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From: William R. Jones, RES, 415-7558

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DFX2

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

October 14, 1999

TO: Michael E. Mayfield, Chief
Materials Engineering Branch
Division of Engineering Technology
Office of Regulatory Research

THRU: Edwin M. Hackett, Assistant Branch Chief
Materials Engineering Branch
Division of Engineering Technology
Office of Regulatory Research

FROM: William R. Jones, Senior Nuclear Engineer
Materials Engineering Branch
Division of Engineering Technology
Office of Regulatory Research

SUBJECT: SUMMARY OF SEPTEMBER 28, 1999, PUBLIC MEETING ON PROPOSED DRAFT REGULATORY GUIDE 1053, "CALCULATIONAL AND DOSIMETRY METHODS FOR DETERMINING PRESSURE VESSEL NEUTRON FLUENCE"

A public meeting was held on September 28, 1999, at NRC to discuss the proposed draft Regulatory Guide 1053, "Calculational and Dosimetry Methods for Determining Pressure Vessel Neutron Fluence." The purpose of the meeting was to discuss the proposed draft regulatory guide (DRG), request public comments on the current version, inform the public of recent activities associated with the regulatory guide, present previous important comments and their resolution, answer questions about the guide, and discuss the associated benchmark problem NUREG/CR.

The agenda for the meeting is Attachment 1. Presentation slides are found as Attachments 2 (for NRC) and 3 (for Brookhaven National Laboratory). Edwin Hacket opened the meeting by focusing attendees on the DRG and the day's planned discussions. I provided a brief introduction to the DRG (Attachment 2) and planned schedule for finalization of the guide. Lambros Lois of NRR, provided a summary of the regulatory perspective within which the DRG fits (Attachment 2). John Carew of Brookhaven National Laboratory, the primary contractor, provided a detailed discussion of the DRG (Attachment 3). This discussion included a description, history, and current status of the DRG; discussion of previous substantive comments; and major additions to the guide (e.g., Monte Carlo flux calculations, development and distribution of a benchmark problem set). Also John Carew provided a discussion of the benchmark problem set in Draft NUREG/CR-6115, "PWR and BWR Pressure Vessel Fluence Calculation Benchmark Problems and Solutions." This document was produced because of previous comments.

Throughout the meeting, there was lively interchange between members of the public and presenters. About 17 members of the public, including power reactor licensees, and several NRC staff attended the meeting.

Public comments were requested. Based on discussions, the comments were requested to be provided within 60 days (about the end of November, 1999).

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ATTACHMENT 1

Meeting Agenda

OPENING REMARKS -- Edward Hacket

INTRODUCTION & FUTURE SCHEDULE -- William R. Jones

REGULATORY PERSPECTIVE -- Lambros Lois, NRR

DRG DETAILED DISCUSSION –John Carew, BNL
- Background & Status
- Previous Significant Comments
- Changes Since 1996 Version

BENCHMARK PROBLEMS/NUREG/CR-6115 -- John Carew, BNL

FEEDBACK -- QUESTIONS & ANSWERS

WRAP UP

ATTACHMENT 2

NRC Presentation Slides

AGENDA

- OPENING REMARKS
- INTRODUCTION & FUTURE SCHEDULE
- REGULATORY PERSPECTIVE
- DRG DETAILED DISCUSSION

    Background & Status
    Previous Significant Comments
    Changes Since 1996 Version

- BENCHMARK PROBLEMS
- FEEDBACK -- QUESTIONS & ANSWERS
- WRAP UP

INTRODUCTION

- NEED FOR REGULATORY GUIDE
- OBJECTIVES OF THE REGULATORY GUIDE
- CONTENTS SUMMARY
- HISTORY
- SCHEDULE & FINALIZATION PLANS

NEED FOR REGULATORY GUIDE

- A WAY TO COMPLY WITH REGULATIONS ON REACTOR PRESSURE VESSEL INTEGRITY
  - -- Appendix G & Appendix H
  - -- 10 CFR 50.61 &50.60
  - -- Input to Reg Guide 1.99
  - -- TS LTOP LCOs

- WIDE VARIETY OF APPLICATION OF EXISTING METHODS FOR DETERMINING FAST NEUTRON FLUX

- PROVIDE STANDARDIZED METHODS AND PROCEDURES FOR FLUENCE CALCULATION AND USE OF VESSEL DOSIMETRY DATA

- ELIMINATE EXTENSIVE REVIEW AND ADDITIONAL LICENSEE INTERACTION

OBJECTIVES OF REGULATORY GUIDE

PROVIDE:

- METHODS FOR FLUENCE CALCULATION AND USE OF DOSIMETRY FOR DETERMINING RPV NEUTRON FLUENCE THAT SATISFY REGULATIONS.
- DESCRIPTION OF FLUENCE CALCULATION METHODS
- USE OF DOSIMETRY MEASUREMENTS FOR VALIDATION OF CALCULATIONS
- PROCEDURES FOR QUALIFICATION OF CALCULATIONS & DETERMINATION OF UNCERTAINTY
- MEASUREMENT PROCEDURES

UNITED STATES NUCLEAR REGULATORY COMMISSION

CONTENTS SUMMARY

- FLUENCE CALCULATION METHODS
  - Input Data
    - Materials & Geometry
    - Cross-Sections
    - Neutron Source
  - Fluence Calculation
  - Qualification, Uncertainly & Bias

- DOSIMETRY
  - Procedures
  - Dosimeters
  - Measurement Uncertainties
  - Validation
  - Fluence Estimates Based on Measured Data

CONTENTS SUMMARY

(CONTINUED)

- REPORTING
  - Methods
  - Calculation vs Measurement
- IMPLEMENTATION
- REGULATORY ANALYSIS

HISTORY

- 09/18/96 SECOND PUBLIC MEETING ON DRG

  ROUND 2 COMMENTS EVALUATED & INCORPORATED
  - MONTE CARLO ADDED
  - NUREG ON BENCHMARKS
  - BWR BENCHMARK
  - ADDITIONAL PWR CHECK OUT USING THE CALCULATION PROCEDURES

- 09/28/99 THIRD PUBLIC MEETING ON DRG

SCHEDULE AND FINALIZATION PLANS

- RECEIVE PUBIC COMMENTS THROUGH NOV 19, 1999
- PUBLIC COMMENTS & INDUSTRY EXPERIENCE RESOLVED AND INCORPORATED AS APPROPRIATE
- NRC STAFF REVIEW OF DRG WITH COMMENTS 03/2000
- CRGR & ACRS REVIEW 04 & 05/2000
- PUBLISH FINAL REGULATORY GUIDE LATE 2000

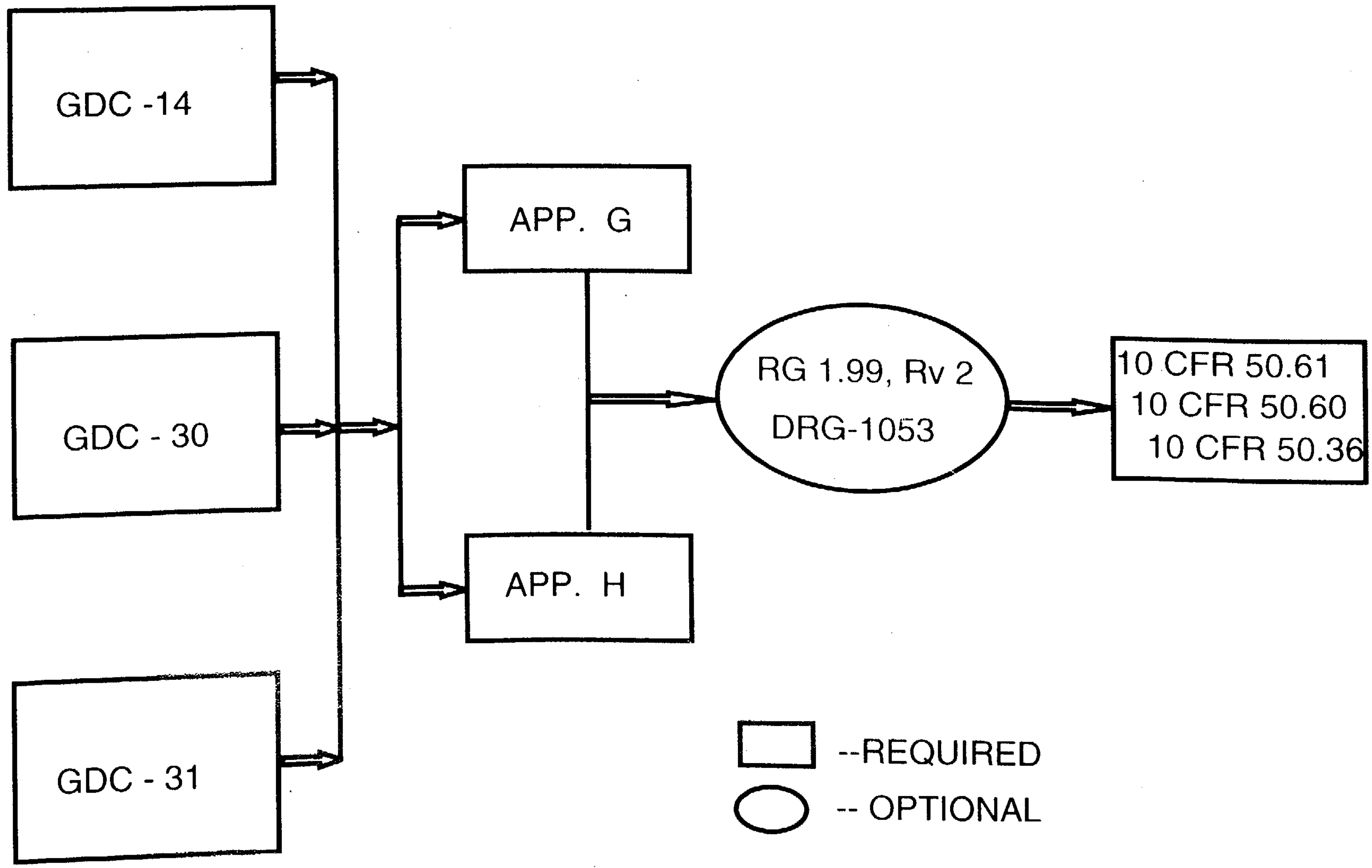
REGULATORY PERSPECTIVE

- OBJECTIVE IS TO SATISFY THE REQUIREMENTS OF GDCs-14, 30, 31
- DRG WILL COMPLIMENT RG 1.99 Rv 2 FOR INPUT PREPARATION FOR 50.61, 50.60 & 50.36
- DRG DESCRIBES ACCEPTABLE PRACTICES FOR FLUENCE ESTIMATION COMPUTATIONAL METHODS AND USE OF DOSIMETRY DATA
- DRG DOES NOT INTRODUCE NEW PRACTICES OR METHODS
- AIM IS TO ACHIEVE GREATER ACCURACY, COMPLETENESS, RELIABILITY BY DESCRIBING ACCEPTABLE METHODS FOR FLUENCE ESTIMATION

REGULATORY PERSPECTIVE

(CONTINUED)

- DRG FACILITATES SUBMITTAL PREPARATION AND REVIEW -- WILL BENEFIT BOTH APPLICANTS AND STAFF
- APPLICATION OF DRG WILL RESULT IN COST SAVINGS FOR INPUT PREPARATION & STAFF REVIEW
- RELIABILITY & COMPLETENESS OF METHODS WILL BE IMPORTANT FOR LICENSE EXTENSION APPLICATIONS WHERE VESSELS MAY BE CLOSE TO LIMITS
- METHODS MAY BE USED FOR APPLICATIONS OTHER THAN 50.61, 50.60 & 50.36 (E.G., INTERNALS, BAFFLE BOLTS, CORE SHROUD)



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ATTACHMENT 3

BNL Presentation Slides

NRC/INDUSTRY MEETING ON DRAFT REGULATORY GUIDE DG-1053 ON CALCULATIONAL AND DOSIMETRY METHODS FOR DETERMINING PRESSURE VESSEL FLUENCE

Presented by

John Carew

Energy and Nuclear Technology Division

Department of Advanced Technology

Brookhaven National Laboratory

September 28, 1999

Regulatory Guide 1053

- Developed
  - For - Materials Engineering
    Division of Engineering Technology
    Office of Nuclear Regulatory Research
  - By - Brookhaven National Laboratory
    National Institute of Standards and Technology
    Oak Ridge National Laboratory

Summary of Regulatory Guide 1053

- Purpose
  - Document calculation and measurement methods for determining pressure vessel fluence that are acceptable to NRC

- Scope
  - Vessel fluence determination for input to CRF 50.61 RT_{PTS}, input to Regulatory Guide 1.99 and Appendix-G

Summary of Regulatory Guide DG 1053

- Includes
  - Detailed description of fluence calculation and measurement methods
  - Procedures for qualification of calculations and measurements
  - Table of specific modeling, dosimetry,qualification and reporting requirements
  - Requires calculation of NUREG/CR-6115 pressure vessel fluence benchmark problems for methods qualification

