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MINERVA: A Multimodality Plugin-based Radiation Therapy Treatment Planning Environment

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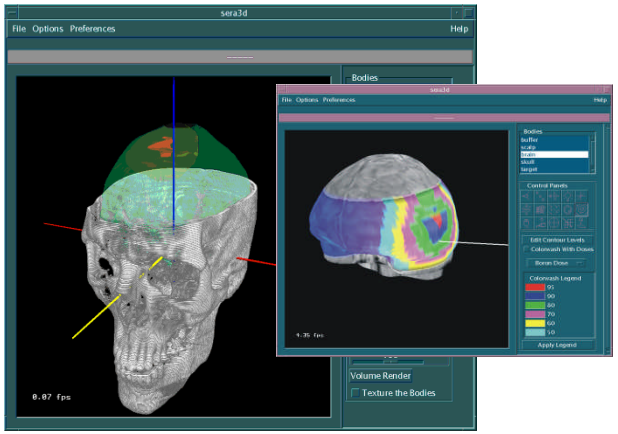
Overview

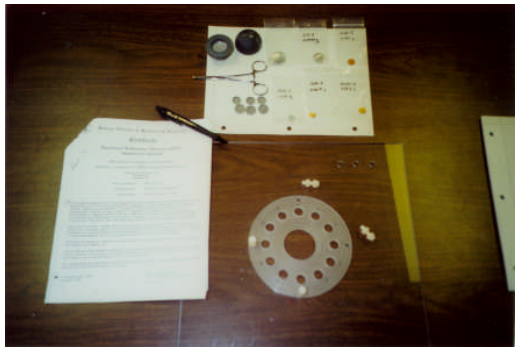
- ***Introduction***
  - ***MINERVA background and history***
  - ***Goals and philosophy***
- ***Description of code modules***
- ***Progress to date***
- ***Future plans***

INL Advanced Radiotherapy Program

Key Historical Components

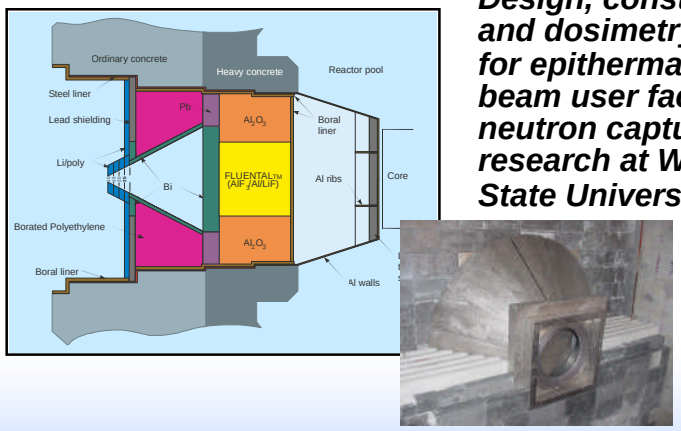


Development of advanced software for computational medical dosimetry

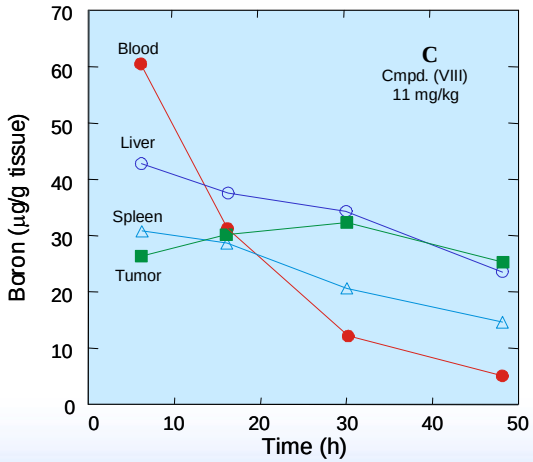


Development of advanced methods for medical neutron dosimetry

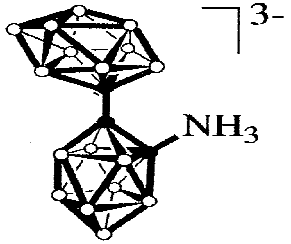
Research collaboration with University of Washington for development of neutron capture enhanced fast-neutron therapy



Design, construction, and dosimetry support for epithermal neutron beam user facility for neutron capture therapy research at Washington State University



M. F. Hawthorne, et al., *Proc. Natl. Acad. Sci. USA* Vol 91, pp. 3029-3033, April 1994



Biochemical analysis and preclinical testing of advanced boron agents for neutron capture therapy

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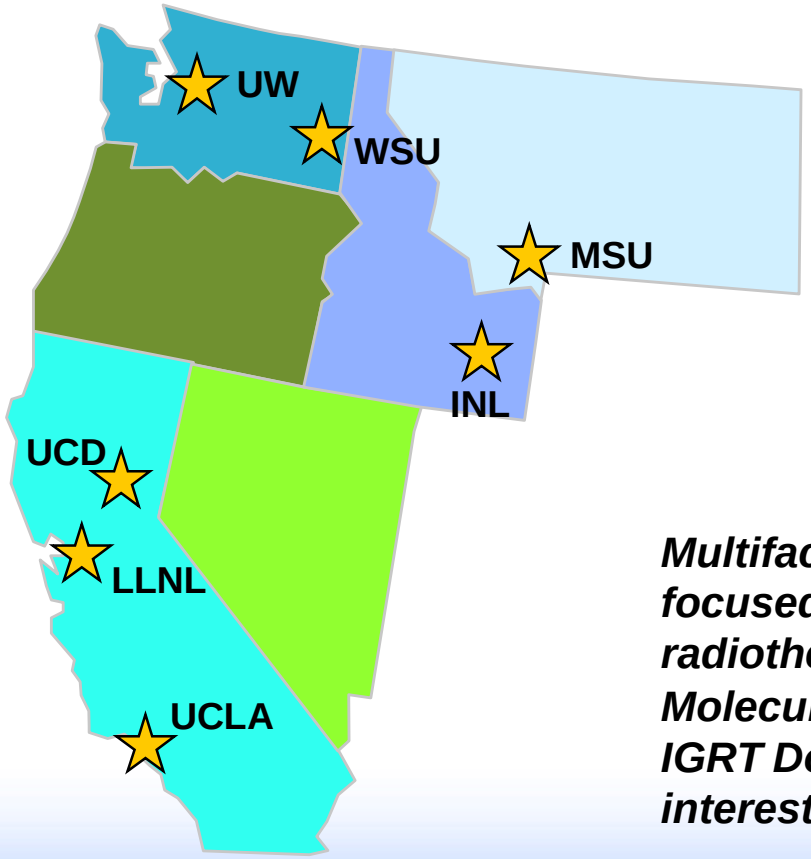
Northwestern Collaboration in Advanced Radiotherapy

Principal Investigators:



D. W. Nigg, C. Wemple (INL)
D. E. Wessol (MSU/INL)
P. R. Gavin, J. Fidel (WSU)
G. E. Laramore (UW)
C. Hartmann-Siantar, J. Lehmann (LLNL)
M. F. Hawthorne (UCLA)
G. DeNardo, J. Purdy(UCD)

Multifaceted set of institutional interrelationships focused on the development of emerging forms of radiotherapy with Neutron Capture Therapy (NCT), Molecular Targeted Radionuclide Therapy,and IGRT Dosimetry as current primary areas of interest.

