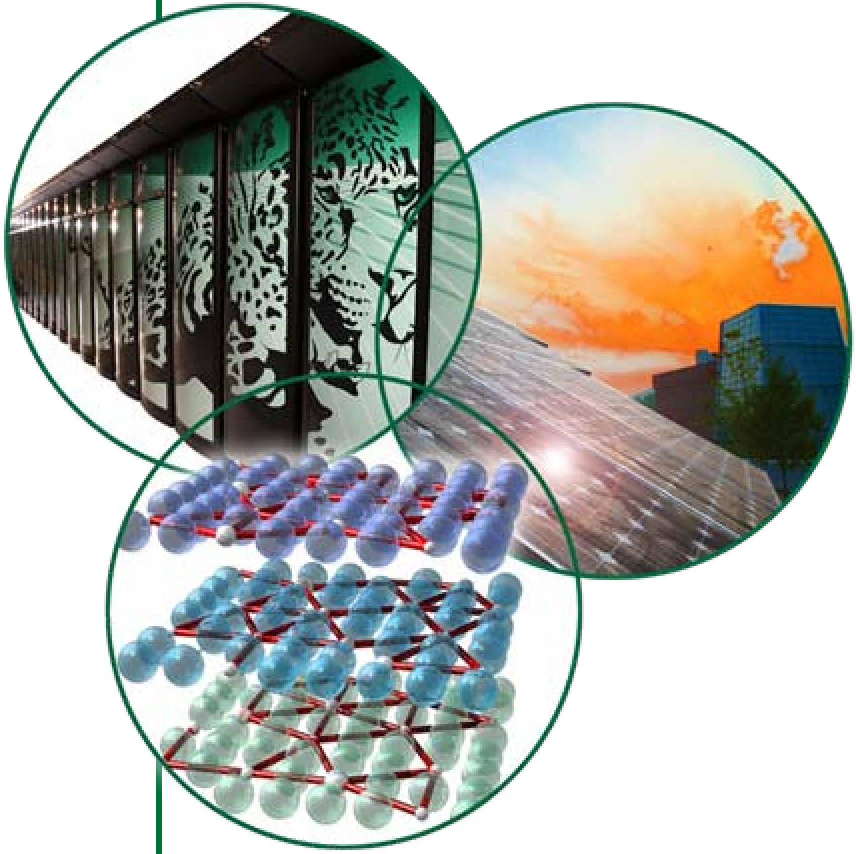
The SNS in the Viewpoint of Users of Spallation models



Benchmark of Spallation Models

October 7, 2009

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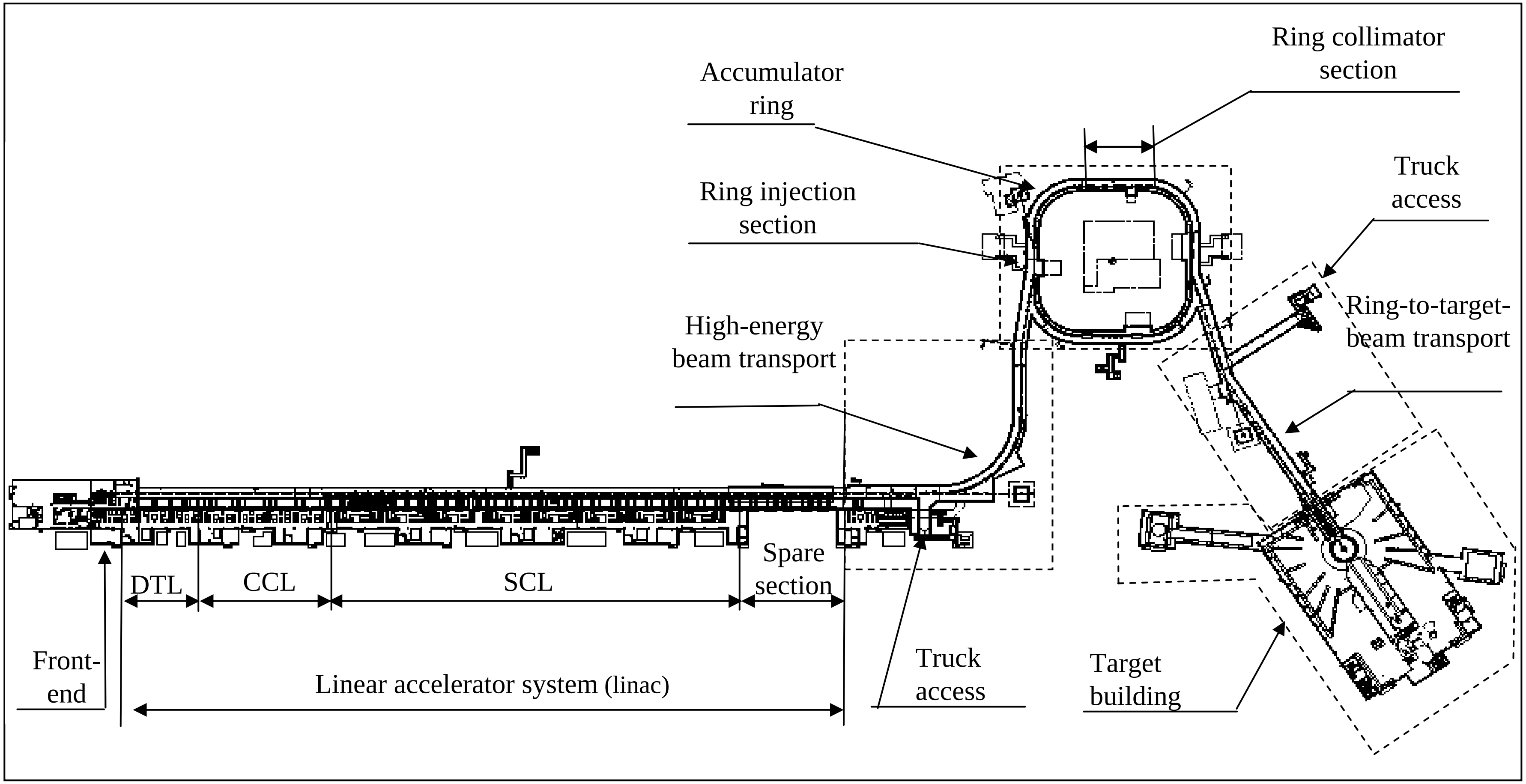
U.S. DEPARTMENT OF ENERGY

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

Outline

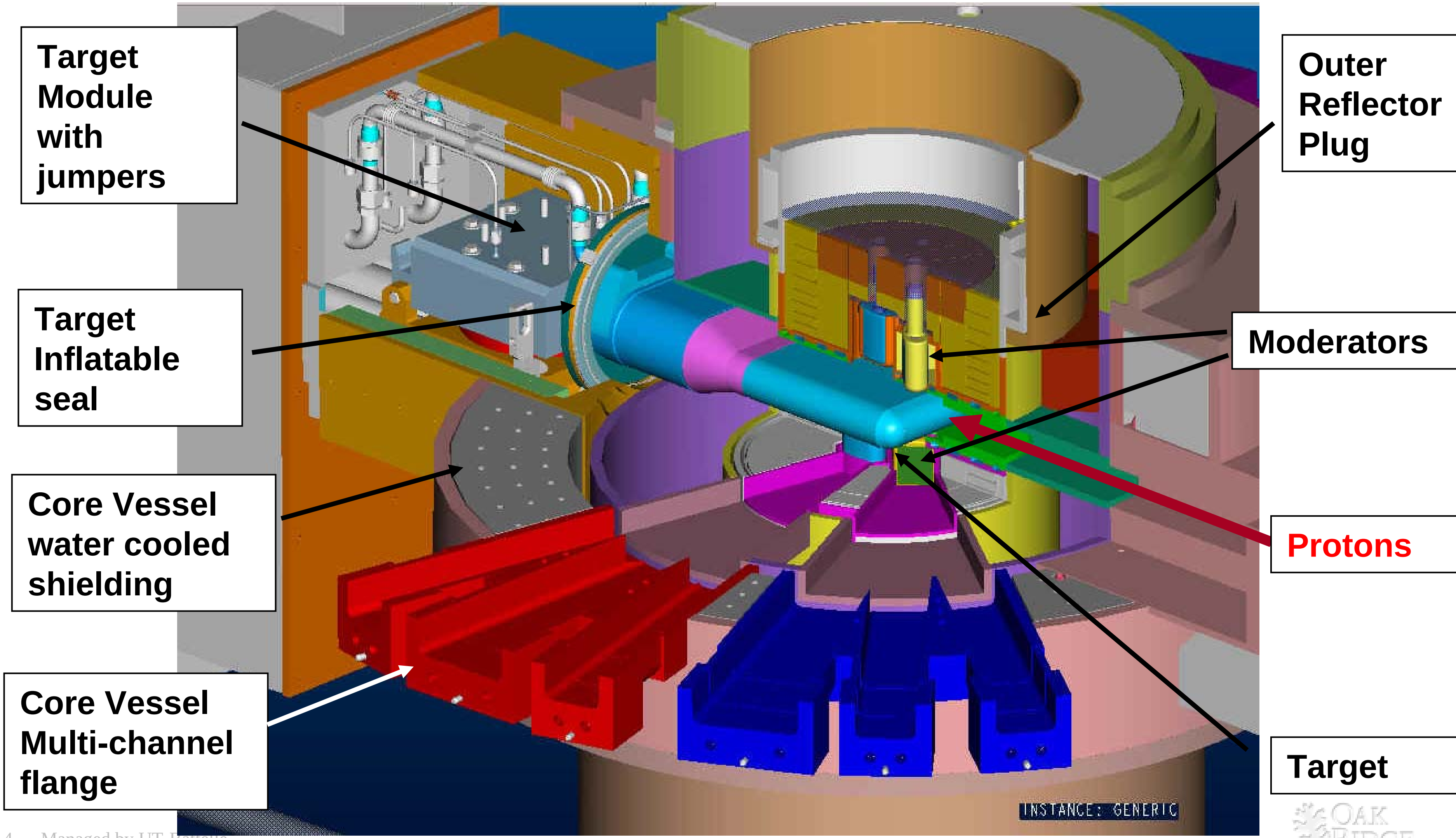
- SNS facility
- Application of SNS neutronics analyses
  - Moderator neutron performance
  - Radionuclide Inventory
  - Shielding
  - Residual radiation fields
  - Material damage
  - Energy deposition
- Which MCNPX physics to use?
- Uncertainties in transport analyses
- Who are the users?
- User's different interest in benchmark