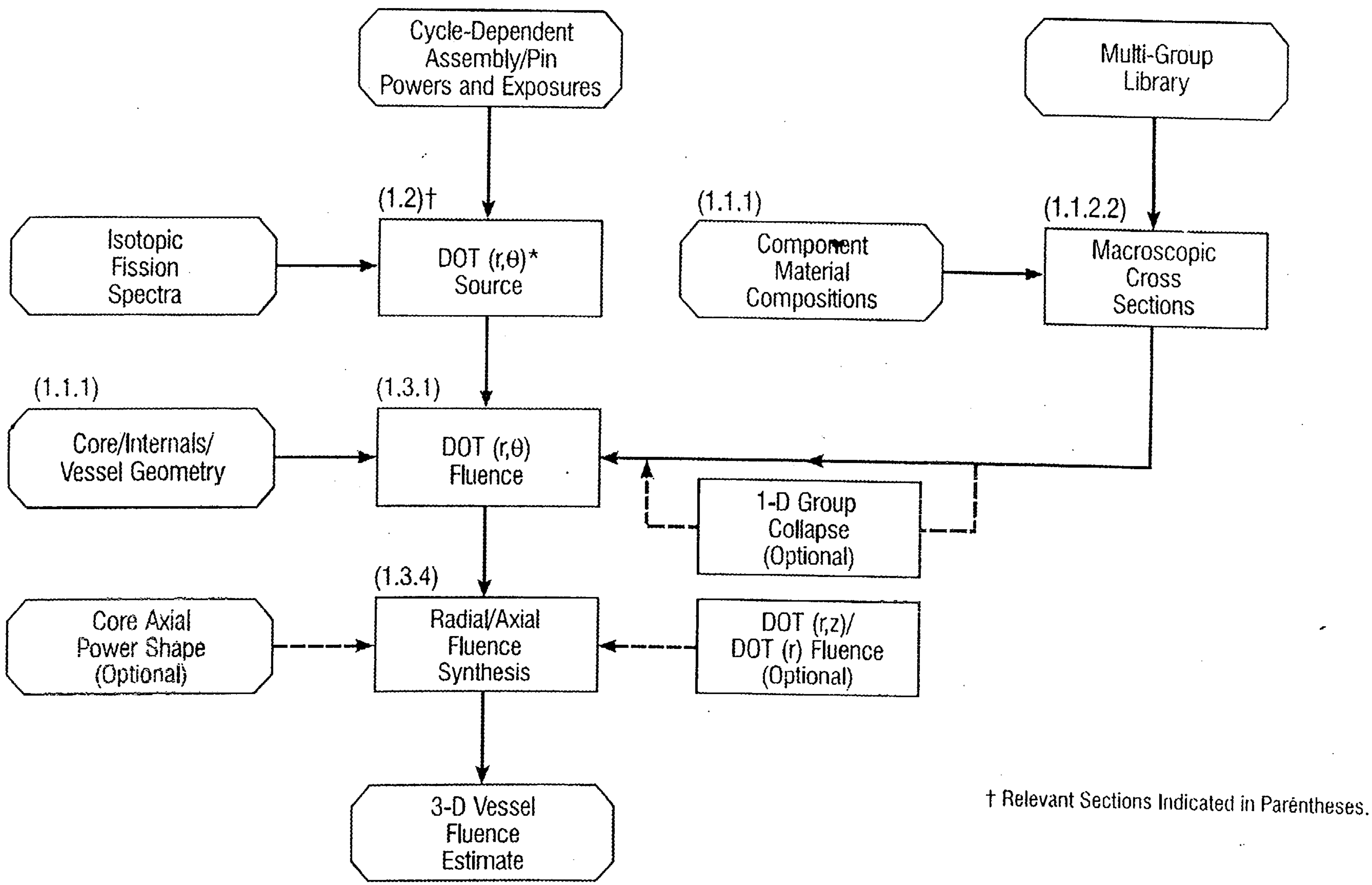


Figure 1. Discrete Ordinates Calculation Methodology

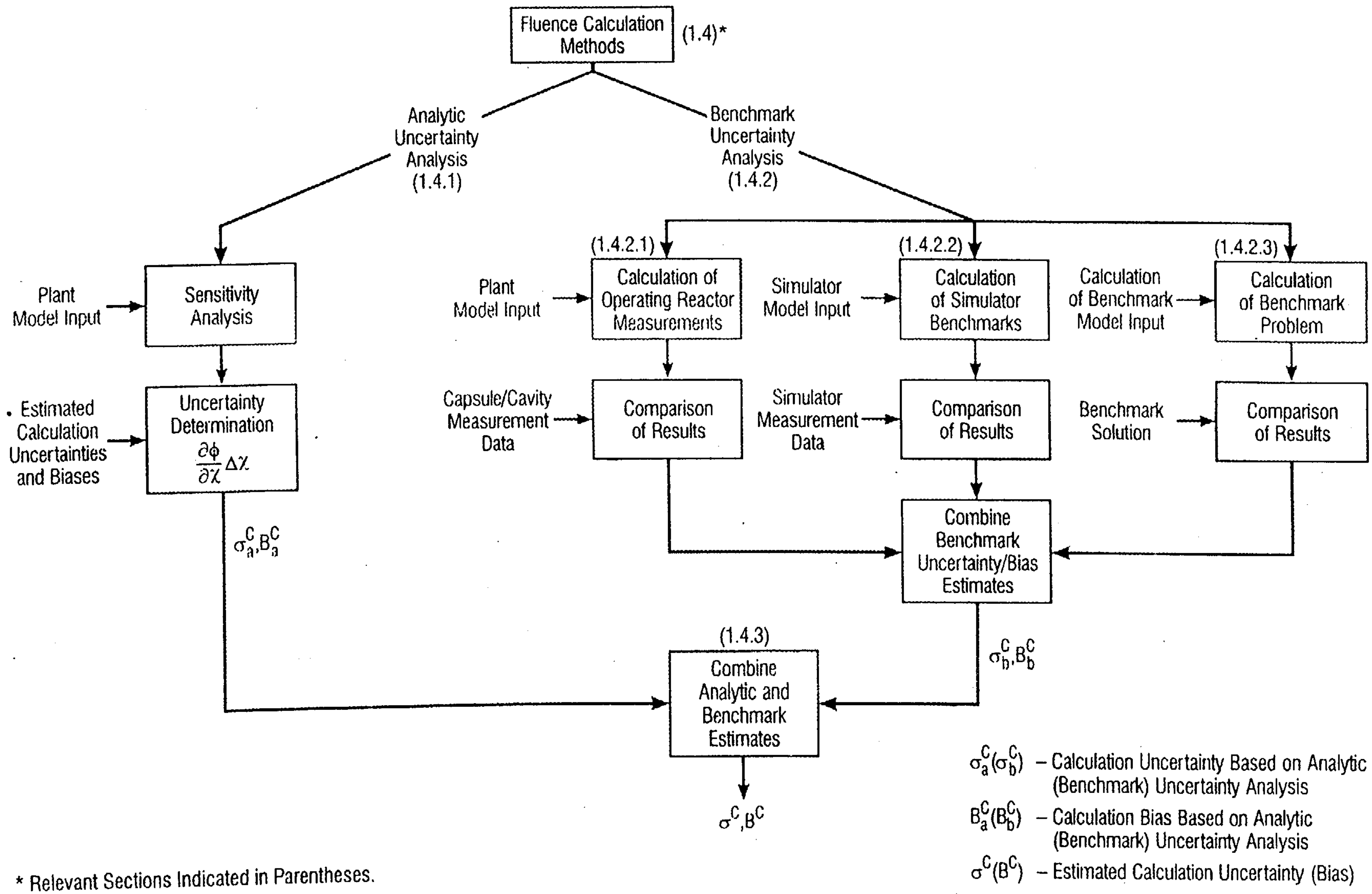


Figure 3. Calculation Methodology Qualification Procedure

Status of Regulatory Guide DG 1053

- NRC Pre-Release Reviews
  - ACRS Subcommittee
  - ACRS Committee
  - CRGR
- NRC Release for Comment
- Formal Review Meeting with Industry
- Round-1 Industry Comments Evaluated and Incorporated where Appropriate

Status of Regulatory Guide DG-1053

- September 18, 1996 Meeting with Industry to Review DG 1053
- Round-2 Industry Comments Evaluated and Incorporated where Appropriate
- September 28, 1999 Meeting with Industry to Review DG-1053
- May 2000 - Complete Evaluation of Industry Response Incorporate Changes and Finalize Guide
- December 2000 - Final Release of Regulatory Guide

Presentation Overview

- Review DG 1053 Resolution of Comments
- Provide Revisions Included in DG 1053
- Present PWR Monte Carlo Pressure Vessel Benchmark Problems
- Present BWR Pressure Vessel Benchmark Problems

Resolution of DG 1053 Comments

- Resolution of Comments
  - Comments from: NEI, EPRI, BGE, CP, PSU (A. Haghighat), GPU (M. Mahgerefteh), and EPL (E. P. Lippincott)
  - Concerned editing, organization, methods and qualification
  - Response to all comments and decision basis
  - Response based on team consensus
  - Resulting changes and additions included in DG 1053

Resolution of DG 1053 Comments

- Requirement for an Independent Uncertainty Analysis
  - Comment VIII.5
    - An independent estimate of the overall calculational uncertainty is a costly evaluation. The weighting process is arbitrary
  - Response VIII.5
    - Need for estimating the calculational uncertainty results from the PTS rule that requires the vessel fluence be calculated to within 20%

Resolution of DG 1053 Comments

- Requirement for an Independent Uncertainty Analysis
  - Analytic uncertainty analysis is simple and does not require a large effort
  - Benchmarking can be limited to a relatively small set of comparisons
  - Optimum weighting depends on the specific application and has not been included to allow analyst flexibility to select the best weighting

Resolution of DG-1053 Comments

- Impact of Nuclear Data Changes
  - Comment VIII.10
    - The Guide requires that the effect of nuclear data changes be evaluated to determine if there is a significant effect on fluence predictions
    - Determination of the effect will require a full implementation of the revised data and a rebenchmarking - which is costly

Resolution of DG-1053 Comments

- Impact of Nuclear Data Changes
  - Response VIII.10
    - The Guide does not require a complete implementation of new data and rebenchmarking
    - Evaluation depends on data changes
    - In most cases, a relatively simple stand-alone analysis can be used to determine if a full implementation and rebenchmarking is necessary

Resolution of DG-1053 Comments

- Plant-Specific Calculation-to-Measurement Bias
  - Comment VIII.25
    - Guide states that plant-specific biases should not be used unless the measurement data is of sufficient quality and quantity. The word sufficient is not required

Resolution of DG-1053 Comments

- Plant-Specific Calculation-to-Measurement Bias
  - Response - VIII.25
    - The measurement data should not be used to bias the fluence calculations unless the data is of sufficient
      - Quality: M/Cs are sufficiently accurate and independent to allow the application of standard statistical techniques
      - Quantity: Sufficient number of measurements to insure that the bias uncertainty is substantially less than the bias adjustment

Resolution of DG-1053 Comments

- Incorporation of New Fluence Measurements
  - Comment VIII.26
    - Guide states that as new measurements become available, they should be incorporated into the data base and calculational biases and uncertainties updated as necessary

Resolution of DG-1053 Comments

- Incorporation of New Fluence Measurements
  - Response VIII.26
    - If the number of new measurements is a significant fraction of the database or the new measurements differ substantially from the existing data, the biases and uncertainties will need to be updated
    - This determination does not require a complete reanalysis but should only require the minimum effort of processing the M/Cs

Resolution of DG-1053 Comments

- Periodic Validation of Measurement Techniques
  - Comment VIII.31
    - Guide requires periodic measurement validation
    - Measurement techniques will be validated as part of initial benchmarking
    - Laboratories have QA programs that consider procedures, equipment and personnel
    - Historically dosimetry measurements have not increased with time
    - M/C comparisons will identify any increase in uncertainties
    - Periodic measurement validation is not cost-effective

Resolution of DG-1053 Comments

- Periodic Validation of Measurement Techniques
  - Resolution VIII.31
    - M/C differences ~ 20% and are too large to allow identification of measurement errors
    - (1) Because of the importance of the measurements and
      (2) To insure the measurements are not biased - periodic validation measurements should be performed

