8th International Training Course/ Workshop

Methodologies for Particle Transport Simulation and Their Application to Nuclear Systems

June 25-29, 2001

Table of Contents

Table of Contents (continued)

Day 4 (Thursday, June 28)

Sensitivity analysis and uncertainty estimation (linear perturbation theory, LEPRICON, PSU's approach) (A. Haghighat)

Methods to reduce uncertainty and/or improve efficiency (developed at Penn state)(A. Haghighat)

- **Directional T -Weighted (DTW) differencing Scheme**
- **Adjoint-weighted bi-linear method for multigroup cross-section generation**
- **PENTRAN - A 3-D parallel Sn code and its pre- and post-processing codes**
- **Automatic Adjoint Accelerated MCNP (A^3MCNP)**

Monte Carlo shielding calculations using A^3MCNP (A. Haghighat, A. Patchimpattapong & V. Kucukboyaci)

Day 5 (Friday, June 29)

3-D Sn calculations using PENTRAN code system, with computer exercises (A. Haghighat & V. Kucukboyaci)

i) PENMSH
ii) PENINP
iii) PENTRAN (Parallel Environment Neutral-particle TRANsport)
iv) PENDATA
v) PENPRL

Benchmarking, Verification, and validation of 3-D Sn calculations (A. Haghighat)

Sn and Monte Carlo methods (advantages/disadvantages) (A. Haghighat)

Opening Remarks

by

A. Haghighat
Monday Morning

? **Organizing/Advising Committee**

Prof. Alireza (Ali) Haghighat, Chair
Mr. Vefa Kucucboyaci, Co-Chair
Dr. Bojan Petrovic, Westinghouse
Mrs. Bernadette Kirk, ORNL
Dr. Douglus Muir, IAEA
Dr. Enrico Sartori, OECD/NEA

? Assistants

Miss Arzu Alpan, PSU
Mr. James Brown, PSU
Mr. Shane Gardner, PSU
Mr. Aarash Haghighat
Mr. Gianluca Longoni, PSU
Ms. Holly Muir, PSU
Mr. Apisit Patchimpattapong, PSU
Mr. Dan Shedlock, PSU
Ms. Kim Sterndale, PSU
Mr. Mike Wenner, PSU

? Workshop Co-Sponsors

Nuclear Engineering Program
Mechanical and Nuclear Engineering Department
RSICC, ORNL
OECD/NEA Data Bank
In co-operation with the IAEA

<u>Increasing need for particle transport simulations</u>

<u>Why?</u>

- ? **Radiation induced material damage in nuclear Aging nuclear systems; Possibility of plant life extension**
- ? **Improved core design (economy and safety)**
- ? **Oil well-logging**
- ? **Criticality safety**
- ? **Shipping cask/storage**
- ? **Identification/assaying of nuclear waste/nuclear materials**
- ? **Radiation therapy and medical diagnostics**
- ? **Decommissioning of nuclear systems**

<u>What is needed?</u>

- ? **It is necessary to estimate (*<u>accurately/efficiently</u>*) the <u>energy-dependent</u> neutron and gamma flux/fluence throughout a large and <u>complex</u> physical model**

<u>Goals of this training course</u>

? **To learn the state-of-the-art methodologies for particle transport simulation in real-life nuclear systems**

To become familiar with the transport theory methods and their limitations and associated uncertainties

To become familiar with techniques for estimating uncertainties in transport theory calculations

To become familiar with ongoing research on advanced transport theory techniques and codes developed by the PSTTG group

To acquire sufficient knowledge for decision making (developing in-house capabilities, performing calculations), or identifying critical issues related to particle transport simulations

Penn State Transport Theory Group (PSTTG) and Its Activities

by

A. Haghighat

Monday Morning

Penn State Transport Theory Group

Group Members

Director: Prof. A. Haghighat

Assistant Director: Dr. Vefa Kucukboyaci

Associates: Colonel G.E. Sjoden (USAF), Dr. Bojan Petrovic (Westinghouse), Dr. J.C. Wagner (ORNL), Prof. Arthur Motta (Nuclear Materials, PSU), Dr. A. Dulloo & Dr. T. Congedo (Westinghouse), Dr. Hamid Aït Abderrahim (SCK•CEN), Prof. R.E. Mattis (U. Pitt.), Dr. I.K. Abu-Shumays (Bettis), Lt. H.L. Hanshaw (US Navy), Dr. M. Mahgerefteh (GPU), Dr. S. Sitaraman (GE), Dr. T. Sutton (KAPL), Dr. Yousry Azmy (ORNL), Dr. Enrico Sartori (OECD), Dr. Doug Muir (IAEA), Mrs. Bernadette Kirk (RSICC), Dr. Luiz Leal (ORNL)

Former graduate students:

John DeMarco (B.S. with honors, 1991), Ronald Mattis (PhD, 1991)
Basil Nanayakkara (M.S., 1992), Asam Khan (M.S., 1993)
Chris Pozsgai (M.S., 1994), Lt. Heath Hanshaw (M.S., 1995)
Capt. Young-Su Kim (MS, 1995), Bojan Petrovic (PhD, 1995)
Melissa Hunter (MS, 1991; PhD, 1996), Wilford Stevenson (M.S., 1996)
Major Glenn Sjoden (PhD, 1997), John Wagner (PhD, 1997)
Hikaru Hiruta (MS, 1999), Vefa Kucukboyaci (PhD, 2001)

Present graduate students:

Arzu Alpan (PhD Candidate)
James Brown (MS)
Shane Gardner (MS)
Gianluca Longoni (PhD Candidate)
Apisit Patchimpattapong (PhD Candidate)
Dan Shedlock (MS)
Michael Wenner (MS)

Visiting Scholars:

Farida Mohd. Idris, MINT, Malaysia (Spring 1995)
Marion Dubuisson, INSTN, France (Spring 1997)
Veronique Souvignet, INSTN, France (Spring 1997)
Attiya Abou-Zaid, Egypt (Fall & Spring, 1999)

Penn State Transport Theory Group

Research:

Development of efficient and accurate methods for solving the transport equation.
Application of these methods for simulation of large/complex systems (reactor physics and shielding, radiation facilities, waste assaying devices, medical applications, etc.)

Teaching:

Courses on transport theory methods and high performance computing (HPC), and their application to reactor physics and shielding.
[Advanced Reactor Theory, Neutron Transport Theory methods, Monte Carlo Methods, Parallel/Vector Algorithms for Scientific Applications]

PSTTG's Distributed Computing & Visualization Lab

PCTRAN cluster, HP visualization workstations & NETComputing

Institute for HPC Applications (IHPCA):

Advisory board
A graduate minor in HPC

Distance Education:

Taught *Neutron Transport Theory* and *Monte carlo Methods* (with lecture notes on WWW) remotely (through CVI) to students from Westinghouse.

National & International Activities:

- **International workshops on "Methodologies for Particle Transport Simulation and Their Application to Nuclear Systems", June 19-23, 1995, June 2-7, 1996, May 19-23, 1997, at Penn State; June 19-23,1997 at the University of Stuttgart, Germany; May 25-29, 1998 at Sck.CEN, Mol, Belgium; May 17-21, 1999, and June 26-30, 2000 at Penn State.**
- **Chairing an ANS standards subcommittee on transport theory calculations for "Reactor Cavity Dosimetry"**
- **Member of an international committee on "Adaptation of Computer Codes in Nuclear Applications to Parallel Architectures"**
- **Member of an international task force on "Computing Radiation Dose and Modeling of Nuclear Radiation-Induced Degradation of Reactor Components"**
- **Benchmarking of transport theory methods for real-life problems**
- **Training international scholars**

Penn State Transport Theory Group

Funding sources:

- NSF (Computer time, parallel course development)
- GPU Nuclear Corporation
- Penn State FERMI Project (Nuclear Engineering Dept. Affiliates Program : GPU, PP&L, PECO, PSE&G, Westinghouse, and Duquesne Light Company)
- PP&L
- IBM
- Harris Semiconductors
- Penn State Breazeale Reactor (PSBR)
- Westinghouse
- DOE

Seeking international collaborations and funding:

- European trip (Finland (VTT), Germany (Rossendorf), NRI and Skoda (Czech Republic), Belgium (SCK/CEN), France (Saclay, OECD)); To form an international group on "Particle Transport Simulation (PTS)" for providing research and training services, 1996.

- Mexico (IIE) (IAEA expert, BWR project, graduate students), 1996.

- Austria (IAEA) (training courses, sponsorship, etc.), 1996-present.

- France (INSTN) (training students, graduate students), 1997.

- Sabbatical leave at SCK.CEN, Mol, Belgium; training of the Fuel Research Unit on transport theory methods and codes, Spring and Summer, 1998.

- Collaboration with the SCK.CEN personnel, 1999-present.

Penn State Transport Theory Group

Projects

Shielding and dosimetry

Developed improved methodologies for calculation of pressure vessel neutron fluence and associated uncertainties

Defined a benchmark problem for PWR cavity dosimetry

Developed methodologies for estimation of neutron and gamma flux and DPA throughout a BWR core shroud (using PENTRAN and A^3MCNP)

Developing advanced methodologies for generation of multigroup cross sections based on the adjoint-weighting approach (FERMI)

Evaluation of neutron and gamma dose for a shipping cask/storage (A^3MCNP)

Novel investigation of Fe cross-section using an iron shell shield and time-of-flight measurements and particle transport calculation (with NIST and U. of Ohio) (DOE/NERI) (using PENTRAN and A^3MCNP)

Research Reactor

Monte Carlo modeling of the Penn State Breazeale Reactor (PSBR) Core
Monte Carlo modeling and optimization of the D_2O tank at the PSBR
Monte carlo modeling for the design of the Fast Neutron Irradiator (FNI)

Special devices

Optimization of the Westinghouse PGNAA device for assaying waste (Using MCNP and PENTRAN) (Westinghouse/DOE)

Simulation of CT scanning device (Medical Imaging, using PENTRAN and A^3MCNP)

Advanced methods, formulations and codes

- **Parallel algorithms, differencing schemes, acceleration methods, automatic variance readuction techniques, multigroup cross section generations**

- **PENTRAN™ code system (PENMSH/PENINP, PENTRAN, PENDATA/PENPRL)**
- **Advanced Algorithms and Automation Tools for Discrete Ordinates Methods in Parallel Environments (DOE/NEER)**

- **A^3MCNP™ (Automated Adjoint Accelerated MCNP)**

Benchmarking activities

Simulation of the VENUS-3 experimental facility located at SCK•CEN, Mol, Belgium (organized by OECD)
Simulation of the 3-D Kobayashi benchmark problems (organized by OECD)

Modeling of the Penn State Breazeale Reactor (PSBR)

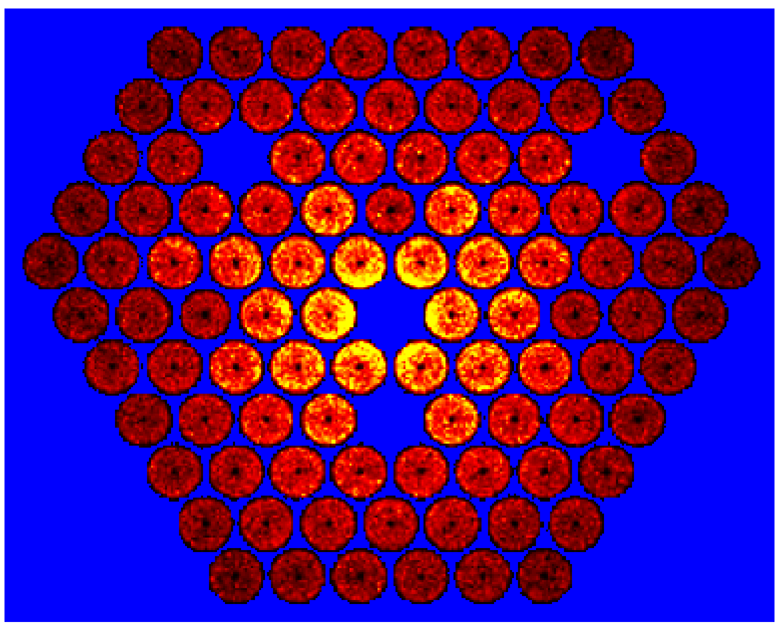
- Developed a 3-D MCNP model for the PSBR core

