

Tracking neutrons with FLUKA

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**Workshop on modern methods using fast neutrons for
research related to the transmutation of nuclear waste**

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Description of FLUKA

- FLUKA is a general purpose Monte Carlo tool for calculations of particle transport and interactions with matter
- Applications:
 - cosmic ray physics
 - accelerator design (LHC systems)
 - particle physics: calorimetry, tracking and detector simulation etc. (ALICE, ICARUS)
 - neutrino physics (CNGS)
 - shielding design
 - dosimetry and radioprotection
 - space radiation (space related studies partially funded by NASA)
 - hadron therapy (treatment planning, in-beam PET monitoring)
 - neutronics
 - ADS systems (Energy amplifier)
- Maintained and developed under INFN-CERN agreement

FLUKA collaboration

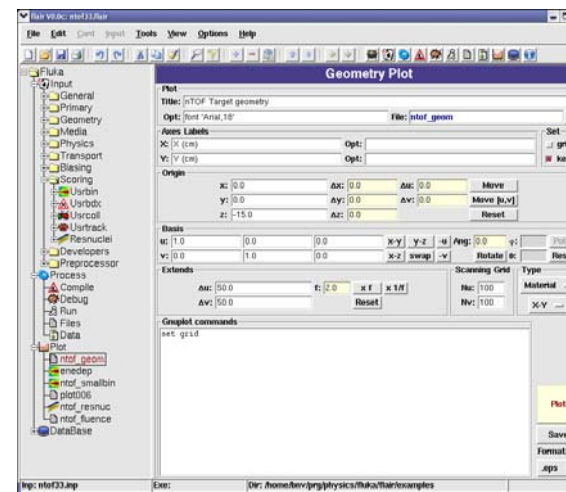
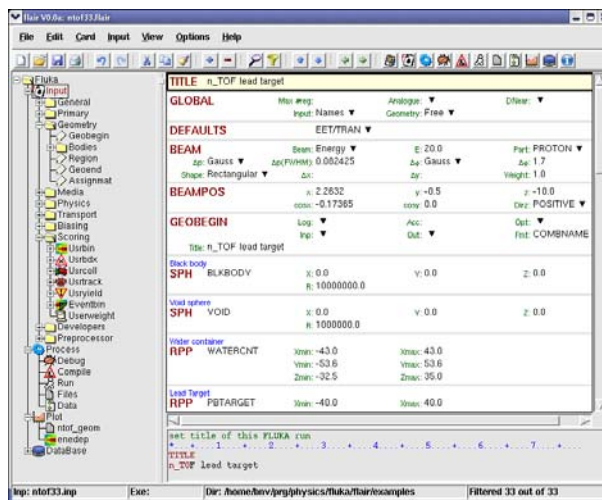
- **CERN (Switzerland)**: M. Brugger, F. Cerutti, A. Ferrari, M. Mauri, G. Lukasik, S. Roesler, L. Sarchiapone, G. Smirnov, F. Sommerer, C. Theis, S. Trovati, H. Vinke, V. Vlachoudis
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- **Univ. of Siegen (Germany)**: J. Ranft
- **INFN & Univ. Milano (Italy)**: G. Battistoni, F. Broggi, M. Campanella, P. Colleoni, E. Gadioli, S. Muraro, P.R. Sala
- **INFN Frascati**: M. Carboni, C. D'Ambrosio, A. Ferrari, A. Mostacci, V. Patera, M. Pelliccioni, R. Villari
- **Univ. Roma II (Italy)**: M.C. Morone
- **INFN & Univ. Bologna (Italy)**: A. Margiotta, M. Sioli
- **DKFZ & HIT (Heidelberg, Germany)**: A. Mairani, K. Parodi
- **Univ. of Houston (USA)**: A. Empl, L. Pinsky
- **NASA-Houston (USA)**: K.T. Lee, T. Wilson, N. Zapp
- **ARC Seibersdorf (Austria)**: S. Rollet
- **Chalmers Univ. of Technology (Sweden)**: M. Lantz

Description of FLUKA

- FLUKA handles 60 different particles and Heavy Ions
 - Hadron-hadron and hadron-nucleus interactions up to 10000 TeV
 - Electromagnetic and μ interactions 1 keV - 10000 TeV
 - Nucleus-nucleus interactions 100 MeV/n (with BME: ~ 10 MeV/n) to 10000 TeV/n
 - Charged particle transport – ionization energy loss
 - Neutron multi-group transport and interactions 0-19.6 MeV
 - Neutrino interactions
 - Transport in magnetic field
 - Combinatorial and Voxel geometry
 - Double capability to run either fully analogue and/or biased calculations