Resolution of DG-1053 Comments

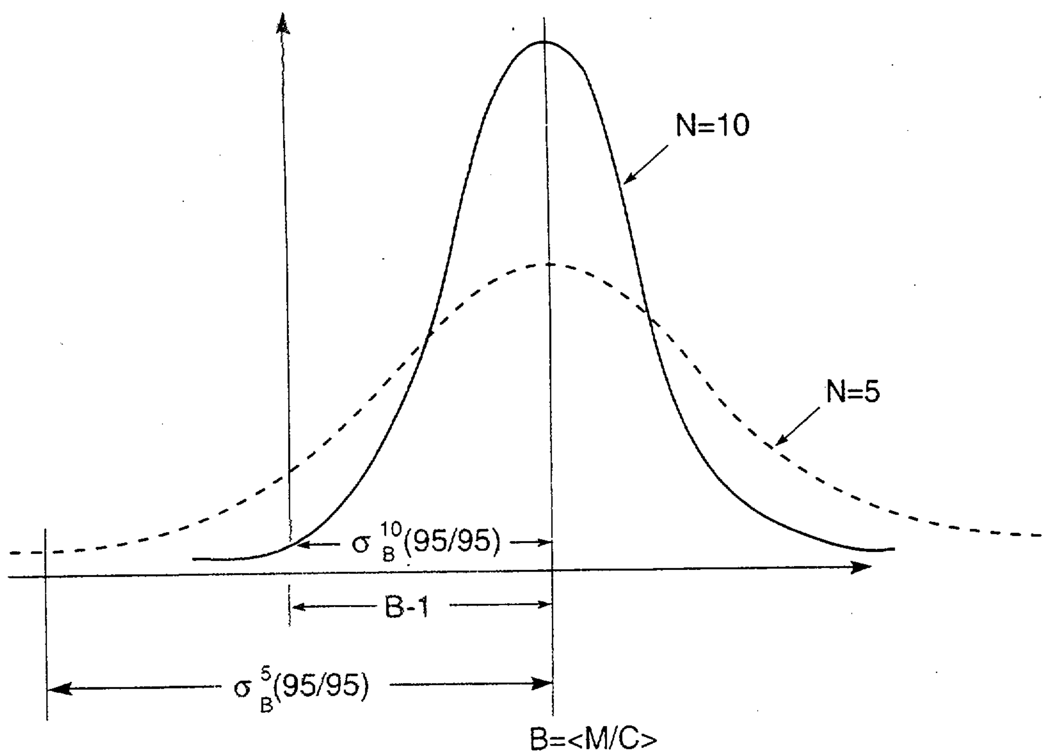
- Monte Carlo Transport Methods
  - Comment XI.6
    - The Guide should include Monte Carlo transport methods for vessel fluence applications
  - Response XI.6
    - The application of Monte Carlo transport methods has been included in both DG-1053 and the NUREG/CR-6115 benchmark problems report

Guidance on Monte Carlo Calculation

- Describes Vessel Fluence Monte Carlo Application DG-1053 Requirements
  - Solution Should Satisfy Statistical Acceptance Criteria
  - Talley Region for Point Estimates Should not Include Material Boundaries or be Located Near Reflecting, Periodic or White Boundaries
  - Variance Reduction Methods Should be Qualified by Comparison with Calculations Performed Without Variance Reduction

Adjustment of the Calculated Fluence Using Dosimetry Measurements

- Measurement-to-Calculation (M/C) Data Requirements
  - Independence (e.g., No systematic Trends versus Dosimeter Location, Energy Thresholds, Half-Life, Fuel Cycle)
  - Data of Sufficient Quality and Quantity to Provide a Reliable Estimate of the M/C Bias
- Typical Plant-Specific M/C Data Alone is not Sufficient for Adjusting Fluence Calculation.


N=10
N=5
σ B 10(95/95)
B-1
σ B 5(95/95)
B=<M/C>

NRC/INDUSTRY MEETING ON DRAFT REGULATORY GUIDE DG-1053 ON CALCULATIONAL AND DOSIMETRY METHODS FOR DETERMINING PRESSURE VESSEL FLUENCE

PRESSURE VESSEL BENCHMARK PROBLEMS

Presented by

John Carew

Energy and Nuclear Technology Division
Department of Advanced Technology
Brookhaven National Laboratory

Background

- Motivation
  - Vessel fluence calculations are extremely complex and involve substantial calculational uncertainties
    - Strong fluence attenuation results in large sensitivity to material compositions, nuclear data, core geometry modeling, source representation and transport methods
  - Accurate calculations are required for input to 10 CFR 50.61 (~20%) and Appendix-G
  - Detailed multi-group/multi-dimensional analyses are required

Background

- Purpose
  - Insure accurate fluence predictions and quantify uncertainty
  - Standardize vessel fluence methods
  - Streamline licensing process

Application of Benchmark Problems

- Fluence Methods Provided in DG 1053
- NUREG/CR-6115 Provides Problem Definitions and Reference Solutions
- Licensee Calculates the Benchmark Problems
- Comparisons to the Reference Solutions Provided to NRC in a Topical Report
- Fluence Methods Accepted (in part) Based on Agreement with Reference Solutions

Status of Fluence Benchmark Problems

- Problem Definition and Solutions Complete
- Sensitivity Calculations Complete
- Solution Verification Complete
- NUREG/CR-6115 Documentation Issued

Problem Definition

- Core Types Include
  - PWR - Standard Core, Low-Leakage Core (LL), and Partial Length Shield Assembly (PLSA) Core
  - BWR - Standard Core
- Detailed Description of Problem Materials, Geometry and Pin-Wise Source
- Typical Operating Reactor Geometry and Materials
- Complete Fluence Analysis Involving the Execution of Steps Required for the Determination of RT_{PTS} Input

Benchmark Problem Solution

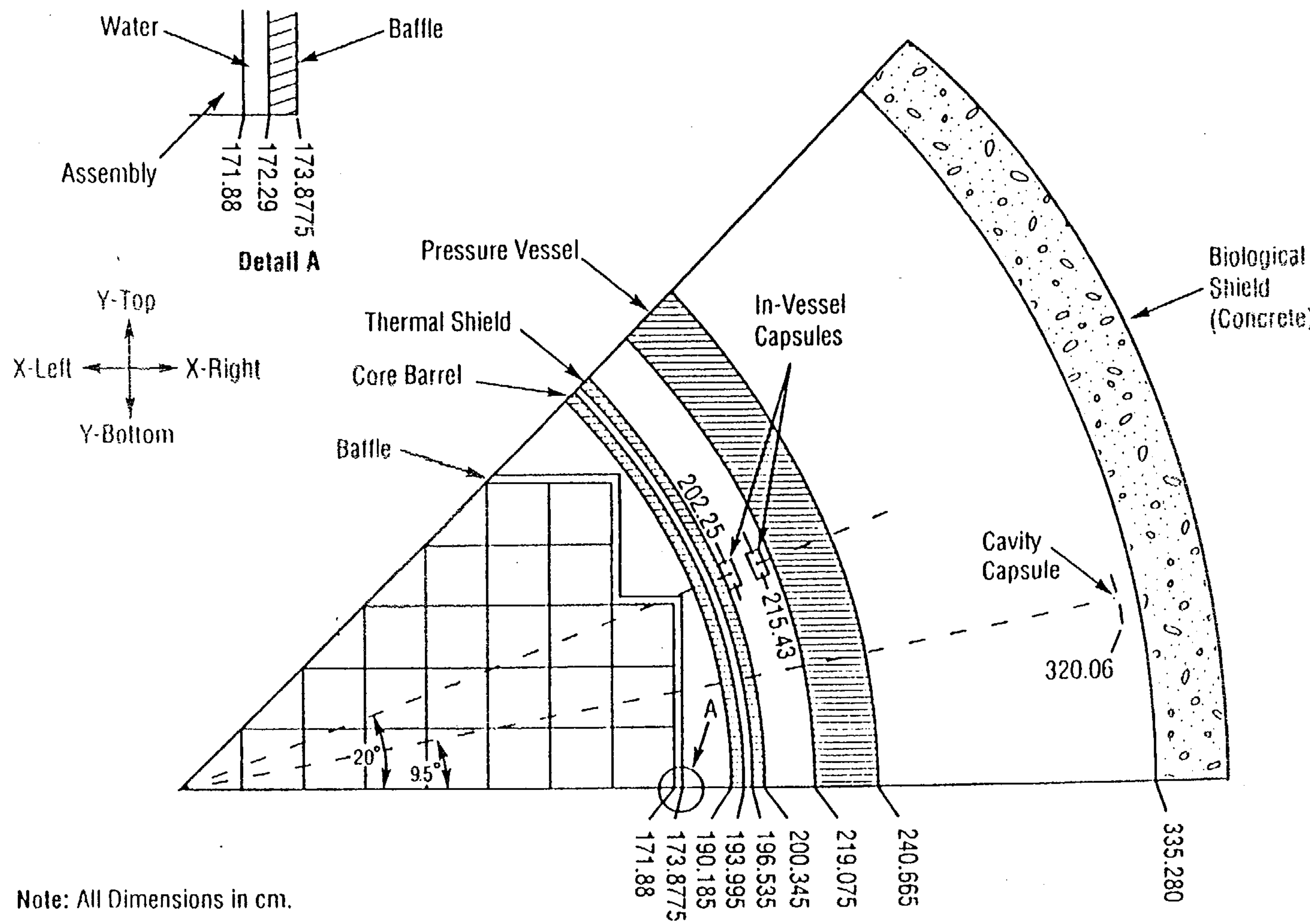
- Tabulated Solution Based on Standard Fluence Analysis Predictions
- Problem Solution Includes
  - Fluence > 1-MeV, > 0.1 MeV, dpa and spectrum
  - Accelerated and wall capsules, nT/4 and cavity locations
  - Dosimeter reaction rates at capsule and cavity locations
  - Fluence sensitivity calculations

Benchmark Problem Solution

- Calculational Methods Based on DG 1053
  - DORT S_8 P_3 transport
  - (r, θ) / (r,z) synthesis
  - BUGLE-93 / ENDF/B-VI cross sections
  - ENDF/B-VI dosimeter cross sections provided
  - ENDF/B-VI fission spectrum

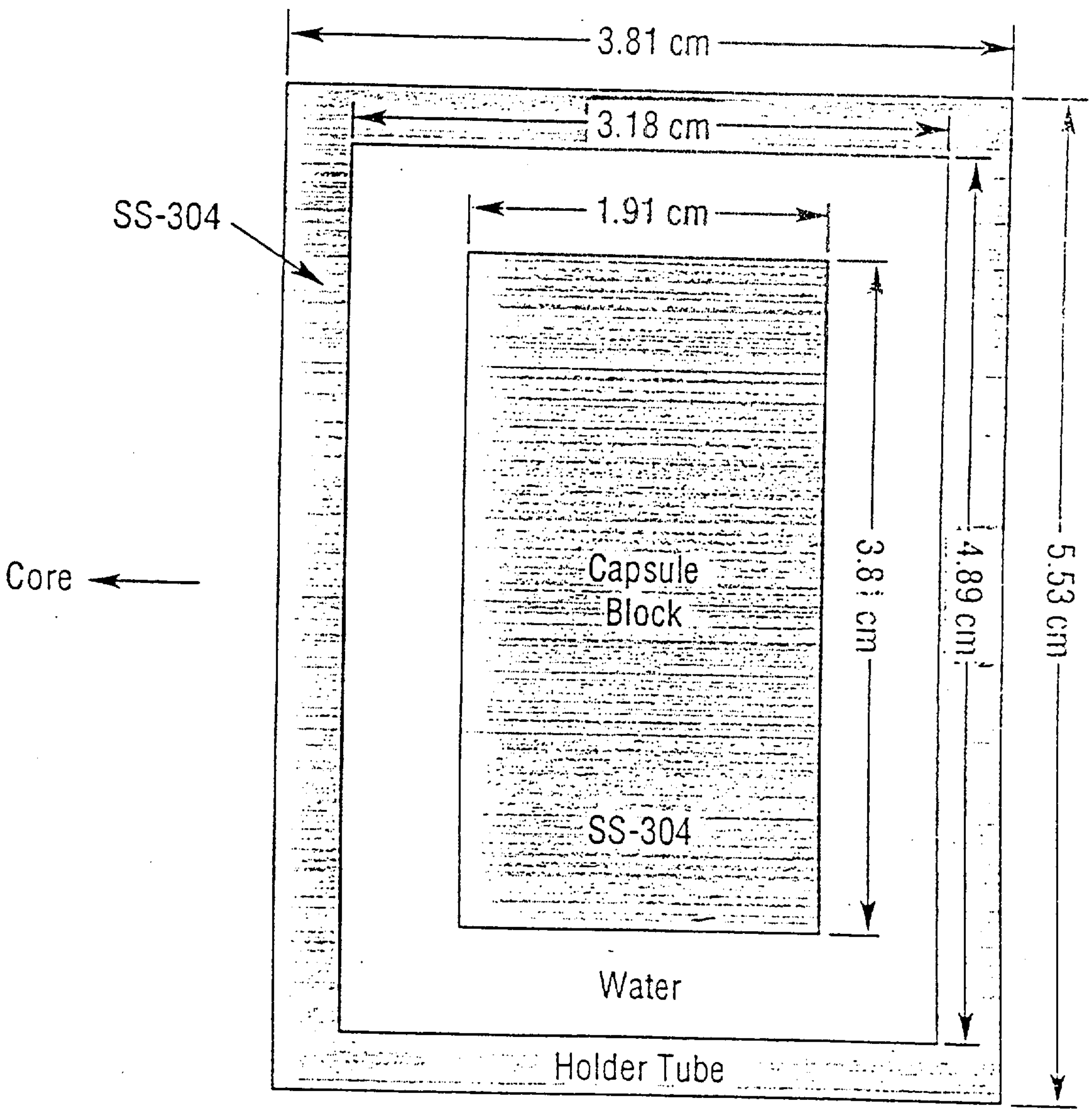
PWR Standard Core Benchmark Problem

- Geometry
  - Typical core-to-cavity dimensions and materials including a thermal shield and biological shield
- Core Neutron Source
  - Pin-wise power distribution with fuel isotopics vs burnup
- Complete and Detailed Set of Calculation Input Provided
- Dosimeters Located in Standard Wall Capsule and in Cavity
- ENDF/B-VI Dosimeter Cross Sections Provided



