an accurate three-dimensional RAMA computer model of the reactor system. A summary of the important design inputs is presented in this subsection.

Susquehanna Unit 2 is a General Electric BWR/4 class reactor. The rated thermal power output of the reactor was 3293 MWt for cycles 1-6. Power up-rates were achieved in cycle 7, raising the power to 3441 MWt, and cycle 11 raising the thermal power output to 3489 MWt. Figure 3-1 shows a planar view of the reactor at an axial elevation near the core mid-plane. The primary radial components and regions are shown, including the core region, core reflector, shroud, downcomer, jet pumps, pressure vessel, mirror insulation, cavity regions, and biological shield (concrete wall). The reactor core region has a core loading of 764 fuel assemblies. There are 10 jet pump assemblies in the downcomer region that are positioned azimuthally at 30, 60, 90, 120, 150, 210, 240, 270, 300, and 330 degrees. Three surveillance capsules were initially loaded in the reactor and were positioned azimuthally at 30, 120, and 300 degrees.

3.2 Reactor System Material Compositions

Each region of the reactor is comprised of materials that include reactor fuel, steel, water, insulation, and air. Accurate material information is essential for the fluence evaluation as the material compositions determine the scattering and absorption of neutrons throughout the reactor system and, thus, affect the determination of neutron fluence in the reactor components.

Figure 3-2 depicts the top guide model at an axial elevation near the mid-plane elevation of the top guide. The reactor design at this elevation is similar to the core elevations shown in Figure 3-1 with the following exceptions: the top guide structure is present, the jet pump assemblies and surveillance capsules are removed, and the upper shroud has a larger radius than the central shroud.

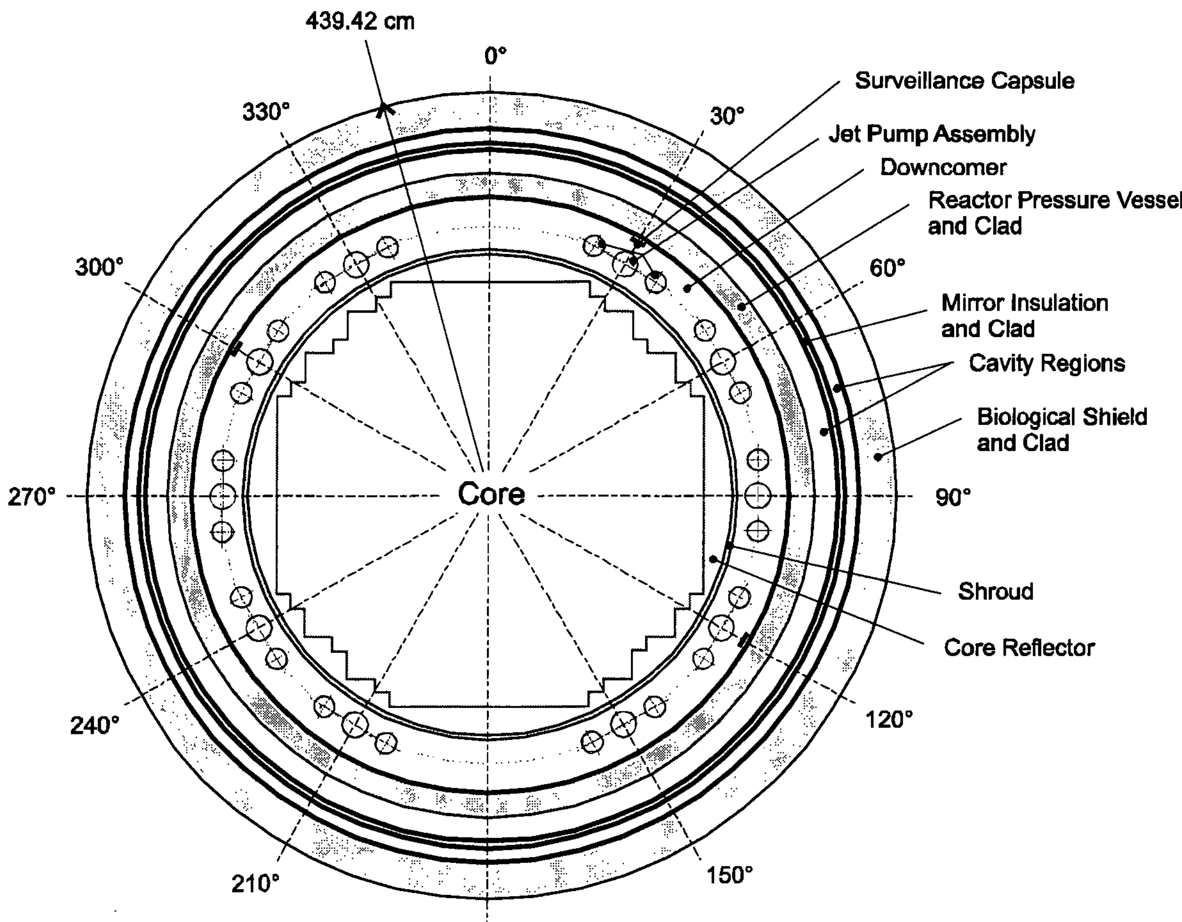

Figure 3-1
Planar View of the Susquehanna Unit 2 Reactor at the Core Mid-Plane Elevation

The primary architecture of the top guide structure is a grid of plates that form fuel cells. The interior fuel cells contain four fuel assemblies (denoted by "F" in the figure) in a two-by-two configuration. Outer fuel cells can contain one or two fuel assemblies. It is shown in Figure 3-2 that the primary radial components and regions at the top guide elevation include the top guide plates and rim, fuel assemblies, core inner and outer reflector regions, upper shroud, downcomer, and pressure vessel. Note that the cavity, mirror insulation, and biological shield are not shown in this figure.