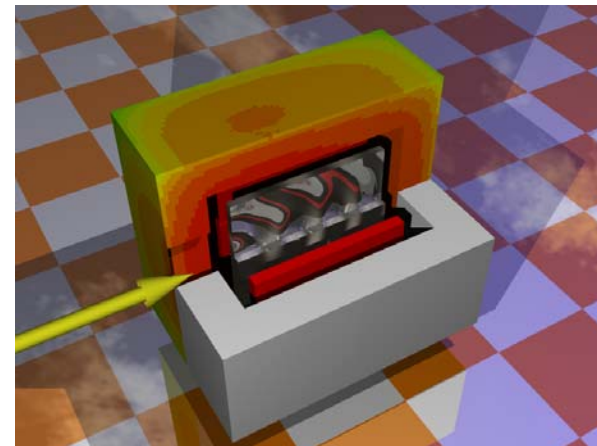
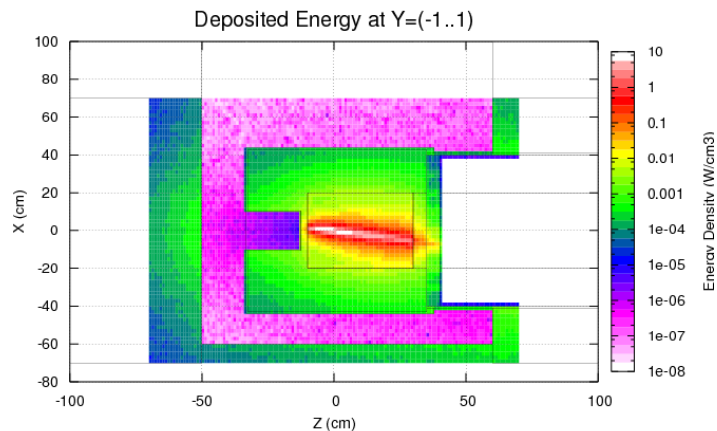
Auxiliary programs: *flair*

- FLUKA has no graphical user interface
- advanced user interface for FLUKA by V. Vlachoudis et al., written in *Python* and *Tkinter*
- facilitates editing of FLUKA input files, execution of the code and visualization of the output files
- download from the FLUKA website but is not part of FLUKA



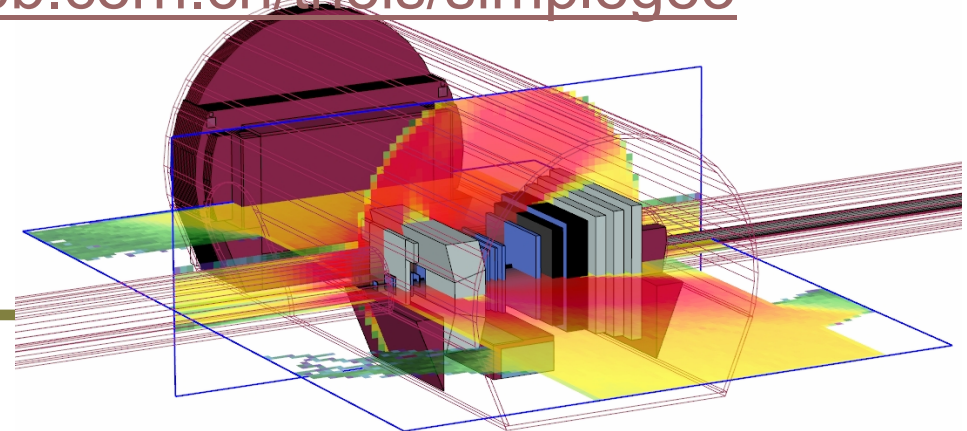
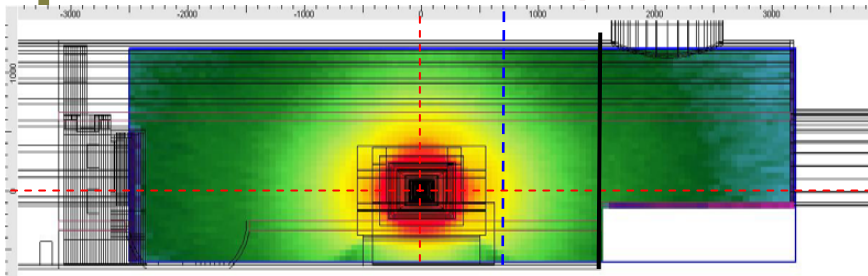
Auxiliary programs: *flair*

- easy editing and validation of the input file
- library of materials and geometrical objects
- debugging, compiling, running and monitoring of the status during a run
- back-end interface for post-processing of the output files and plot generation through an interface to *gnuplot* or 3D photorealistic images with *povray*



Auxiliary programs: *SimpleGeo*

- *SimpleGeo* is an interactive solid modeler which allows for flexible and easy creation of the geometry models via drag & drop, as well as on-the-fly inspection
- Imports existing geometries for viewing
- Creating new geometries from scratch
- Export to various formats (FLUKA, MCNP, MCNPX)
- Download: <http://theis.web.cern.ch/theis/simplegeo>



FLUKA activities

- More than 1000 registered users all over the world
- User support by mailing list: FLUKA experts answer to questions of the users
- Monthly meeting of CERN FLUKA users (presentations, lectures from experts, discussion)
- FLUKA courses:
 - 23-27 June 2008, CERN, Geneva, Switzerland
 - 29 Sep - 3 Oct 2008, NEA, Paris, France
- Further information and download of FLUKA:
 - www.fluka.org
 - Further reading: The physics of the FLUKA code: Recent developments *Advances in Space Research* 40 2007, 1339-1349