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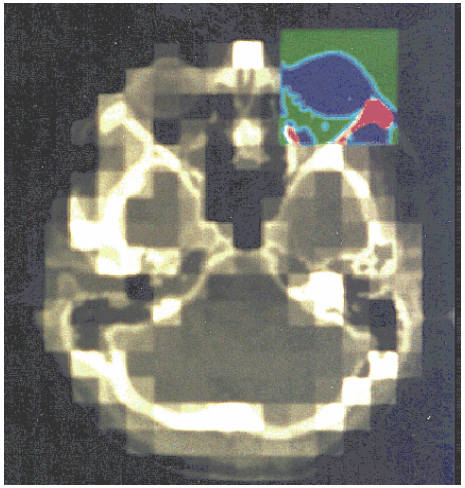
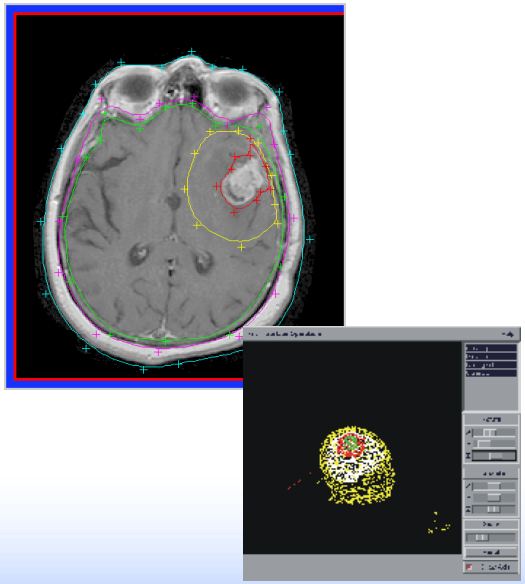
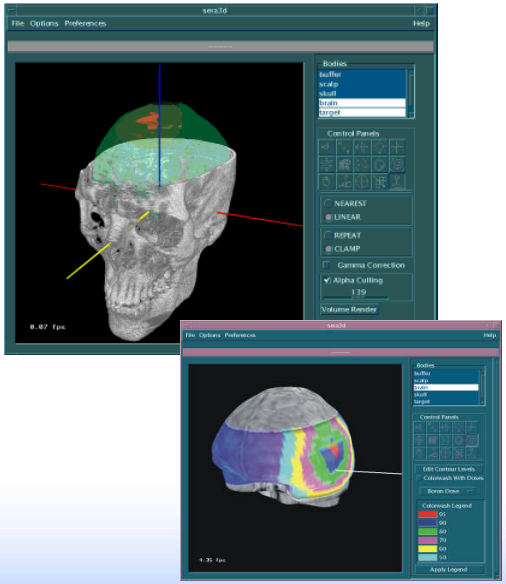
Medical-Image-Based Treatment Planning for Neutron Therapy/BNCT

Voxel-Reconstruction Method	*Surface-Reconstruction Method*	*Pixel-Reconstruction Method*
NCT-PLAN	*BNCT_rtpe*	*SERA*
MIT/Harvard	*INL/MSU*	*INL/MSU*







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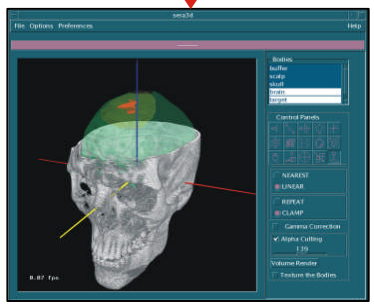
SERA - An Advanced System for Computational Dosimetry and Treatment Planning of Neutron Radiotherapy

Medical Image Input

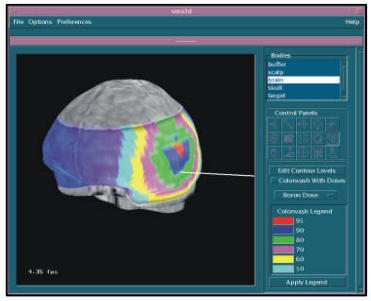


Geometric Reconstruction

- ***Medical image modality independent.***
- ***Medical image based geometric reconstruction and Monte Carlo flux and dose computational algorithm are fully-integrated on a pixel by pixel basis.***
- ***Single-CPU computation times on the order of a few minutes per field for neutrons.***
- ***Optimized for fast-neutron therapy and neutron capture therapy.***
- ***Licensed worldwide for neutron applications. Freely available via RSICC at ORNL beginning in 2005.***

Radiation Transport Computation

Radiation Source file



Dose Display

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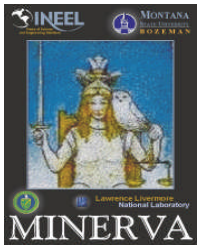
MINERVA - Modality INclusive Environment for Radiotherapeutic Variable Analysis



Patient-Specific Graphic User Interface Modules (GUI)