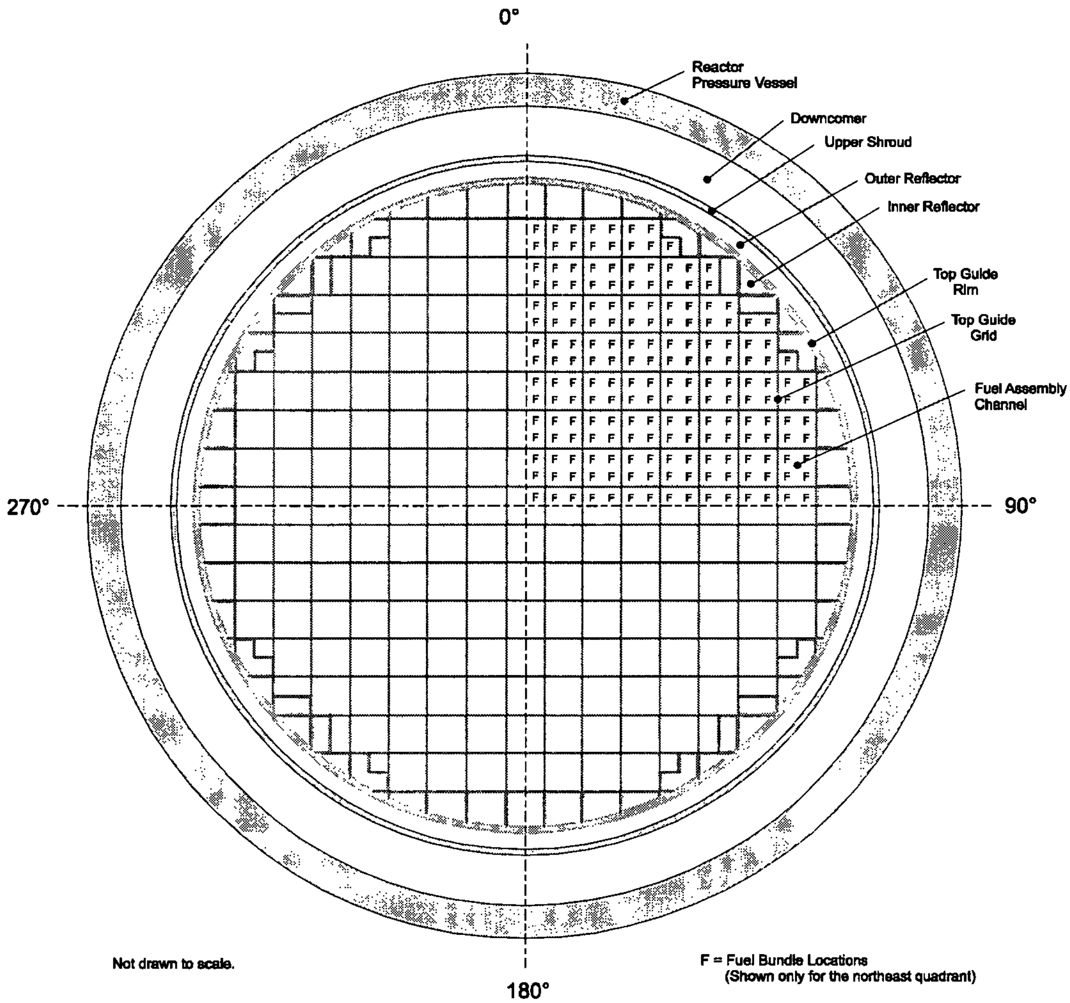

Figure 3-2
Planar View of Susquehanna Unit 2 at the Top Guide Mid-Plane Elevation

Table 3-1 provides a summary of the material compositions in the various components and regions of the Susquehanna Unit 2 reactor. The attributes for the steel, insulation, and air compositions (i.e., material densities and isotopic concentrations) are assumed to remain constant for the operating life of the reactor. The attributes for the ex-core water compositions will vary with the operation of the reactor, but are generally represented at nominal hot operating conditions and are assumed to be constant throughout an operating cycle. The attributes of the fuel compositions in the reactor core region change continuously during an operating cycle due to changes in power level, fuel burnup, control rod movements, and changing moderator density levels (voids). Because of the dynamics of the fuel attributes with reactor operation, one to several data sets describing the operating state of the reactor core are used for each operating cycle. The number of data sets used in this analysis is presented in Section 3.3.2.