SNS Setup

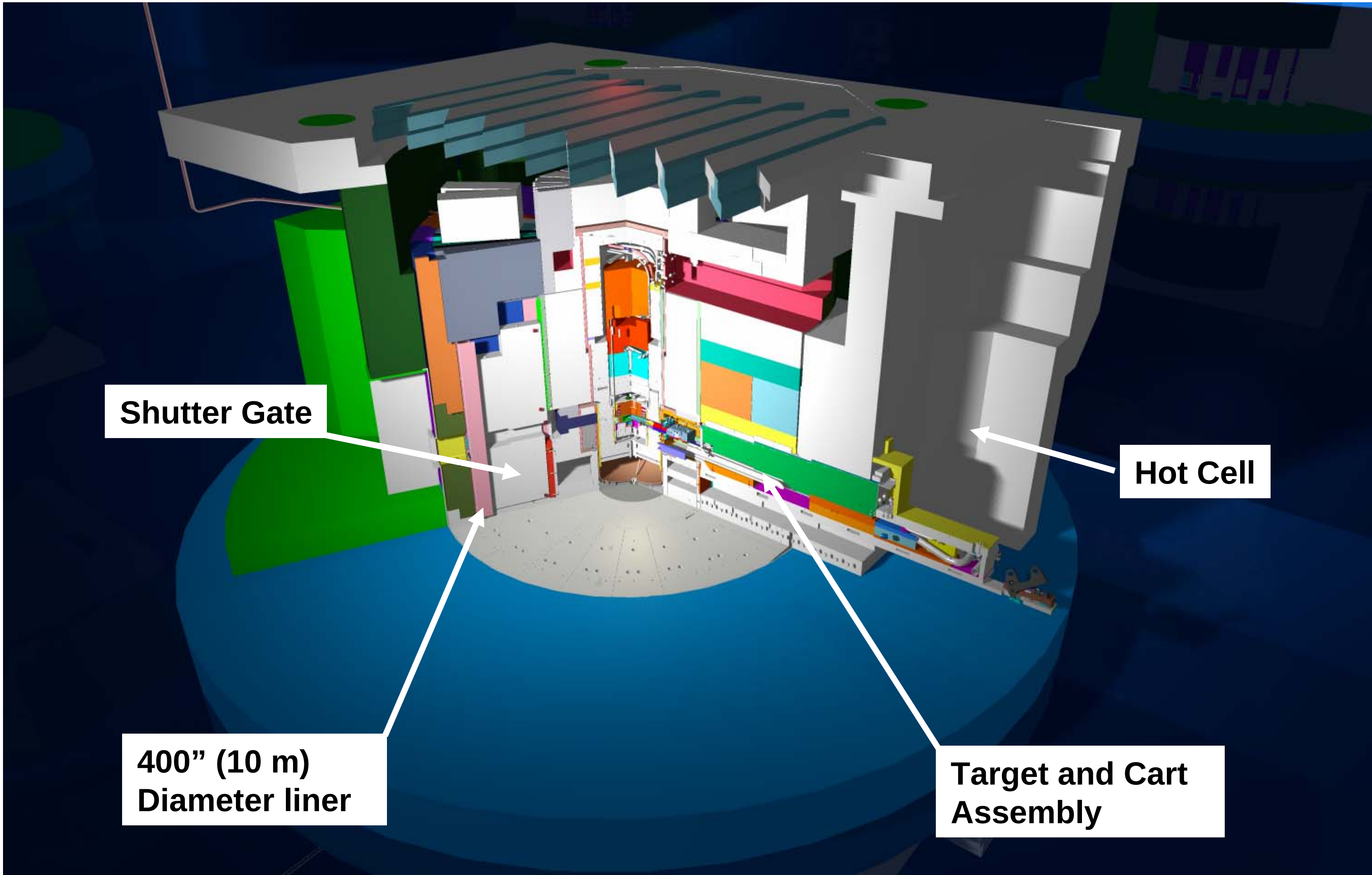


Accumulator ring
Ring collimator section
Ring injection section
Truck access
Ring-to-target-beam transport
High-energy beam transport
DTL
CCL
SCL
Spare section
Front-end
Linear accelerator system (linac)
Truck access
Target building

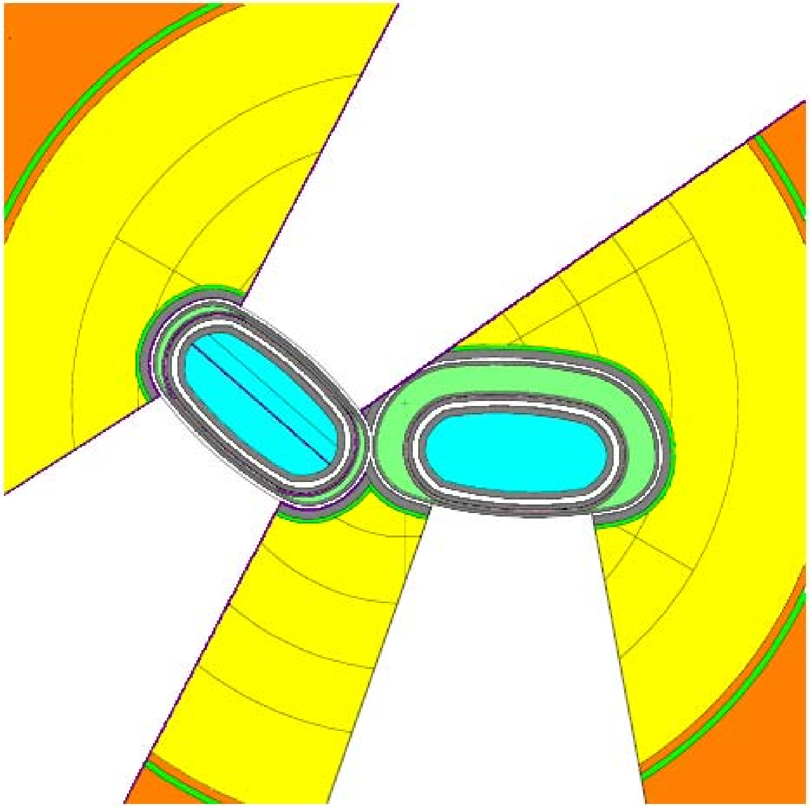
Target Region within Target Monolith



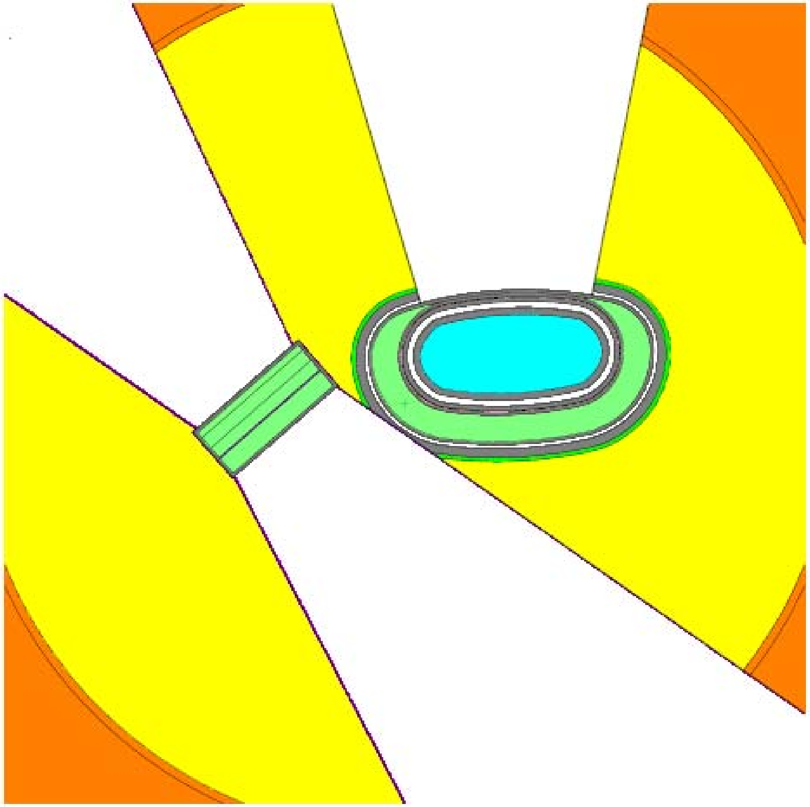
The Target Monolith
(designed and being built at Oak Ridge National Lab.)