- Prepared a database of core loading and burnup between 1966-1995

- Performed criticality calculation to determine k, flux, power, and control rod worth

- Performed analysis on core loading for improving reactor safety margin

PSBR fission density distribution

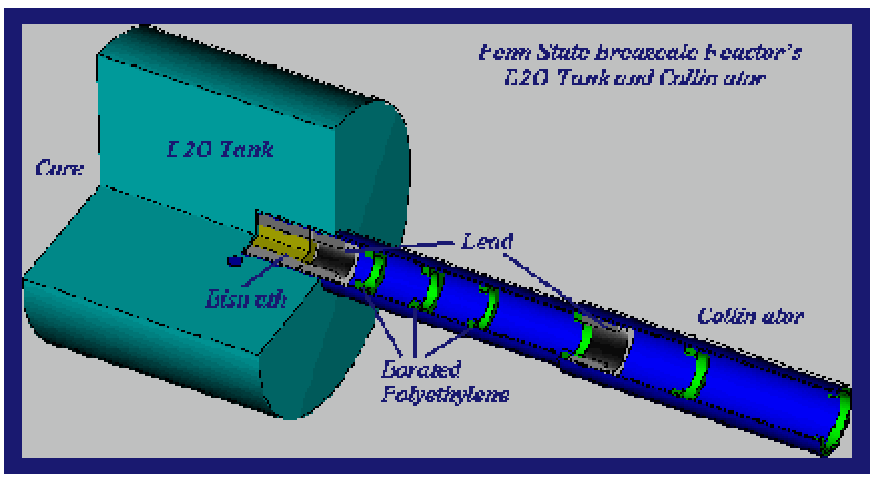


<u>Modeling and optimization of the D_2O tank at the PSBR</u>

This tank is used for generation of thermal neutron s for neutron radiography.

Using MCNP, analyzed the original D_2O tank, and developed a new design (size, shape, and orientation) by maximizing the thermal-neutron-to-gamma ratio

<u>3-D MCNP model for the original D_2O Tank and collimator</u>



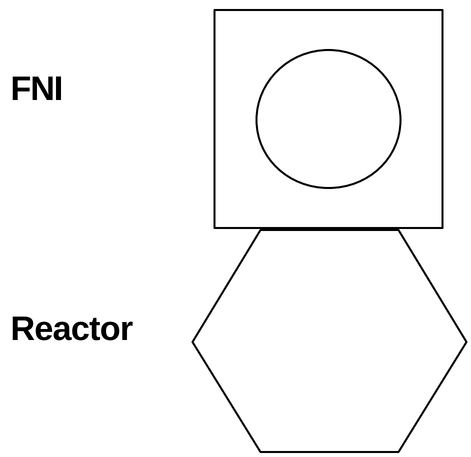
Design of the Fast Neutron Irradiator (FNI) facility

This facility is being used for irradiating semi-conductors.

Developed a 3-D MCNP model for the FNI for irradiation of 8" wafers

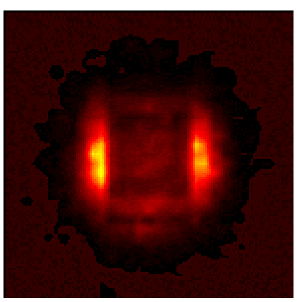
In this design, maximized the fast neutron, while minimizing the thermal neutron and gamma fluxes.

The MCNP model for the FNI design

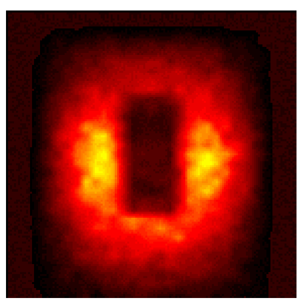


At the interface of the FNI and reactor

Thermal neutron



Gamma



PWR Pressure Vessel (PV) Fluence Estimation

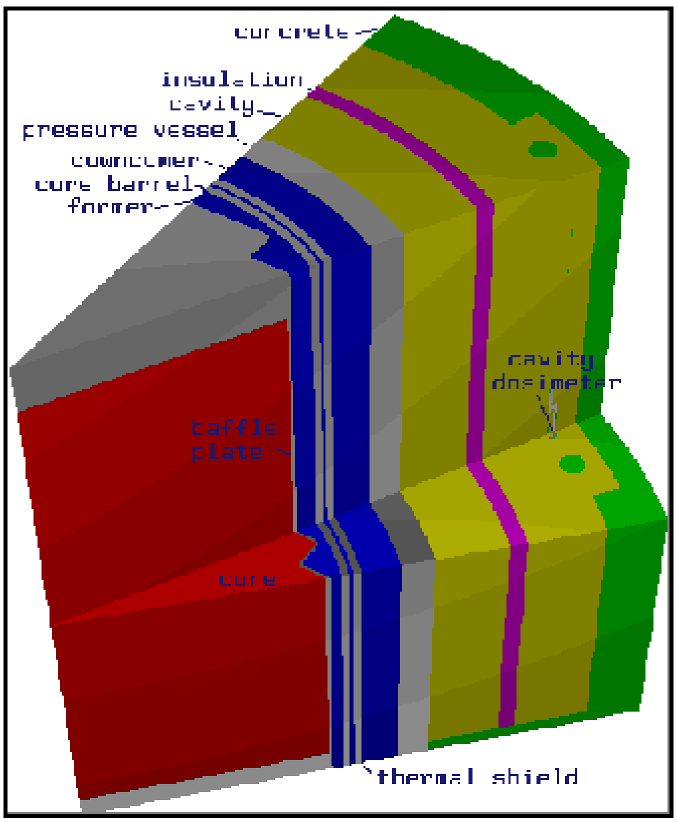
Numerous studies performed to estimate the neutron fluence at the reactor pressure vessel, and its dosimeters.

Besides the fluence, detailed sensitivity studies performed to estimate the uncertainties associated with the estimated fluence.

3-D fluence were obtained via a 3-D synthesis approach using the DORT code, and also the 3-D MCNP code for benchmarking.

Our sensitivity studies led to the development of more accurate and efficient methods and techniques for performing large deep penetration calculations.

Our studies have contributed to an ANS standard and also and OECD working group on reactor cavity dosimetry and PV fluence estimation.



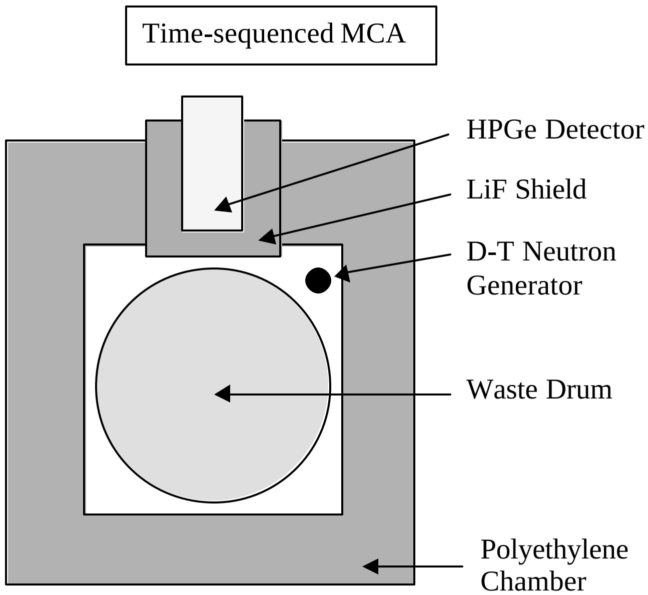
Optimization of the PGNAA device

Determined the thermal neutron flux distribution throughout the waste using a time-dependent MCNP model

Determined the gamma flux at the face of a gamma detector using an "importance function" obtained from a 3-D PENTRAN calculation.

Achieved excellent agreement with the experimental results (within the experimental uncertainties).

Schematic of the PGNAA device



Mesh **Contribution to the detector**

response

“Importance”
function

Simulation of the VENUS-3 experimental facility

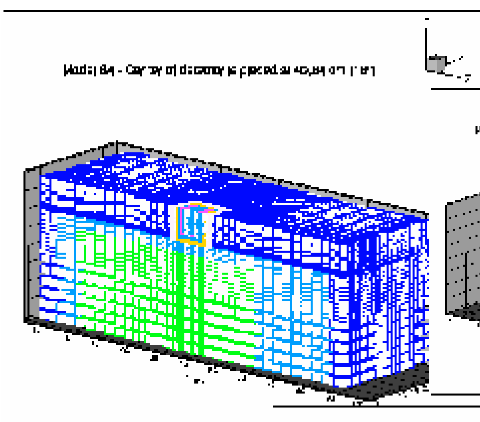
The VENUS-3 is the mock-up of a PWR with partial length assemblies (SCK•CEN, Belgium)

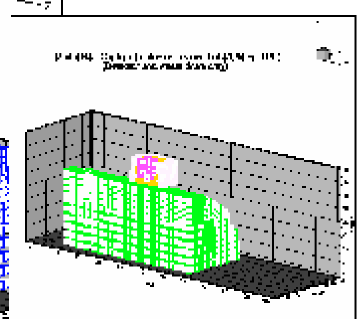
This facility has been used for an OECD activity on benchmarking computer codes used for shielding calculations.

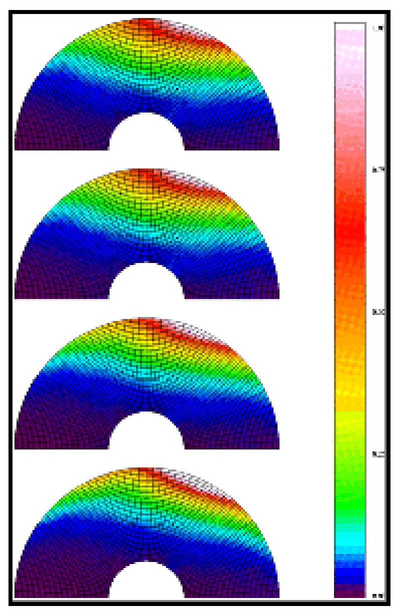
Over 300 experimental values are available throughout the reactor.

The PENTRAN 3-D parallel Sn code has been benchmarked based on this 3-D facility.

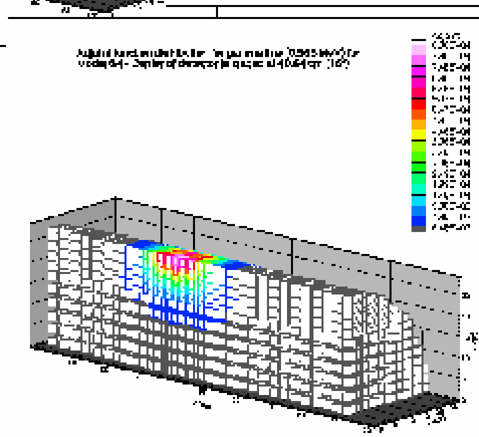
PENTRAN model includes 84748 meshes and 26 energy groups. The calculation is performed on an IBM SP2 parallel computer in ~80 min. A scalability of ~90% is achieved for this p r







oblem.



C/E (calculation- to- e x p e r i m e n t) rat ios are within ±1. 15:

260 values are wit hin ±5%, 78 values are in a range of ±(5-10)%,

and only 16 values are in a range of ±(10-15)%.