Table 3-1
Summary of Material Compositions by Region for Susquehanna Unit 2

Region	Material Composition
Reactor Core	^{235}U, ^{238}U, ^{239}Pu, ^{240}Pu, ^{241}Pu, ^{242}Pu, O_{fuel}, Zr, Water
Core Reflector	Water
Fuel Support Piece	Stainless Steel
Lower Tie Plate	Stainless Steel, Zr, Inconel
Top Guide	Stainless Steel
Upper Tie Plate	Stainless Steel, Zr, Inconel
Shroud	Stainless Steel
Downcomer Region	Water
Jet Pump Riser and Mixer Flow Area	Water
Jet Pump Riser and Mixer Metal	Stainless Steel
Surveillance Capsule	Stainless Steel
Reactor Pressure Vessel Clad	Stainless Steel
Reactor Pressure Vessel Wall	Carbon Steel
Cavity Regions	Air
Insulation Clad	Stainless Steel
Insulation	Glass Wool
Biological Shield Clad	Carbon Steel
Biological Shield	Reinforced Concrete

3.3 Reactor Operating Data Inputs

An accurate evaluation of fluence in the reactor requires an accurate accounting of the reactor operating history. The primary reactor operating parameters that affect neutron fluence evaluations for BWR's include the reactor power level, core power distribution, core void fraction distribution (or equivalently, water density distribution), and fuel material distribution.

3.3.1 Power History Data

The reactor power history used in the Susquehanna Unit 2 top guide and shroud fluence evaluation was obtained from daily power history edits provided by PPL Susquehanna for the first eleven completed operating cycles [6]. The daily power values represent step changes in power on a daily basis and the power is assumed to be representative of the power over the entire day. Also taken into account in the analysis are the reactor shutdown periods which are predominately refueling outages.

3.3.2 Reactor State Point Data

Reactor operating data for Susquehanna Unit 2 was provided as state point data files by PPL Susquehanna [6]. Each state point file represents the operating conditions of the unit at a specified moment in time. The data files include three-dimensional data arrays that describe the fuel materials, moderator materials, and the relative power distribution in the core region.

A total of 136 state point data files were used in the fluence evaluation for the eleven reported operating cycles of Susquehanna Unit 2. Table 3-2 shows the number of state point data files and the rated core thermal power used for each cycle in this fluence evaluation.

Table 3-2
Number of State-point Data Files for Each Cycle in Susquehanna Unit 2

Cycle Number	Number of State Point Data Files	Rated Thermal Power MWt
1	18	3293
2	13	3293
3	11	3293
4	9	3293
5	12	3293
6	10	3293
7	8	3441
8	12	3441
9	14	3441
10	14	3441
11	15	3489[1]

Note 1: Rated power was 3441 for the first 2 ½ months of Cycle 11.

A separate neutron transport calculation was performed for each state point. The calculated neutron flux for each state point was combined with the appropriate power history data described in Section 3.3.1 to predict the neutron fluence in the reactor pressure vessel.

3.3.3 Core Loading Pattern

It is common in BWRs that more than one fuel assembly design will be loaded in the reactor core in any given operating cycle. For fluence evaluations, it is important to account for the fuel assembly designs that are loaded in the core peripheral locations in order to accurately represent the neutron source distribution and flux gradients at the core boundary.

Susquehanna Unit 2 used four different fuel assembly designs during cycles 1 through 11. Table 3-3 provides a summary of the fuel designs loaded in the reactor core for these operating cycles. The cycle core loading patterns provided by PPL Susquehanna were used to identify the fuel assembly designs in each cycle and their location in the core loading pattern. For each cycle, appropriate fuel assembly models were used to build the reactor core region of the RAMA fluence model for Susquehanna Unit 2. Note that for cycles 3 and 10 two different fuel assembly designs were used in the peripheral locations and both were represented in the model.

Table 3-3
Summary of the Susquehanna Unit 2 Core Loading Pattern

Cycle	Number of General Electric (GE) 8x8 Fuel Assemblies	Number of Siemens Power Co (SPC) 9x9 Fuel Assemblies	Number of General Electric (GE) LUA 10x10 Fuel Assemblies	Number of Framatome Atrium 10x10 Fuel Assemblies	Dominant Peripheral Fuel Design in the RAMA Model
1	764	0	0	0	GE 8x8
2	440	324	0	0	GE 8x8
3	208	556	0	0	GE 8x8 & SPC 9x9
4	0	764	0	0	SPC 9x9
5	0	764	0	0	SPC 9x9
6	0	764	0	0	SPC 9x9
7	0	764	0	0	SPC 9x9
8	0	760	4	0	SPC 9x9
9	0	448	4	312	SPC 9x9
10	0	168	4	592	SPC 9x9 & Atrium 10x10
11	0	0	0	764	Atrium 10x10

4 CALCULATION METHODOLOGY

The Susquehanna Unit 2 core shroud and top guide activation and fluence evaluation was performed using the RAMA Fluence Methodology software package. The RAMA Fluence Methodology and the application of the RAMA Fluence Methodology to the Susquehanna Unit 2 reactor are described in this section.

4.1 Description of the RAMA Fluence Methodology

The RAMA Fluence Methodology is a system of codes that is used to perform fluence evaluations in light water reactor components. The significance of the RAMA Fluence Methodology is the integration of a three-dimensional arbitrary geometry modeling technique with a deterministic transport method to provide a flexible and accurate platform for determining neutron fluence in light water reactor systems. The RAMA Fluence Methodology is complemented with model building codes to prepare the three-dimensional models for the transport calculation and a post-processing code to calculate fluence from the neutron flux calculated by the transport code.

The primary inputs for the RAMA Fluence Methodology are mechanical design parameters and reactor operating history data. The mechanical design inputs are obtained from reactor design drawings (or vendor drawings) of the plant. The reactor operating history data is obtained from reactor core simulation calculations, system heat balance calculations, and daily operating logs that describe the operating conditions of the reactor.