Neutron Performance Calculations

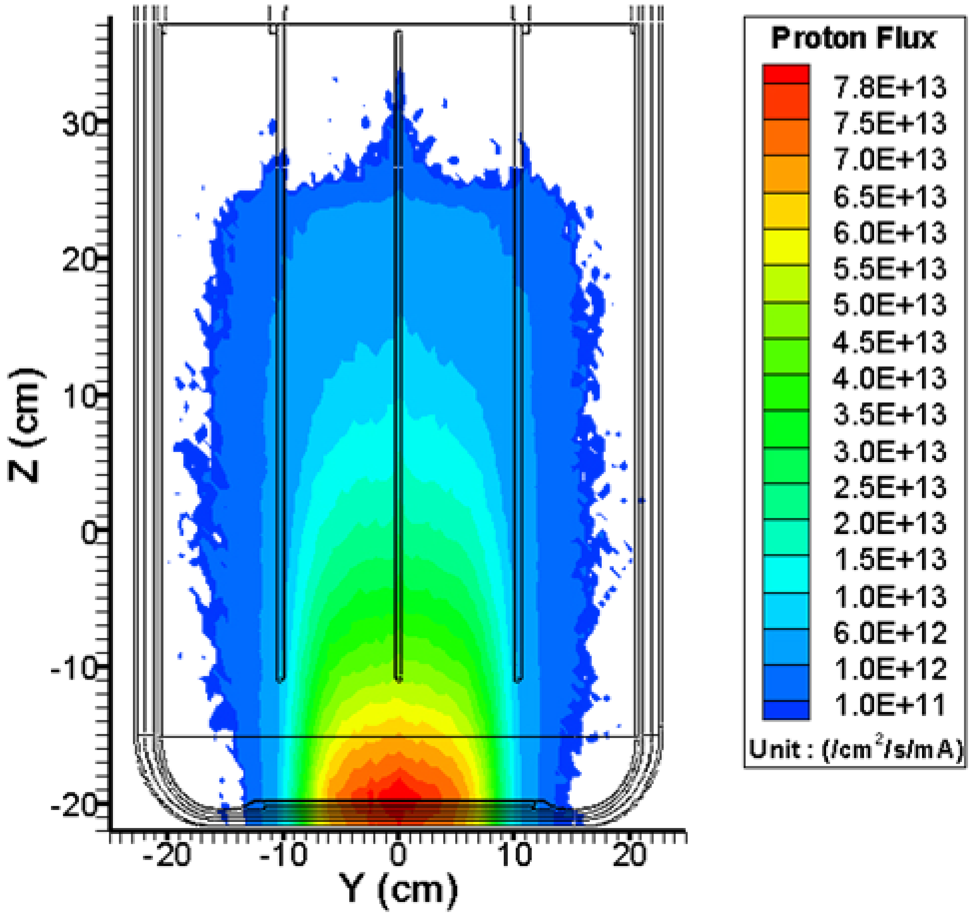


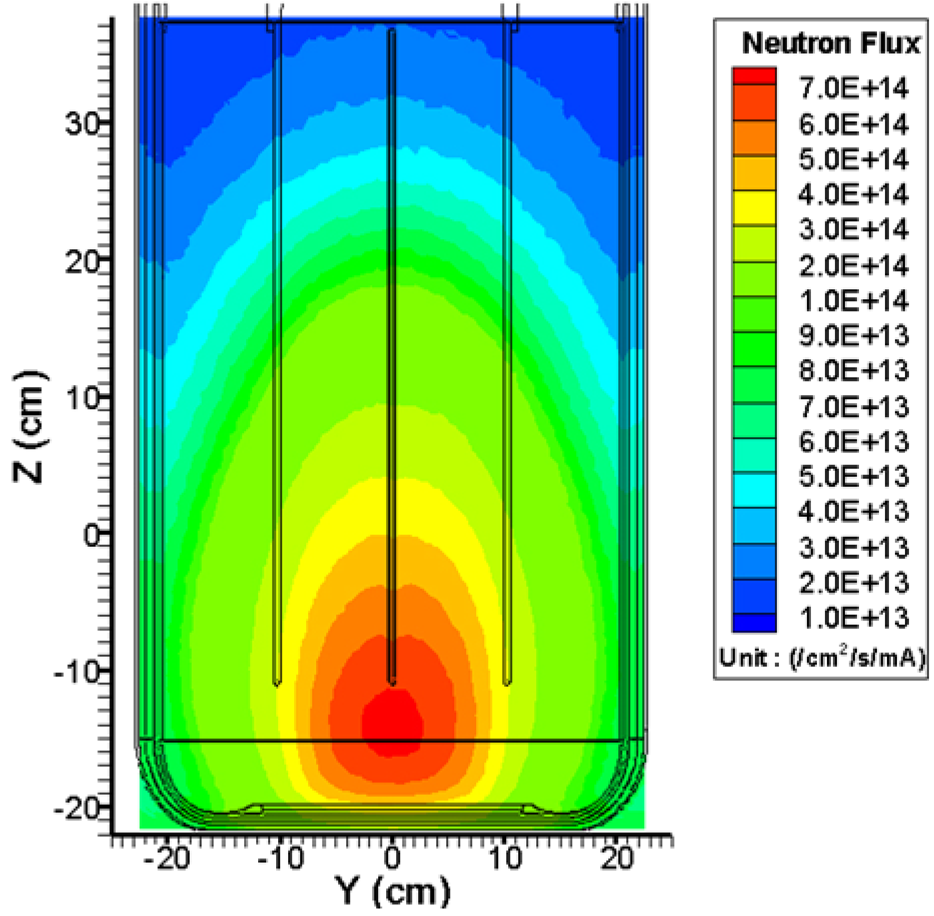
(a) Top Moderators



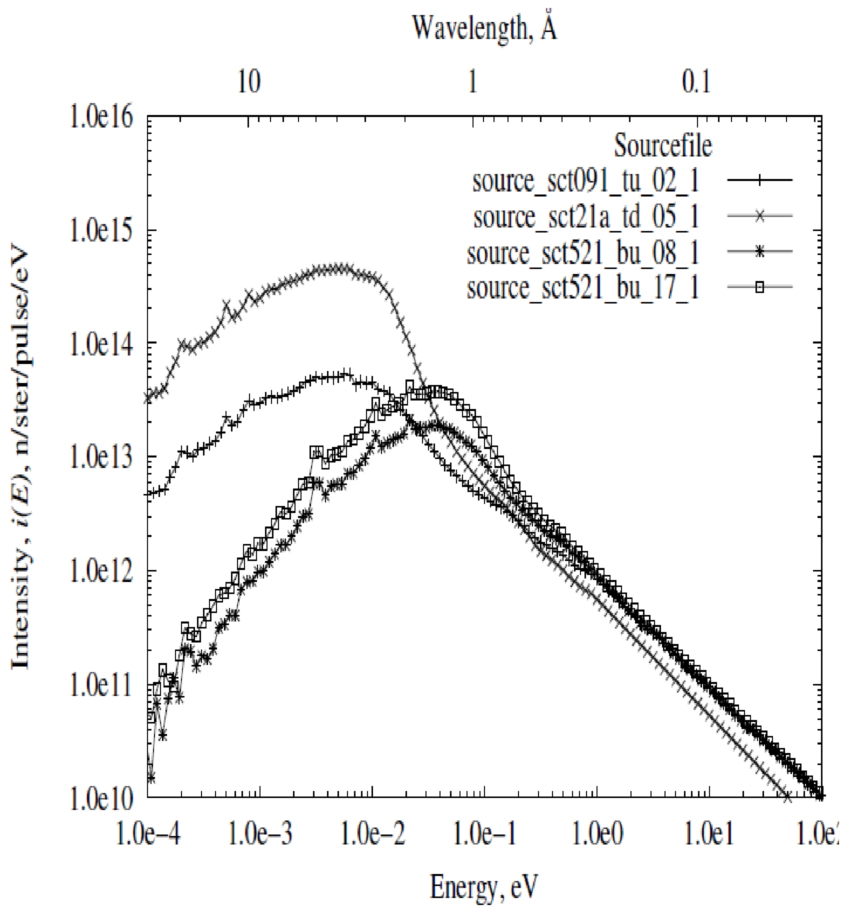
(b) Bottom Moderators

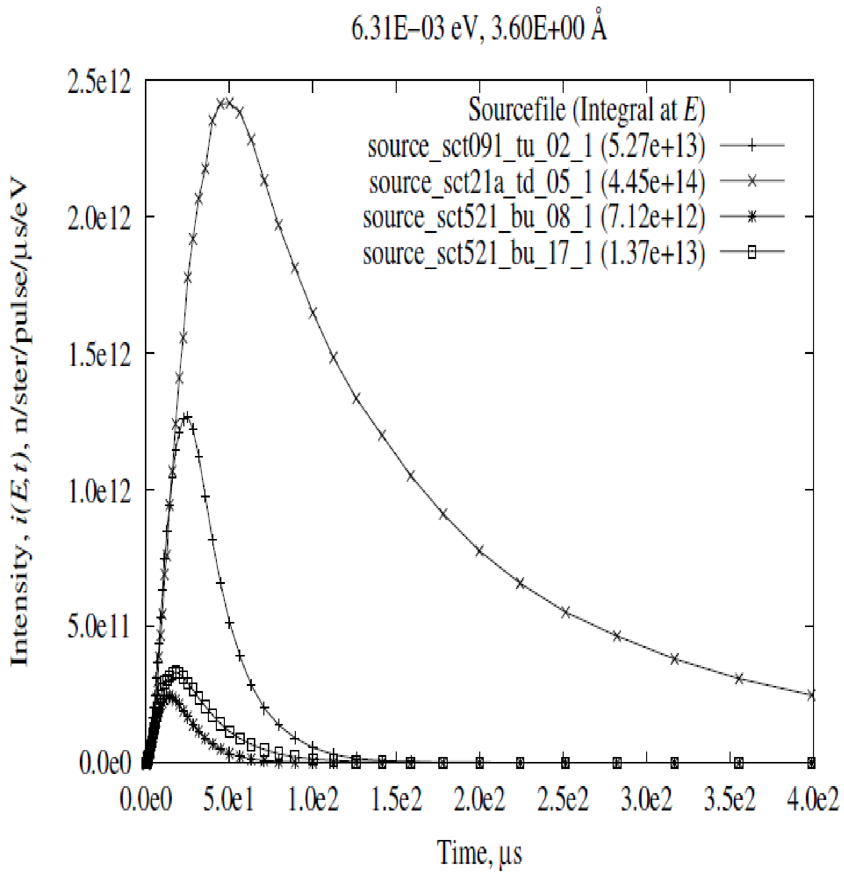
Proton and neutron distributions in the SNS target