Image Processing

Anatomical Modeling

Treatment Plan Development

Plan Reporting and Archiving

Modality Specifications

Patient-Centric Control Module

Open Data Base

Particle Delivery System Modeling Tool Kits

External Beams

Targeted Internal Radionuclide

Future Sources

Application Programmer's Interface

Computational Modules and Transport Modality-Specific Basic Data

Targeted Radionuclides & External Beam Photon/Electron

Neutron Radiotherapy and NCT

Alternate Future Transport Modality
e.g. Protons

Alternate Future Transport Modality
e.g. MCNP or S_n/P_n

Introduction to MINERVA

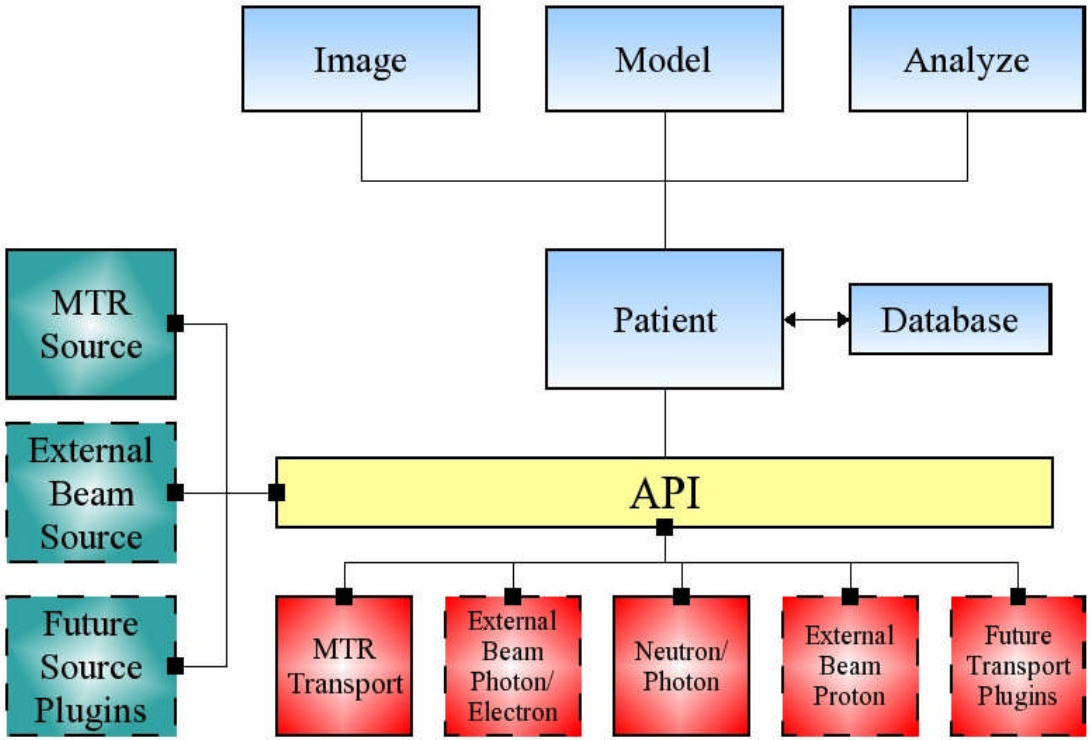
- ***Generalized, multiple modality treatment planning system***
- ***Patient-centric planning system***
- ***Emerging forms of radiotherapy (e.g., MTR)***
- ***Compare different radiotherapy modalities with common planning tools***
- ***Evaluate combinations of modalities***
  - ***Example: external beam photon with brachytherapy boost***

Background

- *Joint development venture between INL, MSU, LLNL, UC-Davis*
- *INL/MSU – experience with NCT treatment planning systems and neutron MC*
- *LLNL – experience with clinical photon-electron MC transport code development*
- *UC-Davis – clinical experience, MTR, IGRT*
- *Driving forces behind MINERVA*
  - *Lack of planning tools for emerging radiotherapies*
  - *No tools allow combinations of modalities*
  - *No tools allow self-consistent comparisons*

MINERVA System Design

- ***Fully Java-based***
- ***Openly-published, XML-based API***
- ***ODBC/JDBC compliant database engines***
- ***All external data transfer via XML-based API***
- ***Plugin-based desig***
- ***Univel geometry for models and calculations***
- ***Use of wizards for order-dependent functions***



Univel Geometry

- *Uniform Volume Elements*
- ***RPP solid volume***
  - ***Corresponds to one pixel***
  - ***Height is depth of one image slice***
- ***Requires uniform spacing between images***
- ***Retains full resolution of images***
- ***Flexible geometry model definition***
- ***Allows very fast tracking in MC calculations***

Patient Module Interface

- *Central control module for MINERVA*
- *Provides database connection*
- *Launches and monitors other modules*
- *Creates patient data entries in database*
- *Generates XML files for export*

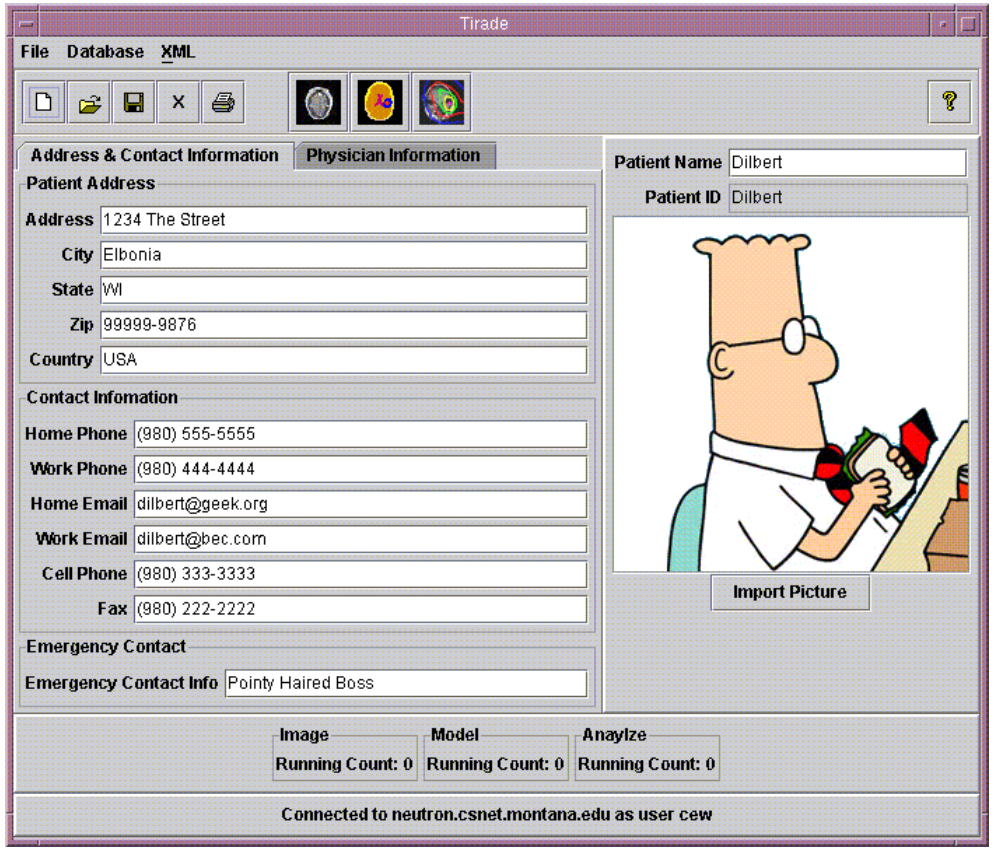


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Image Module Interface

- ***Prepares and processes images***
- ***Import raw, QSH, DICOM-RT, JPEG formats***
- ***Plugin support for additional image formats***
- ***Image processing and filtering functions***
- ***Reslicer – creates uniform slice spacing via interpolation***