Location of Surveillance Capsules

Fig. 2.2.3



Surveillance Capsule

Fig. 2.2.4

Table 2.2.1

Standard Core Loading

Basic Design Data

Reactor		Material
Thermal Power	2527.73 MW(TH)	--
Core Inlet Temp.	536 °F	--
Core Operating Pressure	2010 psia	--
Baffle Thickness	1.5875 cm	SS-304
By-Pass	--	H_2O (560 °F 2010 psia)
Inner Radius of Core Barrel	190.185 cm	--
Barrel Thickness	3.81 cm	SS-304
Inner Inlet Thickness	2.54 cm	H_2O (536 °F 2010 psia)
Inner Radius of Thermal Shield	196.535 cm	--
Thermal Shield Thickness	3.81 cm	SS-304
Outer Inlet Thickness	18.095 cm	H_2O (536 °F 2010 psia)
Inner Radius of Liner Clad	218.440 cm	--
Vessel Liner Clad Thickness	0.635 cm	SS-304
Vessel Thickness	21.59 cm	SA-302B
PV Insulation Air Thickness	1.835 cm	Air
PV Insulation Thickness	10.16 cm	PV Insulation
Cavity Thickness	82.62 cm	Air
Inner Radius of Biological Shield	335.280 cm	--
Bio-Shield Liner Thickness	0.635 cm	SA-302B
Bio-Shield Thickness	213.36 cm	Concrete

Table 2.2.3

Standard Core Loading

Design Specification Material Compositions

Mixture	Component	Atom Densities (atom/b*cm)
Core	H	2.82500E-02
	B	2.69200E-05
	O	1.41200E-02
	C	2.58100E-05
	O (fuel)	1.28500E-02
	Al	3.56000E-04
	Cr	1.60800E-05
	Fe	2.20500E-05
	Ni	3.87700E-05
	Zr	5.44800E-03
	U-235	1.12000E-04
	U-238	6.03000E-03
	Pu-239	2.20000E-05
	Pu-240	7.12000E-06
Baffle (SS-304)	Cr	1.85300E-02
	Mn	1.75200E-03
	Fe	5.80700E-02
	Ni	8.57400E-03
Bypass+ (560 F)	H	4.92900E-02
	O	2.46400E-02
	B	4.90000E-06
Core Barrel (SS-304)	Cr	1.85300E-02
	Mn	1.75200E-03
	Fe	5.80700E-02
	Ni	8.57400E-03
Inlet Water Gap (536 F)	H	5.09600E-02
	O	2.54800E-02
	B	5.10000E-06
Thermal Shield (SS-304)	Cr	1.85300E-02
	Mn	1.75200E-03
	Fe	5.80700E-02
	Ni	8.57400E-03
RPV Liner (SS-304)	Cr	1.85300E-02
	Mn	1.75200E-03
	Fe	5.80700E-02
	Ni	8.57400E-03
Cavity (Air)	N	3.20000E-05
	O	8.00000E-06

+This composition is also to be used in the water region between the fuel assembly and the core baffle (see Figure 2.2.1).

Table 2.2.6

Standard Core Loading

Pin Geometry, Power, and Burnup Distributions

Assembly 6 Pin Power Set 13

X-Left	X-Right	Y-Bot	Y-Top	Relative Pin Power	BOC Burnup (MWD)	EOC Burnup (MWD)
1.07425E+02	1.08857E+02	0.00000E+00	1.43223E+00	1.09342E+00	6.621E+03	1.892E+04
1.07425E+02	1.08857E+02	1.43223E+00	2.86446E+00	1.03256E+00	6.621E+03	1.892E+04
1.07425E+02	1.08857E+02	2.86446E+00	4.29669E+00	1.00315E+00	6.621E+03	1.392E+04
1.07425E+02	1.08857E+02	4.29669E+00	5.72892E+00	1.00619E+00	6.621E+03	1.892E+04
1.07425E+02	1.08857E+02	5.72892E+00	7.16115E+00	0.00000E+00	6.621E+03	1.892E+04
1.07425E+02	1.08857E+02	7.16115E+00	8.59338E+00	9.98075E-01	6.621E+03	1.892E+04
1.07425E+02	1.08857E+02	8.59338E+00	1.00256E+01	9.75760E-01	6.621E+03	1.892E+04
1.07425E+02	1.08857E+02	1.00256E+01	1.14578E+01	9.69674E-01	6.621E+03	1.892E+04
1.07425E+02	1.08857E+02	1.14578E+01	1.28901E+01	9.77789E-01	6.621E+03	1.892E+04
1.07425E+02	1.08857E+02	1.28901E+01	1.43223E+01	1.00213E+00	6.621E+03	1.892E+04
1.07425E+02	1.08857E+02	1.43223E+01	1.57545E+01	0.00000E+00	6.621E+03	1.892E+04
1.07425E+02	1.08857E+02	1.57545E+01	1.71868E+01	1.00517E+00	6.621E+03	1.892E+04
1.07425E+02	1.08857E+02	1.71868E+01	1.86190E+01	9.90975E-01	6.621E+03	1.892E+04
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1.07425E+02	1.08857E+02	2.00512E+01	2.14835E+01	1.01633E+00	6.621E+03	1.892E+04
1.08857E+02	1.10289E+02	0.00000E+00	1.43223E+00	1.09038E+00	6.621E+03	1.892E+04
1.08857E+02	1.10289E+02	1.43223E+00	2.86446E+00	1.03358E+00	6.621E+03	1.892E+04
1.08857E+02	1.10289E+02	2.86446E+00	4.29669E+00	1.00112E+00	6.621E+03	1.892E+04
1.08857E+02	1.10289E+02	4.29669E+00	5.72892E+00	1.02850E+00	6.621E+03	1.892E+04
1.08857E+02	1.10289E+02	5.72892E+00	7.16115E+00	1.03256E+00	6.621E+03	1.892E+04
1.08857E+02	1.10289E+02	7.16115E+00	8.59338E+00	1.02546E+00	6.621E+03	1.892E+04
1.08857E+02	1.10289E+02	8.59338E+00	1.00256E+01	1.00923E+00	6.621E+03	1.892E+04
1.08857E+02	1.10289E+02	1.00256E+01	1.14578E+01	1.00213E+00	6.621E+03	1.892E+04
1.08857E+02	1.10289E+02	1.14578E+01	1.28901E+01	1.01126E+00	6.621E+03	1.892E+04
1.08857E+02	1.10289E+02	1.28901E+01	1.43223E+01	1.02952E+00	6.621E+03	1.892E+04
1.08857E+02	1.10289E+02	1.43223E+01	1.57545E+01	1.03560E+00	6.621E+03	1.892E+04
1.08857E+02	1.10289E+02	1.57545E+01	1.71868E+01	1.02648E+00	6.621E+03	1.892E+04
1.08857E+02	1.10289E+02	1.71868E+01	1.86190E+01	9.84889E-01	6.621E+03	1.892E+04
1.08857E+02	1.10289E+02	1.86190E+01	2.00512E+01	9.91989E-01	6.621E+03	1.892E+04
1.08857E+02	1.10289E+02	2.00512E+01	2.14835E+01	1.00112E+00	6.621E+03	1.892E+04
1.10289E+02	1.11722E+02	0.00000E+00	1.43223E+00	1.09240E+00	6.621E+03	1.892E+04
1.10289E+02	1.11722E+02	1.43223E+00	2.86446E+00	1.03256E+00	6.621E+03	1.892E+04
1.10289E+02	1.11722E+02	2.86446E+00	4.29669E+00	1.00619E+00	6.621E+03	1.892E+04
1.10289E+02	1.11722E+02	4.29669E+00	5.72892E+00	1.01126E+00	6.621E+03	1.892E+04
1.10289E+02	1.11722E+02	5.72892E+00	7.16115E+00	1.01126E+00	6.621E+03	1.892E+04
1.10289E+02	1.11722E+02	7.16115E+00	8.59338E+00	6.09596E-01	6.621E+03	1.892E+04
1.10289E+02	1.11722E+02	8.59338E+00	1.00256E+01	9.99089E-01	6.621E+03	1.892E+04
1.10289E+02	1.11722E+02	1.00256E+01	1.14578E+01	9.90975E-01	6.621E+03	1.892E+04
1.10289E+02	1.11722E+02	1.14578E+01	1.28901E+01	1.00112E+00	6.621E+03	1.892E+04
1.10289E+02	1.11722E+02	1.28901E+01	1.43223E+01	6.16697E-01	6.621E+03	1.892E+04
1.10289E+02	1.11722E+02	1.43223E+01	1.57545E+01	1.01329E+00	6.621E+03	1.892E+04
1.10289E+02	1.11722E+02	1.57545E+01	1.71868E+01	1.00720E+00	6.621E+03	1.892E+04
1.10289E+02	1.11722E+02	1.71868E+01	1.86190E+01	9.86917E-01	6.621E+03	1.892E+04
1.10289E+02	1.11722E+02	1.86190E+01	2.00512E+01	9.86917E-01	6.621E+03	1.892E+04
1.10289E+02	1.11722E+02	2.00512E+01	2.14835E+01	9.99089E- [illegible]	6.621E+03	1.892E+04

Table 2.1.1

Fraction Of Fissions by Isotope as Function of Exposure

Exposure (MWD)	U-235	U-238	Pu-239	Pu-240	Pu-241	Pu-242
1.500E+02	9.28100E-01	6.17165E-02	1.01828E-02	1.65450E-07	4.25775E-07	0.00000E+00
5.000E+02	9.05149E-01	6.21387E-02	3.26955E-02	1.77633E-06	1.49927E-05	1.38872E-10
1.000E+04	5.57019E-01	7.07435E-02	3.39497E-01	3.10546E-04	3.24187E-02	1.08465E-05
2.000E+04	3.56399E-01	7.81926E-02	4.64707E-01	7.40748E-04	9.98821E-02	7.83614E-05
4.000E+04	1.23133E-01	9.01198E-02	5.82823E-01	1.43769E-14	2.03544E-01	3.80635E-04

Table 2.3.8

Low Leakage Core Loading Edit Locations

	R(cm)	Z(cm)	θ(degrees)
Thermal Shield Capsule:			
Flux Spectrum and			
Peak Reaction Rates	202.25	195.76	20
Pressure Vessel Capsule:			
Flux Spectrum and			
Peak Reaction Rates	215.43	195.76	20
Cavity Capsule:			
Flux Spectrum and			
Peak Reaction Rates	320.06	184.665	9.5
Fluxes and DPA Rates	320.06	184.665	0-45
Pressure Vessel 0-T:			
(A) Axial Peak Location			
(a) E > 1.0 MEV	219.393	195.760	0-45
(b) E > 0.1 MEV	219.393	195.760	0-45
(c) DPA Rates	219.393	195.760	0-45
(d) Flux Spectrum	219.393	195.760	15.5
(B) Lower Weld Location	219.393	67.1048	0-45
Pressure Vessel 1/4 T:			
(A) Axial Peak Location			
(a) E > 1.0 MEV	224.473	195.760	0-45
(b) E > 0.1 MEV	224.473	192.062	0-45
(c) DPA Rates	224.473	195.760	0-45
(d) Flux Spectrum	224.473	195.760	15.5
(B) Lower Weld Location	224.473	67.1048	0-45
Pressure Vessel 1/2 T:			
(A) Axial Peak Location			
(a) E > 1.0 MEV	229.870	195.760	0-45
(b) E > 0.1 MEV	229.870	192.062	0-45
(c) DPA Rates	229.870	192.062	0-45
(d) Flux Spectrum	229.870	195.760	15.5
(B) Lower Weld Location	229.870	67.1048	0-45
Pressure Vessel 3/4 T:			
(A) Axial Peak Location			
(a) E > 1.0 MEV	235.268	192.062	0-45
(b) E > 0.1 MEV	235.268	192.062	0-45
(c) DPA Rates	235.268	192.062	0-45
(d) Flux Spectrum	229.870	192.062	15.5
(B) Lower Weld Location	235.268	67.1048	0-45
Pressure Vessel Outer T:			
(A) Axial Peak Location			
(a) E > 1.0 MEV	240.342	192.062	0-45
(b) E > 0.1 MEV	240.342	188.363	0-45
(c) DPA Rates	240.342	188.363	0-45
(d) Flux Spectrum	240.342	195.760	15.5
(B) Lower Weld Location	240.342	67.1048	0-45
Downcomer	210.50	195.76	0-45

+The inner-wall (O-T) and vessel outer-wall (T) edits were taken at the center of the mesh blocks immediately inside the vessel. The vessel internal edits were taken at mesh blocks centered about the required edit location.

