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Status of the LAHET\textsuperscript{\textregistered} Code System

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Abstract
The LAHET Code System (LCS) is extensively used for medium energy accelerator applications, including spallation target design and deep penetration shielding problems. Current applications include Accelerator Production of Tritium (APT), Accelerator Driven Transmutation Technologies (ADTT), LANSCE and WNR spallation target upgrades, as well as various medical projects. We will discuss recent upgrades to the MCNP and LAHET components of LCS, and review the work in progress now funded under the APT program.

1 Introduction
The Los Alamos High Energy Transport (LAHET) Code System \cite{lcs1} consists of two monte carlo codes, LAHET\textsuperscript{\textregistered} and MCNP\textsuperscript{\textregistered}, both of which use the same geometry package. LAHET transports charged and neutral hadrons and mesons down to user defined cutoff energies, while neutrons below the cutoff are passed to the MCNP code. LCS offers a variety of analysis methods, standard tallies and user defined histogramming capability. This paper will review recent advances in the codes, user interfaces, and data libraries, particularly as they relate to medium energy accelerator applications. Further information may be found on the LCS Web page:
http://www-xdiv.lanl.gov/XTM/lcs/lcs-dir.html

2 MCNP
The Monte Carlo N Particle (MCNP) version 4a \cite{mcnp2} was released to RSIC on October 4, 1993. Improvements to the code include the following \cite{mcnp3}:
- PVM Multiprocessing \cite{mcnp4}
- X window and color graphics display
- 10 statistical tests for assessing convergence \cite{mcnp5}
- Repeated structures tallies
- Dynamic memory allocation on UNIX systems
- MS-DOS compatibility
- PTRAK data output files \cite{mcnp6}

The estimated release date for MCNP version 4b is October, 1996, and will include the following improvements:
- PVM load balancing/fault protection
- Postscript graphics files on all systems
- Online cross section plotting
- Multigroup adjoint improvements \cite{mcnp7}
- Perturbation capability \cite{mcnp8}
- ITS3 electron/photon physics \cite{mcnp9}

In addition, work is being done on formalizing source biasing techniques, as well as user interfaces to do customized data analysis and histogramming online as a compliment to the current tally procedure \cite{mcnp10}.

A variety of classes for MCNP are now available, and are listed on the Web site:
http://www-xdiv.lanl.gov/XTM/mcnp/mcnp.html
A newsletter is available, along with an internet discussion group, which may be joined by sending email to listserv@pss018.psi.ch, and including the message:
subscribe mcnp-1 [first name, last name]

MCNP complies with a Software Quality Assurance plan that is consistent with both IEEE and ISO-9000 guidelines for SQA.

3 Data
Of particular interest to accelerator applications are the high energy libraries now available for MCNP. ENDF/B-VI libraries for MCNP were released in the Fall of 1994 \cite{mcnp11}. Within this release are several nuclides with data above the traditional 20 MeV limit:
- \textsuperscript{1}H to 100 MeV
- \textsuperscript{nat}C to 32 MeV
- \textsuperscript{127}I to 30 MeV
- \textsuperscript{165}Ho to 30 MeV
- \textsuperscript{197}Au to 30 MeV
- \textsuperscript{241}Am to 30 MeV
A new MCNP data library known as 100XS [12, 13] contains continuous energy neutron cross sections up to 100 MeV for the following materials:

\[ ^9\text{Be}, ^{12}\text{C}, ^{16}\text{O}, ^{27}\text{Al}, \text{Si}, ^{40}\text{Ca}, \text{Fe}, \text{W} \]

Multigroup neutron and/or proton cross sections may also be used for these materials to 100 MeV in MCNP versions having multigroup and BFP capability. A major effort to upgrade libraries to 150 MeV is now underway for the APT project, and will be described below.

Photon and electron data are available from 1 keV to 100 GeV (photons), and 1 GeV (electrons).

### 4 Justine™

Demand has been growing for a graphical user interface for MCNP and other codes maintained by the Transport Group at Los Alamos. Justine [14] is such a GUI, which allows the user to define geometries via constructive solid geometric operations on three dimensional objects. Through menu driven options the user can also input all parameters needed to build an MCNP output file. MCNP itself can be run through the Justine interface, and output displayed.

The new automatic variance reduction program AVATAR™ [15] is also implemented through Justine. Weight windows are an important variance reduction technique which involve setting upper and lower particle weight limits within a cell, and a particle will be split or Russian Roulette if its weight is outside the limits. This weight function is continually modified as the problem proceeds, and thus is particularly sensitive to the initial function input by the user. The procedure is meant to direct particles toward the most probably phase space path from the source to a tally. AVATAR (Automatic Variance And Time of Analysis Reduction) uses an approximate adjoint solution from a three-dimensional deterministic code calculation (THREEDANT™) to design the initial weight function. The forward calculation then proceeds as usual with MCNP, which continually modifies the weight function via the standard weight window generator. Justine prepares the THREEDANT spatial grid, converts results to MCNP weight windows, and runs both codes without any intervention of the user. The user need only set up the forward MCNP problem.