PENTRAN simulation of the VENUS-3 facility

Mesh distribution **C/E**

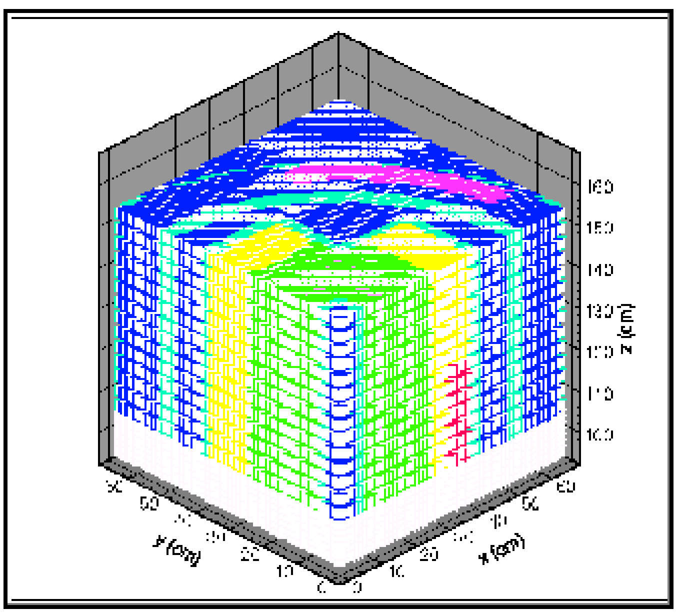
Kobayashi 3-D calculation benchmark

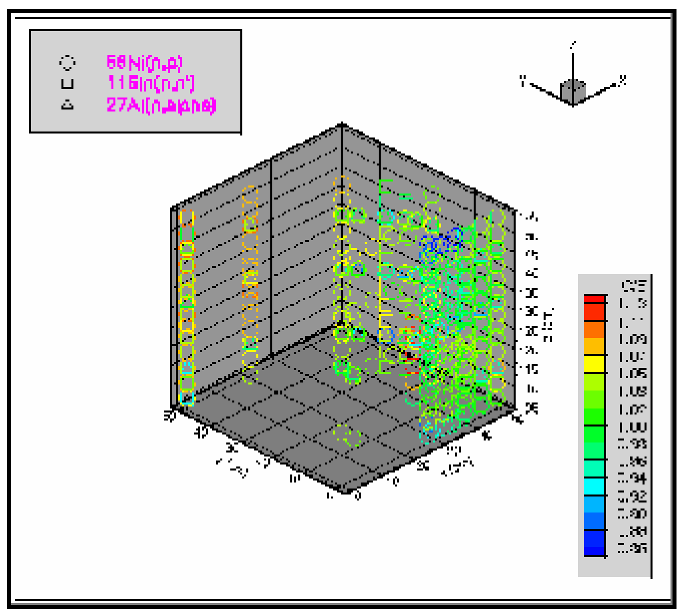
Kobayashi contributed three 3-D void duct problems to an OECD activity on benchmarking 3-D Sn codes.

PENTRAN has been used successfully to simulate these problems. Here, we only present the results for the dog-leg void duct problem with a pure absorber. Excellent agreement has been achieved even at positions more than several mfp's from the neutron source.

We have demonstrated that PENTRAN's unique features including adaptive differencing, variable meshing, and TPMC projection scheme are essential for obtaining this close agreement.

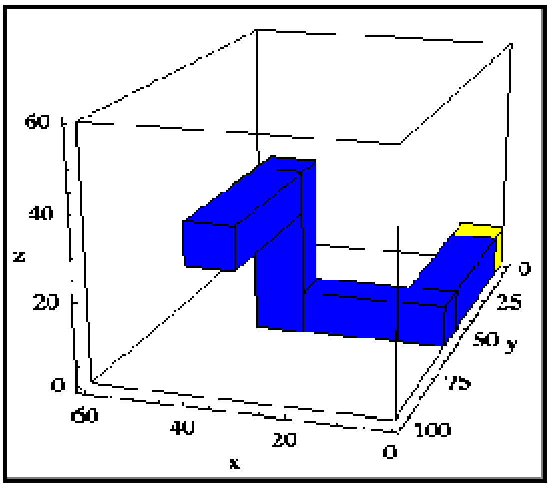
Problem 3 with pure absorber

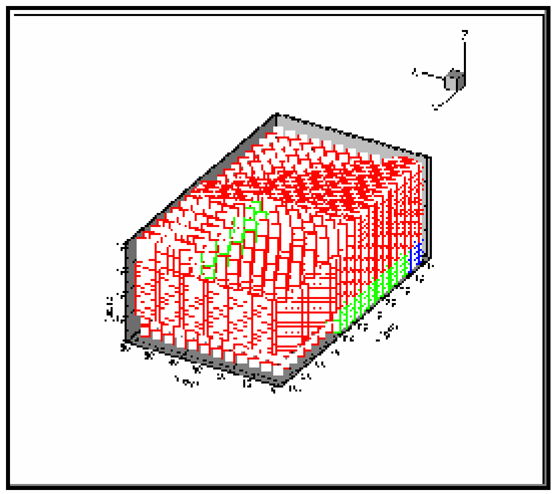


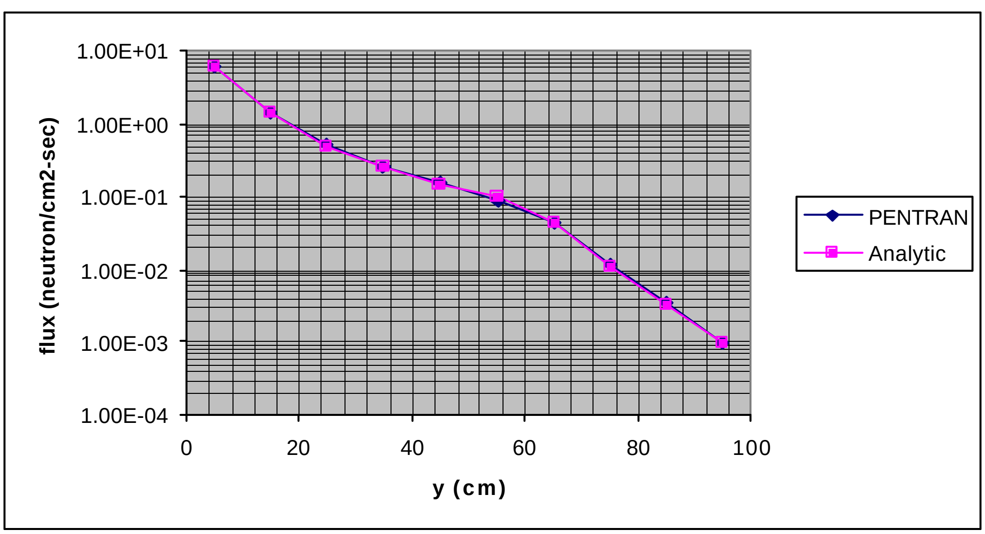


Model **Mesh**

Comparison of PENTRAN and Analytical fluxes along y at z=5 cm, x=5 cm

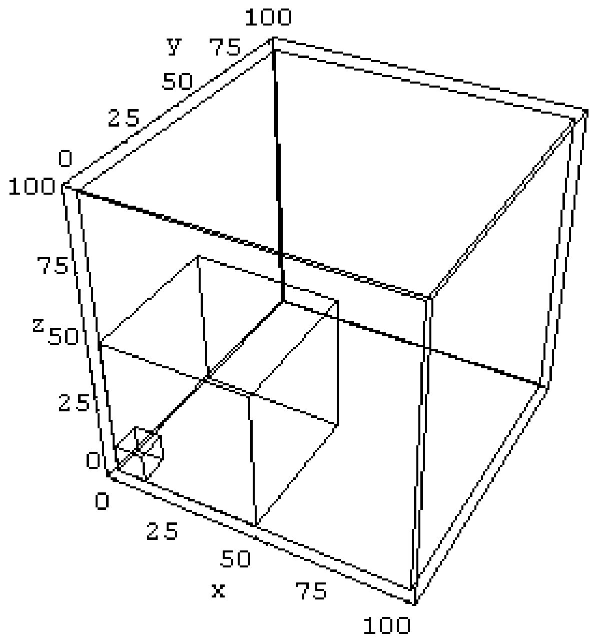






Kobayashi 3-D calculation benchmark (using A^{3}MCNP)

Kobayashi contributed three 3-D void duct problems to an OECD activity on benchmarking 3-D Sn codes. Problem 1 is simulated using the A^{3}MCNP code.

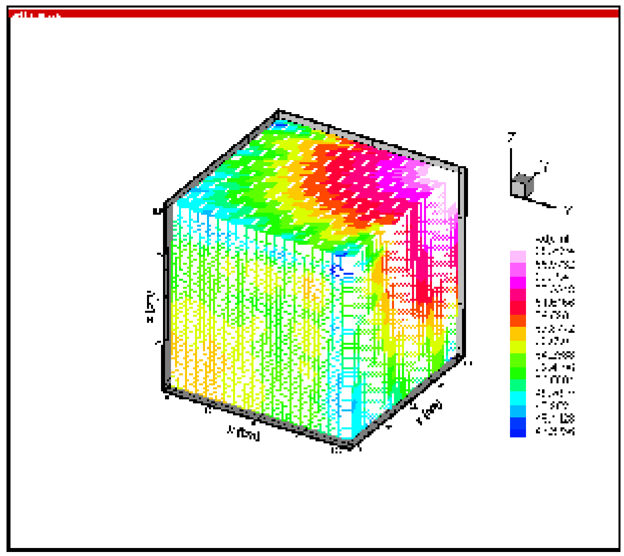


With this problem, we are examining the impact of the "ray-effects" on the performance of A^{3}MCNP. It is demonstrated that even in such an extreme case, A^{3}MCNP leads to a speedup of 40 over MCNP.

<– Schematic of problem 1

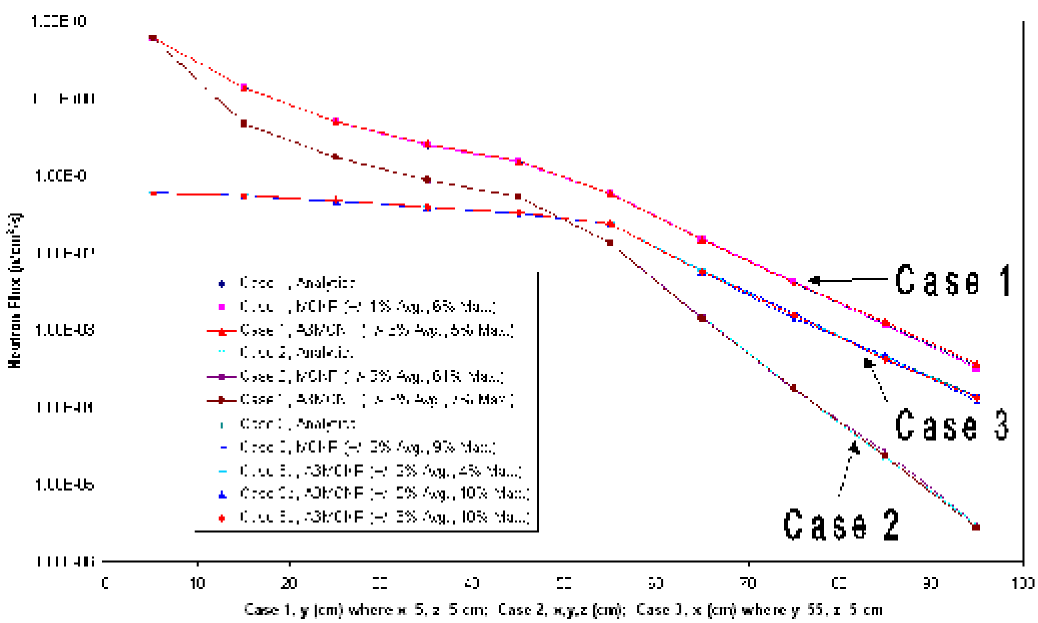
Adjoint ("Importance") function distribution, when our objective is obtain flux tallies along the main diagonal.