Table 4.2.1

Standard Core Loading

Flux (E>1.0 MEV) At Pressure Vessel

z	125.488cm	125.488cm	129.186cm	129.186cm	140.282cm
θ	0-T	1/4 T	1/2 T	3/4 T	T
1	3.14799E+10	1.78931E+10	8.69114E+09	4.00968E+09	1.63867E+09
2	3.14939E+10	1.78948E+10	8.69181E+09	4.01204E+09	1.63590E+09
3	3.15515E+10	1.79309E+10	8.71023E+09	4.01916E+09	1.63546E+09
4	3.18090E+10	1.80707E+10	8.77347E+09	4.04608E+09	1.64438E+09
5	3.22184E+10	1.82947E+10	8.87711E+09	4.09152E+09	1.65943E+09
6	3.27523E+10	1.85911E+10	9.01599E+09	4.15139E+09	1.67925E+09
7	3.34669E+10	1.89955E+10	9.20569E+09	4.23439E+09	1.70608E+09
8	3.44603E+10	1.95427E+10	9.45942E+09	4.34323E+09	1.74117E+09
9	3.54574E+10	2.00747E+10	9.70318E+09	4.44796E+09	1.77511E+09
10	3.63728E+10	2.05806E+10	9.93677E+09	4.54712E+09	1.80693E+09
11	3.74744E+10	2.11727E+10	1.02041E+10	4.66105E+09	1.84307E+09
12	3.85964E+10	2.17730E+10	1.04749E+10	4.77398E+09	1.87884E+09
13	3.96873E+10	2.23491E+10	1.07308E+10	4.88026E+09	1.91205E+09
14	4.06848E+10	2.28693E+10	1.09581E+10	4.97269E+09	1.94069E+09
15	4.15408E+10	2.33066E+10	1.11436E+10	5.04551E+09	1.96229E+09
16	4.22000E+10	2.36185E+10	1.12659E+10	5.08990E+09	1.97516E+09
17	4.25965E+10	2.37640E+10	1.13064E+10	5.09949E+09	1.97593E+09
18	4.25805E+10	2.36866E+10	1.12453E+10	5.06928E+09	1.96689E+09
19	4.21634E+10	2.34630E+10	1.11362E+10	5.02312E+09	1.95418E+09
20	4.20061E+10	2.32440E+10	1.10309E+10	4.98065E+09	1.93913E+09
21	4.11917E+10	2.27246E+10	1.08174E+10	4.90050E+09	1.91354E+09
22	4.02185E+10	2.21933E+10	1.06133E+10	4.82491E+09	1.89446E+09
23	3.88038E+10	2.17186E+10	1.04642E+10	4.77406E+09	1.88876E+09
24	3.82263E+10	2.15915E+10	1.04226E+10	4.75869E+09	1.88401E+09
25	3.73962E+10	2.12952E+10	1.03327E+10	4.72600E+09	1.86809E+09
26	3.67420E+10	2.09653E+10	1.02152E+10	4.68137E+09	1.85169E+09
27	3.63552E+10	2.07451E+10	1.01082E+10	4.63723E+09	1.83997E+09
28	3.64033E+10	2.06613E+10	1.00430E+10	4.60702E+09	1.83573E+09
29	3.65714E+10	2.06166E+10	1.00083E+10	4.59093E+09	1.83048E+09
30	3.70498E+10	2.05760E+10	9.92482E+09	4.54562E+09	1.80541E+09
31	3.68078E+10	2.04258E+10	9.81075E+09	4.48443E+09	1.78065E+09
32	3.62594E+10	2.02359E+10	9.70994E+09	4.43473E+09	1.76407E+09

Table 4.2.12

Standard Core Loading

Effect of Selected Cross Sections on the Calculated Reaction Rates

Axial Peak Reaction Rate (reactions/sec*atom)

Pressure Vessel Capsule ($r=215.43 cm, z=125.49 cm, \theta=20^{\circ}$)

Detector Material	BUGLE93	SAILOR ENDF/B-IV	ORNL/TM-11476
^{27}Al (n,α)	1.13574×10^{-16}	1.17931×10^{-16}	
^{32}S (n,p)	5.08199×10^{-15}	5.20481×10^{-15}	
^{46}Ti (n,p)	1.17613×10^{-15}	1.14241×10^{-15}	
^{54}Fe (n,p)	6.57302×10^{-15}	6.78698×10^{-15}	6.50612×10^{-15}
^{56}Fe (n,p)	1.43009×10^{-16}	1.54390×10^{-16}	
^{58}Ni (n,p)	8.62894×10^{-15}	8.68697×10^{-15}	8.45897×10^{-15}
^{63}Cu (n,α)	6.86179×10^{-17}	5.63829×10^{-17}	
^{65}Cu $(n,2n)$	8.29140×10^{-16}	1.01544×10^{-16}	
^{115}In (n,n')	1.38141×10^{-14}	1.33868×10^{-14}	
^{237}Np (n,f)	1.18077×10^{-13}	1.27145×10^{-13}	1.22359×10^{-13}
^{238}U (n,f)	2.37573×10^{-14}	2.39417×10^{-14}	2.38418×10^{-14}

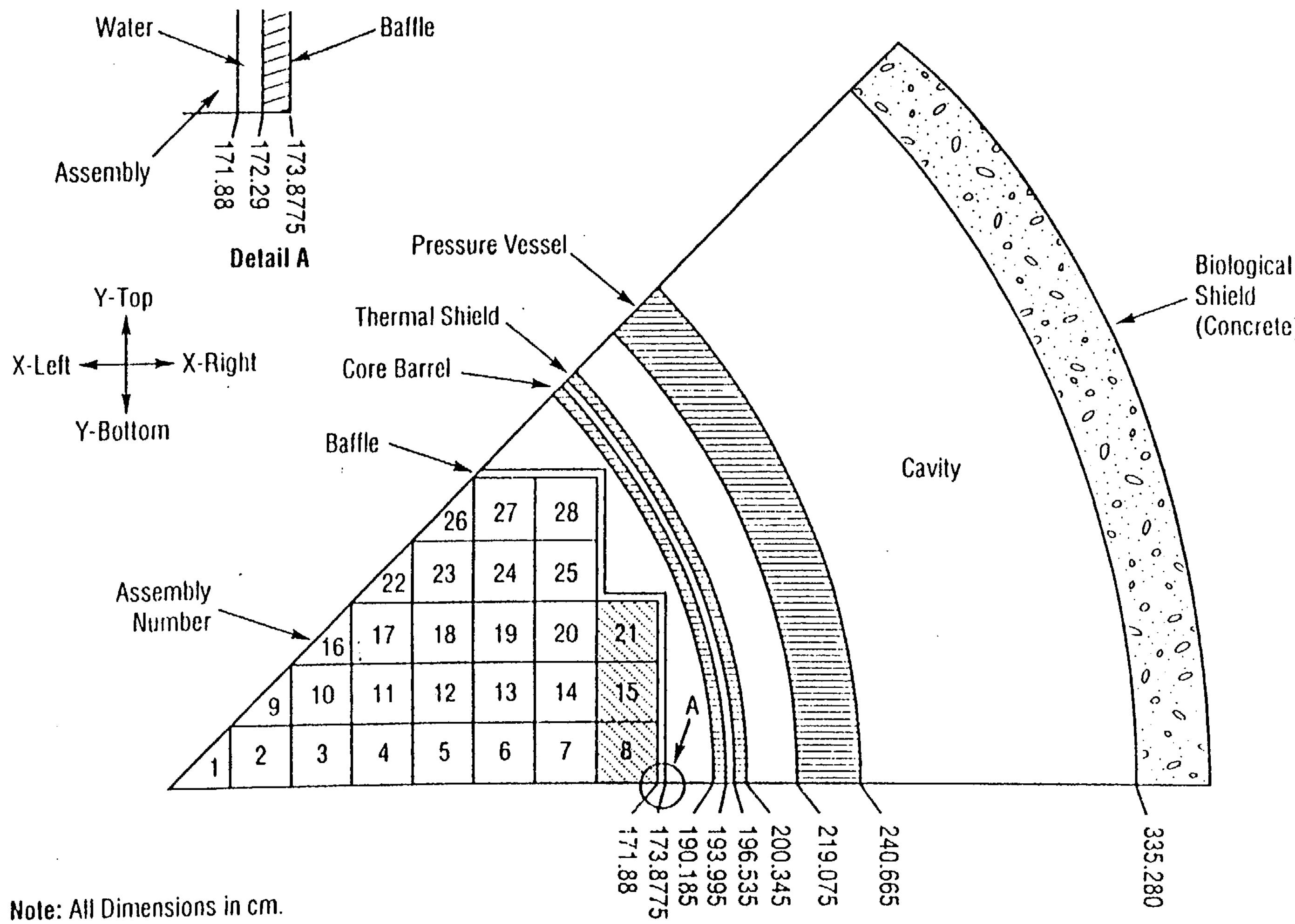
BUGLE93 used pressure vessel 1/4T weighting spectrum to collapse cross sections.
SAILOR used flat weighting spectrum to collapse cross sections.

PWR Partial Length Shield Assembly Problem

- Six Fuel Assemblies on the Core Flats are Replaced with Partial Length Shield Assemblies
- Fuel Pins are Replaced with Stainless Steel Rods in Lower ~3.5 ft of Fuel Assembly Opposite a Circumferential Weld
- Except for Assemblies with Stainless Steel Pins, the Materials and Geometry are the Same as the Standard Core Problem
- Core Power Distribution Corresponds to the PLSA Fuel Loading

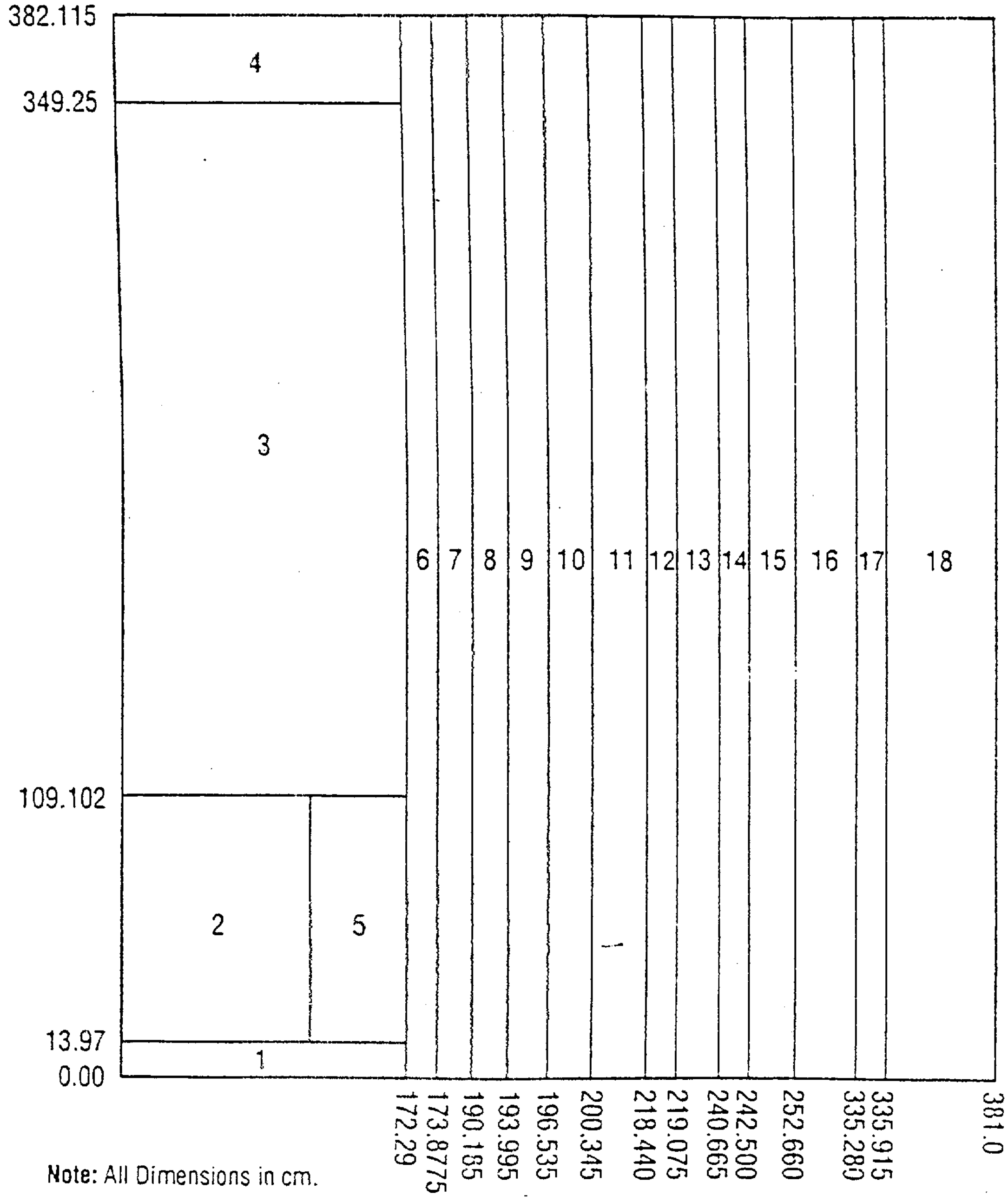
PWR Partial Length Shield Assembly Problem