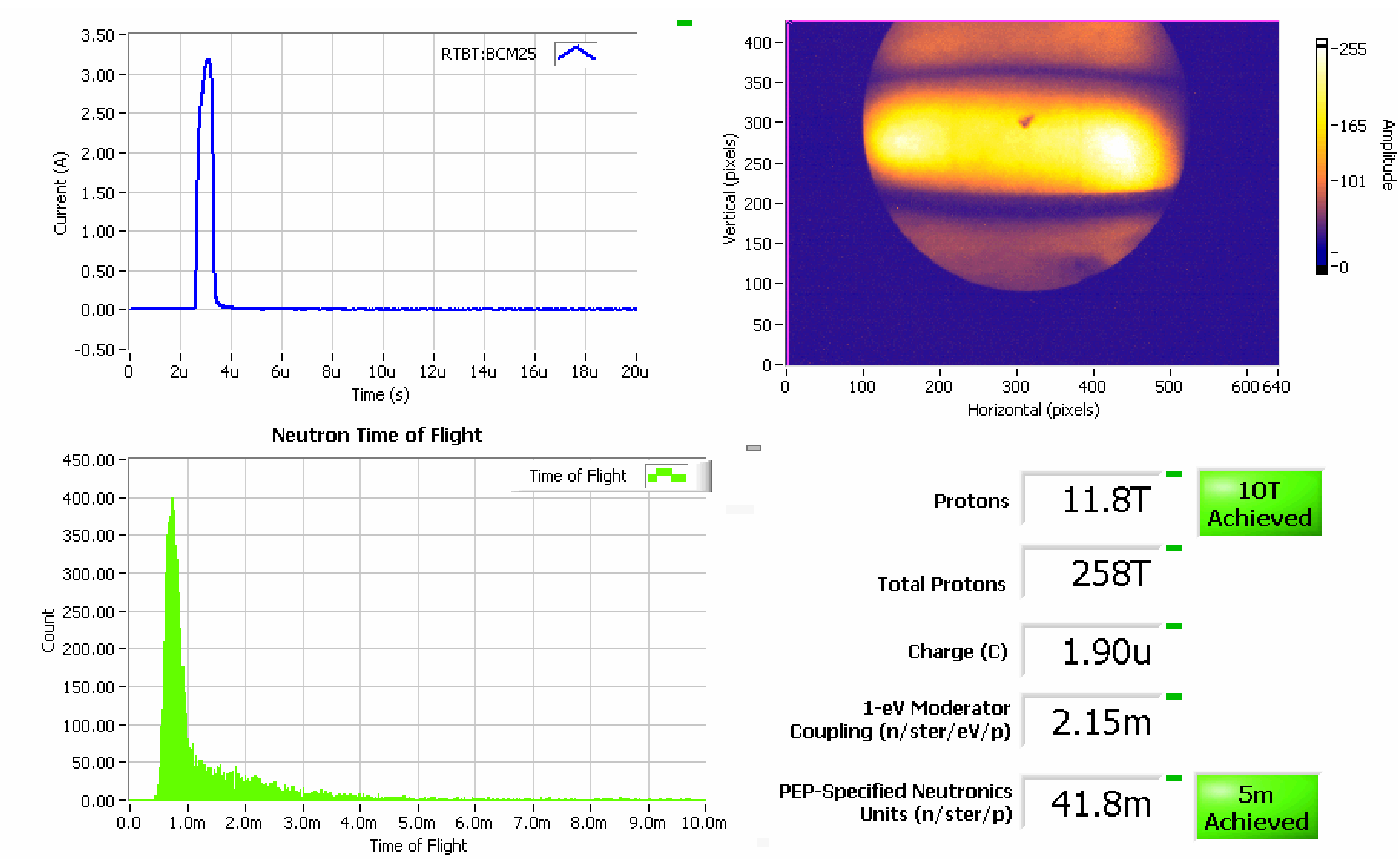


Neutron Performance Evaluations

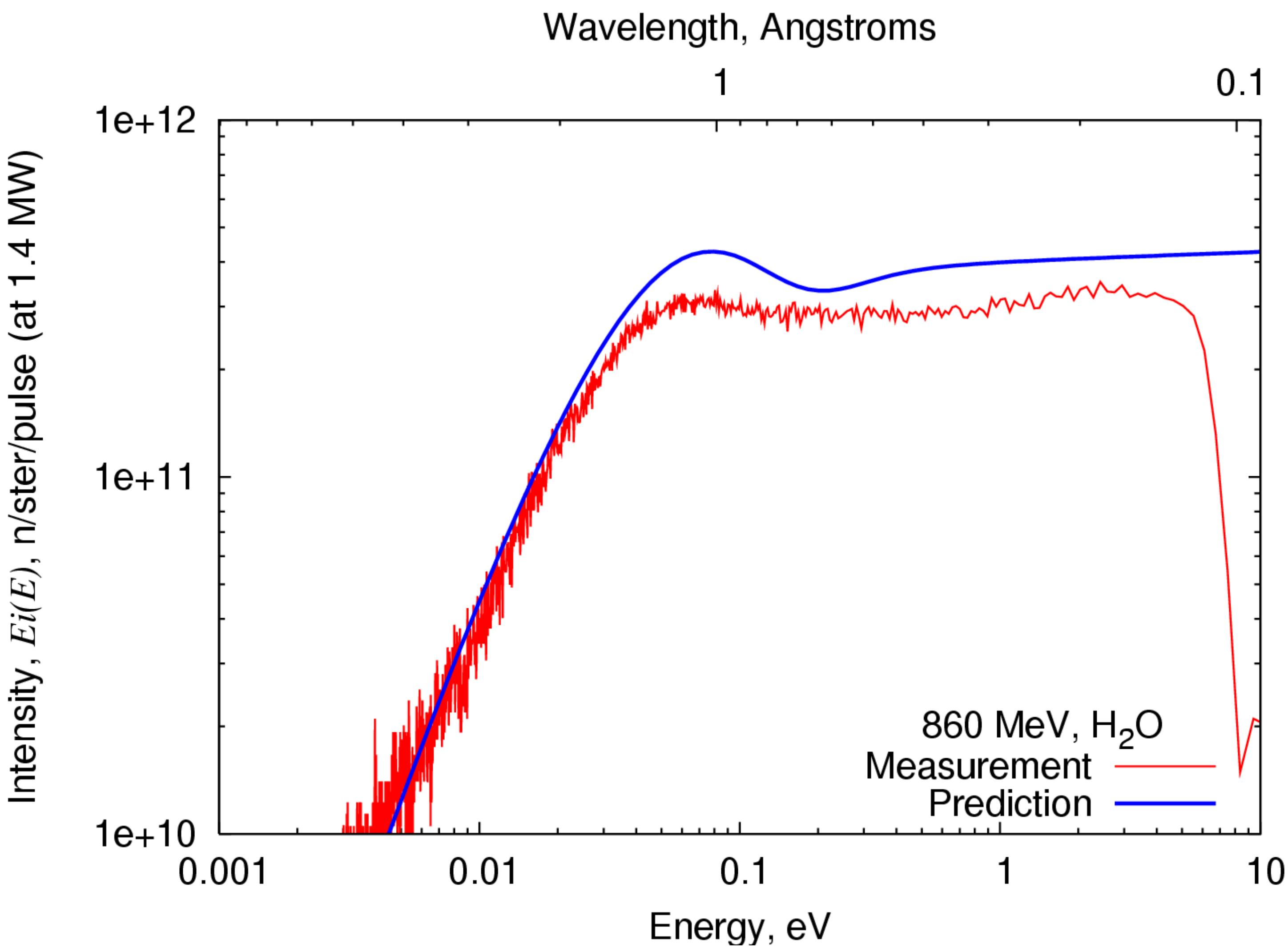




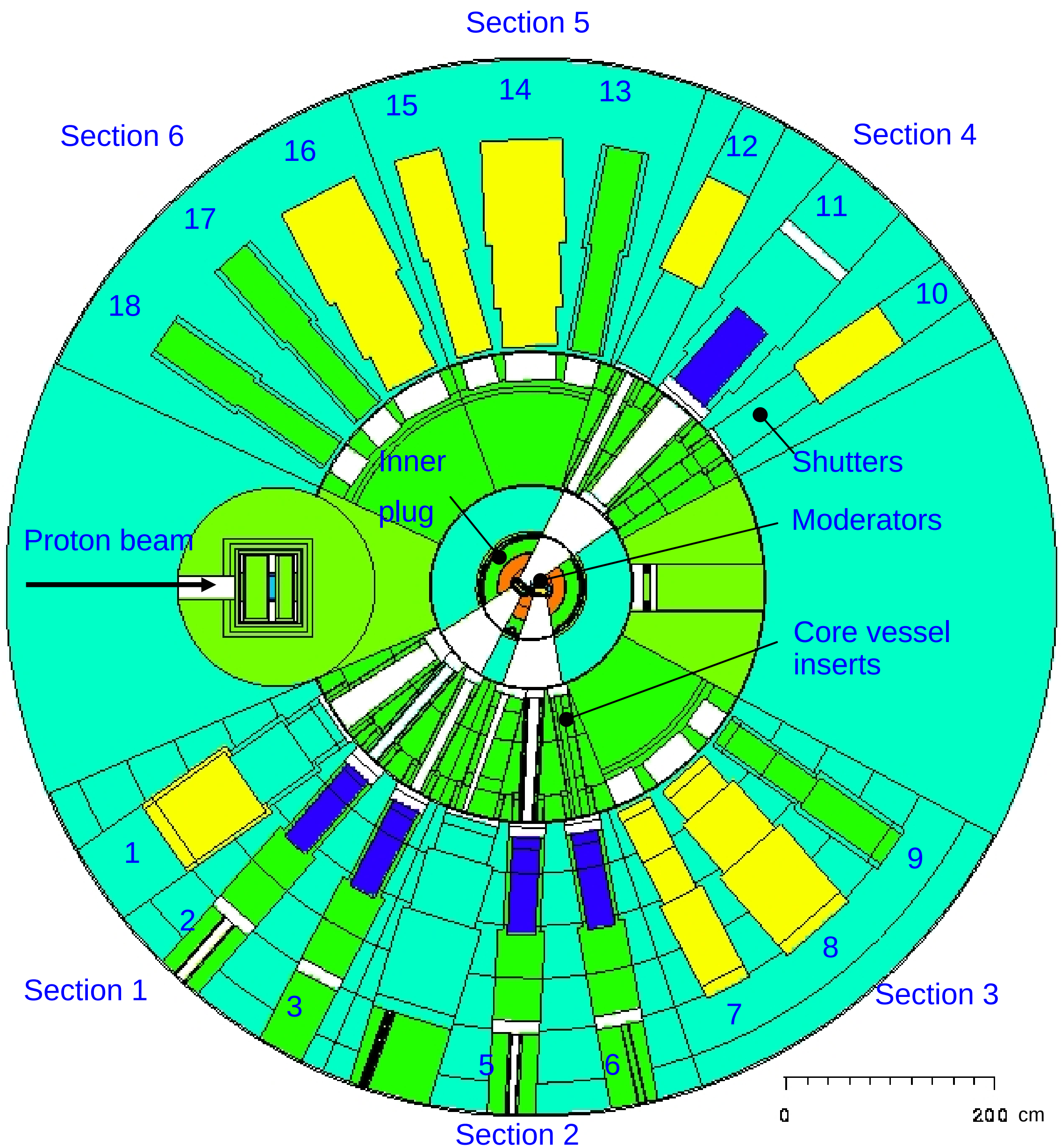
SNS produced first neutrons on April 28, 2006



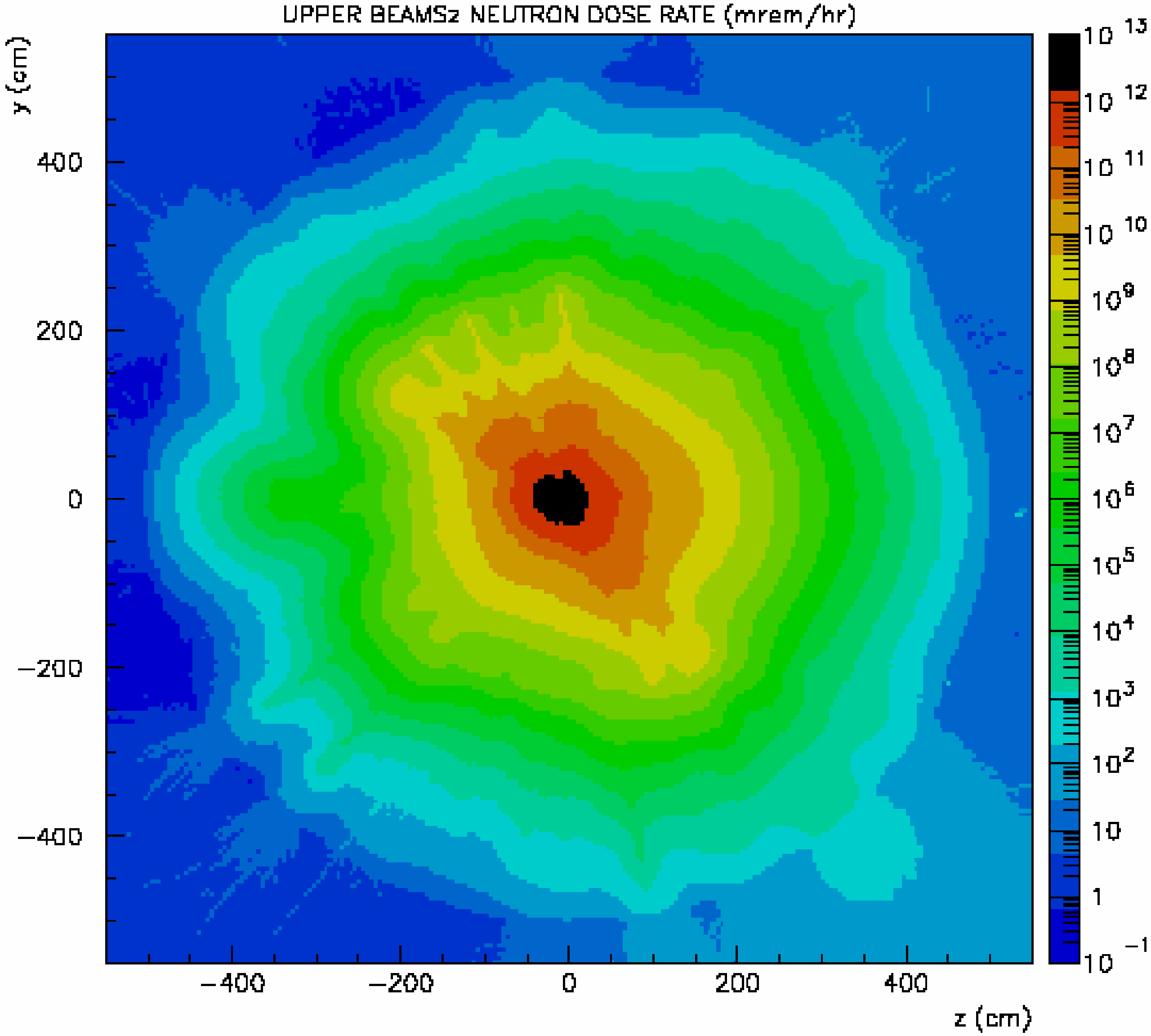
CD4
Beam Line 7 Intensity Measurement



Shielding: Target Monolith Model (1)