The primary outputs from the RAMA Fluence Methodology calculations are neutron flux, neutron fluence, and uncertainty determinations. The RAMA transport code calculates the neutron flux distributions that are used in the determination of neutron fluence. Several transport calculations are typically performed over the operating life of the reactor in order to calculate neutron flux distributions that accurately characterize the operating history of the reactor. The post-processing code (RAFTER) is then used to calculate component fluence and nuclide activations using the neutron flux solutions from the transport calculations and daily operating history data for the plant.

4.2 The RAMA Geometry Model for Susquehanna Unit 2

The RAMA Fluence Methodology uses a flexible three-dimensional modeling technique to describe the reactor geometry. The geometry modeling technique is based on the Cartesian coordinate system in which the (x,y) coordinates describe an axial plane of the reactor system and the z-axis describes elevations of the reactor system.

A previous reactor pressure vessel fluence evaluation was performed for Susquehanna Unit 2 using the RAMA Fluence Methodology [7]. The RAMA geometry model used in that evaluation provided the basis for the model used in this evaluation. The model was expanded in the axial direction to encompass the top guide locations where the samples were taken. Meshing sensitivity studies and parameter sensitivity studies were conducted in the top guide region to refine the model to accurately determine fluence in the core shroud and top guide regions.

Figure 4-1 illustrates the planar configuration of the Susquehanna Unit 2 reactor model at an elevation near the core mid-plane of the reactor pressure vessel. In the radial dimension the model extends from the center of the core to the outside surface of the biological shield (439.42 cm). Nine radial regions are defined in the Susquehanna Unit 2 model: the core region (comprised of interior and peripheral fuel assemblies), core reflector, shroud, downcomer with jet pumps, pressure vessel, inner and outer cavities, mirror insulation, and biological shield. The pressure vessel and biological shield walls each have cladding on the wall inner surfaces. The mirror insulation has cladding on the inner and outer surfaces; however, the cladding was homogenized with the insulation in the model. Octant symmetry is assumed in the azimuthal dimension which spans from 0 to 45 degrees (the north-northeast octant). Azimuth 0 degrees corresponds to the north compass direction that is specified in the reactor design drawings.

Figure 4-2 provides an illustration of the axial configuration of the Susquehanna Unit 2 RAMA model for three significant components: a fuel column, the core shroud, and the reactor pressure vessel. Also shown in the figure are the relative axial positioning of the jet pumps, surveillance capsules, top guide, and core spray sparger pipes in the reactor model. The cavities, mirror insulation and biological shield wall are included for completeness. Figure 4-3 is a more detailed axial depiction showing the elevations of interest for this evaluation including the material sample locations in the core shroud and top guide regions. Radial regions beyond the core shroud are not shown in this figure. The elevation parameters are relative to reactor elevation 0 as defined by the reactor vendor. (Elevation 0 corresponds to the inside surface of the pressure vessel wall at the bottom drain plug location.). The reactor fluence model spans axially from below the jet pump riser inlet to above the core shroud head flange for a total of 655.32 cm (21.5 feet) in length.

The reactor core region is modeled to preserve the rectangular shape of the core region. This is illustrated in Figure 4-1. The core region model is characterized in two layers: the interior fuel assemblies and the peripheral fuel assemblies. The peripheral fuel assemblies are the primary contributors to the neutron source in the fluence calculation. The peripheral fuel assemblies are, therefore, modeled to preserve the pin-wise source contribution to the neutron fluence determination.

The RAMA model for Susquehanna Unit 2 consists of 73,626 mesh regions. The axial planes are divided into several groups representing particular component regions of the model as follows: the core region, the top guide, the shroud head flange, the core spray spargers, the fuel support pieces, core support plate, and core inlet region. Sub-planar meshing is used in the model, as needed, to properly represent the positioning of reactor components, such as the surveillance capsules, jet pump rams head, flanges, top guide, and core spray spargers.