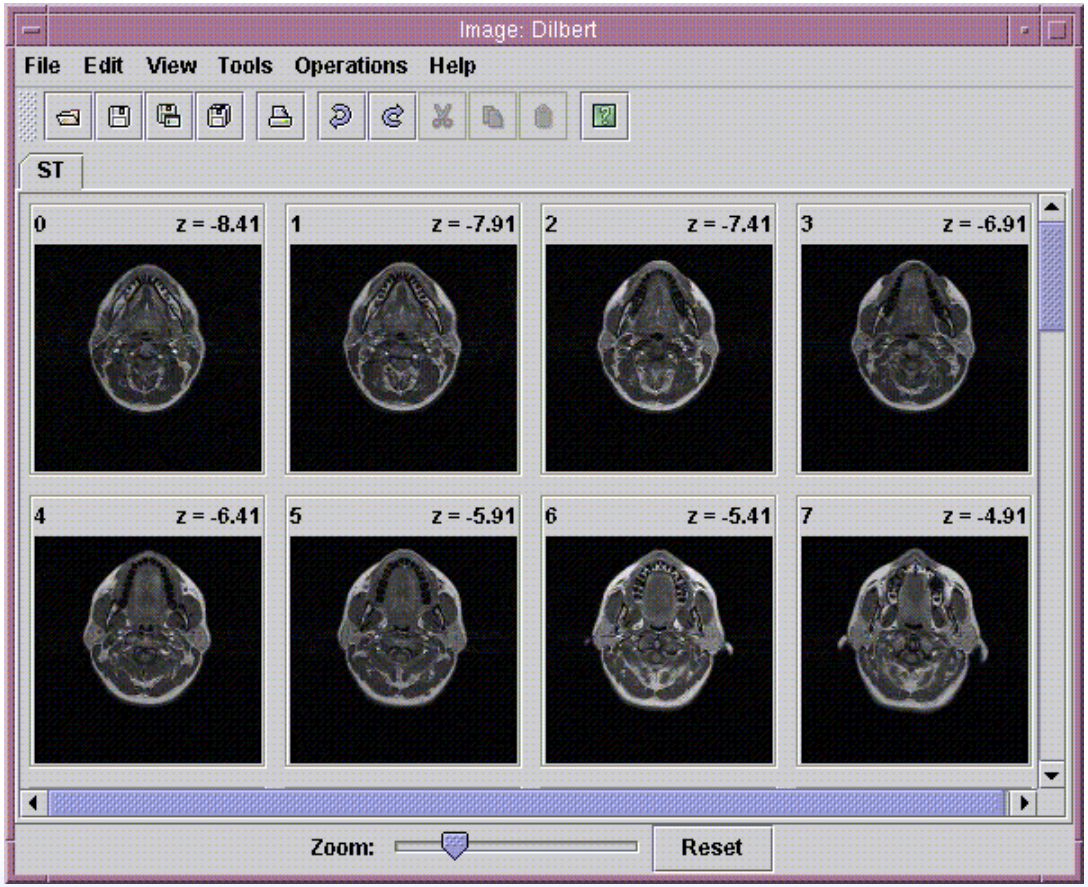
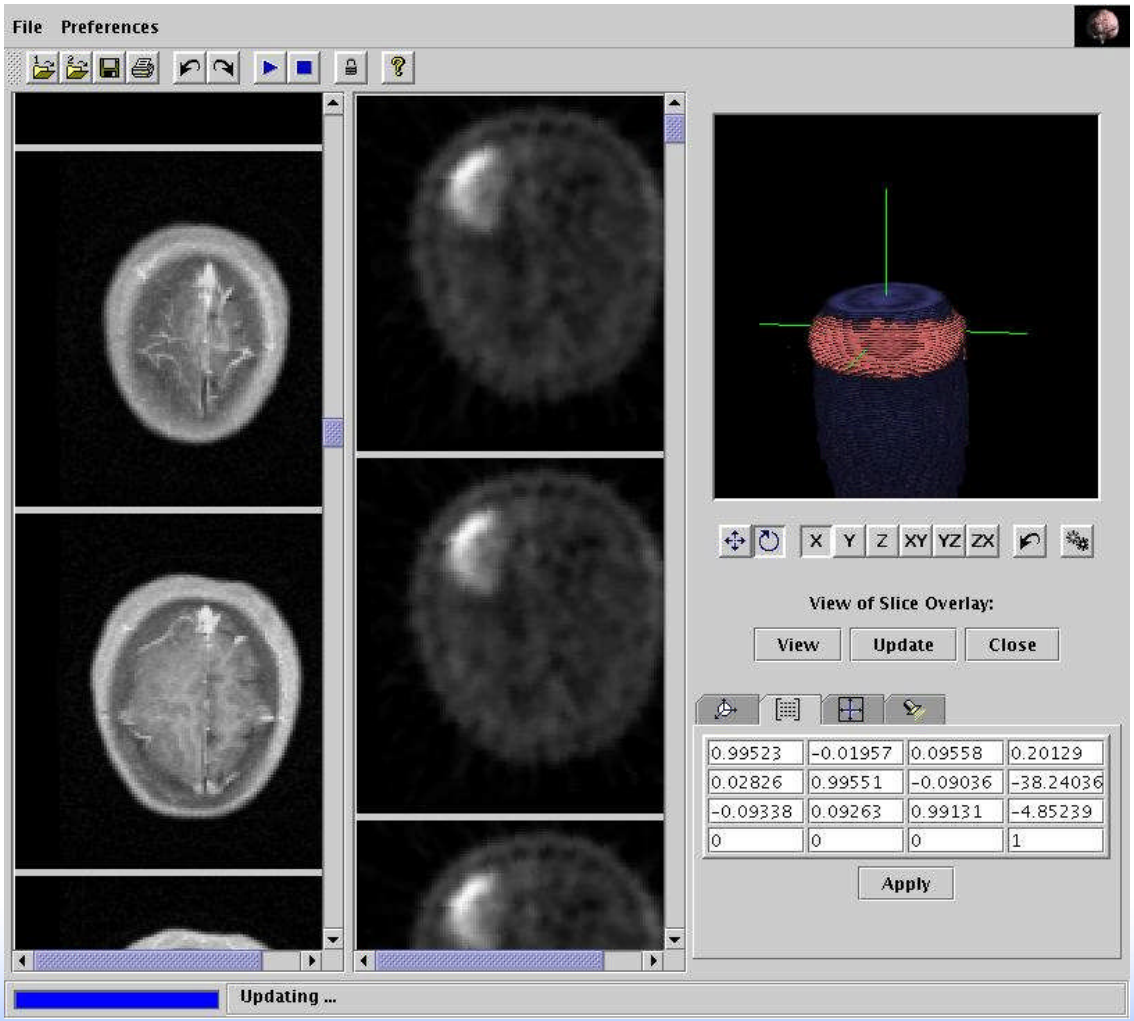