- Calculational Methods and Nuclear Data used are the Same as the Standard Core Problem
- Axial-Dependence of Flux is Determined using the Synthesis Approach
- Fluence is Edited at the Vessel Inner-Wall at the Circumferential Weld
- Fluence Reduction Factors (~ x 10) are Determined at the Weld Location



Partial Length Shield Assembly Core Loading

Fig. 2.4.1



Partial Length Shield Assembly Core Loading
Axial Geometry at $\theta=0^{\circ}$

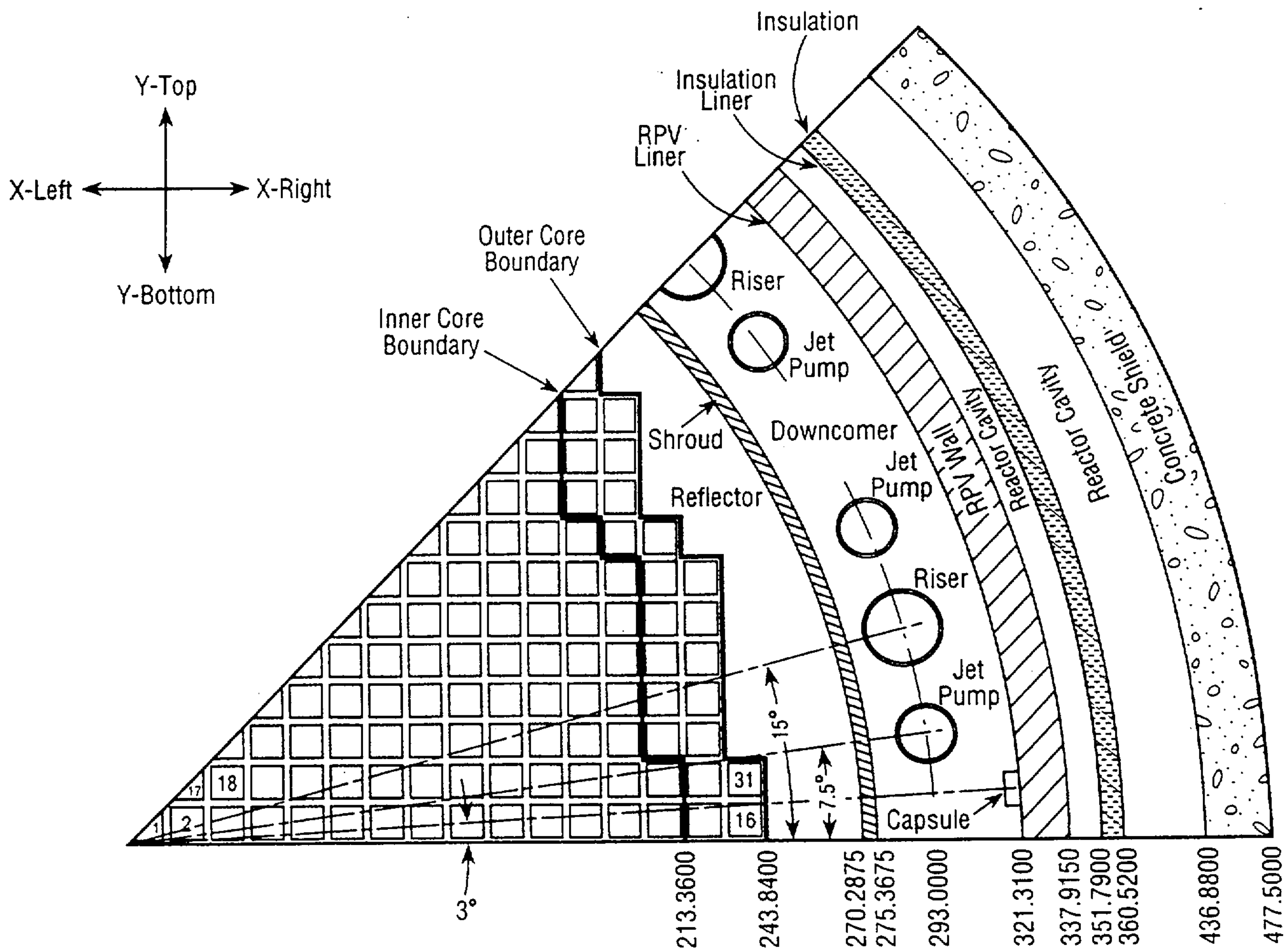
Fig. 2.4.3

BWR Benchmark Problem

- Geometry - Typical Core-to-Cavity Dimensions and Materials Including Core, Vessel Internals and Jet pumps
- Core Neutron Source - Pin-Wise Power Distribution with Fuel Isotopics versus Burnup
- Three-Dimensional Core Void Distribution
- Complete Set of Fluence and Reaction-Rate Edits
- In Channel and Bypass Coolant
  - Homogenized in DORT calculations
  - Explicitly modeled in MCNP calculations

Figure 2.2.2.1

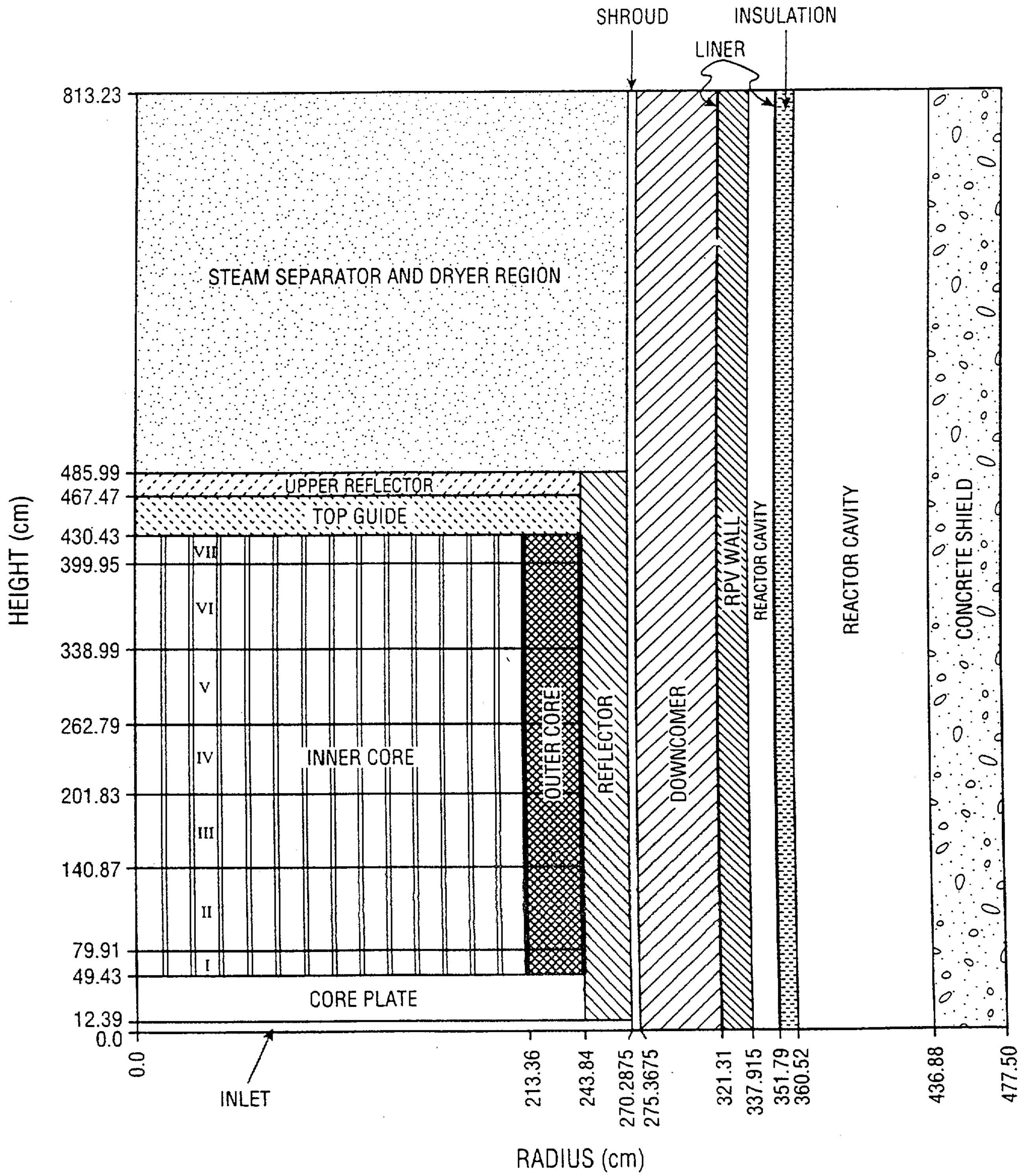
BWR Planar Geometry



NOTE: All Dimensions in cm

Figure 2.2.2.2

BWR Axial Geometry



NOTE: All Dimensions in cm

MCNP Calculations of Benchmark Problems

- Based on NUREG/CR-6115 Problem Definitions
  - Standard core
  - PLSA core
  - BWR core
- Exact Three-Dimensional Geometry
  - Explicit pellet/clad, internals, etc.
  - Pin-wise source description for peripheral assemblies
- Multi-Group ENDFB/VI Library Based on BUGLE-93