Horizontal Dose Rate Map



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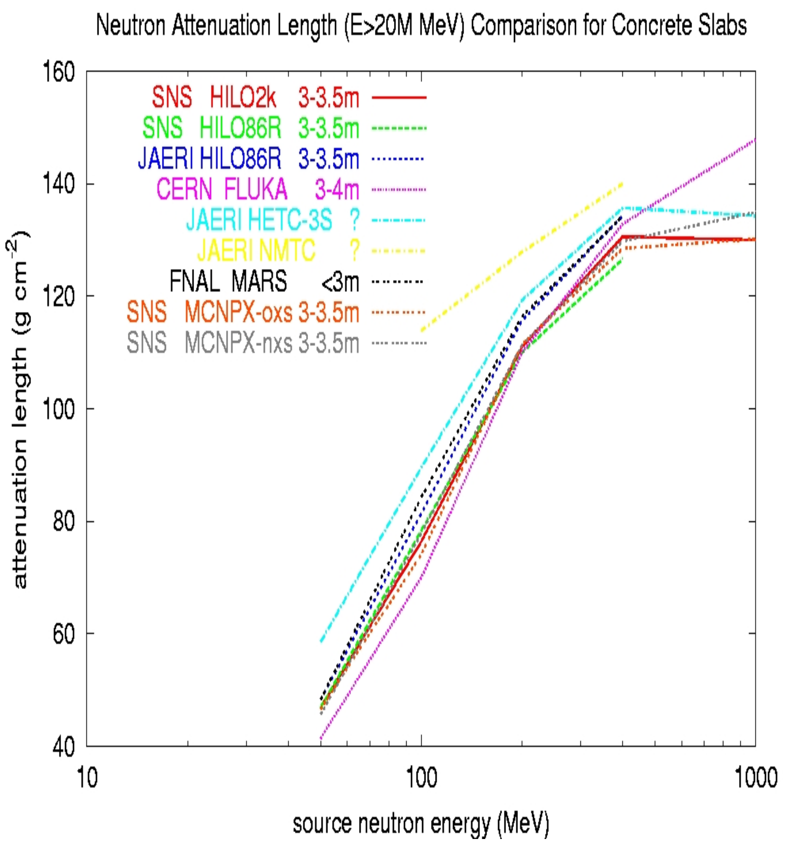
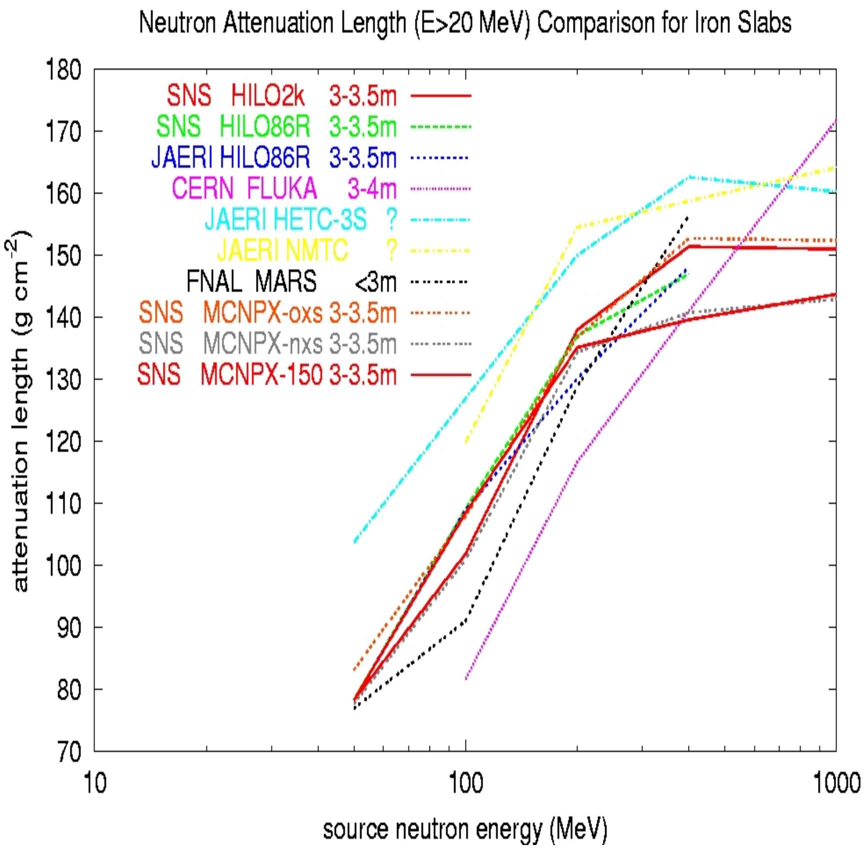
for the U.S. Departme

Verification of Shielding Calculations

- **By Moyer type hand calculations: $D=D_o/R^2*exp(-\lambda*t)$**
- **By discrete-ordinates calculations**





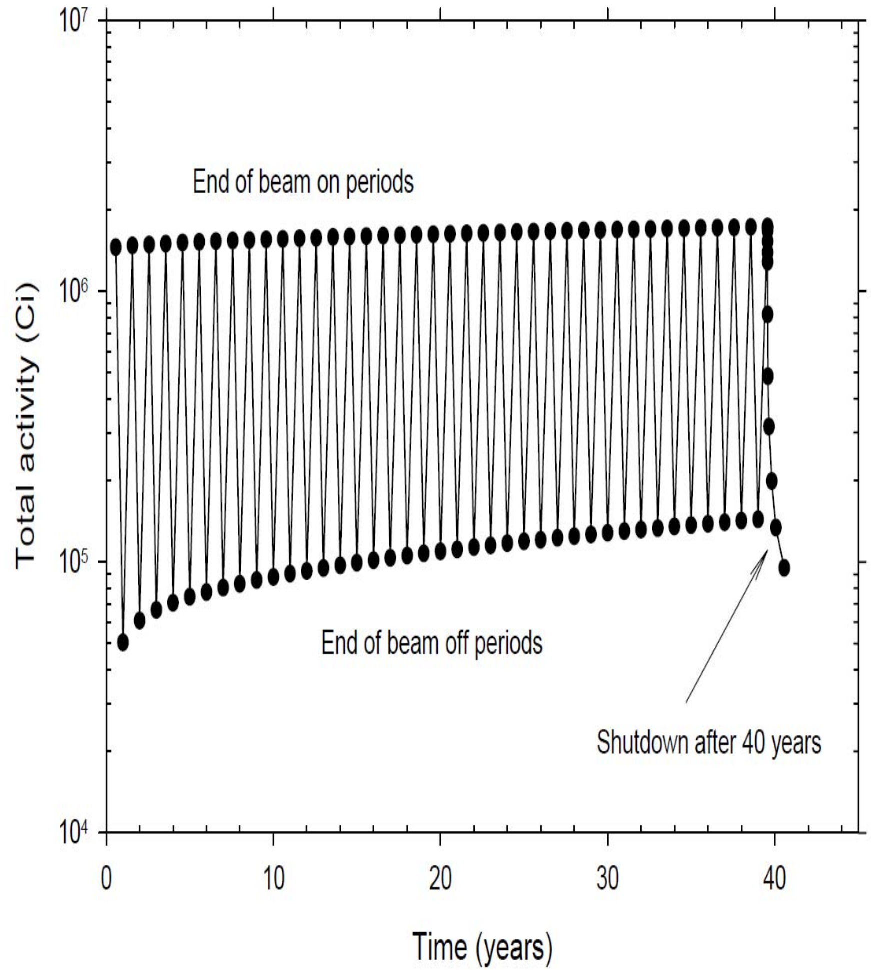
Mercury Radionuclide Inventory

- **Critical for safety analyses: Hg203, Hg199, Gd148**

Top Ten contributors to activity

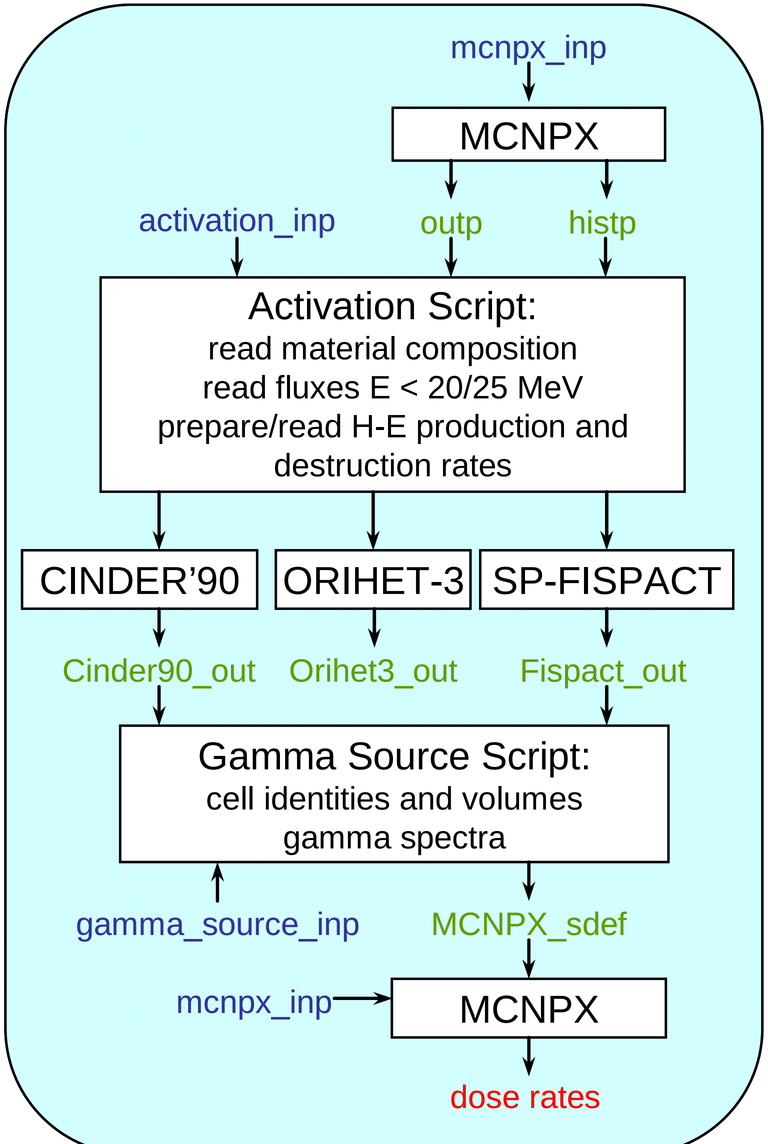
Nuclide	Half-life (s)	Activity after 40 yrs (Ci)	Fraction of total activity
Hg203	4.03E+06	1.79E+05	0.10
Hg197	2.31E+05	1.16E+05	0.07
Hg199*	2.56E+03	1.15E+05	0.07
Au198	2.33E+05	1.01E+05	0.06
H 3	3.89E+08	5.86E+04	0.03
Au195	1.61E+07	3.53E+04	0.02
Hg195	3.56E+04	3.43E+04	0.02
Au193	6.35E+04	2.72E+04	0.02
Pt191	2.51E+05	2.47E+04	0.01
Au199	2.71E+05	1.98E+04	0.01
	total	7.10E+05	0.41