Low-energy neutron transport

- Low-energy neutron (<19.6 MeV) transport performed by **multigroup** algorithm
- Widely used in low-energy neutron transport codes
- Energy range of interest is divided in a given number of discrete intervals “energy groups”
- Elastic and inelastic reactions simulated not as exclusive process, but by group-to-group transfer probabilities (down-scattering matrix)
- Advantage: multigroup treatment is faster than pointwise treatment, needs less memory

Present neutron library

General description

- The library contains 140 different materials/isotopes
- Both fully biased and semi-analog approaches available
- Energy range up to 19.6 MeV divided in 72 energy groups of approximately equal logarithmic width, one group is thermal
- Continuously enriched and updated on the basis of the most recent evaluations (ENDF/B, JEF, JENDL, etc.)
- Prepared using a specialized code (NJOY, Los Alamos) and auxiliary programs
- Neutron energy deposition calculated by means of kerma factors

Present neutron library

Additional features

- Cross sections of some materials are available at 2 or 3 different temperatures (0, 87 and 293 K) + Doppler broadening
- Hydrogen cross sections available for different types of molecular binding (free, H₂O, CH₂)
- H recoil protons, protons from $^{14}\text{N}(n,p)$ and $(\alpha, ^3\text{H})$ from neutron capture in ^6Li and ^{10}B can be produced and transported explicitly
- **Pointwise cross sections** are available only for reactions in H, ^6Li , ^{10}B , Ar, Xe, Cd

Residual Nuclei

- For many materials group-dependent information on the residual nuclei produced by low-energy neutron interactions is available in the FLUKA library
- This information can be used to score residual nuclei

Gamma generation

- Gamma generation by low energy neutrons also treated by a multigroup scheme
- gamma transport like all other gammas in FLUKA
- A downscattering matrix provides the probability, for a neutron in a given energy group, to generate a photon in each of 22 gamma energy groups
- Actual energy of photon sampled randomly in energy interval corresponding to its gamma group
- Exception: few important gamma lines, 2.2 MeV transition of Deuterium and 478 keV photon from $^{10}\text{B}(n,\gamma)$ reaction, all ^{40}Ar lines, capture lines for Cd and Xe

Work within EFNUDAT

- Present approach is sufficient for many applications, fast, good results
- However, there are some shortcomings:
 - Only one thermal group
 - Groupwise treatment not adequate when simulating cases where resonance effects are important
 - Self shielding isotopes have to be processed separately
- To overcome the limitations two steps:
 - Step 1: new groupwise neutron library: latest data files, more groups, several thermal groups,...
 - Step 2: new library with pointwise cross sections (execution time much slower)

Comparison old and new library

1st Step: Groupwise treatment

Old library	New library
Up to 19.6 MeV	Up to 20.0 MeV
72 neutron groups, 1 thermal	260 neutron groups, 31 thermal (30 upscatter groups)
22 gamma groups	42 gamma groups
140 different materials/isotopes	About 200 materials/isotopes at 87K and 296K
Self-shielding for Fe, Cu, Pb	Self-shielding for most isotopes

2nd Step: Pointwise treatment

Few isotopes

all isotopes

Producing groupwise library

- Evaluated nuclear data files (ENDFB-6.8, ENDFB-7.0, JEFF-3.0, JENDL-3.3, ENDL-78) are processed by NJOY (Los Alamos).
Steps in NJOY:
 - Reconstruction of pointwise cross sections from ENDF resonance parameters and interpolation schemes
 - Doppler broadening of pointwise cross sections
 - Calculation of self-shielded pointwise cross sections
 - Calculation of heating, kerma, radiation damage
- Output of NJOY:
 - Neutron scattering/absorption cross section files
 - Gamma production file (if data available)
 - Charged particle production cross section (if data available)

Producing groupwise library

- The output files of NJOY are further processed to produce binary and auxiliary files with matrices of downscattering/upscattering/gamma production, kerma factors and partial cross sections for residual nuclei production
- Consistency checks
- Files containing isotopes are summed up to elements of natural composition
- Implementation in FLUKA
- Testing, benchmarking
- New groupwise library will be available for the FLUKA users in the next FLUKA release: scheduled for summer 2008

Status

- Processing with NJOY almost finished
- About 95% of the materials/isotopes are processed
- Remaining problems are some isotopes/materials for which NJOY crashes, will (hopefully) be fixed in the next 2-3 weeks
- Work on consistency checks has started (will take several weeks)
- When consistency checks are finished: production of final library, implementation into FLUKA, can be done fast
- Afterwards work on pointwise library will start

Summary

Purpose of the work

- implementation of new neutron libraries in FLUKA
- First step: improvement of present groupwise treatment
- Second step: implementation of a library with pointwise treatment

Status

- work on groupwise treatment is far advanced
- New library (groupwise) will be ready for the next FLUKA release which is scheduled for begin of summer

Outlook

- After the release work on pointwise treatment will start



Thanks for the attention