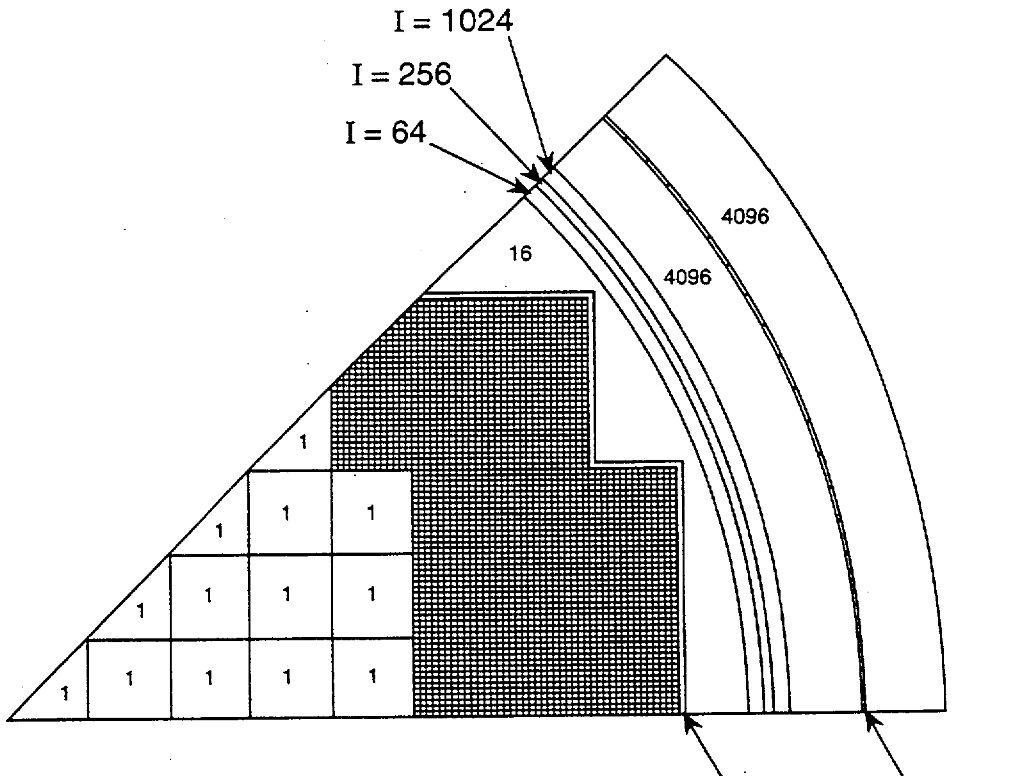


Figure 5.3.1

Region-wise Importance I For The Standard Core Problem

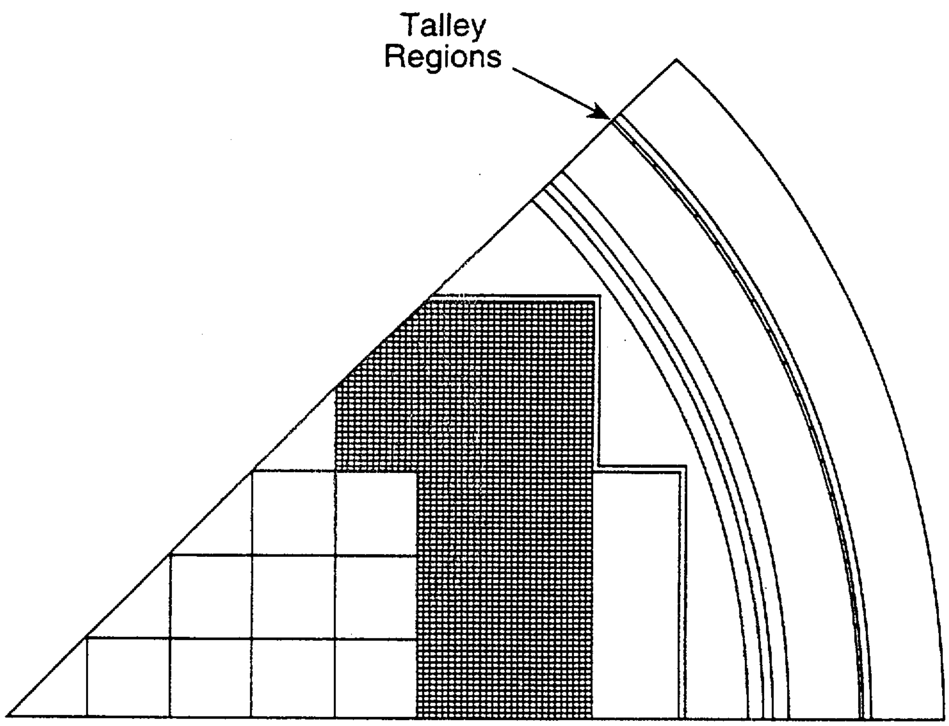


Figure 5.3.4

MCNP Radial Geometry
PLSA Core Loading

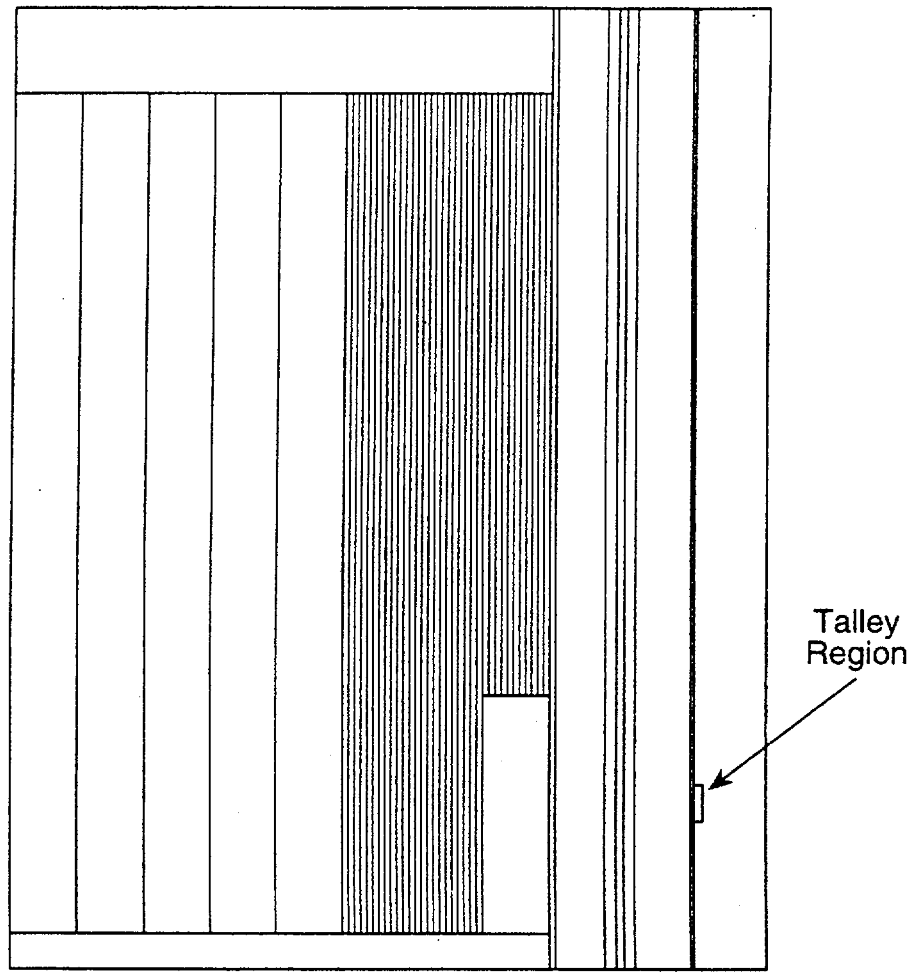


Figure 5.3.5

MCNP Axial Geometry
PLSA Core Loading

Figure 5.4.3

Radial Region-Wise Importance I

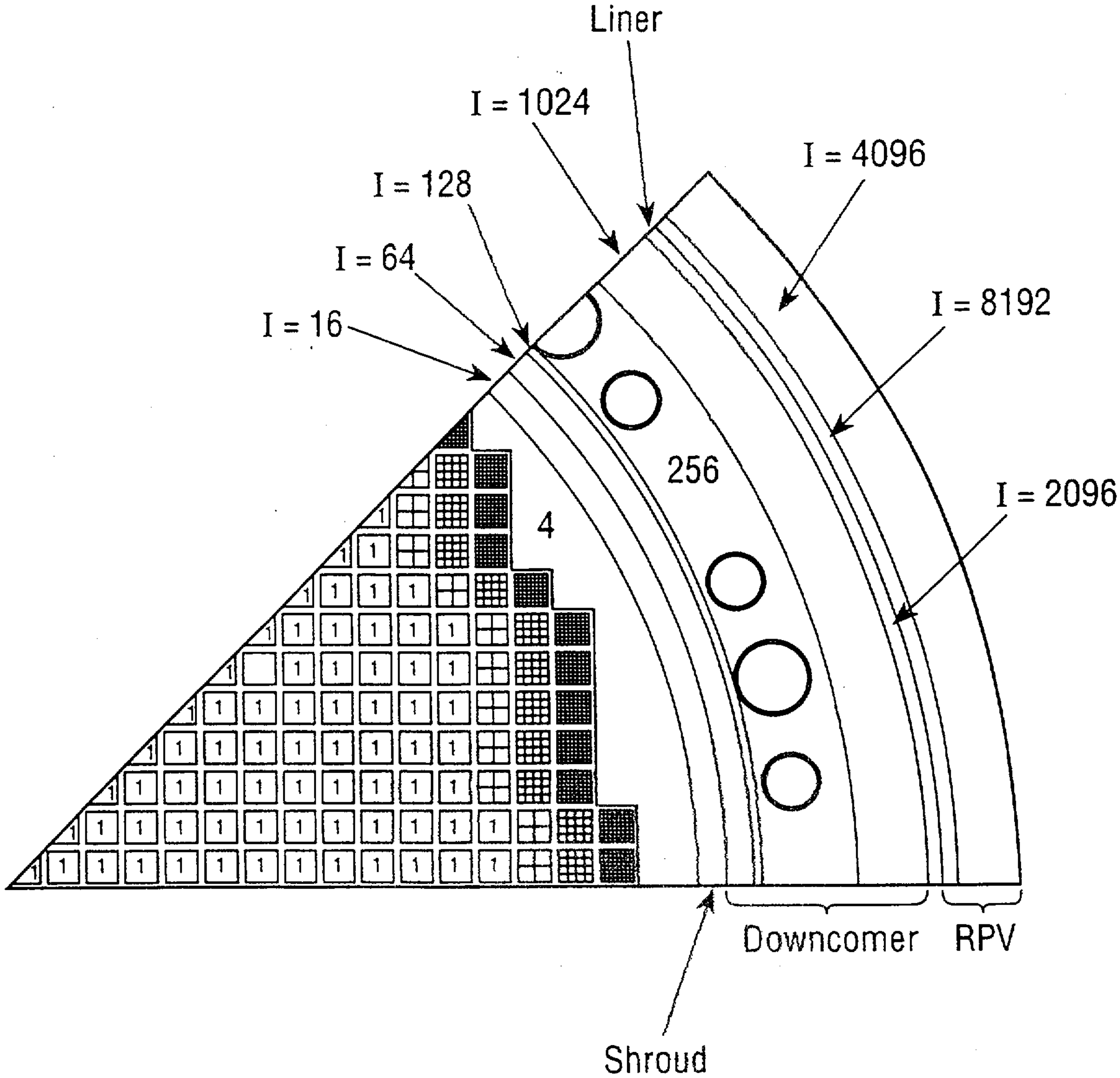
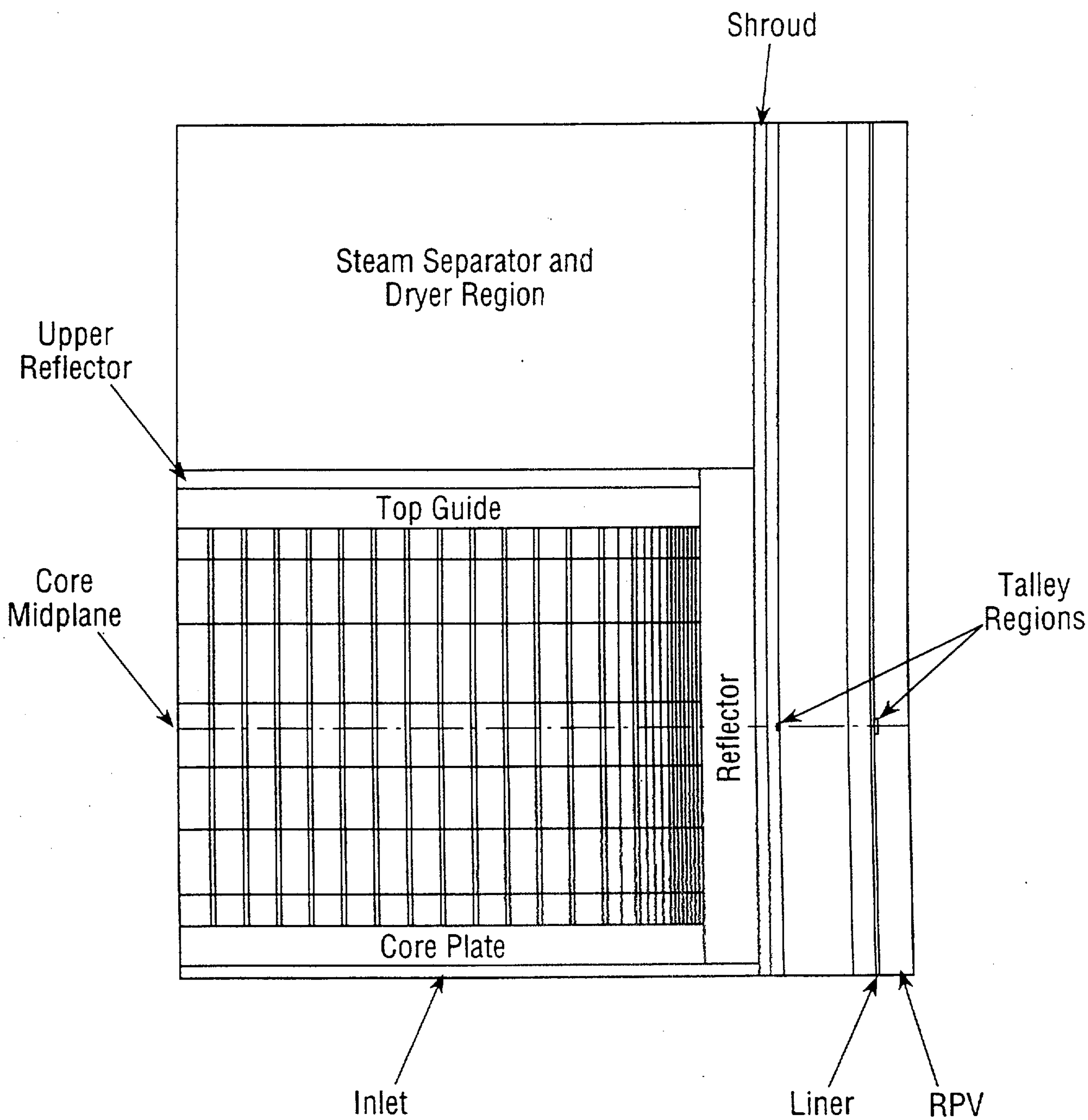