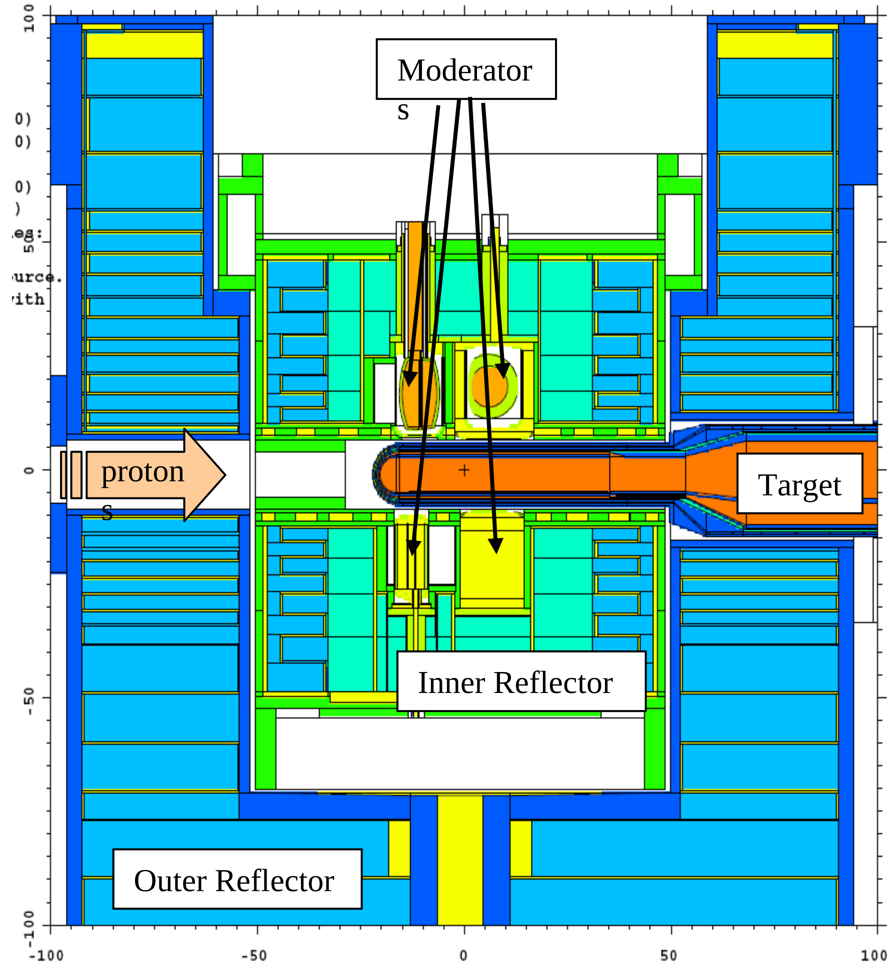
* indicates the metastable state



Impurity of 0.1ppm U almost makes 40-year irradiated Hg a trans-uranic waste

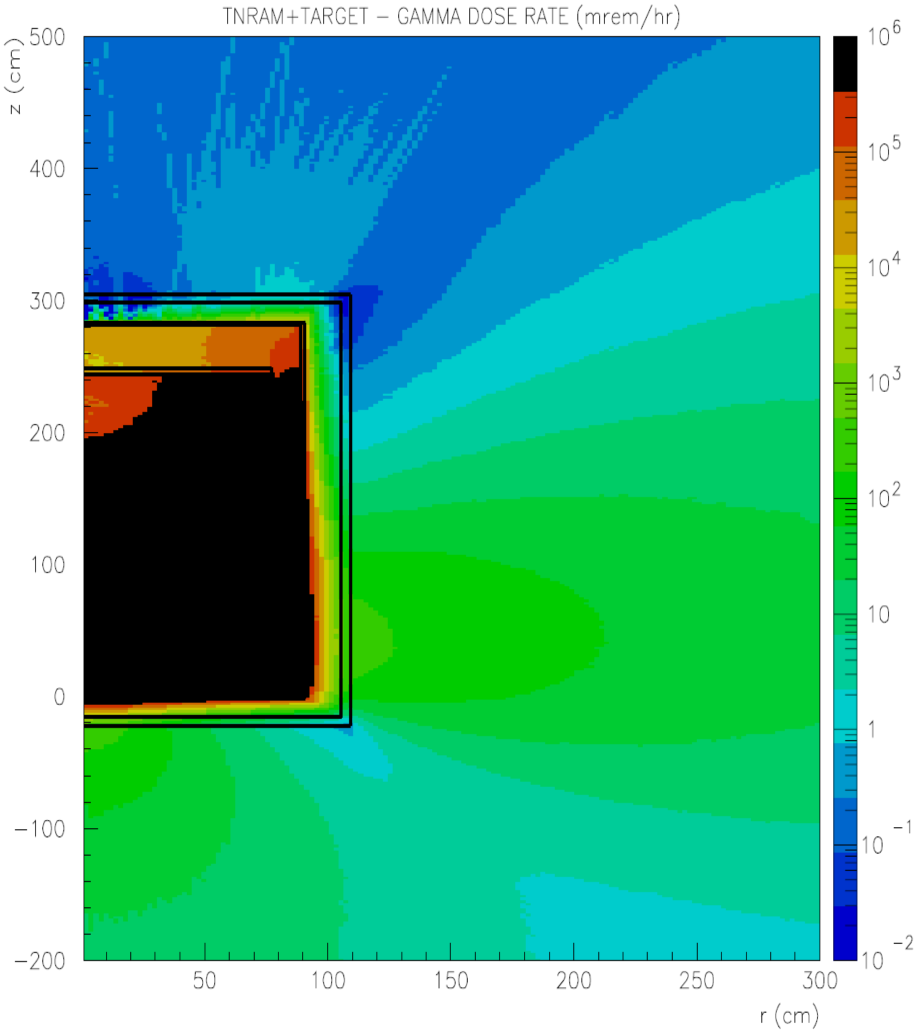
Target Vessel Activation and Handling

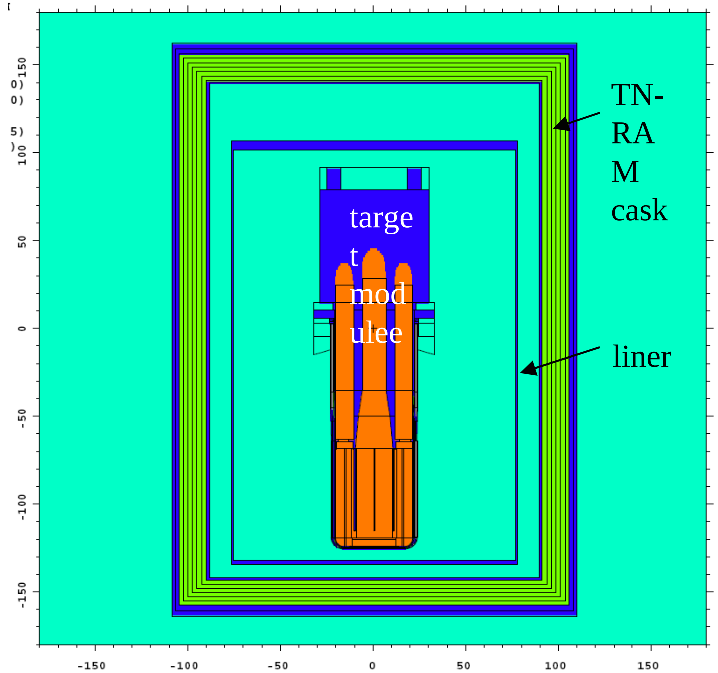


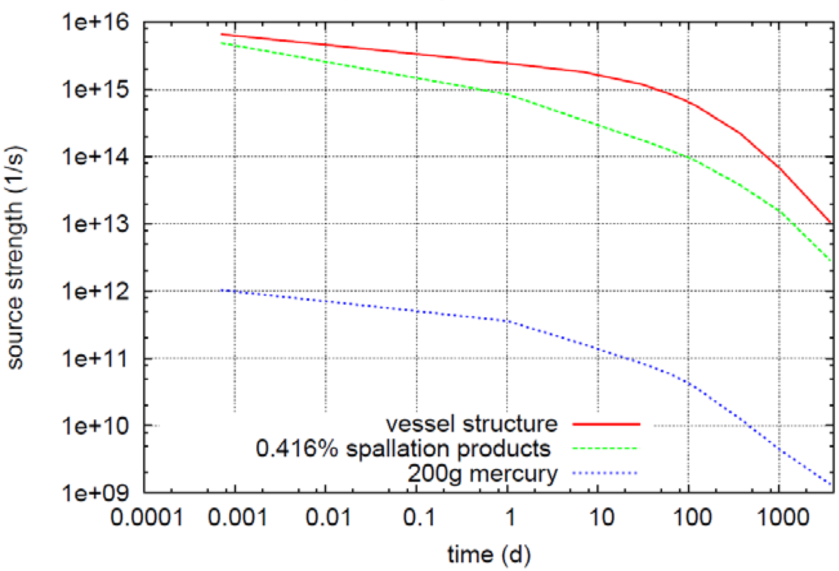


- **Target Vessel activation:**
  - **Steel activation**
  - **200 g mercury dispersed**
  - **10% spallation products plated out**