Image Module Registration Tool

- ***Rigid-body registration tool***
- ***Maximization of mutual information (Viola and Wells 1997)***



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Model Module

- *Creates anatomical model of patient*
- *Assignment of materials*
- *Several region definition tools (paint, wand, grow, make margin, etc.)*
- *Multiple image sets may be used*

- *Scripting support – record actions for model reproducibility and to create convenience templates*
- *Plugin support to permit definition of new tools*

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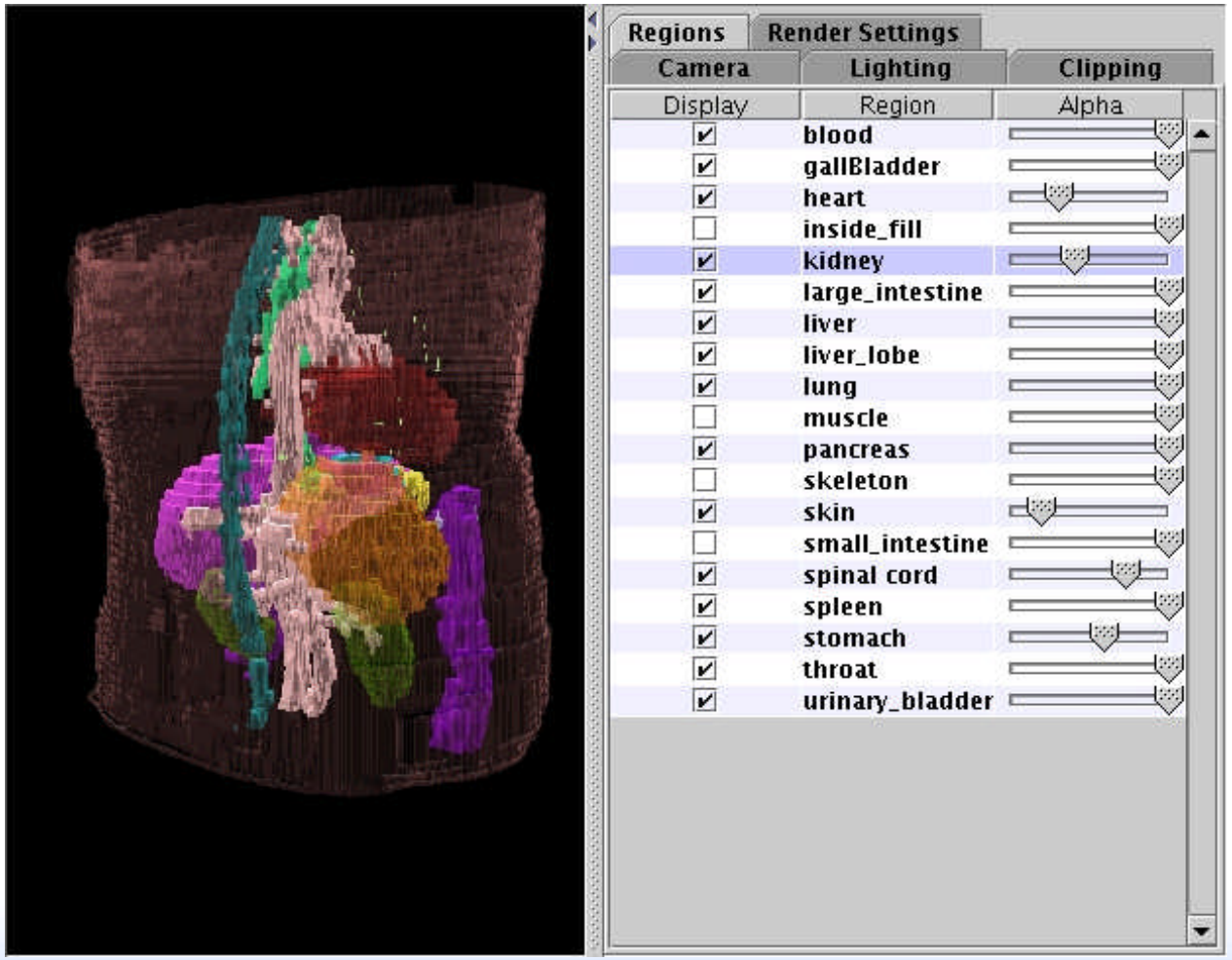
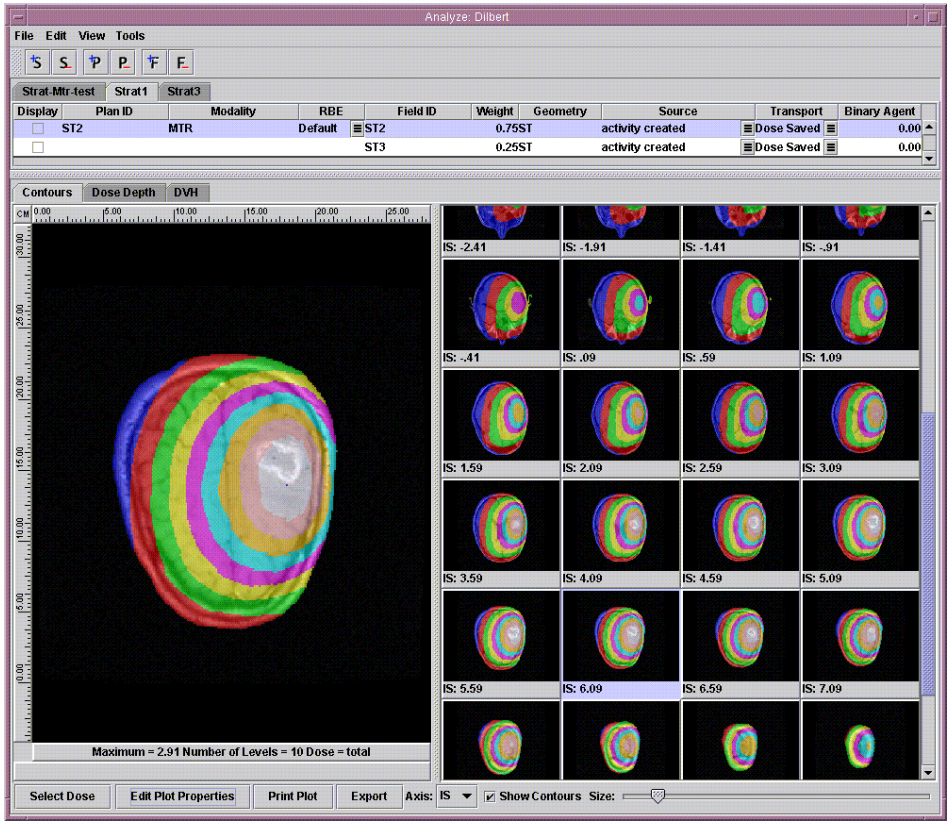
Model Module 3D View

