Simulations in support of RIA Target Area R&D (Part 2)

- Conceptual Design of 2-Step ISOL targets
- Examples of Simulations with "Large-Scale" Models

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- Conclusions

Conceptual Design of RIA Targets

Challenging requirements for simulations:

- P, n, d, and ion transport and interactions in the targets, beam dumps, magnets, etc.
  - Transport in magnetic fields required
- Calculation of isotope yields, energy deposition, and radiation damage
- Simulation of rare isotopes “extraction” from the target and transport to the experiments
- Determination of the radiation fields, dose levels, and shielding requirements during operation
- Calculation of radioactive inventory build up in the target, post-operation decay heat, and dose rates
- Determination of cooling requirements and stress analysis

RIA Targets Conceptual Design (Cont.)

The codes we use for simulations

Particle and ion transport

- PHITS (RIST, Japan)
  - Includes heavy-ion transport and interaction
  - Allows magnetic fields
- MCNPX (LANL)
- MARS15 (Fermilab)

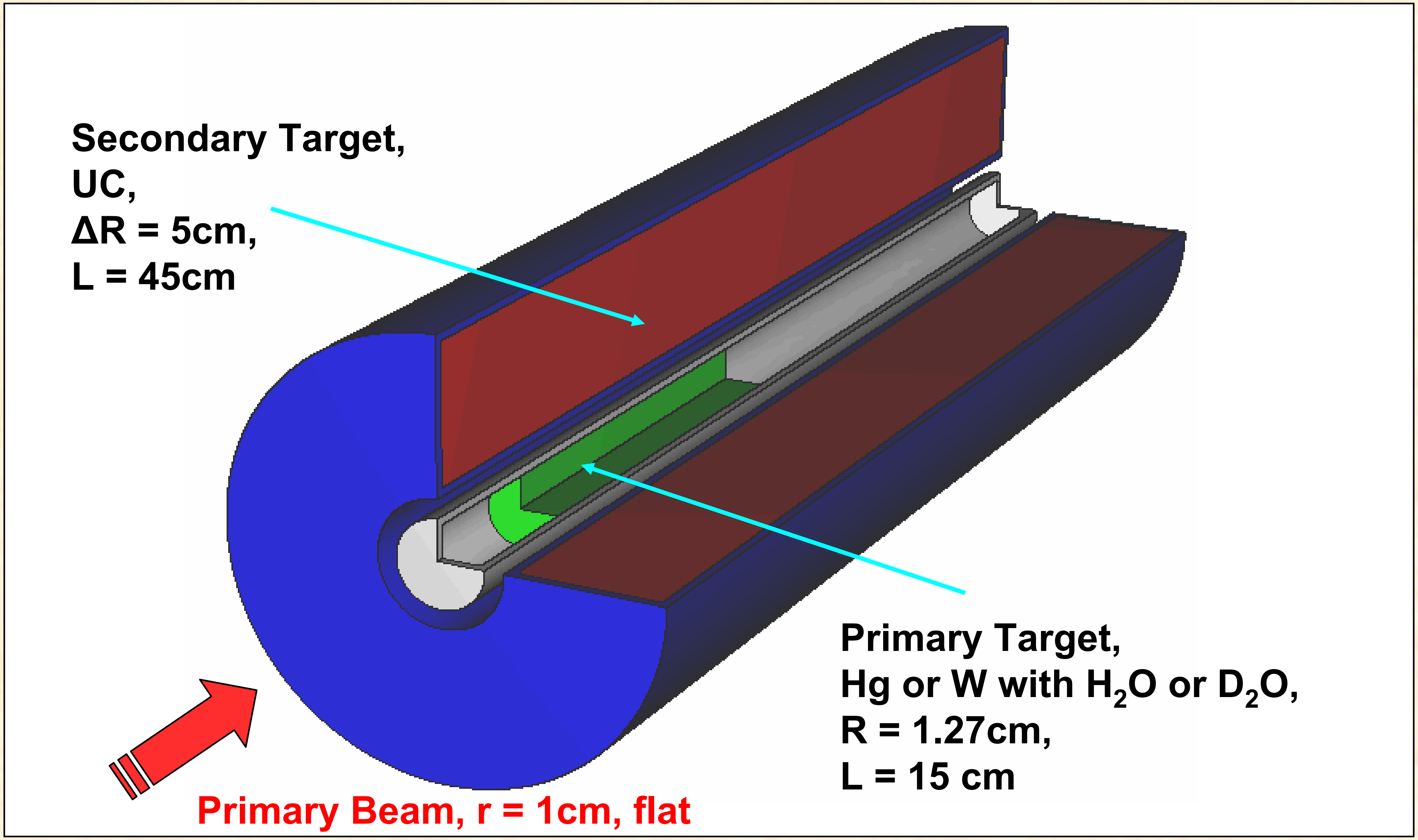
Activation calculations

- Activation Analysis System (AAS) (ORNL, with MCNPX)
- ACAB98 (LLNL)
- DCHAINSP2001 (JAERI, with PHITS)