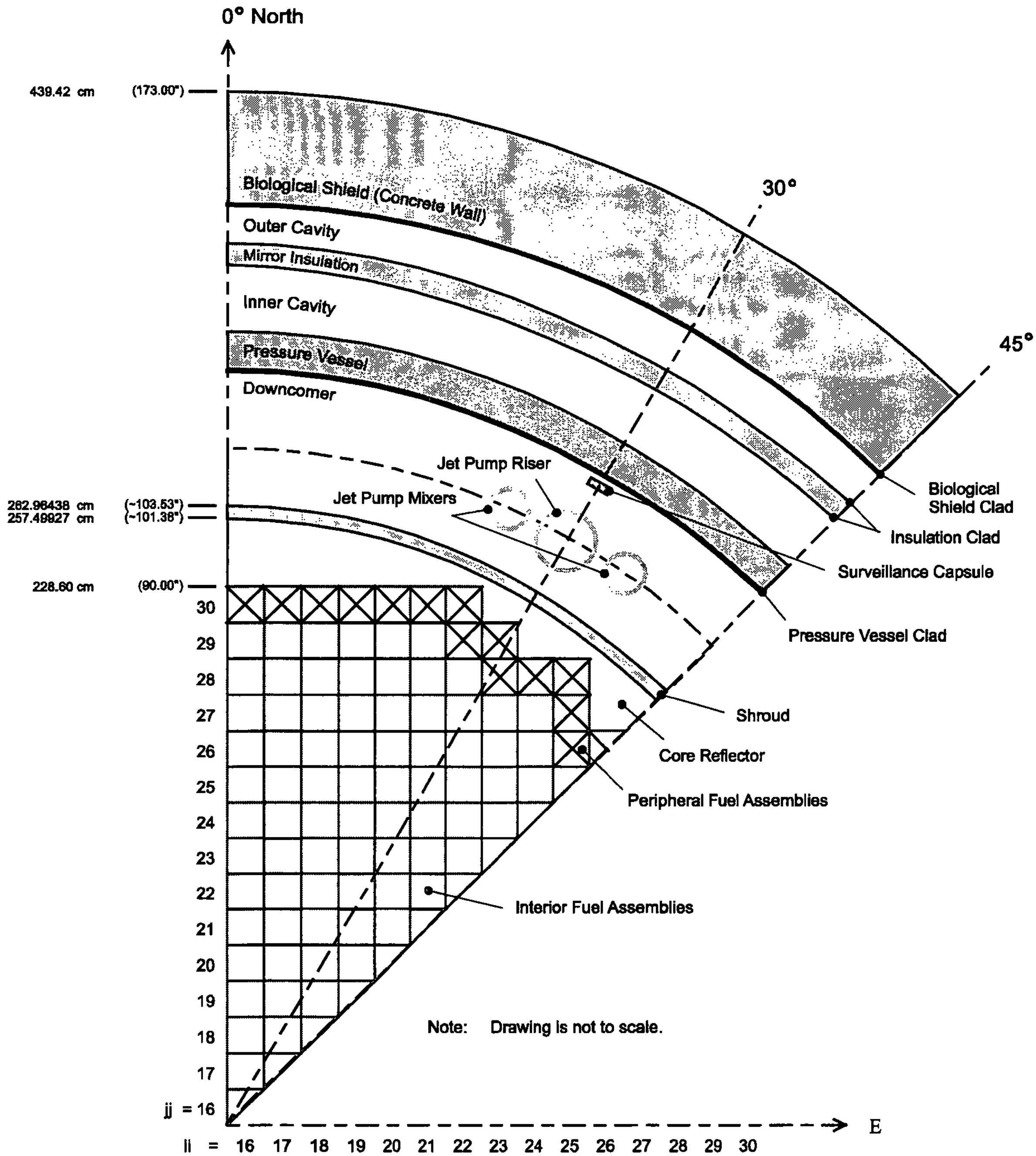

Figure 4-1
Planar View of the Susquehanna Unit 2 RAMA Model at the Core Mid-Plane Elevation