-------------->



Comparison of A^{3}MCNP tallies with

anal
ytic
al
resu
lts



BWR Core Shroud Modeling

Neutron and gamma flux distributions are determined throughout a BWR core shroud.

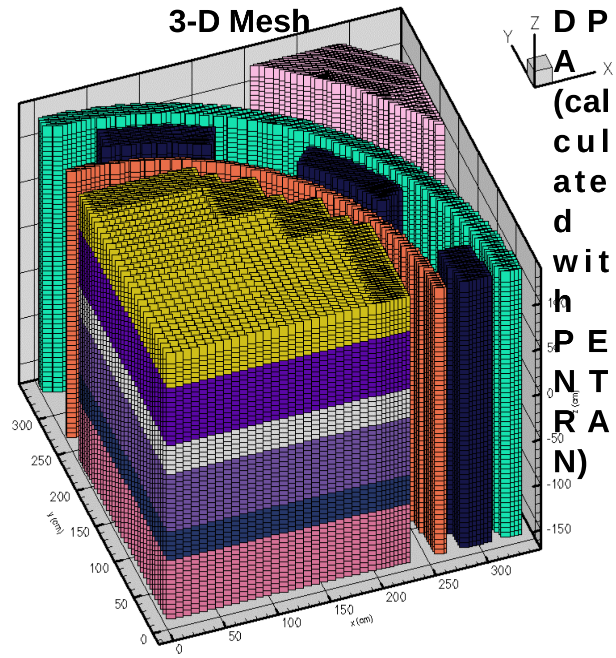
Using the "importance function" obtained from 1-D and 2-D Sn calculations, we developed an effective control volume for simulating H4, H3, and H2 welds.

For this calculation, we have used the PENTRAN and A^3MCNPcodes. PENTRAN and A^3MCNP results agree within the Monte Carlo statistical uncertainties.

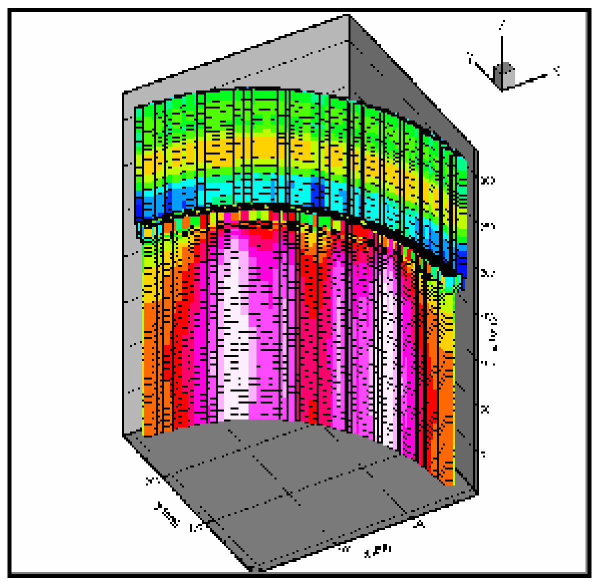
PENTRAN calculation was performed on 48 processors of the San Diego Supercomputing Center in 12 hours; similar calculation with TORT required over 100 hrs and partitioning of the model into two segments.
A scalability of ~90% was obtained for this problem.

Core shroud model and results

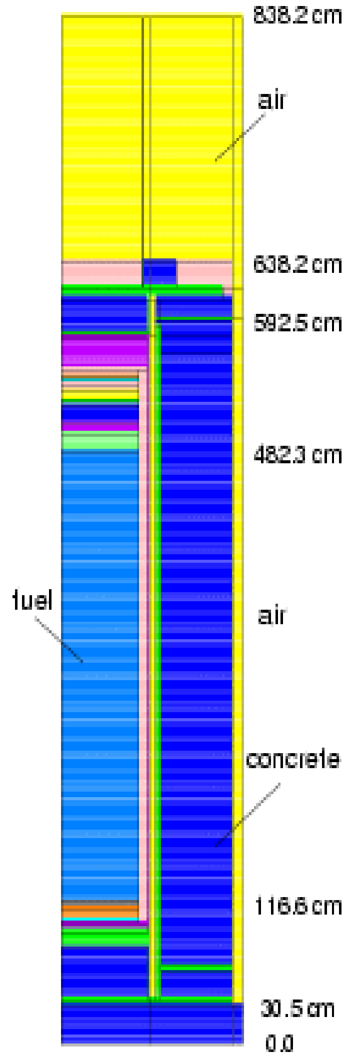
3-D Mesh



DPA (calculated with PENTRAN)



Comparison of DPA 's (PENTRAN vs. A3MCNP) at H3 weld



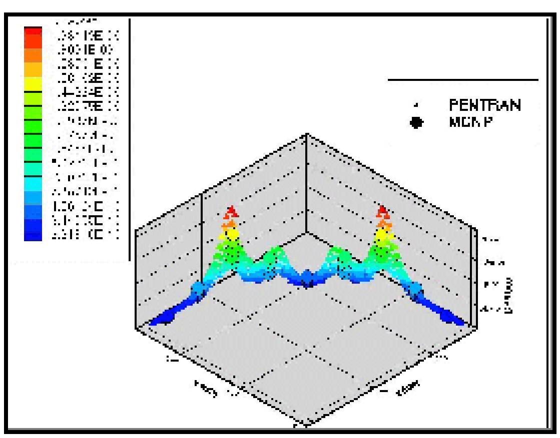
Gamma and Neutron dose determination for a Shipping/Storage Cask

Using the A³MCNP code, neutron and gamma dose is calculated over the surface of a shipping cask.

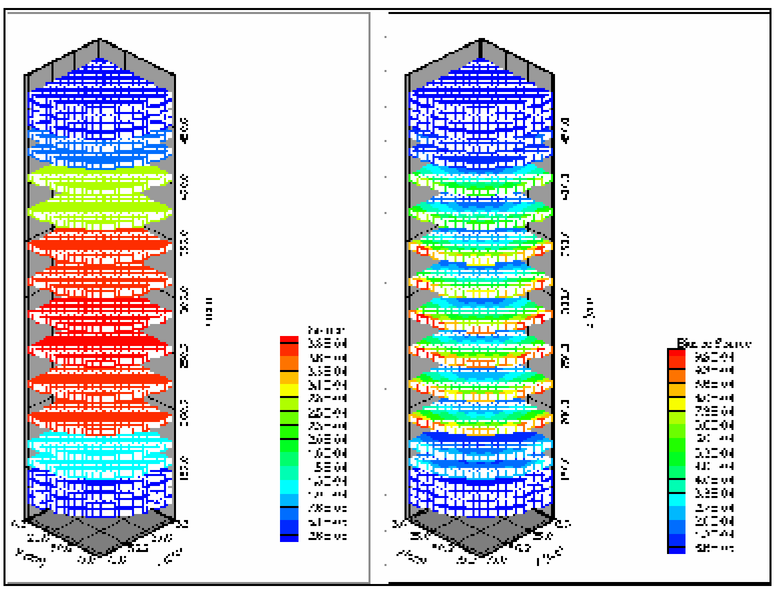
The physical model is very large, 180 cm x 180 cm x 840 cm, so the particles have to travel several mean-free-paths. Hence a Monte Carlo simulation requires the use of variance reduction methods.

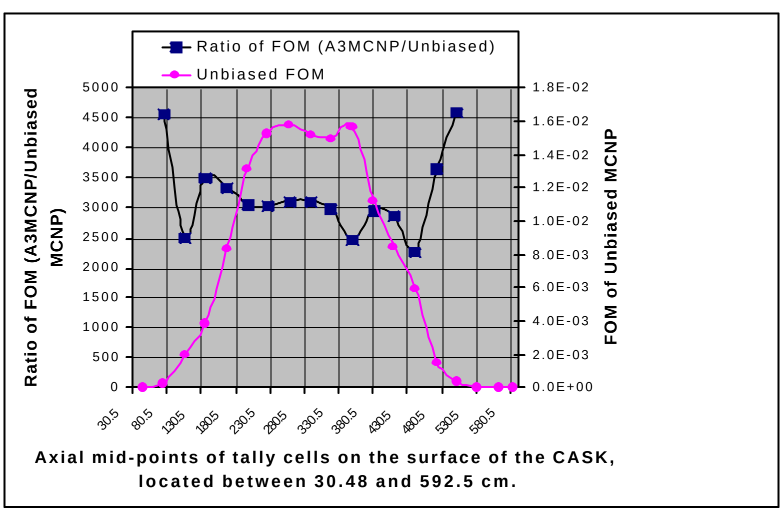
Figures below shows the unbiased and biased source for the situation that an estimate of gamma dose is needed only over the whole surface of the cask.

