NNSA/DOE CONTRACT 1

Development of Accurate and Fast Monte Carlo Spectral Simulation Algorithms for Proliferation Detection

Robin Gardner

TOPICS

- Passive Gamma-Ray Detection
- Accuracy Issues
- Efficiency Issues
- The Monte Carlo – Library Least-Squares (MCLLS) Approach
- Results to Date – ANS Paper
- Future Work

Passive Gamma-Ray Detection

- Radioisotopes of interest – HEU, Pu, Cs-137, Co-60, Am-Be etc.
- Sources of Background Radiation
  + fertilizer
  + mineral ores
- Radiation Detectors
  + Plastic scintillators
  + NaI detectors

ACCURACY ISSUES

- NaI and Other Scintillator Detector Non-linearity
- The Flat Continuum Problem caused by Electron Escape
- MCNP Usage

EFFICIENCY ISSUES

- Electron transport calculations are very time consuming and inaccurate for single crystals – so the F8 tally in MCNP is not good
- Use of Detector Response Functions (DRFs) gives good efficiency and accuracy

EFFICIENCY ISSUES, 2

- Many groups use the weight windows approach and calculate importances with deterministic codes for adjoint solutions.
- We believe that adequate importances can be obtained with simple adjoint models or simple forward Monte Carlo models.

EFFICIENCY ISSUES, 3

- We looked at the use of spherical coordinate meshes first and then converting to Cartesian meshes later. MCNPX has this as a built-in.
- Our first work considered spherical meshes centered on the detector rather than the source.
- We are considering doing the same thing with:
(1) centering on the source and
(2) using two intersecting spherical meshes – one centered on the source and one on the detector.

The Monte Carlo – Library Least-Squares (MCLLS) Approach

- The cargo monitoring problem is often a non-linear one (like PGNAA and EDXRF analysis) in terms of shielding and linear in source intensity.
- So the usual MCLLS approach can be taken by using pre-calculations with the forward Monte Carlo code that include differential operators (Dos) for the libraries of each shielding material.
- Then with initial estimates of the non-linear parameters (shield thicknesses) one can solve the inverse problem very rapidly by interpolating the pre-calculated results with the DOs that are provided.

Monte Carlo Simulation of Oil Well Logging Tools Using Spherical Coordinate Meshes for Weight Window Importances

Robin P. Gardner and Cody R. Peeples
Center for Engineering Applications of Radioisotopes
North Carolina State University

June 16, 2009

TOPICS

- INTRODUCTION
- DESCRIPTION OF THE APPROACH
- THE NEUTRON POROSITY LOGGING TOOL
- THE GAMMA-RAY DENSITY LOGGING TOOL
- SPHERICAL COORDINATES RESULTS
- DISCUSSION AND FUTURE WORK
- ACKNOWLEDGEMENT

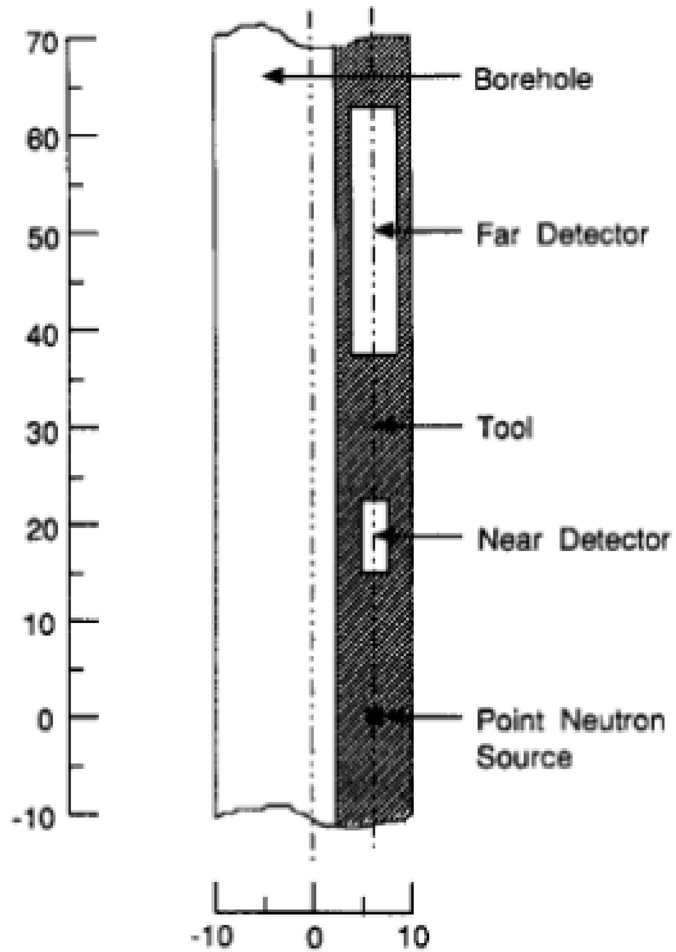
DESCRIPTION OF THE APPROACH

- Previous work (Ref. 1) indicated that a Cartesian coordinate independent mesh provides a good basis for applying the Monte Carlo weight windows approach to neutron porosity and gamma-ray density logging tools.
- Other work (Refs. 2 and 3) indicated that very simple 1D adjoint diffusion models for importances also gave excellent results.
- Mickael (Ref. 2) homogenized both problems by using a few analog histories to obtain the appropriate diffusion model parameters.
- It occurred to us that the use of a spherical coordinate system might do the same thing more efficiently. The MCNPX code has this capability and was used in this work.