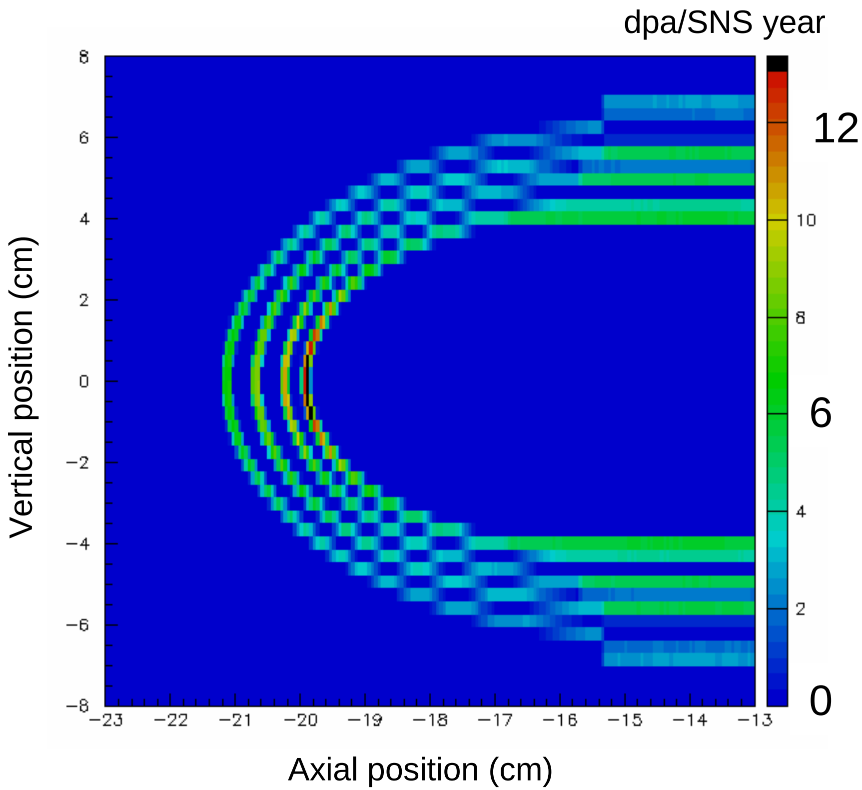
Target Vessel Activation and Handling



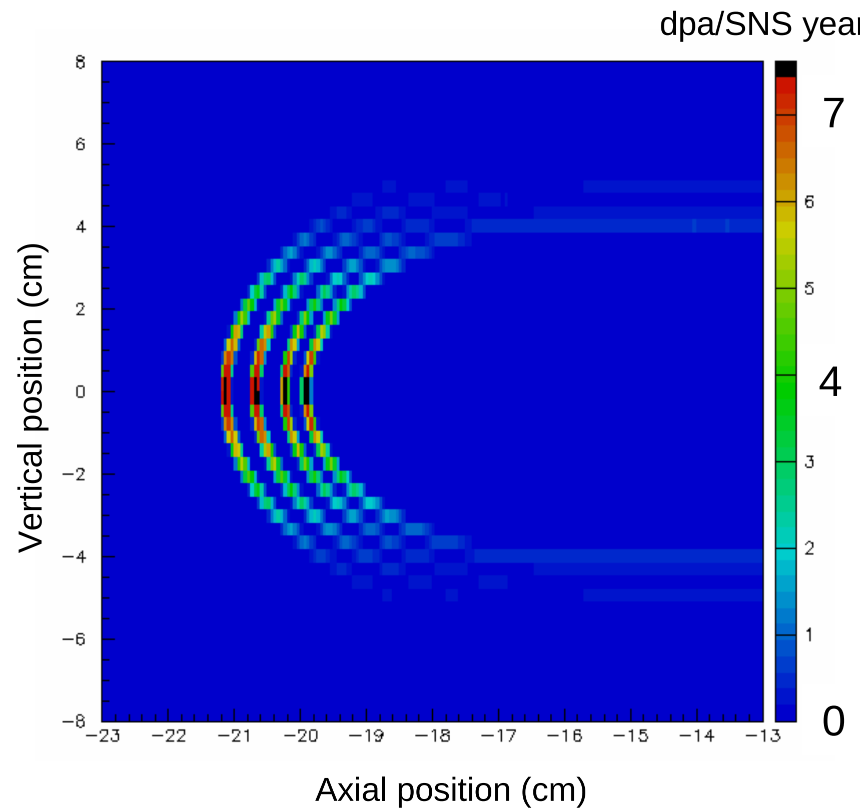




Material damage and lifetime studies



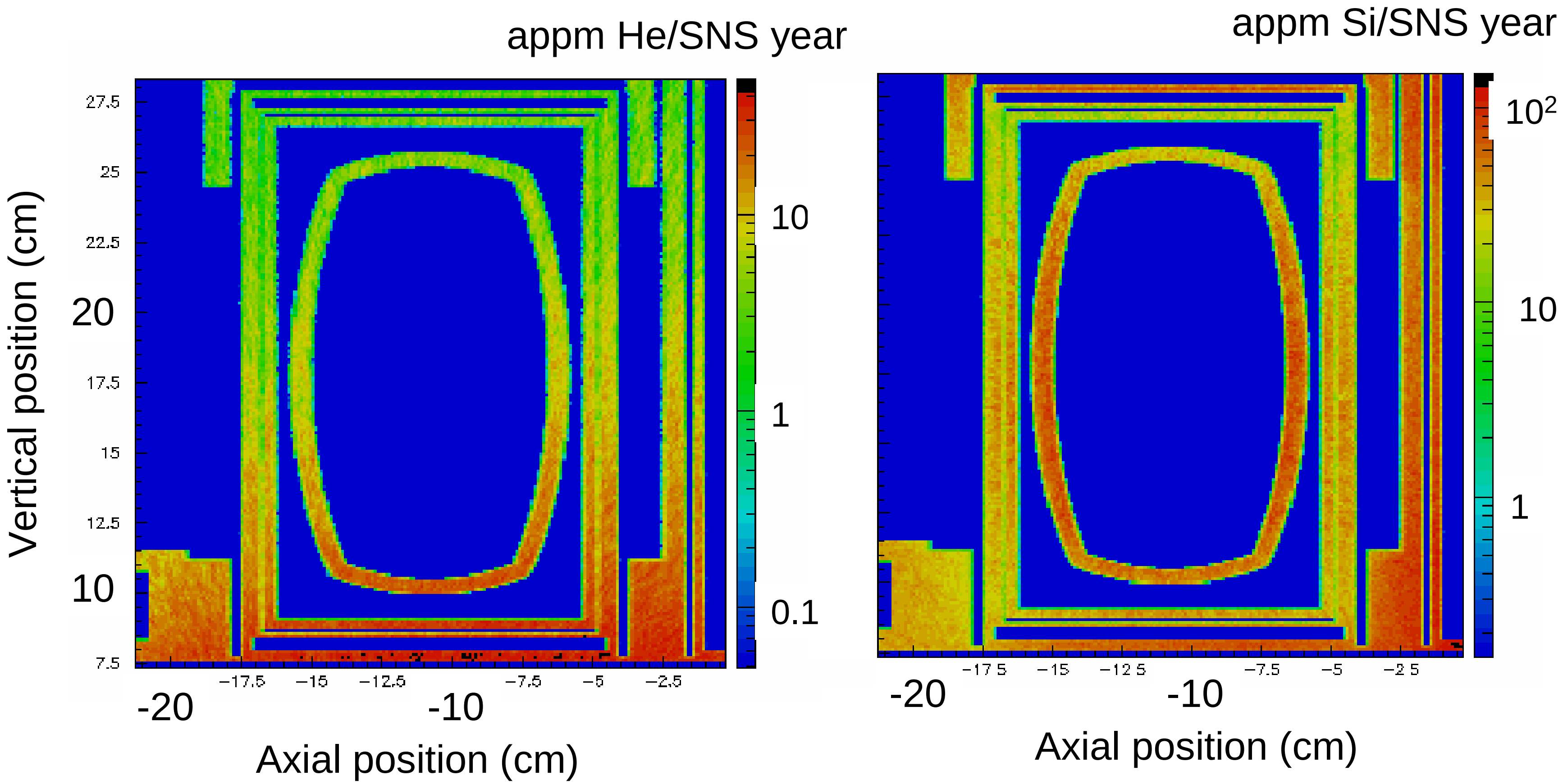
neutrons



protons

As a test case for the tip of the innermost mercury container nose, the results of the new mesh tally technique were compared with older results given in Barnett et al., *AccApp99 Proceedings*, pp. 555-559, ANS, 1999, and Proceedings, IWSMT-4, *J. Nucl. Mater*., Vol. **296**, pp. 54-60, 2001. Good agreement was obtained (total, 36 dpa/yr or 21 dpa/SNS yr).

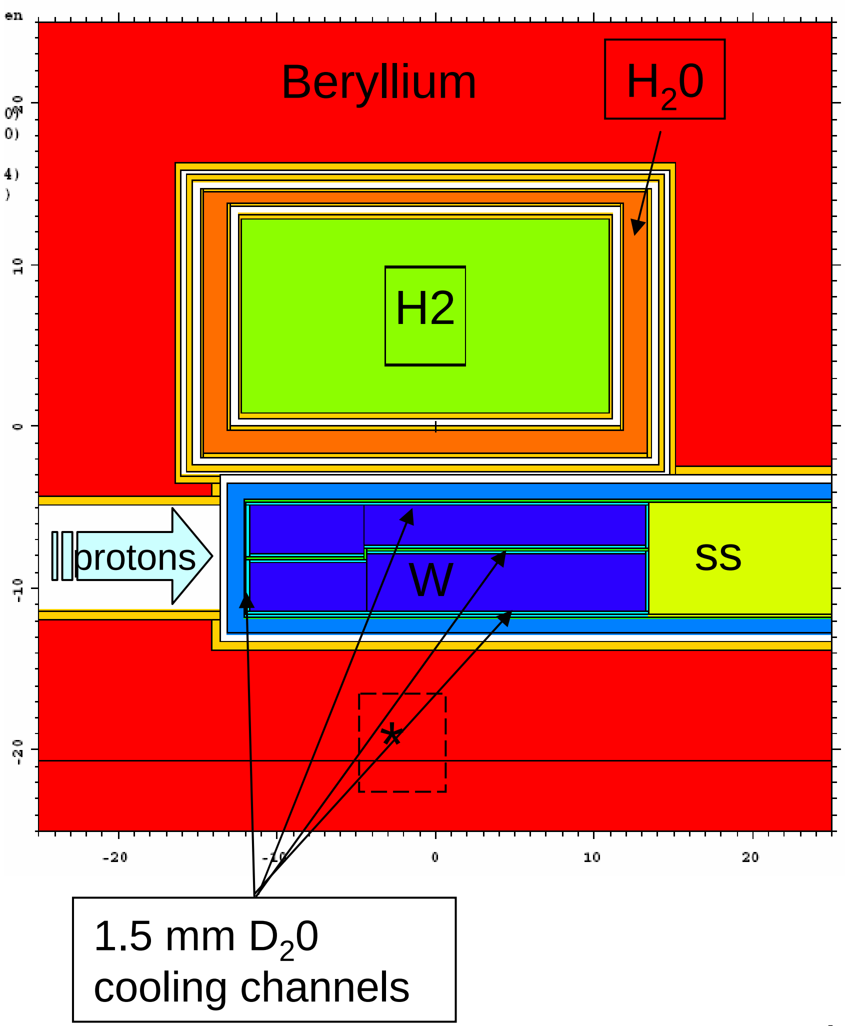
Helium and Silicon production in Al6061 moderator cans

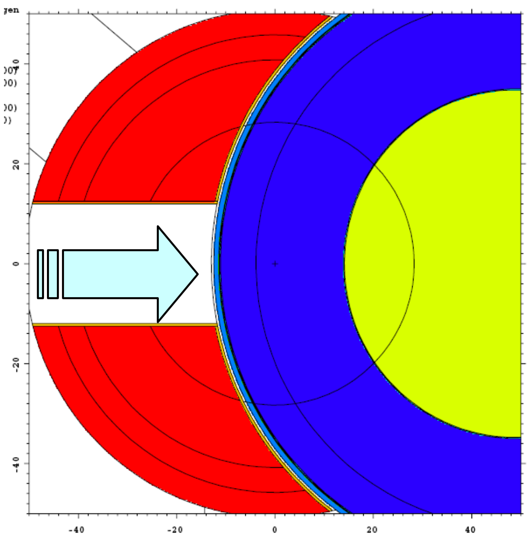


- **DPA cross sections, and He/Si production cross sections are applied with neutron and proton fluxes**

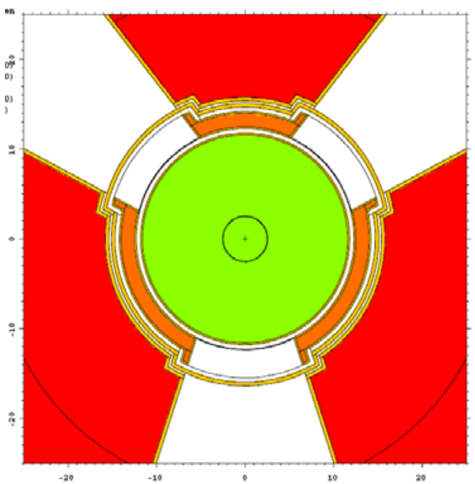
Energy-deposition in Rotating Target of a Second SNS Target Station