- *3D view of geometry*
- *Real-time display and update*



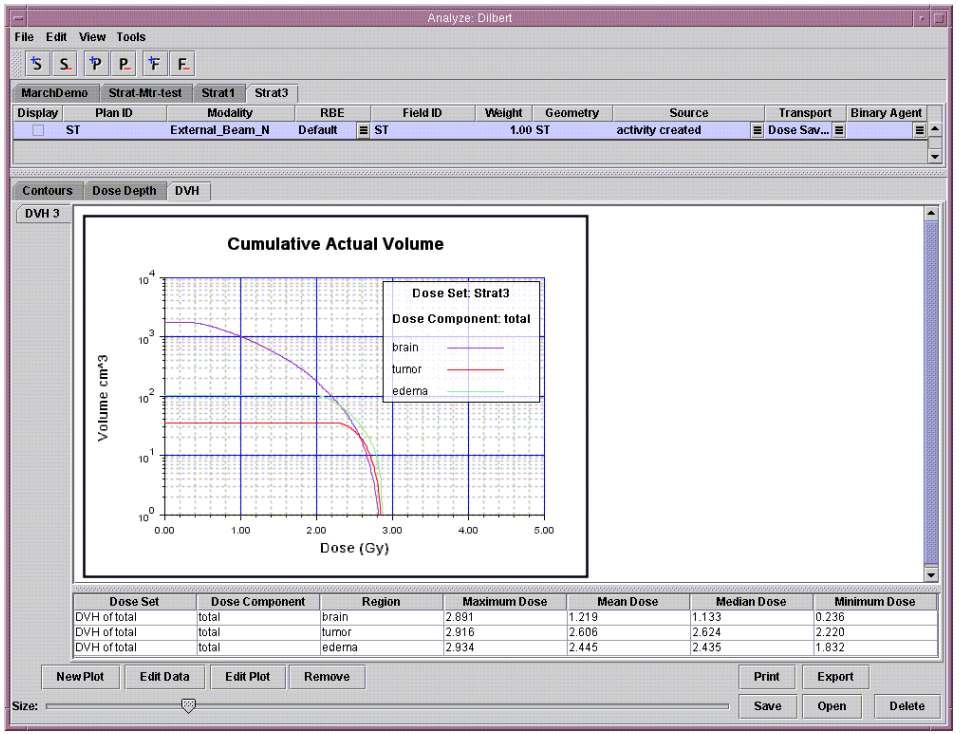
Analyze Module – Isodose Display

- *Dose reporting*
  - *Isodose display on images (contours, colorwash)*
  - *Automatic update of displayed data*
  - *Plugin support permits addition of new plot tools*



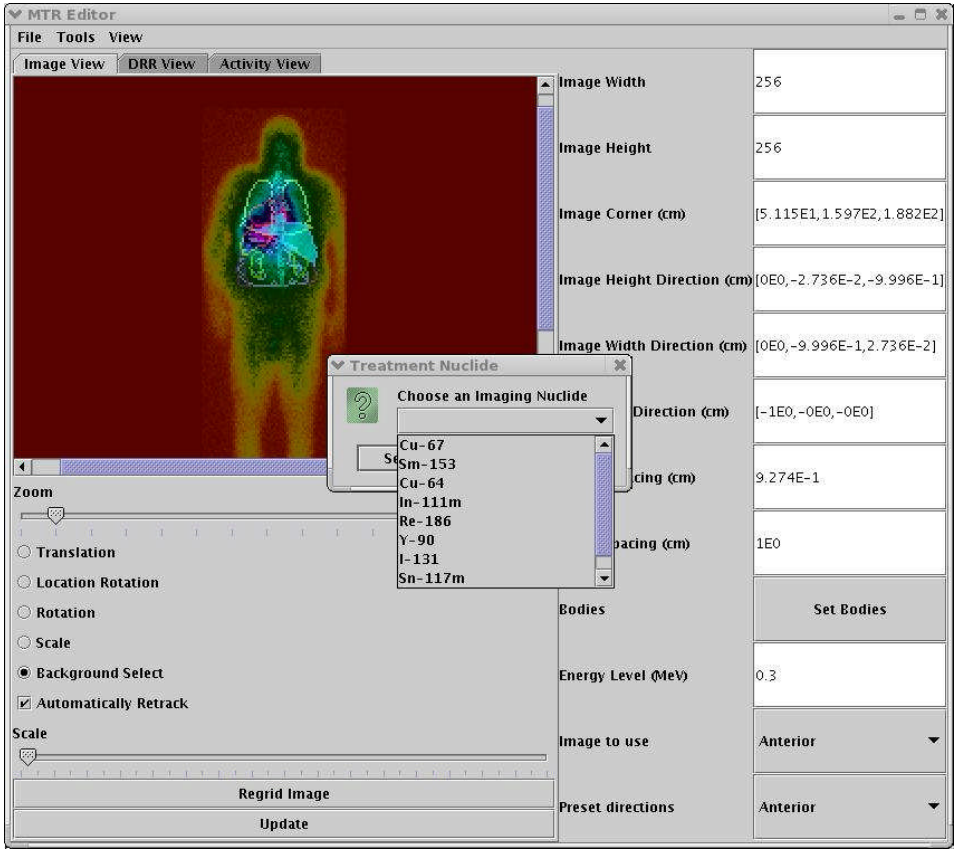
Analyze Module – Data Plotting

- *Dose reporting*
  - *Dose-volume histogram*
  - *Dose-depth plots*
  - *Automatic update of displayed data*
  - *Plugin support permits addition of new plot tools*



MTR Source Plugin Interface

- *Defines 3D internal radiation source for MTR*
- *Calculate from 2D radiographic image*
  - *Select image to use (anterior or posterior)*
  - *Align projected geometry with image*
  - *Calculation of background activity*
  - *Simple attenuated back projection algorithm to assign activity to each univel*
  - *Accounts for overlapping source regions*
- *Assign constant source by region*



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MTR Transport Plugin

- ***PEREGRINE code is computation engine***
  - ***Coupled photon-electron MC transport***
  - ***Single- or multi-threaded execution***
- ***GUI wrapper around PEREGRINE***
- ***Communicates with other modules via API***
- ***V&V effort performed at LLNL and UCD[1]***
  - ***Computational benchmarks***
  - ***Compare to phantom measurements (UC-Davis)***