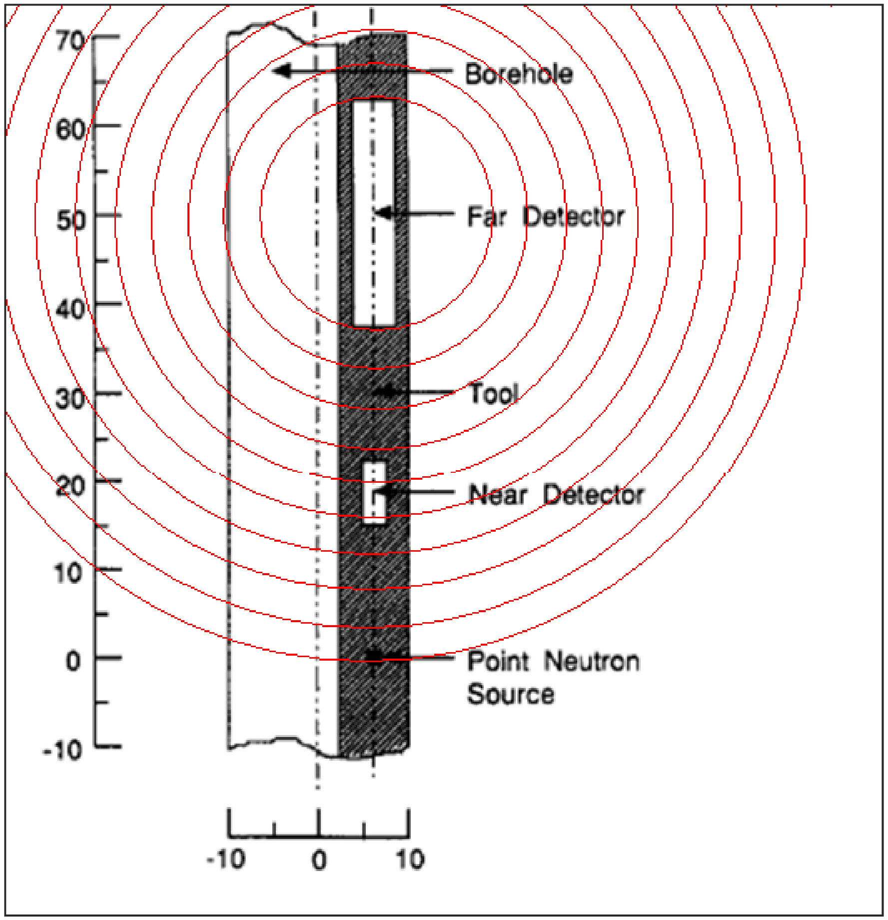
THE NEUTRON POROSITY LOGGING TOOL

- A benchmark neutron porosity logging tool was designed and tested in 1991 (Ref. 4) at a workshop held at NCSU.
- The tool design is shown in Figure 1.
- The average yield for this log is ≈ 2×10^{-4} and the number of scatters per history range from 100 to 200.
- This benchmark was very useful in determining the relative efficiency and accuracy of various Monte Carlo codes used to simulate it including MCNP, McBEND, and McDNL.

Fig.1. Neutron porosity benchmark tool (in cm).