### 5 LAHET

The current version of LAHET is 2.81, which will be considered frozen (except for correction of obvious errors) until the work described in the next section is completed. We anticipate the full release of LAHET to RSIC in 1996.

The following improvements have been included in latest version of the code [16]:

1. **Variance Reduction**: Cell-wise importances, as used in MCNP, have been adapted for LAHET. Separate importances can be implemented for muons, if desired.

Roulette/splitting has long been present in LAHET for neutrons written to the file which is passed to MCNP, controlled by the user defined variable SWTM (neutrons with weight less than SWTM are killed with probability (1-weight/SWTM), all others are kept and given weight SWTM). The new scheme further weights the neutrons written to the interim file by the inverse of the importance of the cell. Similar modifications have been made to the weight controls already present for decaying pions and emerging muons.

2. **Nucleon-Nucleus Elastic Scattering [16]**: A new elastic scattering model has been implemented in LAHET for neutrons above 15 MeV and protons above 50 MeV. Previously elastic scattering was limited to neutrons below 100 MeV with the Bechetti-Greenlees potential. The new model is a modification of the HERMES code [17]. It includes a complete rewrite of the sampling algorithm for the center-of-mass scattering angle, and the elastic cross section data has been replaced from 50 to 400 MeV with a global medium-energy nucleon-nucleus phenomenological optical model potential. HERMES data has been kept above 400 MeV. Below 50 MeV there is no elastic scattering implementation for protons, and HERMES data is used for neutrons.

The optical potential is based on a relativistic Schrodinger representation using the proton optical potential of Schwant et al. as a starting point. Cross sections for 9 mass values and 20 energies are tabulated in LAHET, and interpolations made to other masses.

3. **Secondary Multiple Scattering**: A user defined parameter now controls whether multiple scattering is applied to all particle, or just primaries.

4. **User Hook**: A set of user routines is now available which links to the standard LAHET code. These may be used for online data analysis and histogramming techniques not available in the current HTAPE analysis routines.

5. **HMCNP**: A new code, TRANSM, may be used to process LAHET output into MCNP "surface source read (SSR)" RSSA files. Such files may be read by any recent version of MCNP, thereby eliminating the need for the special HMCNP version.

6. **New Tally Options** Two new edits have been added to the LAHET analysis routine HTAPE. A collision rate edit will tabulate all collisions,
neutron elastic scattering, or non-elastic events. This edit may also be used to generate a CINDER90 removal rate input file.

The second new edit produces spectra of total recoil energy, neutron elastic recoil energy, total damage energy and neutron elastic damage energy. The mean weight of recoiling fragments, damage energy, and energy per fragment is also produced. The damage energy $U$ comes from a parameterization of the Lindhard function: $U = E + E_L(E)$, where $E$ is recoil energy. This edit is primarily used for materials damage studies.

6 APT

The immediate task of the Accelerator Production of Tritium program is to design, build and test critical components of the proposed accelerator. Baseline parameters currently are 1000 MeV 200 mAmp machine, where beam is incident on a lead-Tungsten target. Neutrons provided by this source will be moderated in $D_2O$, and capture on $^3He$ to produce tritium. A machine of this intensity makes severe demands on the accuracy of simulation codes involved in its design, and a program to upgrade the LAHET Code System is now underway. It is estimated that it will take three years to complete the major components of this effort.

One element of the program is a complete merger of LAHET with MCNP. This will enable the user to take advantage of the extensive MCNP variance reduction techniques, source description, and convergence tests. It also eliminates the need for large interim files now present in LCS. Where library data is not present the LAHET physics routines will be substituted. The code will be highly modular so that new routines can be easily implemented, and the whole will be controlled through the Justine GUI.

Another element of the program is the generation of continuous energy data libraries for neutrons and protons up to the pion threshold (about 150 MeV). Data for all isotopes of approximately 26 elements will be generated using FKK-GNASH formalism, and the merged MCNP/LAHET code modified to read new data formats and perform charged particle transport. The present physics contained in LAHET is not adequate for energies below 150 MeV, and the development of the libraries is given high priority.

Improvement of physics in LAHET is also anticipated, primarily through the continuation of the Optical Model work discussed above. This work will affect items such as total cross section in the LAHET code, as well as the independent library generation. Improved nuclear masses will also be added to the code. Other improvements will take place as funding allows.

7 References

REFERENCES