Work on Conceptual Design of Two-Step ISOL Target for RIA

- A two-step target was first proposed by J.A. Nolen (ANL)
  - Primary beam incident on a neutron-producing high-Z "primary" target
  - Neutrons induce fissions in a "secondary" target filled with fissionable material
- Advantage:
  - thermally decouples primary beam region and fission region (important at high power beams when cooling is a problem)
  - Decouples fission (secondary) and spallation (primary) regions, and therefore reduces isobar contamination in the production of neutron-rich fission products

Two-Step “Generic” Target



Two-Step "Generic" Target (Cont.)

- **Primary targets considered (to date):**
  - Hg (serves as target and coolant, can be reused, etc.)
  - W with H_2O or D_2O coolant
    - 10% coolant } (by volume)
    - 20% coolant }
- **Secondary target - UC at 5 $g \cdot cm^{-3}$**
- **Primary beams:**
  - 1-GeV protons
  - 622-MeV/u deuterons
  - 777-MeV/u He-3
- **Primary beam power 400 kW**

Two-Step "Generic" Target (Cont.)

Results for 400-kW beam of 1-GeV protons on Hg primary

- Produces 1.8×10^{15} fissions/s in secondary
- Deposits:
  - 106 kW in primary,
  - 71 kW in secondary
- Maximum heating rate in primary ~4.3 kW/cm^3
- Dpa rate in steel "beam window" ~5 dpa/month