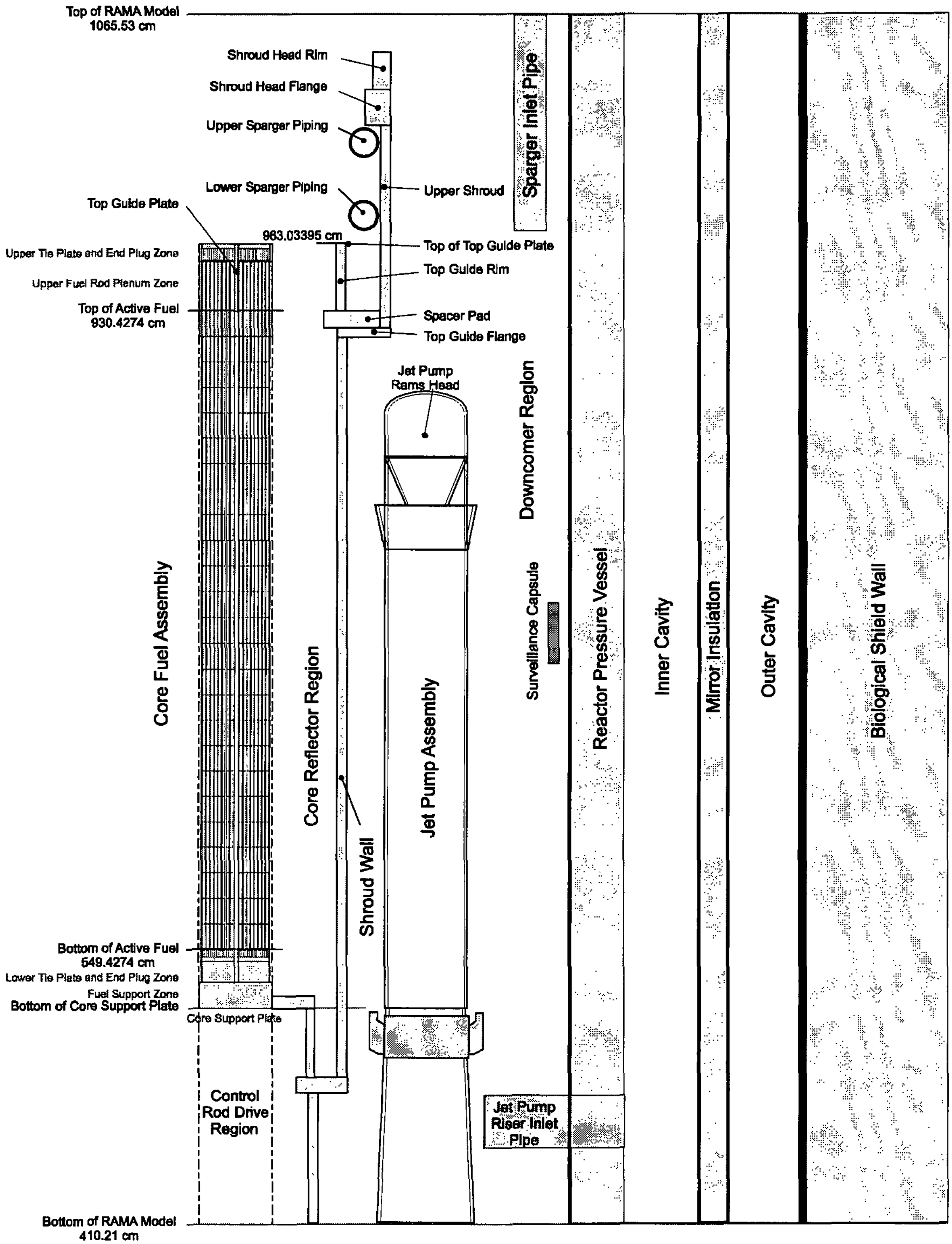

Figure 4-2
Axial View of the Susquehanna Unit 2 RAMA Model

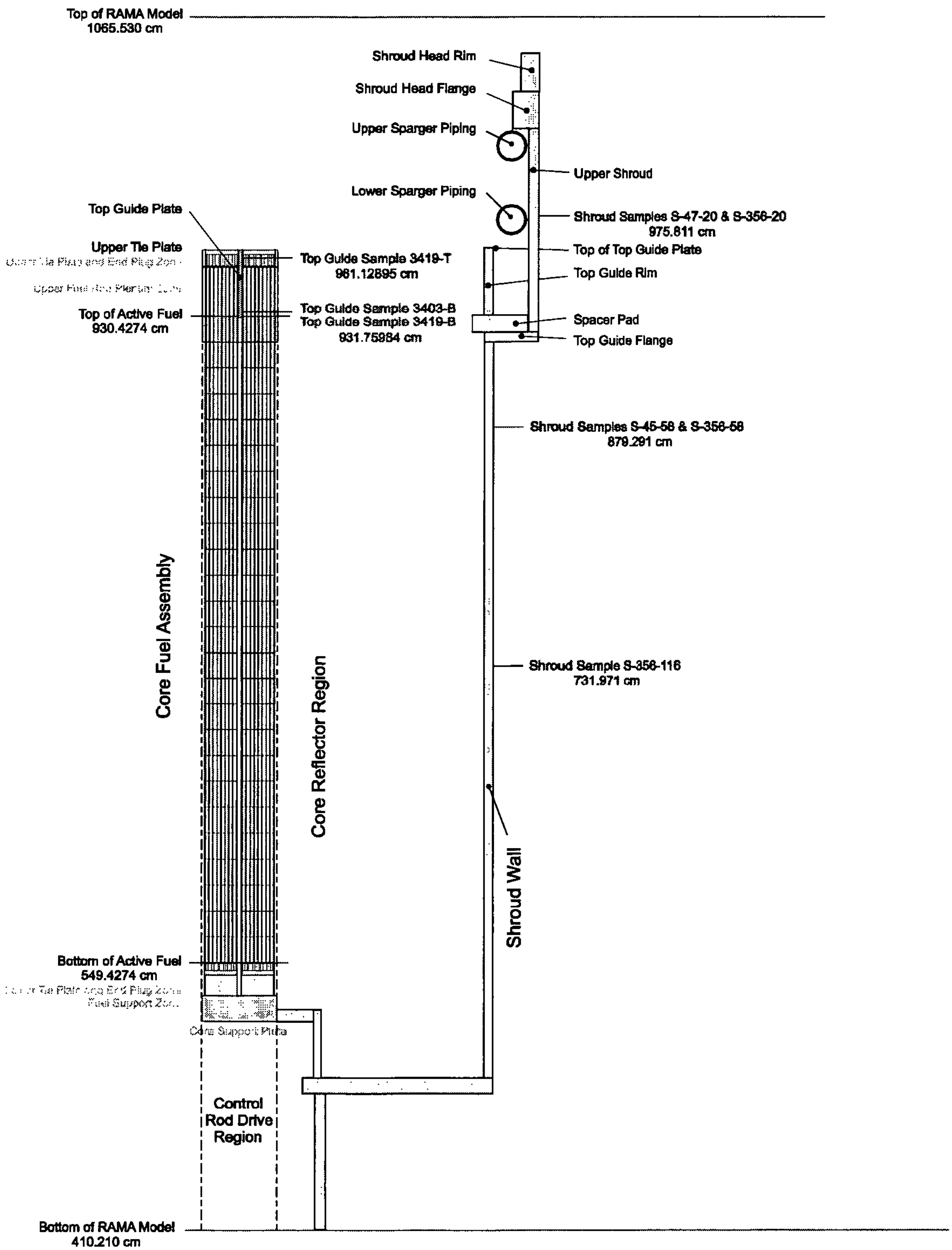

Figure 4-3
Axial View of the Susquehanna Unit 2 RAMA Model Showing Shroud and Top Guide Sample Elevations

There are several key features of the RAMA code system that allow the Susquehanna Unit 2 design to be accurately represented for this core shroud and top guide activation and fluence evaluation. Following is a list of some of the key features of the model.