Unbiased Source **Biased Source**



Performance of A^{3}MCNP compared to the MCNP (unbiased) calculations

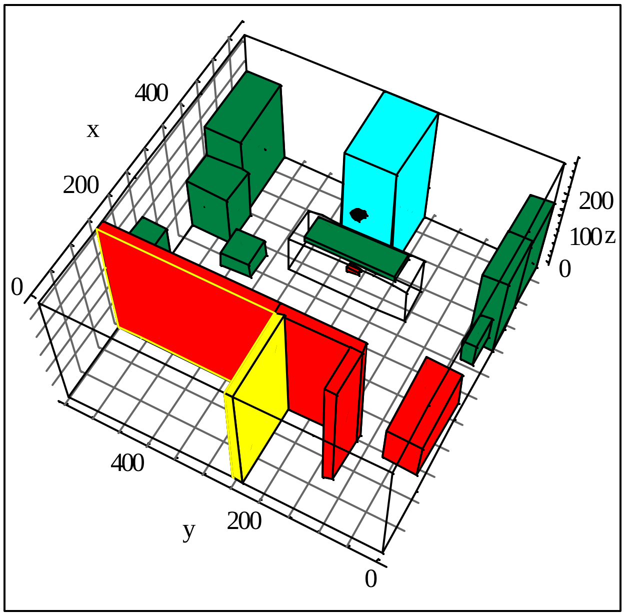


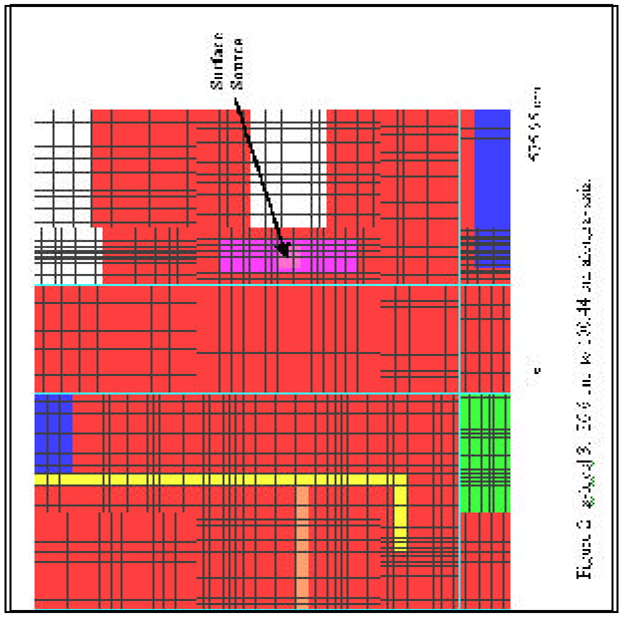


Determination of radiation dose in an x-ray room

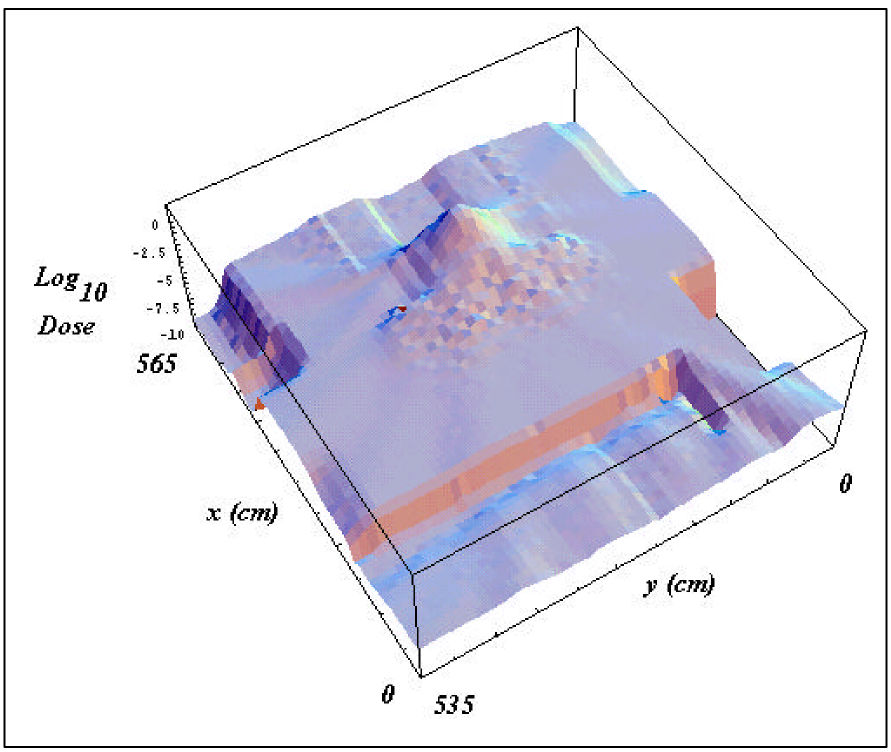
An x-ray room with a physical size of 90 m^3 is simulated using the PENTRAN code system on the SPARKY2 cluster.

X-Ray room schematic **PENTRAN model**





X-ray dose throughout the room



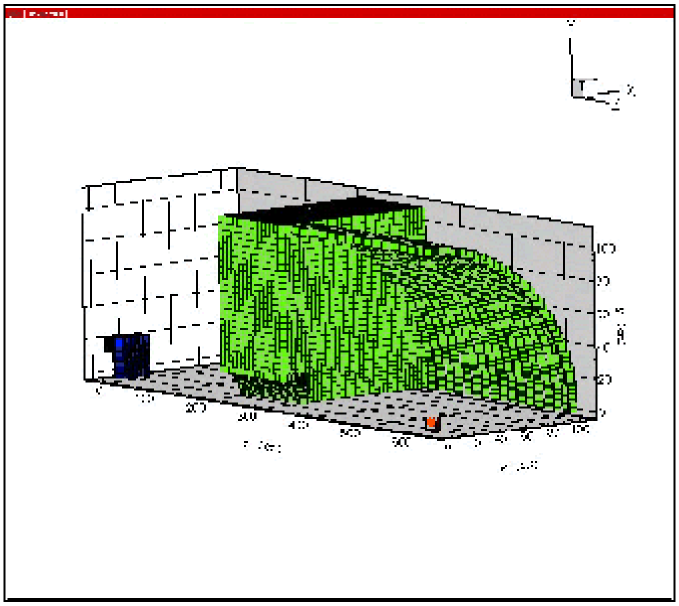
Simulation of an experimental setup for measurement of Fe cross-section

We are developing PENTRAN models for performing sensitivity studies in support of a joint project with NIST and Ohio University (DOE NERI).

The unique feature of this model is that neutrons are emanated from a very localized source, and detector is located at a distance of over 600 cm that is mostly occupied by air.

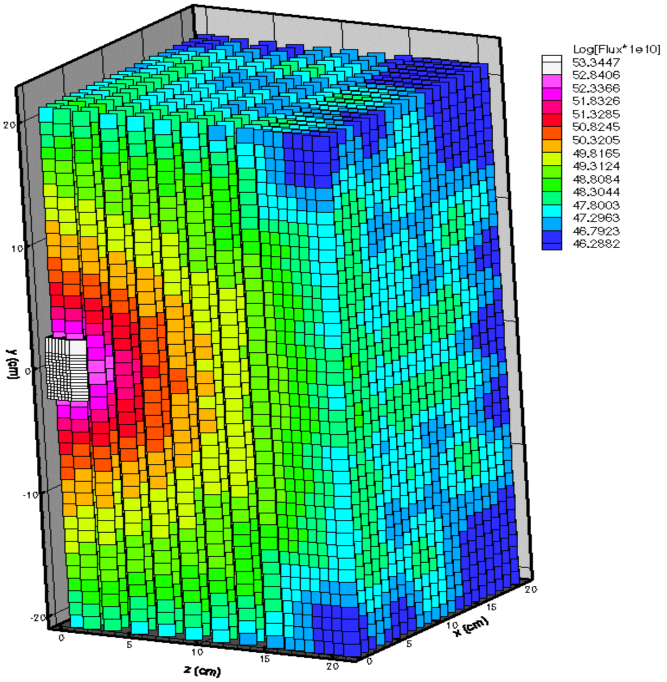
Physical model

Neutron source
(Left/Front/Bottom corner)
Fe Shield (blue) ---------->
Wall (green)
Tunnel (green)
Detector (red)

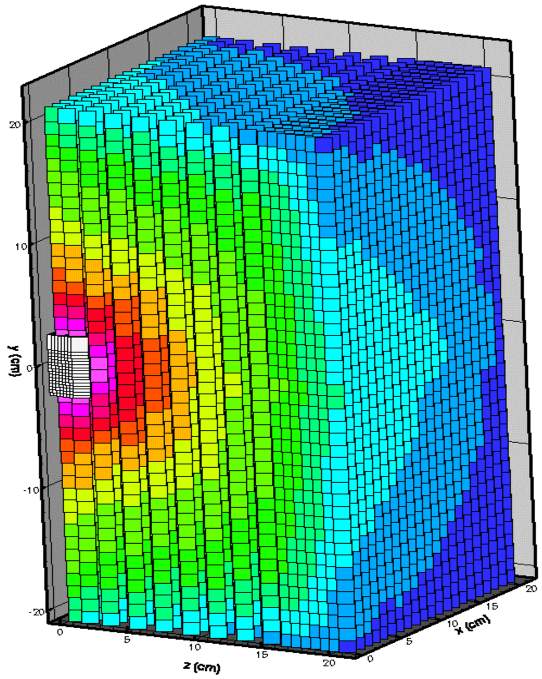


Flux distribution

S20 level symmetric



S30 Pn-Tn with ordinate splitting

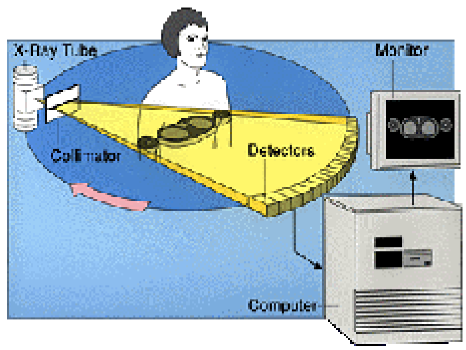


Simulation of a CT scanning device

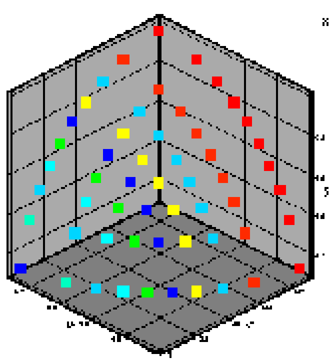
A CT scan that uses ?-ray imagery is mostly modeled with empirical formulations that are obtained based on simple theoretical formulations adjusted by data from experiments on phantoms.
Some efforts have been devoted to using Monte Carlo methods for simulation of a CT scan. These methods, however, suffer from long running times.

PENTRAN with new quadrature sets has resulted in accurate results as compared to Monte Carlo predictions. We have demonstrated that our new quadrature sets are necessary for this type of simulation, and PENTRAN can solve for detailed flux distributions in a short (orders of magnitudes) time compared to the Monte Carlo calculations.

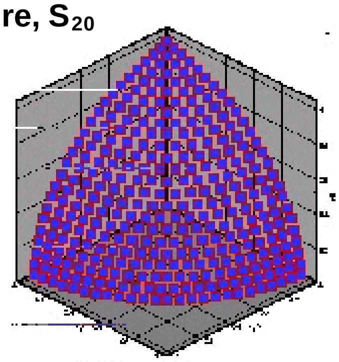
Schematic of a CT scan device



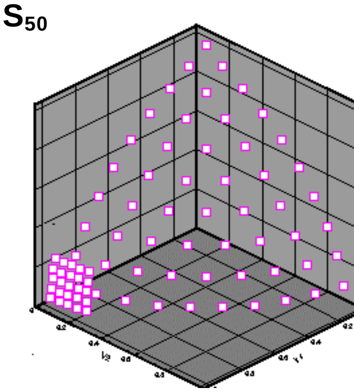
Level-symmetric quadrature, S_{20}



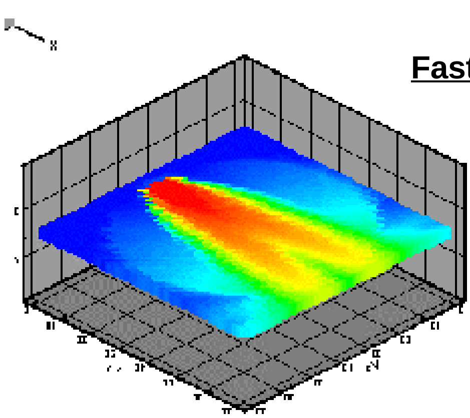
Equal-weight (EW) quadrature, S_{50}

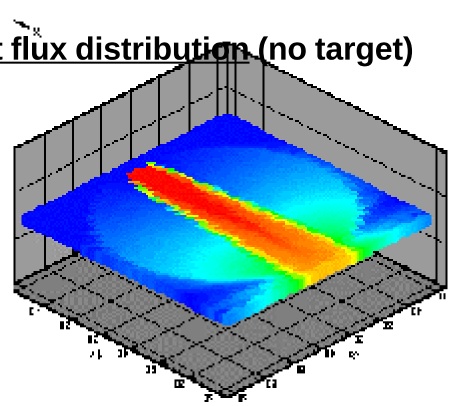


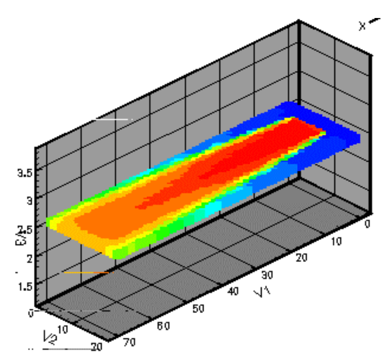
EW with Ordinate Splitting S_{20}



Fast flux distribution (no target)







List of Publications

Refereed Journal

Haghighat, A. and M.A. Robkin, "Actinide Hazard Reduction by Partitioning and Transmutation in a Coupled Reactor System," Nuclear Technology, 61:503-513 (June 1983).

Haghighat, A. and G. Kosaly, "The Influence of Homogenization on the Calculation of the Sensitivity Volume of a BWR Incore Detector," Annals of Nuclear Energy, 12(7):357-371 (1985).

Haghighat, A. and G. Kosaly, "Determination of the Field-of-View of a BWR Incore Detector," Nuclear Science and Engineering, 101(1):8-25 (January 1989).

Haghighat, A. and A.J. Baratta, "Gamma Transport Theory Analysis of the TMI-2 Lower Head," Nuclear Technology, 85(2):127-135 (May 1989).

Baratta, A.J., A. Haghighat and B.R. Bandini, "The Overall Source Range Monitor Response During the Three Mile Island Unit-2 Accident," Nuclear Technology, 87(4):1013-1020 (December 1989).