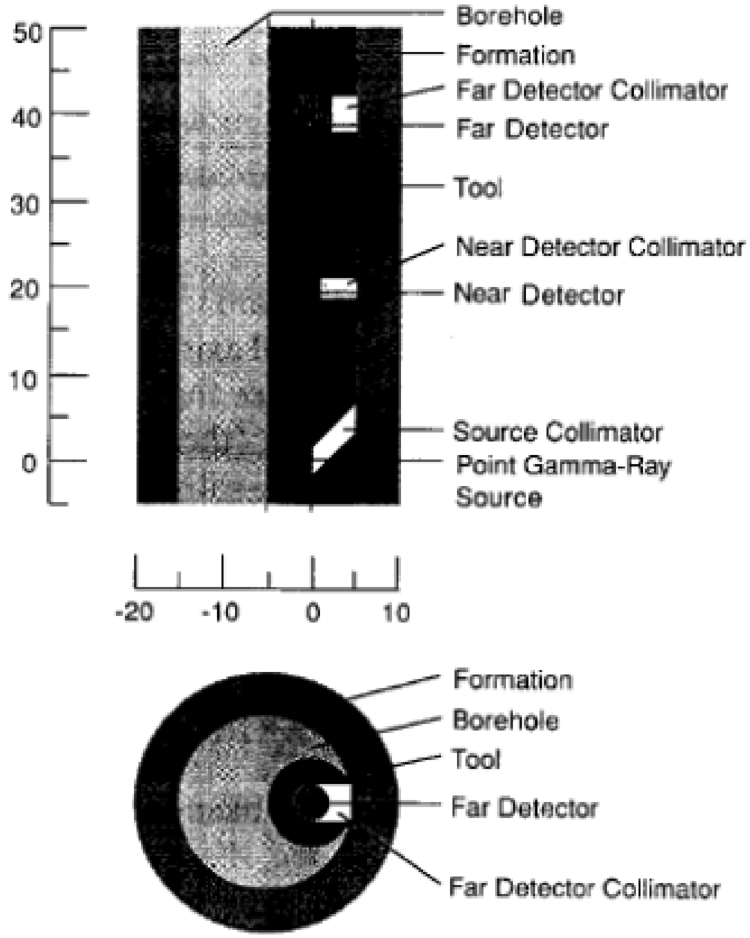
SPHERICAL MESH



THE GAMMA-RAY DENSITY LOGGING TOOL

- The benchmark for the gamma-ray density tool was also designed and tested in 1991 (Ref. 4) at the workshop at NCSU.
- The tool design is shown in Figure 2.
- The average yield for this log is ≈ 3×10^{-8} and the number of scatters per history range from about 4 to 15.
- This benchmark was also very useful in determining the relative efficiency and accuracy of various Monte Carlo codes used to simulate it including MCNP, McBEND, and McDNL.

Fig.2. Gamma-ray lithology-density benchmark tool (in cm).



SPHERICAL COORDINATES RESULTS

- Spherical coordinates were used for both logs by centering the inscribed spheres on the detector center. The largest sphere enclosed the source. The smallest sphere just circumscribed the detector of interest. All other spheres had constant variations in radius.
- Calculations were made for various numbers of total spheres to determine the efficiency of each.
- The calculations in the references were repeated for Cartesian coordinates so that present day computers could be used for both types of mesh.
- The spherical mesh can be changed in MCNPX for a Cartesian mesh whenever desired.

TABLE I. Comparison of Cartesian & Spherical Importance Mesh Approaches.

Logging Type	Neutron Porosity Log (FOM Ratio)	Gamma-Ray Density Log (FOM Ratio)
Cartesian Coordinate Systems:		
Geometry-Based Cells	105 (2,700 cells)	258 (1,266 cells)
Independent Cells	118 (18,125 cells)	2660 (27,000 cells)
Present Study	80	1146
Spherical Coordinate System – 10 Spheres	84	440
Spherical Coordinate System – 20 Spheres	92	582
20 Spheres Hybrid	--	986

REFERENCES

(1.) L. Liu and R. P. Gardner, "A Geometry- Independent Fine-Mesh-Based Monte Carlo Importance Generator", *Nuclear Science and Engineering*, 125, pp.188-196 (1997).

(2.) M. W. Mickael, "Importance Estimation in Monte Carlo Modeling of Neutron and Photon Transport", *Nuclear Geophysics,* Vol. 6, No. 3, pp. 341-350 (1992).

(3.) R. P. Gardner and L. Liu, "Monte Carlo Simulation of Neutron Porosity Oil Well Logging Tools: Combining the Geometry-Independent Fine-Mesh Importance Map and One-Dimensional Diffusion Model Approaches", *Nuclear Science and Engineering*, 133, pp. 80-91 (1999).

(4.) R.P. Gardner and K. Verghese, "Monte Carlo Nuclear Well Logging Benchmark Problems with Preliminary Intercomparison Results", *Nuclear Geophysics,* Vol. 5, pp. 429-438 (1991).

DISCUSSION AND FUTURE WORK

- The spherical mesh method approaches the saturation Figure of Merit (FOM) much more rapidly than the Cartesian coordinate approach.
- The Cartesian mesh method is capable of higher saturation FOM's.
- It appears that an excellent approach would be to start with a low-number spherical mesh and convert to a Cartesian mesh for optimum FOM and ease of use.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the support of the Associates Program for Nuclear Techniques in Oil Well Logging that supports CEAR and includes EXXON Mobil, Baker Atlas, Halliburton, Pathfinder, Weatherford, and Los Alamos National Laboratory.

Results to Date: Cartesian Meshes

TABLE I. A Comparison of Importance Mesh Approaches.

	Neutron Porosity (FOM ratio)	Gamma Density (FOM ratio)
Previous Work:		
Geometry Based (Cylindrical)	105 (2,700 cells)	158 (1,266 cells)
Superimposed (Cartesian)	118 (18,125 cells)	2,660 (27,000 cells)
Present Study:		
Superimposed (Cartesian)	80 (18,125 cells)	1,145 (27,000 cells)
Superimposed (Spherical)	88 (10 cells) 80 (20 cells)	370 (10 cells) 467 (20 cells)
Superimposed (Hybrid)	---	1,058

FUTURE WORK

- We are considering doing the same thing with:
  (1) centering on the source and
  (2) using two intersecting spherical meshes – one centered on the source and one on the detector.