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NEW DEVELOPMENTS ENHANCING MCNP FOR CRITICALITY SAFETY

by

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I. INTRODUCTION

A number of significant new developments have been made to enhance the MCNP Monte Carlo radiation transport code[1] for criticality safety applications. These are available in the newly released MCNP4A version of the code.

II. SPECIFIC CRITICALITY IMPROVEMENTS

A number of MCNP projects have been undertaken at the request of and specifically for the criticality safety community.

A. New Criticality Analysis and Output

Since the early 80's MCNP has had three estimates of k_{eff}: collision, absorption, and track length. MCNP has also had collision and absorption estimators of removal lifetime. These are calculated for every cycle and are averaged over the cycles as simple averages and covariance weighted averages. Correlation coefficients between estimators are also calculated. These criticality estimators are all in addition to the extensive summary information and tally edits used in shielding and other problems.

In MCNP4A the following have been added:

- A summary page of k_{eff} results with confidence intervals. The summary includes:

  a check to determine if each cell with fissionable material had tracks entering, collisions, and fission source points to assess problem sampling;

  - tests for normality of the active k_{eff} values for each estimator;

  - a table of k_{eff} and confidence intervals if the largest value of k_{eff} for each estimator occurs on the next cycle;

  a fission neutron lifetime estimate

- A table of k_{eff} and its variance as it would have been calculated with a different number of k_{eff} sources per batch to assess k_{eff} cycle correlation effects;
- A table showing k_{eff} results by cycle number as well as the largest and smallest values of each k_{eff} estimator and the figure of merit (a measure of problem efficiency);
- A printed plot of the cumulative average k_{eff} by cycle;
- A table of k_{eff} as a function of the number of (inactive) cycles skipped along with the number of inactive cycles that produces the minimum k_{eff} variance. This table also includes an examination of the first two moments of k_{eff} for the first and second halves of the active cycles to assess settling to the spatial distribution normal mode;
- A printed plot of the combined k_{eff} as a function of the number of (inactive) cycles skipped.

In addition, there are new messages sent to the user's terminal, additional error diagnostics and warning messages about criticality problem performance. Most of the new information can be interactively plotted by the MCNP tally plotting package either as a run progresses or afterward.

B. Benchmark Calculations

A major benchmarking program has been undertaken for MCNP. A comparison[2] of MCNP to KENO using the KENO test problem set is presented elsewhere at this meeting.[3] Additional criticality benchmarks can be found in the MCNP neutron benchmarks.[4,5] Collaborators at General Electric have published light water reactor critical benchmarks[6] and collaborators at Westinghouse Idaho Nuclear Company have published several volumes[7,8,9,10] comparing MCNP to SCALE and experiments. These benchmarks all demonstrate that MCNP is an accurate computer model for calculating nuclear criticality.

C. Criticality Primer

A primer on how to use MCNP for criticality safety problems is being prepared in collaboration with Bob Busch of the University of New Mexico. The primer will give new users a step-by-step guide for setting up and interpreting MCNP problems starting with simple examples (critical spheres) and building up to more sophisticated problems likely to be encountered by criticality practitioners.

III. GENERAL MCNP IMPROVEMENTS

A number of MCNP enhancements are of interest to all applications of MCNP, including criticality safety.

A. A New Means of Assessing Tally Quality

MCNP4A features a new, exclusive error analysis in addition to the usual estimate of tally variance. The variance of the variance and the underlying history score probability density function are calculated and analyzed as new aids to assess tally convergence.[11]

Each tally is also subjected to ten statistical checks providing new confidence and insight into the statistical convergence process.

B. X-Windows Graphics

MCNP geometry and tally plotting now work with Xwindow-based window systems (e.g., Open Windows, Motif, etc.) in addition to GKS, CGS, DISSPLA, and PLOT10. The X libraries are well-established and can be found on most workstations and mainframes. This capability has been tested on SUNs, IBM RS/6000s, HP, and Cray UNICOS. The graphics window can be easily resized, iconized, or printed and can be sent to or from other displays.

C. PVM Multiprocessing

MCNP can now be run in parallel on a cluster of workstations[12] using PVM (Parallel Virtual Machine) software. On the 16-machine IBM cluster at LANL, MCNP runs ten times as fast as a single-processor YMP. PVM multiprocessing has also been demonstrated on a network of SUN workstations.

D. Dynamic Memory on Unix Systems

MCNP now dynamically adjusts its memory to problem size on UNIX systems. The new UNIX dynamic memory manager also works in conjunction with the distributed memory multiprocessing.

E. ENDF/B-VI Physics

The Kalbach 87 formalism (ENDF/B-VI file 6 LAW=1, LANG=2) and correlated energy angle scattering (ENDF/B-VI file 6 LAW=7) have been incorporated in MCNP to handle new ENDF/B-VI data formats. A new algorithm has been developed for next event estimators so that collisions using these laws now contribute to point and ring detectors as well as the DXTRAN variance reduction method. Preliminary libraries are available and work is proceeding to process, test, and release entirely new ENDF/B-VI libraries.

F. Repeated Structure Tallies

MCNP tallies can now be made in individual lattice elements or repeated cells or combinations thereof in repeated structures geometries.

G. SABRINA Particle Tracks

History files are now optionally output from MCNP to describe particle trajectories which can be plotted with the three-dimensional color graphics code SABRINA. This new visualization capability will provide important insight into Monte Carlo solutions.

H. White and Periodic Boundaries

MCNP now models both white and periodic boundaries. White boundaries are useful for comparison with deterministic methods. Periodic boundaries are valuable in a wide range of reactor lattice calculations.

I. Other Features

A completely new MCNP manual is nearing completion. New Software Quality Assurance (SQUA) standards are being applied, along with even more rigorous quality control, configuration management, and installation verification. For example, every change in MCNP for the past three years can be traced to written documentation, and the code is subject to numerous and periodic reviews.

New installation procedures have been developed which we hope are even easier than those for MCNP4.

Protection for long runs with workstations, including better random number control[13] and enlarged output formats, is now available in MCNP4A. Restart capabilities are improved.

And for the first time MCNP is case insensitive, which is particularly of interest on VMS systems.

IV. SUMMARY

The MCNP Monte Carlo code is increasingly being used by the criticality safety community. Every three years or so a new version is released internationally. The MCNP4A version released in summer 1993 has many enhancements specifically for criticality safety. These are in addition to numerous other enhancements which benefit all MCNP applications including criticality safety. Not described here are the many additional enhancements, such as new electron transport options and extended photon energy physics, which do not apply to criticality safety. All of these capabilities are available *now* in MCNP4A. And as active development of MCNP continues, along with a vigorous research program in such areas as nonlinear and non Boltzman Monte Carlo, hybrid Monte Carlo S_n methods, angle bias, and quasi deterministic variance reduction, more enhancements will be available in future versions of the code.

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