Haghighat, A., "Angular Parallelization of a Curvilinear S_N Transport Theory Method," Nuclear Science and Engineering, Vol. 108, No. 3, 267-277 (July 1991).

Mattis R. and A. Haghighat, "Domain Decomposition of a Two-Dimensional S_N Method," 111: 180-196, Nuclear Science and Engineering, (June 1992).

Haghighat A. and R. Veerasingam, "Transport Analysis of Several Cross-Section Libraries Used for the Reactor Pressure Vessel (RPV) Fluence Calculations," 101: 237-243, Nuclear Technology Journal, (Feb., 1993).

Haghighat, A. "Spatial and Angular Domain Decomposition Algorithms for the Curvilinear Sn Transport Theory Method, Transport Theory and Statistical Physics", 22(2&3), 391-417 (1993).

Haghighat, A., M. Mahgerefteh, and B. Petrovic, "Evaluation of the Uncertainties in the Source Distribution for Pressure Vessel Neutron Fluence Calculations," Nuclear Technology, Vol. 109, 54-75, Jan. 1995.

Haghighat, A., M. A. Hunter, and R. E. Mattis, "Iterative Schemes for Parallel Sn Algorithms in a Shared-Memory Computing Environment," Nuclear Science and Engineering Vol. 121 No. 1, 103-113, 1995.

Petrovic, B. G. and A. Haghighat, "Effects of Sn Method Numerics on Pressure Vessel Neutron Fluence Calculations," Nuclear Science and Engineering, Vol. 122, No. 2, 167-193, 1996.

Wagner, J. C., A. Haghighat, and B. G. Petrovic, "Monte Carlo Transport Calculations and Analysis for Reactor Pressure Vessel Neutron Fluence," Nuclear Technology, June 1996.

Petrovic, B. G. and A. Haghighat, "Analysis of Inherent Oscillations in Multidimensional S_N Solutions of Neutron Transport Equation," Nuclear Science and Engineering, Vol. 124, No.1, 31-62, Sept. 1996.

Haghighat, A. "Letter to Editor - on Neutron Fluence at the Pressure Vessel of a Pressurized Water Reactor Determined by the MCNP Code , by Lacky and Tsoulfanidis ," Nuclear Science and Engineering, 124, 364-367, October 1996.

Wagner, J. C. and A. Haghighat, "Acceleration of Monte Carlo Reactor Cavity Dosimetry Calculations with the Discrete Ordinates Adjoint Function," Proceedings of the 9th International Symposium on Reactor Dosimetry, edited by H. Abderrahim and H. Nolthenius, World Scientific Publishing Co., 1998.

Petrovic, B. and A. Haghighat, "New Directional T-Weighted S_N Differencing Scheme and Reduction of Estimated Pressure Vessel Fluence Uncertainty," Proceedings of the 9th International Symposium on Reactor Dosimetry, edited by H. Abderrahim and H. Nolthenius, World Scientific Publishing Co., 1998.

Wagner, J.C. and A. Haghighat, “Automated Variance Reduction of Monte Carlo Shielding Calculations Using the Discrete Ordinates Adjoint Function,” Nuclear Science and Engineering, 128, 186-208, 1998.

V. Kucukboyaci, A. Haghighat, G. Sjoden and B. Petrovic, “Modeling of BWR for Neutron and Gamma Fields Using PENTRAN,” Reactor Dosimetry, ASTM STP 1398, John G. Williams, David W. Vehar, Frank H. Ruddy, and David M. Gilliam, Eds., American Society for Testing and Materials, West Conshohocken, PA, 2000.

Haghighat, H. Hiruta, and B. Petrovic, “Performance of A^3MCNP for Calculation of 3-D Neutron Flux Distribution in a BWR Core Shroud,” Reactor Dosimetry, ASTM STP 1398, John G. Williams, David W. Vehar, Frank H. Ruddy, and David M. Gilliam, Eds., American Society for Testing and Materials, West Conshohocken, PA, 2000.

Petrovic and A. Haghighat, “Design and Characterization of a Facility for Fast Neutron Irradiation of Semiconductors at Penn State,” Reactor Dosimetry, ASTM STP 1398, John G. Williams, David W. Vehar, Frank H. Ruddy, and David M. Gilliam, Eds., American Society for Testing and Materials, West Conshohocken, PA, 2000.

Haghighat, H. Aït Abderrahim, and G. E. Sjoden, “Accuracy and Performance of PENTRAN™ Using the VENUS-3 Benchmark Experiment,” Reactor Dosimetry, ASTM STP 1398, John G. Williams, David W. Vehar, Frank H. Ruddy, and David M. Gilliam, Eds., American Society for Testing and Materials, West Conshohocken, PA, 2000.

Haghighat A., G.E. Sjoden, and V.N. Kucukboyaci, “Effectiveness of PENTRAN’s Unique Numerics for Simulation of the Kobayashi Benchmarks,” accepted for publication in a special issue of the Progress in Nuclear Energy, Sept. 2000.

Refereed Proceedings

Haghighat, A. and M. Mahaffy, "Vectorization of a Spherical S_N-Transport Theory Algorithm on Supercomputers," Proceedings of the 1988 International Reactor Physics Conference, Vol. II, pp. 113-121 (September 1988).

Haghighat, A. and R. Mattis, "Parallel/Vector Algorithms for the Spherical S_N Transport Theory Method," Proceedings of the First International Meeting on Supercomputers in Nuclear Applications (SNA '90), Mito City, Japan (March 1990).

Haghighat, A. and Y.Y. Azmy, "Parallelization of a Spherical S_N Algorithm Based on the Spatial Domain Decomposition," Proceedings of the International Topical Meeting on Advances in Mathematics, Computations, and Reactor Physics, Vol. 1, pp. 3.1-3.12 (1991).
Mattis, R. and A. Haghighat, "New Vector/Parallel Algorithms for the Two-Dimensional Curvilinear S_N Method," Proceedings of the International Topical Meeting on Advances in Mathematics, Computations, and Reactor Physics, Vol. 1, pp. 4.1-4.13 (1991).

List of Publications

Refereed Proceedings (continued)

Livingston, J. and A. Haghighat, "Study of More Efficient Models for Reactor Vessel Fluence Calculations," Proceedings of the topical meeting on "Advances in Reactor Physics," Charleston, SC, Vol. 1, pp. 253-264, (March 1992).
Veerasingam, R. and A. Haghighat, "Neutron Transport Analysis of the SAILOR and ELXSIR Cross-Section Libraries used for the RPV Fluence Estimation," Proceedings of the topical meeting on "Advances on Reactor Physics," Charleston, SC, Vol. 1, pp. 265-276, (March 1992).
Haghighat, A., "Several Spatial Parallel S_N Algorithms for the Curvilinear Geometries," Proc. of the Inter. Symposium on Numerical Transport Theory, Russia, Moscow, pp. 94-97 (May 1992).
Hunter, M. and A. Haghighat, "Combined Spatial/Angular Domain Decomposition Sn Algorithms for Shared Memory Parallel Architectures," Proceedings of the Joint International Conference on Mathematical Methods, and Supercomputing in Nuclear Applications, 2, pp. 112-123, Karlsruhe, Germany, April 19-23, 1993.
Haghighat, A., M. Hunter, and R. Mattis, "Iterative Schemes for Parallel Sn Algorithms," Proceedings of the 1994 Topical Meeting on Reactor Physics, Vol. 1, 423-432, Knoxville, TN, April 11-15, 1994.
Petrovic, B. and A. Haghighat, "Impact of Numerical Options in the DORT Code on PWR Pressure Vessel Fluence Calculations," Proceedings of the 1994 Topical Meeting on Reactor Physics, Vol. 1, 219-228, Knoxville, TN, April 11-15, 1994.
Mattis, R. and A. Haghighat, "Parallel Sn Algorithms on Workstation Networks," Proceedings of the Eighth International Conference on Radiation Shielding, Vol. 1, 558-563, Arlington, TX, April 24-27, 1994.
Petrovic, B., A. Haghighat, J. Luoma, and M. Mahgerefteh, "Validation of Sn Transport Calculations for Pressure Vessel Fluence Determent at Penn State," Proceedings of the Eighth International Conference on Radiation Shielding, Vol. 2, 721-728, Arlington, TX, April 24-27, 1994.
Wagner, J., A. Haghighat, and B. Petrovic, "Comparison of Monte Carlo and Synthesized 3-D Deterministic Models for Reactor Cavity Dosimetry Calculations," Proceedings of the Eighth International Conference on Radiation Shield, Vol. 2, 714-720, Arlington, TX, April 24-27, 1994.
Wagner, J. C., A. Haghighat, and B. G. Petrovic, "Benchmarking of Synthesized 3-D Sn Transport Methods for Pressure Vessel Fluence Calculations with Monte Carlo," Proceedings of the International Conference on Mathematics and Computations, Reactor Physics, and Environmental Analyses, Portland, Oregon, April 30 - May 4, 1995.
Petrovic, B. G. and A. Haghighat "Boundary Conditions Induced Oscillations in the Sn Solutions of Two-Dimensional Neutron Transport Equation," Proceedings of the International Conference on Mathematics and Computations, Reactor Physics, and Environmental Analyses, Portland, Oregon, April 30 - May 4,1995.
Wagner, J. C. and A. Haghighat, "Application of the Discrete Ordinates Adjoint Function to Accelerate Monte Carlo Reactor Cavity Dosimetry Calculations," Proceedings of the 1996 Radiation Protection and Shielding Conference, Falmouth, MA, April 21-25, 1996.
Petrovic, B. and A. Haghighat, "Directional T-Weighted S_N Differencing Scheme and Its Application to Pressure Vessel Fluence Calculations," Proceedings of the 1996 Radiation Protection and Shielding Conference, Falmouth, MA, April 21-25, 1996.
Haghighat, A., H. L. Hanshaw, and J. C. Wagner "Multigroup Cross Section Generation with Adjoint Weighting and Its Application to PV Dosimetry," Proceedings of the 1996 Radiation Protection and Shielding Conference, Falmouth, MA, April 21-25, 1996.
Morris, P. J., L. N. Long, A. Haghighat, M. L. Brady, " Curriculum Development on Advanced Computation," Proc.of the 1996 ASEE Annual Conferecne, 1996.
Haghighat, A., V. Kucukboyaci, G. Sjoden, and B. Petrovic, “Dose Estimation at a BWR Core Shroud Using PENTRAN,” Proceedings of the Joint International Conference on Mathematical Methods and Supercomputing in Nuclear Applications, Vol. I, 819-828, Saratoga Springs, NY, Oct. 6-10, 1997.
Sjoden G. E. and A. Haghighat, “PENTRAN - Parallel Environment Neutral-particle TRANsport in 3-D Cartesian Geometry,” Proceedings of the Joint International Conference on Mathematical Methods and Supercomputing in Nuclear Applications, Vol. I, 232-234, Saratoga Springs, NY, Oct. 6-10, 1997.
Petrovic, B., A. Haghighat, and J.C. Wagner, “Definition of a Calculational 3-D Benchmark Problem for PWR Pressure Vessel Neutron Transport Calculations,” Proceedings of the Joint International Conference on Mathematical Methods and Supercomputing in Nuclear Applications, Vol. I, 292-301, Saratoga Springs, NY, Oct. 6-10, 1997.
Petrovic, B., J. C. Wagner, and A. Haghighat, “Verification of Improved Synthesized 3-D Sn and Monte Carlo Methods for Pressure Vessel Fast Neutron Fluence Calculations,” Proceedings of the Joint International Conference on

Mathematical Methods and Supercomputing in Nuclear Applications, Vol. II, 1586-1595, Saratoga Springs, NY, Oct. 6-10, 1997.
Wagner, J. C. and A. Haghighat, "Monte Carlo PWR Cavity Dosimetry Calculations Using an Automatic Variance Reduction Technique," Proceedings of the Joint International Conference on Mathematical Methods and Supercomputing in Nuclear Applications, Vol. II, 1031-1039, Saratoga Springs, NY, Oct. 6-10, 1997.
Wagner, J. C. and A. Haghighat, "Automatic Variance Reduction for Monte Carlo Shielding Calculations with the Discrete Ordinates Adjoint Function," Proceedings of the Joint International Conference on Mathematical Methods and Supercomputing in Nuclear Applications, Vol. I, 671-680, Saratoga Springs, NY, Oct. 6-10, 1997.