Vertical cut





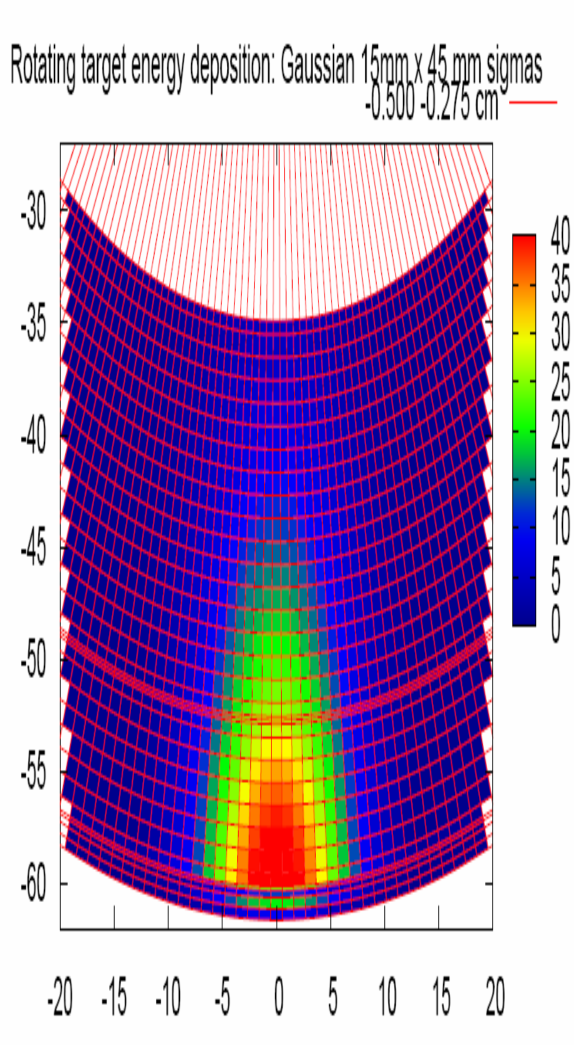
Horizontal cut On mid-plane



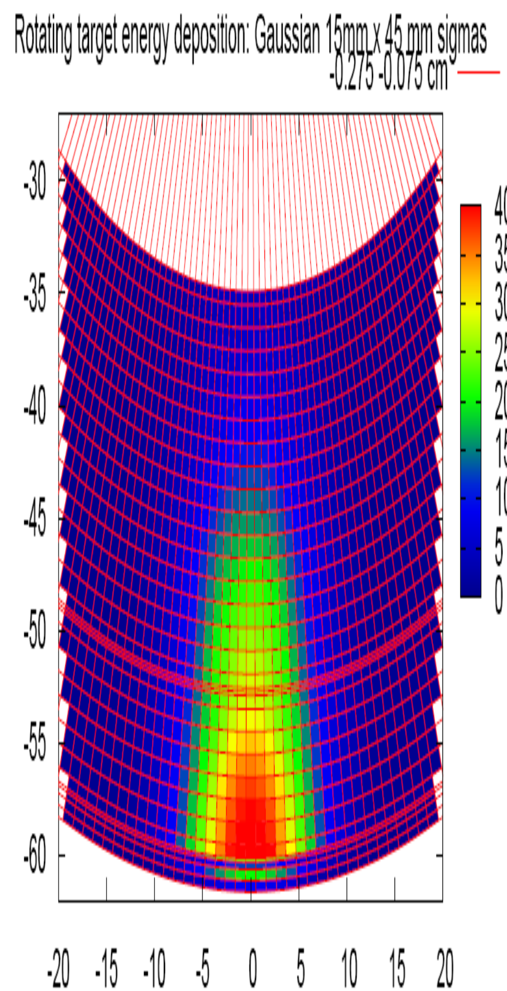
Horizontal cut Through moderator

* Lower moderator not modeled

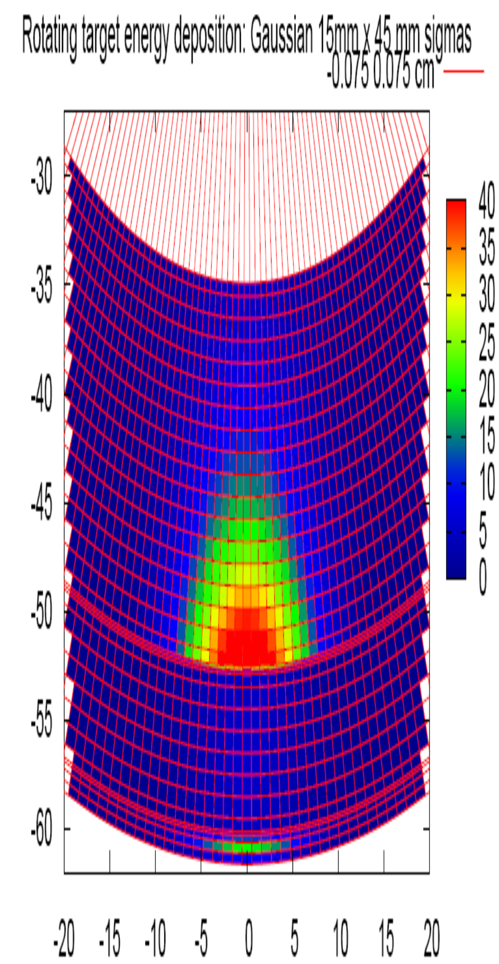
Energy Deposition (J/cc) per Pulse: Gaussian proton beam profile



Bulk tungsten

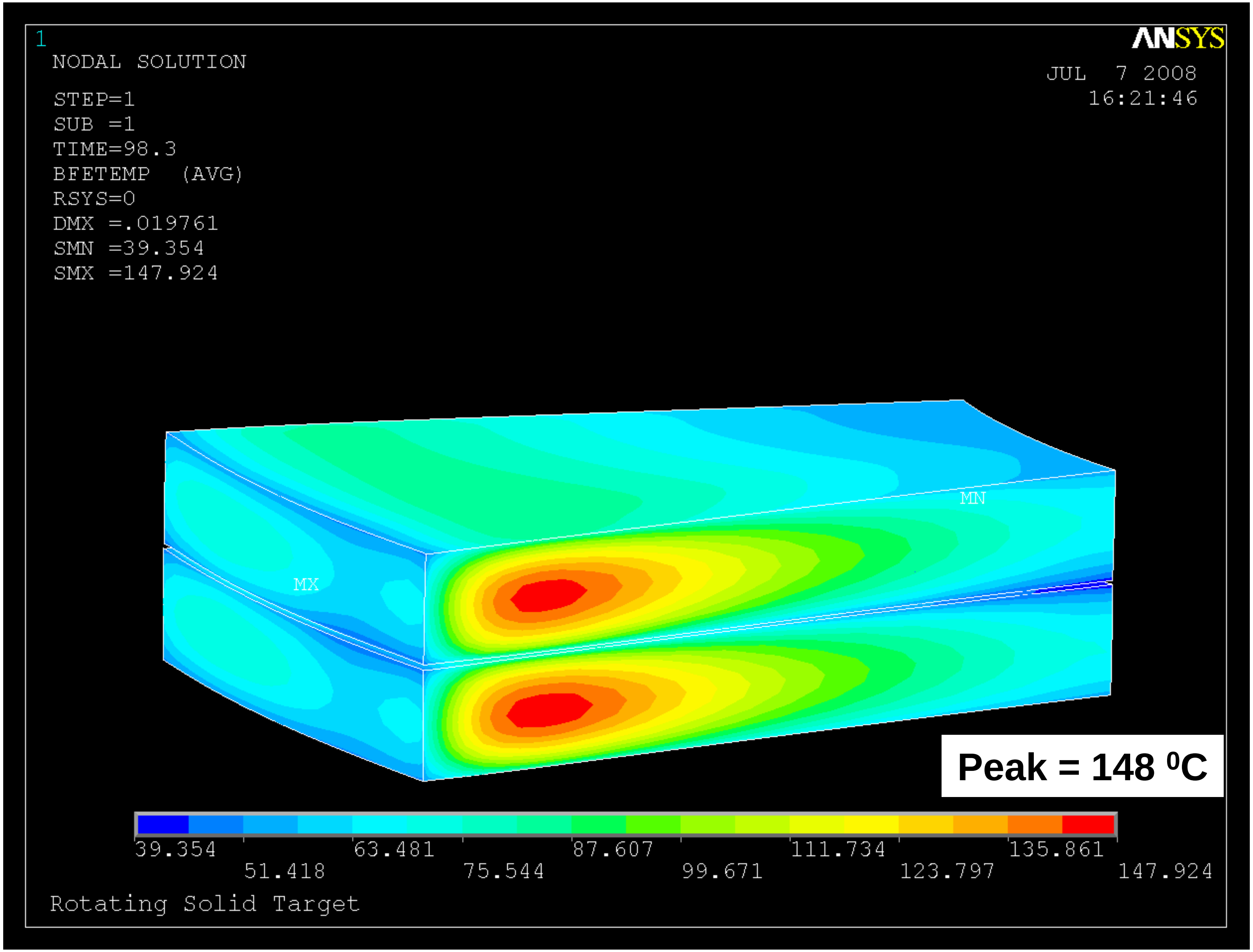


Central Tantalum Cladding



Central D2O Channel

60 rpm Heat Removal



Temperature ^{0}C

Isotope harvesting of target materials

Request for positron source from Al:

Quantity	Option 1	Option 2
Aluminum Volume (cm^3)	236	78
Na-22 Production Rate (1/s)	$1.21\ 10^{12}$	$9.45\ 10^{11}$
Irradiation Time for producing 1Ci Na-22 at 200 kW (days)	42	53

Request for Hf-177 in second metastable state for military application (energy release by stimulated decay)

Next-generation RIB facilitiy projects in Europe and US

Which MCNPX physics model to use?

- Started with MCNPX_2.1.5: Bertini, Dresner, MPM: at LANL existed a significant body of experience and benchmarking for LAHET and was extended to MCNPX for the APT project
- Cem97 was just implemented and not stable yet and too slow at that time (factor 5-8)
- Isabel was not tested well and a factor 10 slower
- Use only frozen, documented, and publicly released versions
- Setting not changed till now
- With second target station we are rethinking our options

Uncertainties

- All simulations performed for design 2MW power with 1.4MW nominal power
- No safety factors applied in neutronics analyses
- Thermal and structural analyses applied safety margin
- DPA limits defined to be on the safe side by a factor of 2 → lifetime of components → may be increased as we learn
- Radionuclide inventory calculations within a factor of 2 (from NEA-1994 report), for isotopes far off the target nucleus used factor 10
- MCNPX manual reminds users to run application near benchmark cases
- Accuracy of moderator neutron performance analyses known by comparison of measurement and calcualation from Lujan Center/LANL and IPNS/ANL
- Radionuclide and energy-deposition benchmarks exist for Bertini/Dresner at LANL

Uncertainties in transport analyses

- Geometry modeling details
- Material composition
- Tabulated nuclear data (completeness of secondary particle yields, heating numbers …)
- Neutron moderation in thermal region (S(a,b)-Kernels)
- Physics models
- Probability of typo
- Normalization error

Who are the users?

- **Spallation model developers (30-50)**
- **Users of spallation models**
  - **Nuclear data evaluater generating and evaluating cross sections and cross section data bases (50-100)**
  - **Developers of particle transport codes (50-100)**
  - **Users of particle transport codes (5000-10000)**
- **Users of information generated by spallation models and/or particle transport codes, design engineers, operators of nuclear and accelerator facilities, regulators (50000-100000)**

Users' interest in benchmark

- **Spallation model developers have highest interest and need most detailed information.**
- **Nuclear data evaluator and transport code developer want to know performance characteristics.**
- **Users of transport codes want to get guidance in as few numbers as possible (which they probably will not get); wish that guidance is hardwired by code developers, use best code/parameter setting for specific mass/energy range.**
- **Engineers and regulators want to have confidence that the values they receive is within a factor x.**
- **Factor x has impact on savety margins applied in design.**