1.M.A. Descalle, C.L. Hartmann Siantar, L. Dauffy, D.W. Nigg, C.A. Wemple, A. Yuan, G.L. Denardo, “Application of MINERVA Monte Carlo simulations to targeted radionuclide therapy”, Cancer Biotherapy and Radiopharmaceuticals, 18(1):71-80 (2003)

Neutron Transport Plugin

- ***General neutron therapy - NCT, fast neutron, etc.***
- ***Univel geometry***
- ***Coupled neutron-photon MC transport***
- ***Written entirely in Java***
- ***Under development at INL/MSU***
- ***Initial testing of transport algorithm underway (Reported at MC2005, Cogliati and Wemple)***

FY-05 Activities

- *Updated and expanded database functionality*
  - *Improved structure*
  - *Improved data reliability*
  - *Tested new DB engines - PostgreSQL, Derby*
- *Expanded DICOM-RT support*
- *Testing ITK (Insight Segmentation and Registration Toolkit) integration*
- *caBIG compatibility effort (Crucial for NIH)*
- *Developing deformable registration method*

FY-05 Activities (2)

- ***Analyze module improvements***
  - ***More intuitive strategy/plan/field creation***
  - ***Expanded plotting capabilities***
    - + ***Compare multiple curves w/basis curve***
    - + ***Display results for strategies, plans, or fields***
- ***Continued JART (Java-based neutron transport code) development***
- ***Developed on-line help system***
- ***Generic installation wizard***

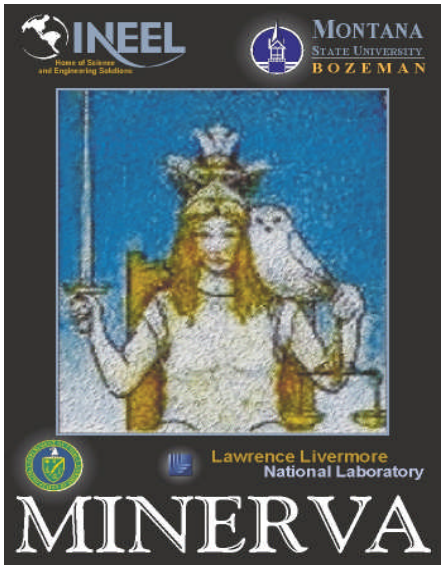
FY-05 Activities (3)

- *Code cleanup*
  - *Removed unused code segments*
  - *Reformatted source code*
  - *Fixed remaining known bugs*
  - *Documentation*
    - *User's manual*
    - *Developer's manual*
    - *Javadoc*
- *Licensing – Open Source Model*

Future Plans

- ***Refinement of common modules***
- ***Complete development and testing of MTR and neutron transport plugins, Initiate IGRT plugin.***
- ***Additional transport and source plugins (brachytherapy, external beam, proton)***
- ***Deformable registration***
- ***Data visualization (2D and 3D)***
- ***Alpha test version of full system planned for 2006 (Pending FY-06 DOE-SC Funding)***
- ***Beta test version planned for 2007 (NIH Proposal)***

Thank you for your attention!



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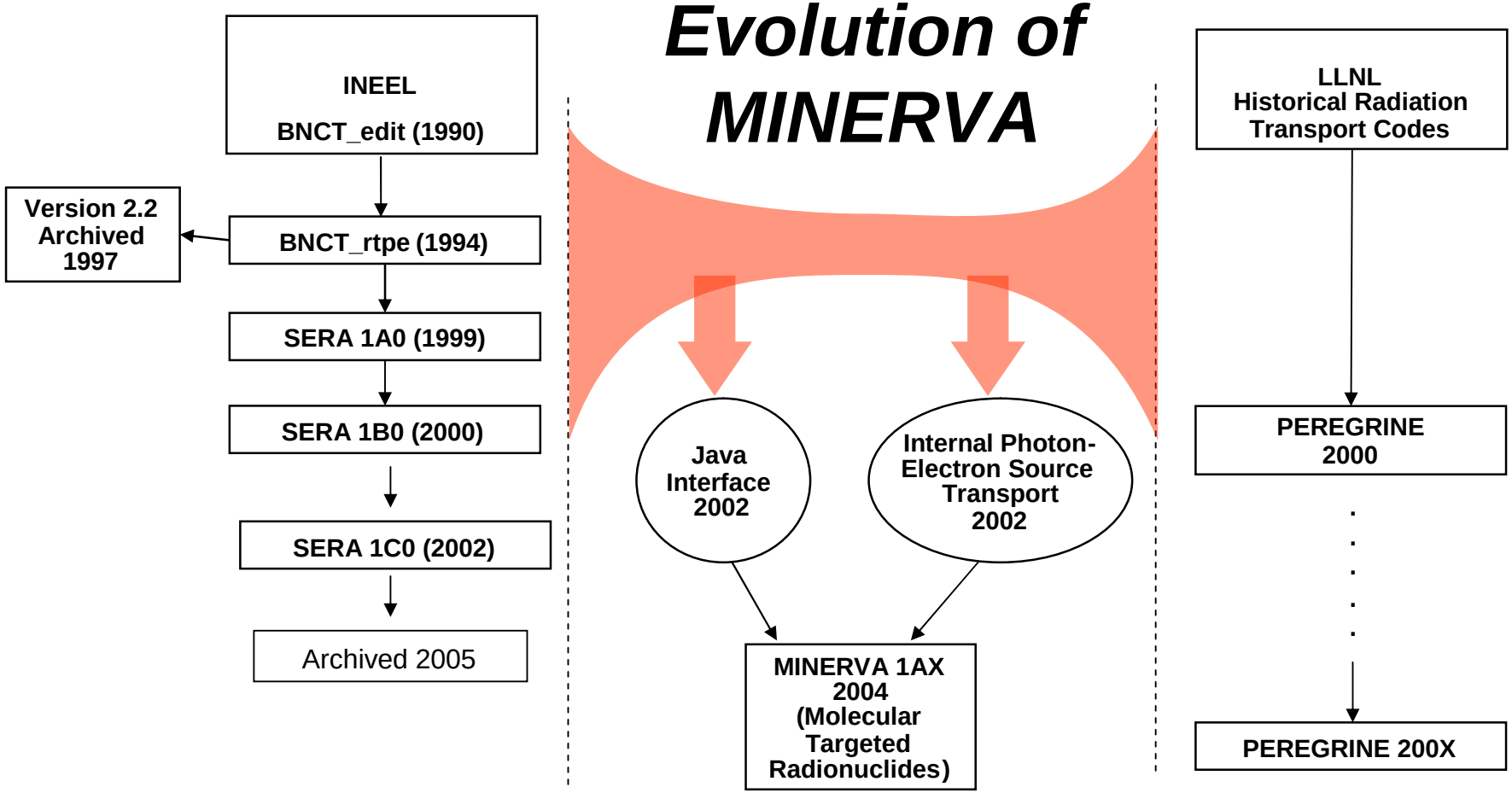
Evolution of MINERVA