Refereed Proceedings (continued)

Sjoden G. E. and A. Haghighat, "PENTRAN - A 3-D Cartesian Parallel Sn Code with Angular, Energy, and Spatial Decomposition," Proceedings of the Joint International Conference on Mathematical Methods and Supercomputing in Nuclear Applications, Vol. II, 1267-1276, Saratoga Springs, NY, Oct. 6-10, 1997.

Sjoden G. E. and A. Haghighat, "The Exponential Directional Weighted (EDW) Sn Differencing Scheme in 3-D Cartesian Geometry," Proceedings of the Joint International Conference on Mathematical Methods and Supercomputing in Nuclear Applications, Vol. I, 553-562, Saratoga Springs, NY, Oct. 6-10, 1997.

Kucukboyaci, V. and A. Haghighat, "Analysis of PENTRAN Parallel 3-D Sn Code (Features/Formulations) for a BWR Shielding Problem," Proceedings of the 1998 ANS Radiation Protection and Shielding Division Topical Conference, Vol.1,I-359:I-366, April 19-23, 1998, Nashville, TN.

Petrovic, B., A. Haghighat, A. Motta, V. Kucukboyaci, and J. Kwon, "Contribution of Gamma Irradiation to Material Damage at BWR Core Shroud and Pressure Vessel," Proceedings of the 1998 ANS Radiation Protection and Shielding Division Topical Conference, Vol.2,II-25:II-32, April 19-23, 1998, Nashville, TN.

Petrovic, B., A. Haghighat, T. V. Congedo, and A. Haghighat, "Development and Validation of Transport Theory Methodology for Accurate Simulation of PGNAA System for Mixed-Waste NDA," Proceedings of the 6th Nondestructive Assay Waste Characterization Conference, 605-627, Nov. 17-19, 1998, Salt Lake City, Utah.

A. Haghighat, H. Hiruta, B. Petrovic, J. C. Wagner, "Performance of the Automated Adjoint Accelerated MCNP (A^{3}MCNP) for Simulation of a BWR Core Shroud Problem," Proceedings of the Mathematics and Computation, Reactor Physics and Environmental Analysis in Nuclear Applications, Vol. 2, 1381-1392, Sept. 27-30, 1999, Madrid, Spain.

G.E. Sjoden and A. Haghighat, "Advanced 3-D Parallel Discrete Ordinates Methods for Criticality Safety Calculations," Proceedings of the Mathematics and Computation, Reactor Physics and Environmental Analysis in Nuclear Applications, Vol. 2, 1403-112, Sept. 27-30, 1999, Madrid, Spain.

A. Haghighat and G. Sjoden, "Significance of Adaptive Differencing, Variable Grid Density and TPMC for Sn Methods," Proceedings of the Mathematics and Computation, Reactor Physics and Environmental Analysis in Nuclear Applications, Vol. 2, 1748, Sept. 27-30, 1999, Madrid, Spain.

B. Petrovic, A. Haghighat, A. Dulloo, and T. G. Congedo, "Hybrid Forward Monte-Carlo - Adjoint Sn Methodology for Simulation of PGNAA Systems, " Proceedings of the Mathematics and Computation, Reactor Physics and Environmental Analysis in Nuclear Applications, Vol. 2, 1016-1025, Sept. 27-30, 1999, Madrid, Spain.

A. Alpan and A. Haghighat, "Advanced Methodology for Selecting Group Structures for Multigroup Cross Section Generation," Proceedings of PHYSOR 2000 - ANS International Topical Meeting on Advances in Reactor Physics and Mathematics and Computation into the Next Millennium, CD, May 7-12, 2000, Pittsburgh, PA.

V. Kucukboyaci and A. Haghighat, "Angular Multigrid Acceleration for Parallel Sn Method with Application to Shielding Problems," Proceedings of PHYSOR 2000 - ANS International Topical Meeting on Advances in Reactor Physics and Mathematics and Computation into the Next Millennium, CD, May 7-12, 2000, Pittsburgh, PA.

A. Patchimpattapong and A. Haghighat, "Impact of Ray Effects on A^{3}MCNP Performance for a Purely Absorbing Medium with Void Region," Proceedings of PHYSOR 2000 - ANS International Topical Meeting on Advances in Reactor Physics and Mathematics and Computation into the Next Millennium, CD , May 7-12, 2000, Pittsburgh, PA.

A. Haghighat and G. E. Sjoden, "PENTRAN^{TM} (Parallel Environment Neutral-partcile TRANsport) Code System," Proceedings of PHYSOR 2000 - ANS International Topical Meeting on Advances in Reactor Physics and Mathematics and Computation into the Next Millennium, CD , May 7-12, 2000, Pittsburgh, PA.

A. Haghighat, "Graduate Education in Reactor Physics - Influence of Advancements in Computing Technologies," Proceedings of PHYSOR 2000 - ANS International Topical Meeting on Advances in Reactor Physics and Mathematics and Computation into the Next Millennium, CD , May 7-12, 2000, Pittsburgh, PA.

J. F. Brown and A. Haghighat, "A PENTRAN^{TM} Model for a Medical Computed Tomography (CT) Device," Proceedings for the 10th International Meeting on Radiation Protection and Shielding (RPS2000), Sept. 17-21, 2000, Spokane, WA.

A. Haghighat, G.E. Sjoden , and V. Kucukboyaci, "Parallel Performance and Robustness of PENTRAN^{TM} for Simulation of Real-Life Shielding Problems," Proceedings for the 10th International Meeting on Radiation Protection and Shielding (RPS2000), Sept. 17-21, 2000, Spokane, WA.

F. A. Alpan and A. Haghighat, "Comparison of PSU and BUGLE Libraries with Application to Pressure Vessel Neutron Dosimetry," Proceedings for the 10th International Meeting on Radiation Protection and Shielding (RPS2000), Sept. 17-21, 2000, Spokane, WA.

V. Kucukboyaci and A. Haghighat, "Utilizing the Angular Multigrid Acceleration for Large Scale Transport Problems," Proceedings for the 10th International Meeting on Radiation Protection and Shielding (RPS2000), Sept. 17-21, 2000, Spokane, WA.

A. Haghighat and J. C. Wagner, "Application of A^{3}MCNP to Radiation Shielding Problems," Proceedings of the International Conference on Advanced Monte Carlo on Radiation Physics, Particle Transport Simulations and Applications (MC 2000), Lisbon, Potugal, Oct. 23-26, 2000.

Refereed Summaries

Haghighat, A. and G. Kosaly, "The Importance of Transport Theory Effects on the Determination of the Field-of-View of a BWR Incore Detector," Transactions of the American Nuclear Society, 54:357-358 (June 1987).
Haghighat, A. and A.J. Baratta, "Theoretical Analysis of the Gamma Detector Data from the TMI-2 Reactor Lower Head," Transactions of the American Nuclear Society, 56:548-550 (June 1988).
Haghighat, A., "Investigation of the Control Rod Material Presence in the TMI-2 Lower Head," Transactions of the American Nuclear Society, 59:348-350 (June 1989).

List of Publications

Refereed Summaries (continued)

Haghighat, A., "Parallelization of a Spherical S_N Transport Theory Algorithm," Transactions of the American Nuclear Society, 59:155-156 (June 1989).
Mattis, R. and A. Haghighat, "A New Vectorized Rebalancing Algorithm for Neutronics Codes," Transactions of the American Nuclear Society, 59:153-154 (June 1989).
Haghighat, A. and R. Lawrence, "Implementation of a Parallel Algorithm for Spherical S_N-Calculations on the IBM 3090," Transactions of the American Nuclear Society, 60:367-369 (November 1989).
Macafee, W. and A. Haghighat, "Simulation of a Steam Turbine Using TRAC-BF1," Transactions of American Nuclear Society, 61:447-448 (June 1990).Mattis, R. and A. Haghighat, "New Vectorized Algorithms for the Spherical S_N Method," Transactions of the American Nuclear Society, 62:303-304 (November 1990).
Haghighat, A., B. Nanayakkara, J. Livingston, M. Mahgerefteh, and J. Luoma, "Application of the Adjoint-function Methodology for Neutron Fluence Determination," Transactions of the American Nuclear Society, 63:419- 420 (June 1991).
Mattis, R. and A. Haghighat, "Spatial Domain Decomposition for a Two-Dimensional S_N Transport Method," Transactions of the American Nuclear Society, 63:181-183 (June 1991).
Haghighat, A. and R. Veerasingam, "Comparison of the Different Cross-Section Libraries used for Reactor Pressure Vessel Fluence Calculations," Transactions of the American Nuclear Society, 64, p. 539 (November 1991).
Haghighat, A. and B. Nanayakkara, "Comparison of the Different Neutron Spectra Used for the Reactor Pressure Vessel Fluence Estimation," Trans. of Am. Nucl. Soc., 65:435-437 (June 1992).
Haghighat, A. "Different Spatial Parallel Sn Algorithms for the 1-D Spherical Geometry," Trans. of Am. Nucl. Soc., 65:206-207 (June 1992).
Petrovic, B. and A. Haghighat, "Effect of Quadrature Order on the Accuracy of Fluence Calculations," Trans. of Am. Nucl. Soc., Vol. 68, Part A, 477-480, 1993.
Wagner, J. and A. Haghighat, "Investigation of Pressure Vessel Neutron Fluence Calculation with Monte Carlo," Trans. of Am. Nucl. Soc., Vol. 68, Part A, 446-448, 1993.
Asam Khan and A. Haghighat, "One and Three-Dimensional Particle Transport Studies of the ANS Hot Source," Trans. of Am. Nucl. Soc., Vol. 69, 459, 1993.
Haghighat, A., B. Petrovic and M. Mahgerefteh, "Estimation of Neutron Source Uncertainties in Pressure Vessel Fluence Calculations," Trans. of Am. Nucl. Soc., Vol. 69, 467, 1993.
Wagner, J., A. Haghighat, and B. Petrovic, "Multigroup versus Continuous Energy MCNP for PWR Fluence Calculations," Trans. of Am. Nucl. Soc., Vol. 70, 1994.
Petrovic B. and A. Haghighat, "Analysis of Oscillations in the T-weighted Differencing Scheme," Trans. Am. Nucl. Soc., Vol. 71, 1994.
Petrovic B., H. Hanshaw and A. Haghighat, "Evaluation of Anisotropy Effects in Pressure Vessel Fluence Calculations Using BUGLE-93 Library," Trans. Am. Nucl. Soc., Vol. 71, 1994.
Balachov I. and A. Haghighat, "Analysis of Database of LEPRICON Adjustment Code," Trans. Am. Nucl. Soc., Vol. 71, 1994.
Hanshaw H. and A. Haghighat, "Estimation of the Effects of Self-Shielding on Multigroup Reactor Vessel Fluence Calculations," Trans. Am. Nucl. Soc., Vol. 71, 1994.
Petrovic B. G. and A. Haghighat, "Oscillations Caused by Spatial Differencing in Multidimensional Sn NeutronTransport Calculations," Trans. Am. Nucl. Soc., Vol. 72, 1995.
Petrovic, B. and A. Haghighat, "A New Directional T-Weighted S_N Differencing Scheme," Trans. Am. Nucl. Soc., Vol. 73, 195-197, 1995.
Petrovic, B. and A. Haghighat, "Application of the Directional T-Weighted S_N Differencing Scheme to Pressur Vessel Fluence Calculations," Trans. Am. Nucl. Soc., Vol. 73, 346-347, 1995.
Hanshaw, H. L., A. Haghighat, and J. C. Wagner "Multigroup Cross Section Generation with Spatial and Angular Weighting," Trans. Am. Nucl. Soc., Vol. 73, 175-177, 1995.
Wagner, J. C. and A. Haghighat, "Deterministic Adjoint Functions for Biasing Monte Carlo Reactor Cavity Dosimetry Calculations," Trans. Am. Nucl. Soc., Vol. 73, 432-434, 1995.
Klevans, E. H. and A. Haghighat, "Remote Site Graduate Instruction Using Interactive Compressed Video," Trans.Am. Nucl. Soc., Vol. 73, 70-71, 1995.
Haghighat, A. et. al, "Uncertainties in Transport Theory Pressure Vessel Neutron Fluence Calculations, "Trans.Am. Nucl. Soc., Vol 74, 1996.
Sjoden, G. and A. Haghighat, "PENTRAN: A 3-D Scalable Transport Code with Complete Phase Space Decomposition," Trans. Am. Nucl. Soc., Vol. 74, 1996.