Figure 5.4.2

MCNP Axial Geometry



MCNP Calculations of Benchmark Problems

- Region-Wise Importance Weighting
- > 1-MeV Fluence Edit at Selected Vessel Inner-Wall Locations
- DORT/MCNP Differences ≤5% Consistent with Methods Uncertainties
  - MCNP statistics
  - DORT geometry
  - DORT numerics
  - DORT synthesis

Figure 5.3.7

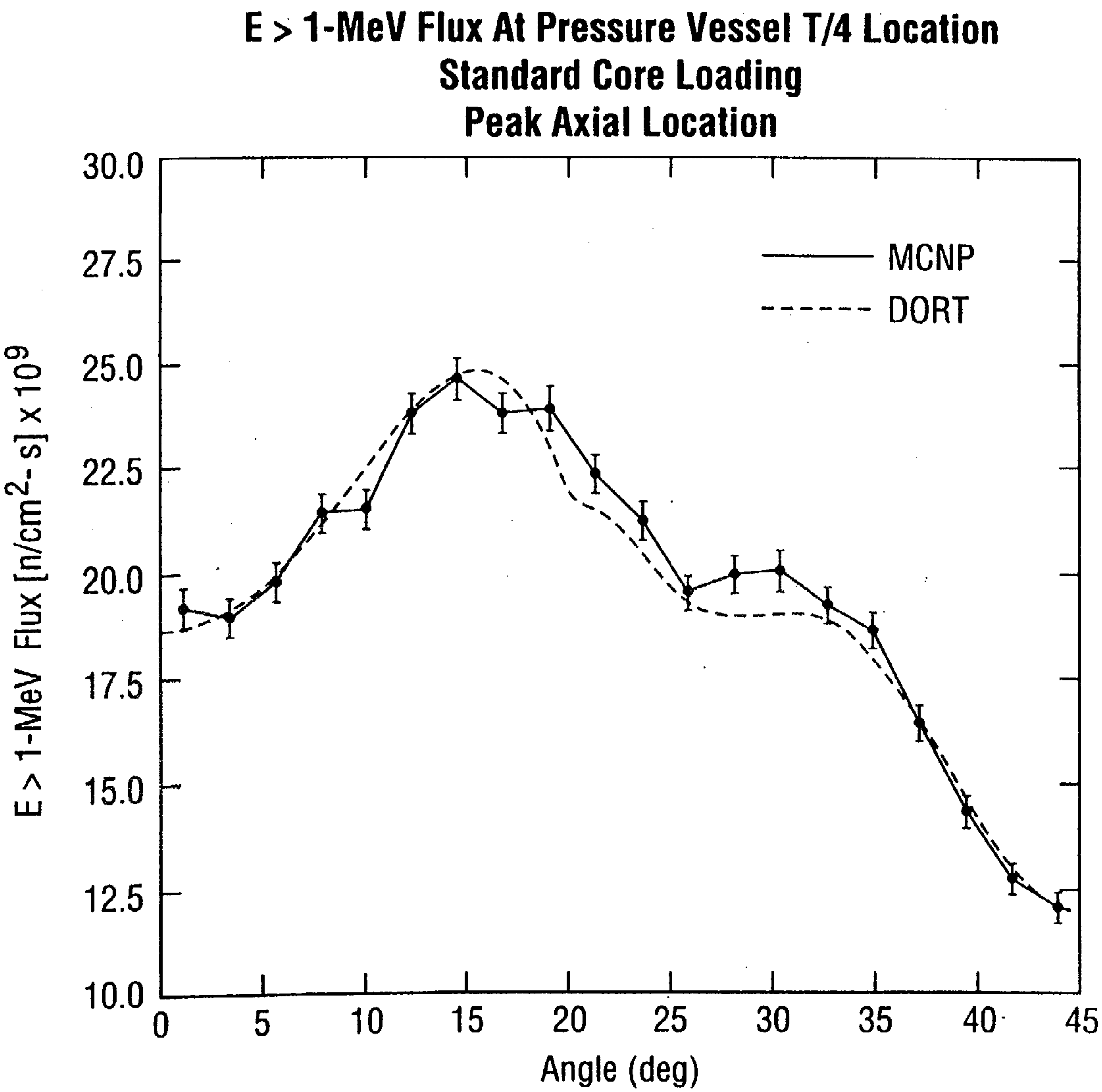

E > 1-MeV Flux At Pressure Vessel T/4 Location
Standard Core Loading
Peak Axial Location
MCNP
DORT
30.0
27.5
25.0
22.5
20.0
17.5
15.0
12.5
10.0
0
5
10
15
20
25
30
35
40
45
Angle (deg)
E > 1-MeV Flux [n/cm2- s] x 109

Figure 5.3.9

E > 1-MeV Flux At Pressure Vessel Lower Weld
Partial Length Shield Assembly Core Loading

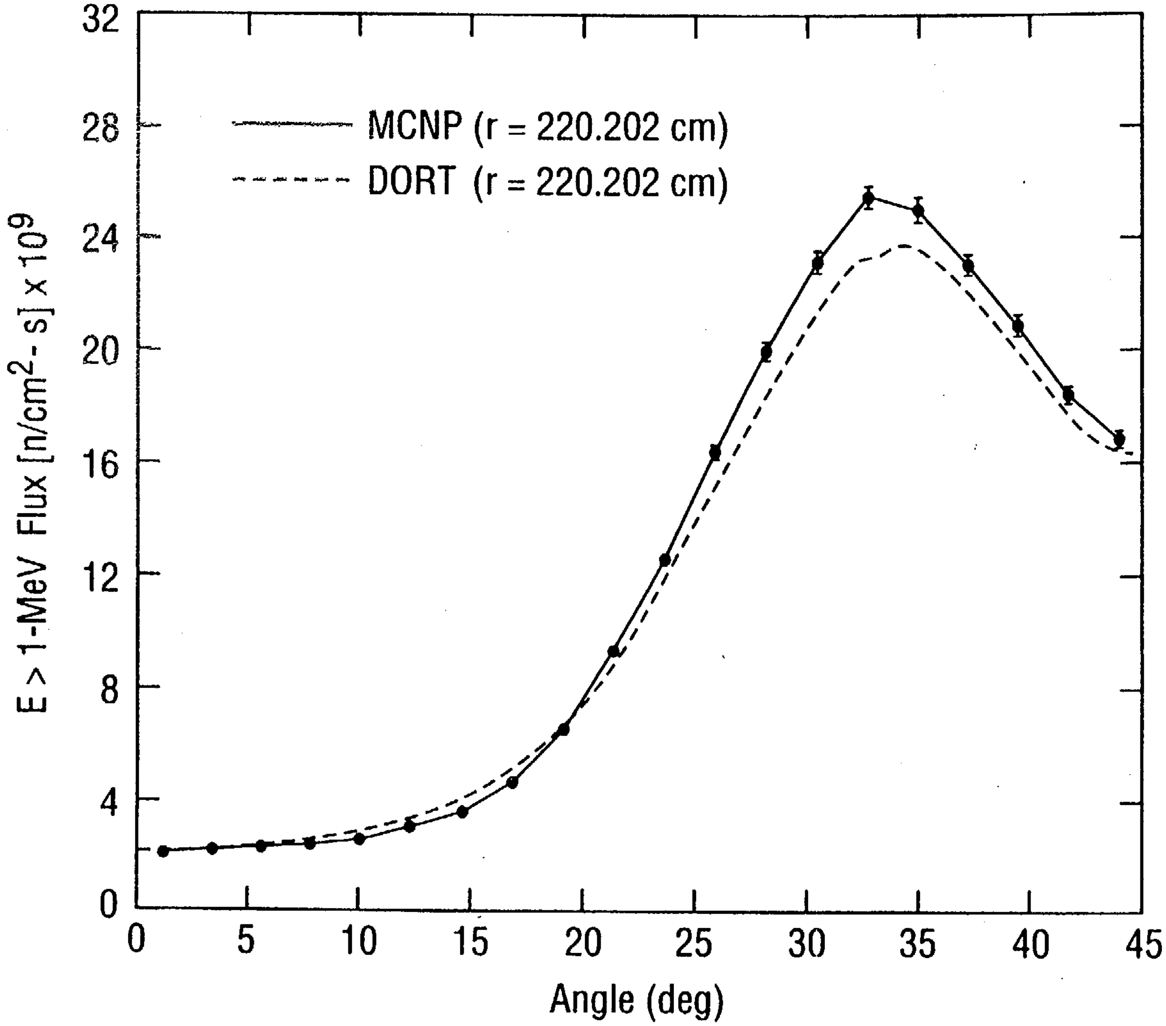


Figure 5.4.5

Comparison of MCNP and DORT E > 1-MeV Flux In Downcomer (r= 278.10 cm) at The Core Axial Midplane

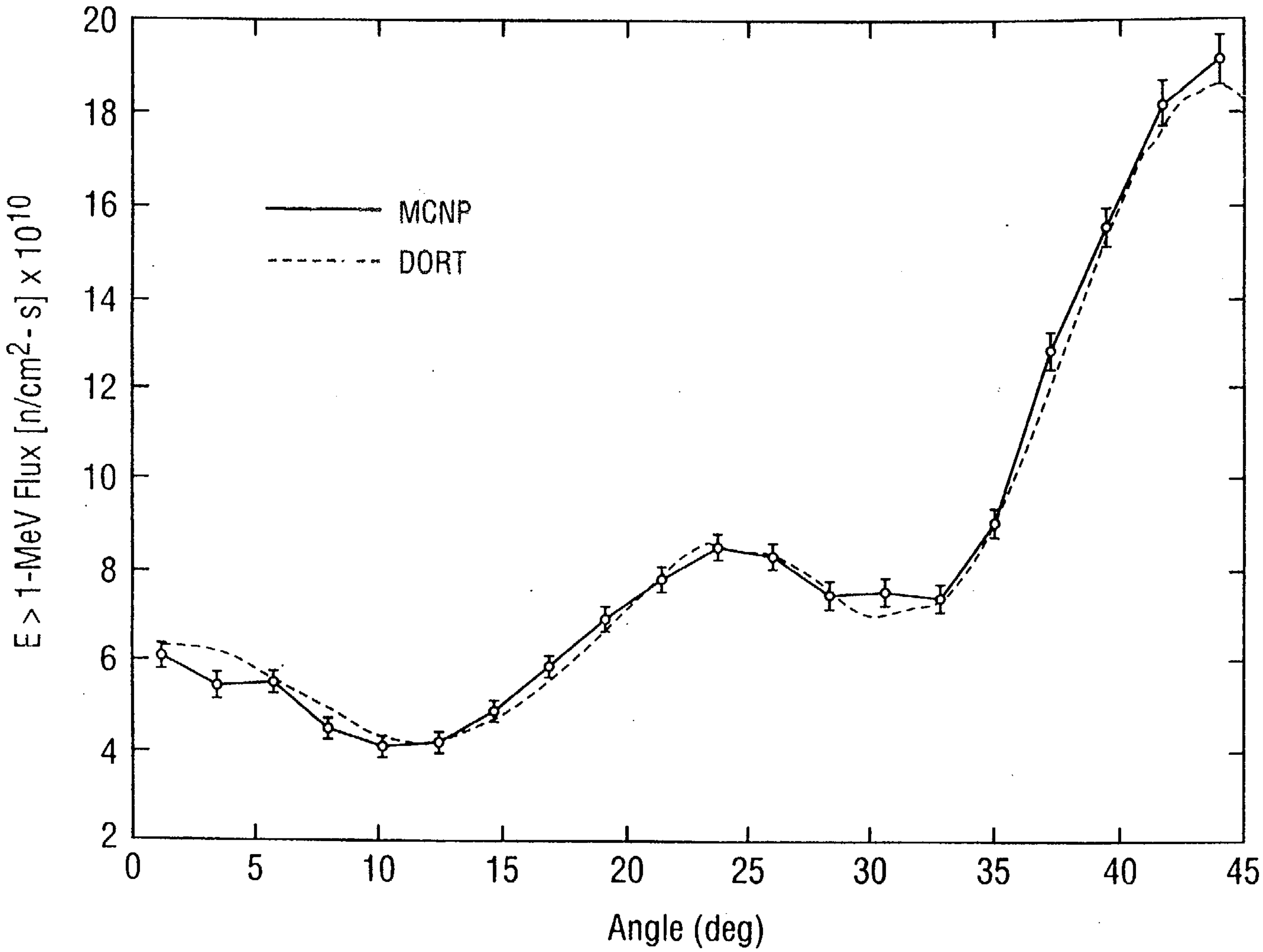


Figure 5.4.7

E > 1-MeV Flux In Downcomer (r = 278.10 cm) at The Core Axial Midplane With Probable Error