- Rectangular and cylindrical bodies are mixed in the model in order to provide an accurate geometrical representation of the components and regions in the reactor.
- The core geometry is modeled using rectangular bodies to represent the fuel assemblies in the reactor core region.
- Cylindrical bodies are used to represent the components and regions that extend outward from the core region.
- A combination of rectangular and cylindrical bodies is used to describe the transition parts that are required to interface the rectangular core region to the cylindrical outer core regions.
- The top guide is appropriately modeled by including a representation of the upper fuel assembly parts that extend into the top guide region. The fuel assemblies are modeled in three axial segments: the fuel rod plenum, fuel rod upper end plugs, and fuel assembly upper tie plate.
- The jet pump assembly model includes representation of the nozzles, riser and diffuser pipes, and mixer pipes. The jet pump assembly design is properly modeled using cylindrical pipe elements. The riser pipe is correctly situated on a linear path between the centers of the mixer pipes; thus, the positioning of the riser is slightly skewed towards the shroud wall and core region in the model.
- The surveillance capsules are represented in the downcomer region at the correct azimuth, at an axial elevation corresponding to the design core mid-plane elevation, and radially near the inner surface of the pressure vessel wall. The surveillance capsule is a rectangular part; but is modeled as an arc element in the model. This is an acceptable approximation since the capsule is a sufficient distance from the core center that the arc element closely approximates the shape of a rectangular element. Downcomer water surrounds the capsule on all sides.
- The core spray spargers are appropriately represented as toruses in the model. The sparger pipes and nozzles reside inside the upper shroud wall above the top guide. The sparger model includes reactor coolant inside the pipes.

Figure 4-4 shows the location of the core shroud and top guide samples for which activation and fluence values are calculated in this evaluation. Shroud samples were taken at azimuths 45°, 47.6°, and 356.2°. Samples were obtained for three elevations below the top of the shroud flange (20 inches, 58 inches and 116 inches) at the 356.2° azimuth, for the 20 inch elevation at 47.6°, and for the 58 inch elevation at 45°. One sample was taken at the bottom of the beam at top guide location 3403. Two samples were taken, one at the bottom of the beam and one at the top, at top guide location 3419.