Sjoden, G. and A. Haghighat, "Taylor Projection Mesh Coupling Between 3-D Discontinuous Grids for S_N," Trans.Am. Nucl. Soc., Vol. 74, 1996.
Hunter, M. A. and A. Haghighat, "Comparison of Acceleration Schemes for Parallel S_N Algorithm Solution of Shielding Problems," Trans. Am. Nucl. Soc., Vol. 74, 1996.
Sjoden, G. and A. Haghighat, "New Adaptive Differencing Strategy in the PENTRAN 3-D Parallel Sn Code," Trans. Am. Nucl. Soc., Vol. 75, 1996.
Sjoden, G. and A. Haghighat, "Simplified Multigrid Acceleration in the PENTRAN 3-D Parallel Code," Trans. Am. Nucl. Soc., Vol. 75, 1996.
Wagner, J. C. and A. Haghighat, "Parallel MCNP Monte Carlo Transport Calculations with MPI," Trans. Am. Nucl.Soc., Vol. 75, 1996.

List of Publications

Refereed Summaries (continued)

Petrovic, B., Young-Su Kim, and A. Haghighat, "Characterization of Neutron and Gamma Radiation Fields at Penn State Breazeale Reactor," Trans. Am. Nucl. Soc., Vol. 75, 1996.
Haghighat, A. and B. Petrovic, "Particle Transport Methods for LWR Dosimetry Developed by the PSTTG Group," Trans. Am. Nucl. Soc., Vol. 77, 1997.
Hiruta, H., A. Haghighat, and B. Petrovic, "Neutron Fluence Calculations at a BWR Core Shroud Using A^3MCNP," Trans. Am. Nucl. Soc., Vol. 79, 1998.
Sjoden, G.E., A. Haghighat, "EDW Sn Differencing Compared to Monte Carlo for Zero-C Problems," Trans. Am. Nucl. Soc., Vol. 80, 1999.
Petrovic, B.., A. Haghighat, A. Dulloo, and T. Congedo, "Study of Kinetics of a PGNAA System for Nondestructive Characterization of Mixed Waste," Trans. Am. Nucl. Soc., Vol. 80, 1999.
V. Kucukboyaci and A. Haghighat, "A Simplified Angular Multigrid Method to Accelerate Sn Calculations," Trans. Am. Nucl.Soc., Vol. 81, P. 140, 1999 ANS Winter Meeting, Nov. 14-18, 1999, Long Beach, CA.
A. Patchimpattapong and A. Haghighat, "Effectiveness of A^3MCNP for a Purely Absorbing Medium with Void Region," Trans. Am. Nucl. Soc., Vol. 81, P. 257, 1999 ANS Winter Meeting, Nov. 14-18, 1999, Long Beach, CA.
A. Alpan and A. Haghighat, "MPI Version of NJOY and Its Application to Multigroup Cross-Section Generation," Trans. Am. Nucl. Soc., Vol. 81, P. 260, 1999 ANS Winter Meeting, Nov. 14-18, 1999, Long Beach, CA.
Kucukboyaci, V., A. Haghighat, H. Hiruta, and B. Petrovic, "Determination and Analysis of Neutron and Gamma Fields at BWR Core Shroud Using the Discrete Ordinates (Sn) Method," Trans. Am. Nucl. Soc., Vol. 80, 1999.
V. Kucukboyaci, A. Haghighat, H. Hiruta, and B. Petrovic, "Determination and Analysis of Neutron and Gamma Fields at BWR Core Shroud Using Discrete Ordinates (Sn) Method," Trans. Am. Nucl. Soc., Vol. 80, P. 129, 1999 ANS Annual Meeting, June 6-10, 1999, Boston, MA.
G. Sjoden, A. Haghighat, A. Patchimpattapong, "EDW Sn Differencing Compared to Monte Carlo for Zero-C Problems," Trans. Am. Nucl. Soc., Vol. 80, P. 147, 1999 ANS Annual Meeting, June 6-10, 1999, Boston, MA.
B. Petrovic, A. Haghighat, A. Dulloo, and T. V. Congedo, "Study of Kinetics of a PGNAA System for Nondestructive Characterization of Mixed Waste," Trans. Am. Nucl. Soc., Vol. 80, P. 62, 1999 ANS Annual Meeting, June 6-10, 1999, Boston, MA.
V. Kucukboyaci and A. Haghighat, "A Simplified Angular Multigrid Method to Accelerate Sn Calculations," Trans. Am. Nucl.Soc., Vol. 81, P. 140, 1999 ANS Winter Meeting, Nov. 14-18, 1999, Long Beach, CA.
A. Patchimpattapong and A. Haghighat, "Effectiveness of A^3MCNP for a Purely Absorbing Medium with Void Region," Trans. Am. Nucl. Soc., Vol. 81, P. 257, 1999 ANS Winter Meeting, Nov. 14-18, 1999, Long Beach, CA.
A. Alpan and A. Haghighat, "MPI Version of NJOY and Its Application to Multigroup Cross-Section Generation," Trans. Am. Nucl. Soc., Vol. 81, P. 260, 1999 ANS Winter Meeting, Nov. 14-18, 1999, Long Beach, CA.
B. Petrovic, A. Haghighat, T. Congedo, and A. Dulloo, "Application of Forward Monte-Carlo-Adjoint Sn Methodology for Simulations of PGNAA System for Assaying of Mixed Waste in 55-gal Drums," Trans. Am. Nucl. Soc., Vol. 82, P. 125, 2000 Annual Meeting, June 4-8, 2000, San Diego, CA.
A. Haghighat, G.E. Sjoden, and J. C. Wagner, "Advanced Three-Dimensional Deterministic and Monte Carlo Codes for Simulation of Real-Life Complex Nuclear Systems," Trans. Am. Nucl. Soc., Vol. 82, P. 125, 2000 Annual Meeting, June 4-8, 2000, San Diego, CA..
G. Longoni, A. Haghighat, J. Brown, and V. Kucukboyaci, "Investigation of New Quadrature Sets for Discrete Ordinates Method with Application to Non-Conventional Problems," ANS 2001 Annual Meeting, June 2001.
Michael T. Wenner, Alireza Haghighat, and Shane Gardner, "Acceleration of the Monte Carlo Criticality Calculation via Discrete Ordinates (Sn) Methods," ANS 2001 Annual Meeting, June 2001. (Invited)
S. Gardner, A. Haghighat, A. Patchimpattapong, J. Adams, A. Carlson, S. Grimes, T. Massey, "A New Monte Carlo Tallying Methodology for Optimizing the NERI Spherical-Shell Transmission Experiment," ANS 2001 Annual Meeting, June 2001. (Invited)
Vefa Kucukboyaci , Alireza Haghighat, James M. Adams , Allan D. Carlson , Steven M. Grimes , Thomas N. Massey, "PENTRAN? Modeling for Design and Optimization of the Spherical-Shell Transmission Experiments," ANS 2001 Annual Meeting, June 2001. (Invited)
V. Kucukboyaci and A. Haghighat, "Analysis of Angular V-Cycle Multigrid Formulation for 3-D Discrete Ordinates Method," ANS

2001 Annual Meeting, June 2001. (Invited)
A. Haghighat, “Monte Carlo Methods in Reactor Physics,” ANS 2001 Annual Meeting, June 2001. (Invited)

Reports

Haghighat, A. and A. Khan, "Modeling a Hot Source for the Advanced Neutron Source Project," ORNL/ANS/INT-47, Oak Ridge National Laboratory, 1993.

Standards

Haghighat, A. et al. "Transport Theory Calculations for Pressure Vessel Cavity Dosimetry," American Nuclear Society (ANS) 19.10 Standard, Draft, June 1996.

Benchmarks

Contributed to the OECD report on “3D Radiation Transport benchmarks for Simple Geometries with Void Region,” OECD/NEA Paris, NEA/NSC/DOC(2000)4, Spring 2000. [A. Haghighat and G. Sjoden, “Solutions to the Kobayashi Benchmark Shielding Problems Using PENTRAN,”]

Contributed to the OECD report on “Prediction of Neutron Embrittlement in the Reactor Pressure Vessel: VENUS-1 and VENUS-3 Benchmarks,” OECD/NEA Paris, NEA/NSC/DOC(2000)5, Spring 2000.[Haghighat, A. G.E. Sjoden, and H. Ait Abderrahim, “Simulation of the VENUS-3 Experimental Benchmark Facility Using PENTRAN]

Non-Refereed Articles

Haghighat, A., "The Concept of LPRMS for BWR Stability Monitoring," Proceedings of the 1989 Stability Symposium, INEL, EG&G Idaho, Inc. (August 10-11, 1989).

Macafee, W. and A. Haghighat, "Simulation of High and Low Pressure Turbines Using TRAC-BF1," Proceedings of the First Joint RELAP-5/TRAC-BF1 Workshop, Commonwealth Edison Co., Chicago, IL (September 1990).

Haghighat, A., "Sn Transport Theory Codes for the Parallel Architectures," Proceedings of the Specialists' Meeting on Adapting Computer Codes in Nuclear Applications to Parallel Architectures, October 14-15, 1993, Madrid, Spain.

Baker, R., Y. Y. Azmy, and A. Haghighat, "Parallel Computing in Nuclear Applications," Section 4.1B, OECD report, 1996.

Haghighat A. and G. Sjoden "PENTRAN - A 3-D Discrete Ordinates Transport Code with Complete Phase Space Decomposition for Parallel Computers," Proceedings of the 3-D Deterministic Radiation Transport Computer Programs-Features, Applications, and Perspectives, OECD Chateau de la Muette, Paris XVI, France, Dec. 2-3, 1996.

Sjoden, G. and A. Haghighat, "Implementation of PENTRAN on Distributed Memory Architectures," Proceedings of the 3-D Deterministic Radiation Transport Computer Programs- Features, Applications, and Perspectives, OECD Chateau de la Muette, Paris XVI, France, Dec. 2-3, 1996.

Sjoden, G. and A. Haghighat, "An Adaptive Differencing Strategy and A Simplified Multigrid Acceleration Method with TPMC in PENTRAN," Proceedings of the 3-D Deterministic Radiation Transport Computer Programs- Features, Applications, and Perspectives, OECD Chateau de la Muette, Paris XVI, France, Dec. 2-3, 1996.

Haghighat, A., G. Sjoden, V. Kucukboyaci, and B. Petrovic, "Determination of Neutron Flux at the BWR Core Shroud Using PENTRAN" Proceedings of the 3-D Deterministic Radiation Transport Computer Programs-Features, Applications, and Perspectives, OECD Chateau de la Muette, Paris XVI, France, Dec. 2-3, 1996.