Neutron Therapy

Photon/Electron Therapy

Multi-Modality

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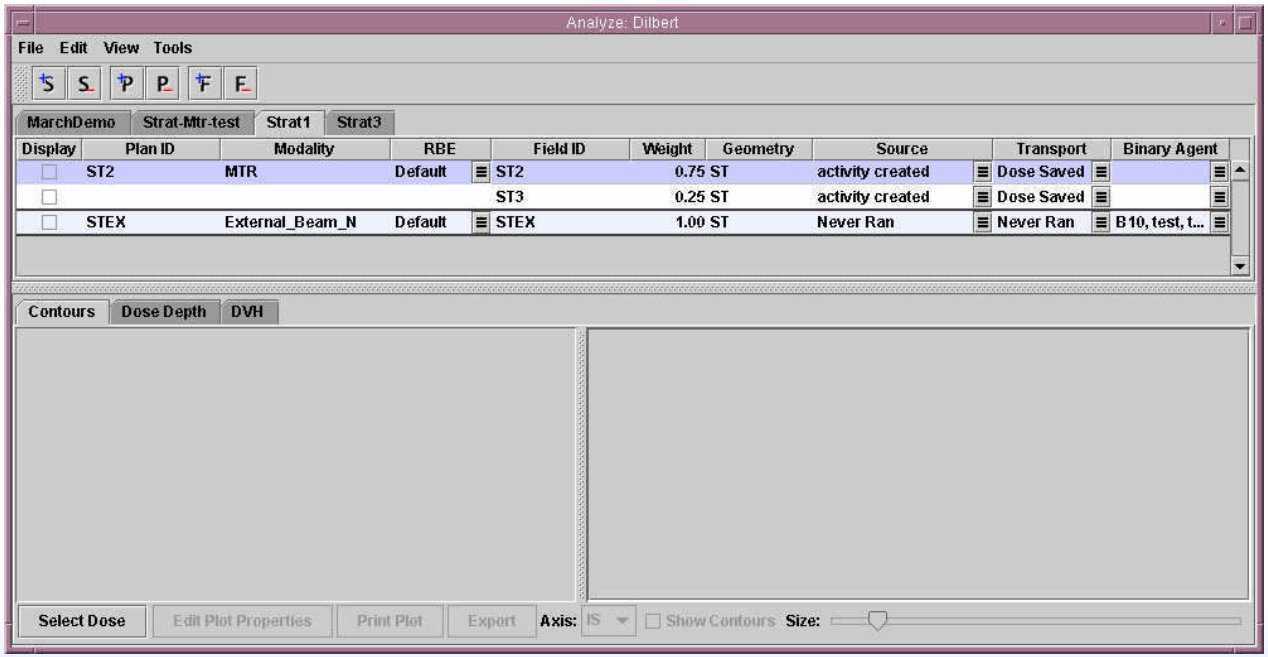
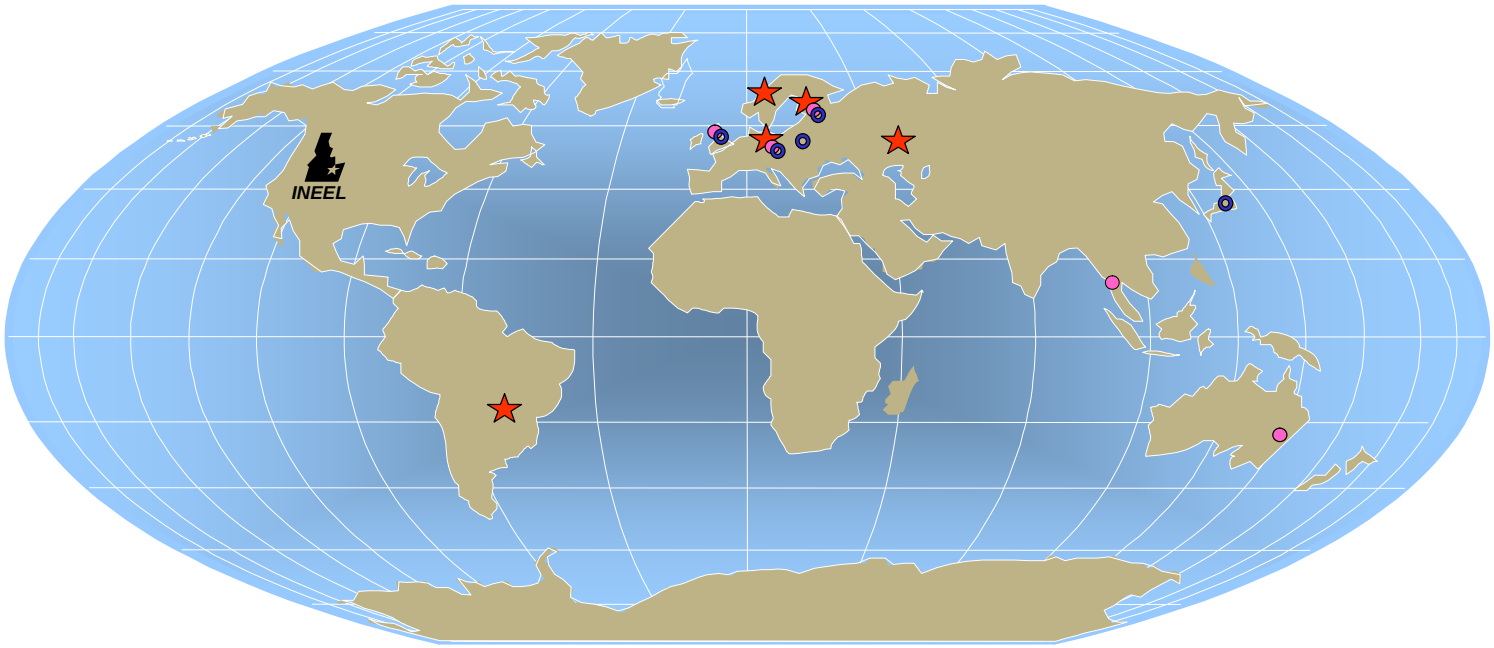
Analyze Module Interface

- *Plan creation*
  - *Launch source and transport plugins*
  - *Input RBE values and binary agent concentrations*
  - *Weighted combination of doses*



International Collaborations



- ★ *Major active collaborations (Finland, Netherlands, Sweden, Argentina, Russia)*
- ● *Personnel exchanges (Australia, Thailand, United Kingdom, Netherlands, Finland, Argentina)*
- ◎ *Software licensing and support (Finland, Sweden, Netherlands, Argentina, Japan, United Kingdom, Russia, Germany)*