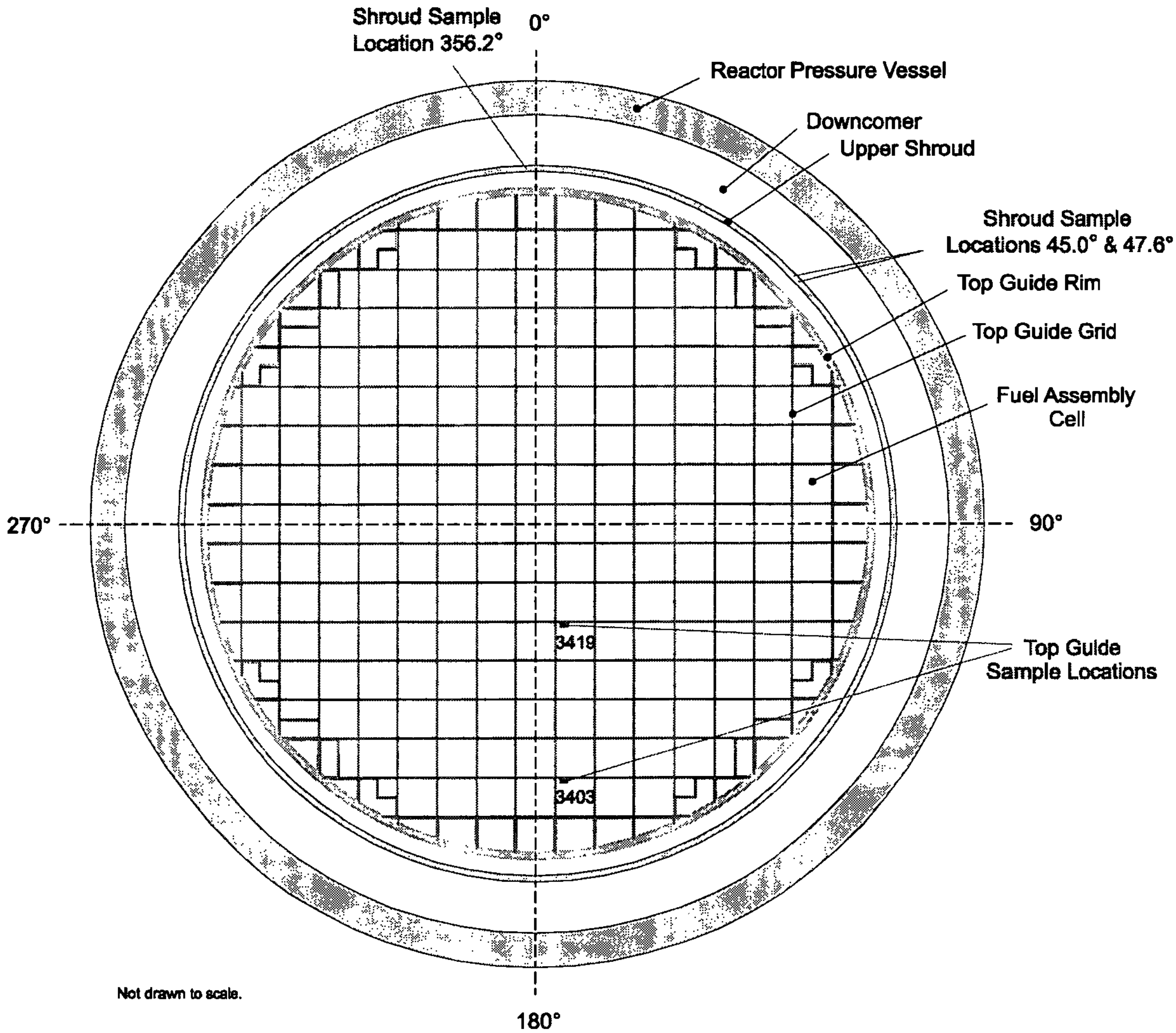

Figure 4-4
Planar View of Susquehanna Unit 2 with Top Guide Details and Sample Locations

Figure 4-5 provides an isometric view of a top guide cell that illustrates the geometry meshing details and identifies the sample locations.

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Figure 4-5
Isometric View of Susquehanna Unit 2 Top Guide Cell with Meshing Details and Sample Locations

4.3 RAMA Calculation Parameters

The RAMA transport code uses a three-dimensional deterministic transport method to calculate neutron flux distributions in reactor problems.

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The impact of these calculation parameter selections on the RAMA fluence evaluation for Susquehanna Unit 2 is presented in Section 4.6.

4.4 RAMA Neutron Source Calculation

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4.5 RAMA Fission Spectra

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4.6 Parametric Sensitivity Analyses

Several sensitivity analyses were performed in a previous Susquehanna Unit 2 fluence evaluation to evaluate the stability and accuracy of the RAMA transport calculation. The results of these sensitivity analyses are documented in [8]. For this study several additional three-dimensional (3-D) sensitivity analyses were performed to further refine the shroud and top guide regions of the fluence model. Several parameters were evaluated including mesh size and the integration parameters discussed in Section 4.3. A summary of the analyses is presented in Table 4-1.

Table 4-1
Three-dimensional Sensitivity Analyses

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5
CORE SHROUD AND TOP GUIDE ACTIVATION RESULTS

This section contains the results from the Susquehanna Unit 2 core shroud and top guide activation analysis. The predicted activations (i.e., specific activities) generated by the RAMA Fluence Methodology were compared to the activation measurements for the shroud and top guide material samples and are presented here. The Susquehanna Unit 2 shroud and top guide samples were removed at the end of cycle 11 after being irradiated from initial reactor start-up on August 1, 1984 through March 8, 2003 for a total of 15.3 effective full power years (EFPY). Details of the analysis are presented in the next subsection.

5.1 Comparison of Predicted Activation to Sample Measurements

Five core shroud samples and three top guide samples were removed from Susquehanna Unit 2 after being irradiated for eleven cycles of operation. Activation measurements were performed for the following fast reactions [2]: $^{54}Fe(n,p)^{54}Mn$, and $^{58}Ni(n,p)^{58}Co$. Tables 5-1 through 5-6 provide a comparison of the RAMA calculated specific activities and the measured specific activities for the shroud and top guide samples. It should be noted that the measured specific activities provided in these tables include a correction for gamma absorption using the appropriate reaction correction factor of 0.990 for both fast reactions as reported in [2].

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Table 5-1
Comparison of Specific Activities for Susquehanna Unit 2 Core Shroud Sample S-45-58

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Table 5-2
Comparison of Specific Activities for Susquehanna Unit 2 Core Shroud Sample S-356-58

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Table 5-3
Comparison of Specific Activities for Susquehanna Unit 2 Core Shroud Sample S-356-116

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Table 5-4
Comparison of Specific Activities for Susquehanna Unit 2 Top Guide Sample TG-3419-T

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Table 5-5
Comparison of Specific Activities for Susquehanna Unit 2 Top Guide Sample TG-3419-B

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Table 5-6
Comparison of Specific Activities for Susquehanna Unit 2 Top Guide Sample TG-3403-B

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6
CALCULATED NEUTRON FLUENCE FOR CORE SHROUD AND TOP GUIDE SAMPLES

The fast neutron fluence for the Susquehanna Unit 2 core shroud and top guide samples in this study is determined by the RAMA Fluence Methodology at 15.3 EFPY for comparison to the computed fluence based upon sample measurements. The results of the fluence evaluation are presented in the tables that follow. Fast neutron fluence values for the core shroud samples are presented in Tables 6-1 and 6-2 for energy >1.0 MeV and energy >0.1 MeV, respectively. Fast neutron fluence values for the top guide samples are presented in Tables 6-3 and 6-4 for energy >1.0 MeV and energy >0.1 MeV, respectively.

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Table 6-1
Comparison of >1.0 MeV Neutron Fluence for Susquehanna Unit 2 Core Shroud Samples at 15.3 EFPY

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Table 6-2
Comparison of >0.1 MeV Neutron Fluence for Susquehanna Unit 2 Core Shroud Samples at 15.3 EFPY

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Table 6-3
Comparison of >1.0 MeV Neutron Fluence for Susquehanna Unit 2 Top Guide Samples at 15.3 EFPY

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Table 6-4
Comparison of >0.1 MeV Neutron Fluence for Susquehanna Unit 2 Top Guide Samples at 15.3 EFPY

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