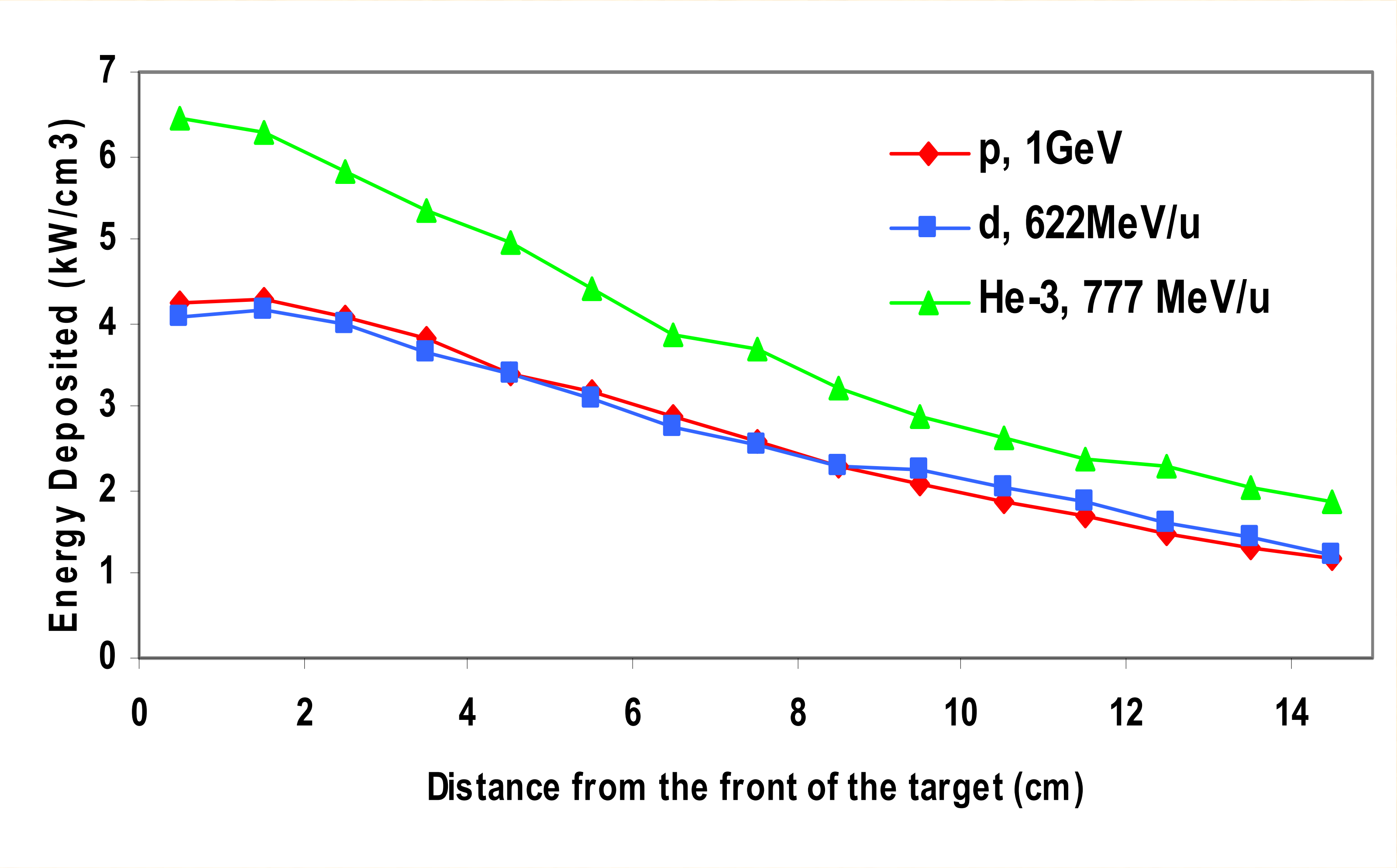
Comparisons at Equal Beam Power

	Number of fissions in UC			Energy deposited in primary		
	Hg	0.9 W + 0.1 H_2O	0.9 W + 0.1 D_2O	Hg	0.9 W + 0.1 H_2O	0.9 W + 0.1 D_2O
p, 1 GeV	1.00	1.03 (1.00)*	1.03 (1.00)*	1.00	1.19 (1.32)*	1.19 (1.30)*
d, 622 MeV/u	0.99	1.05	1.05	0.99	1.20	1.20
He-3, 777 MeV/u	0.85	0.86	0.86	1.44	1.72	1.72

*For 0.8 W + 0.2 H_2O or D_2O

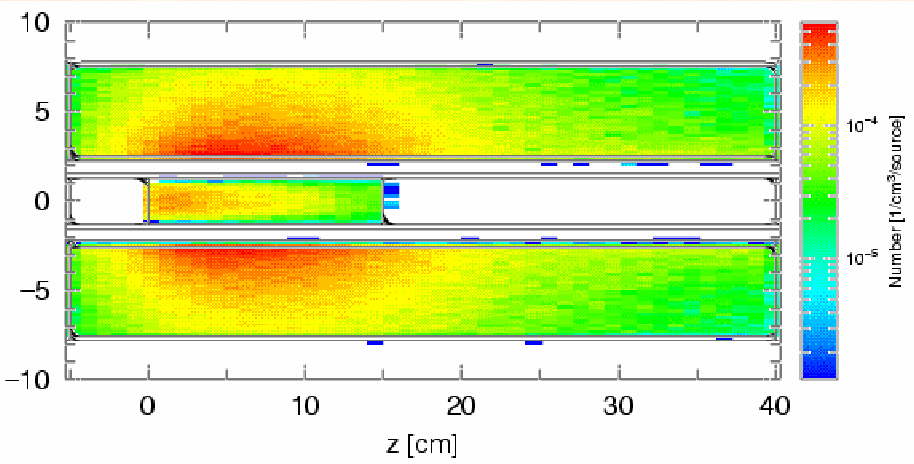
Note that results are normalized to p-on-Hg-target results.

Heating Profiles Along the Target Axis

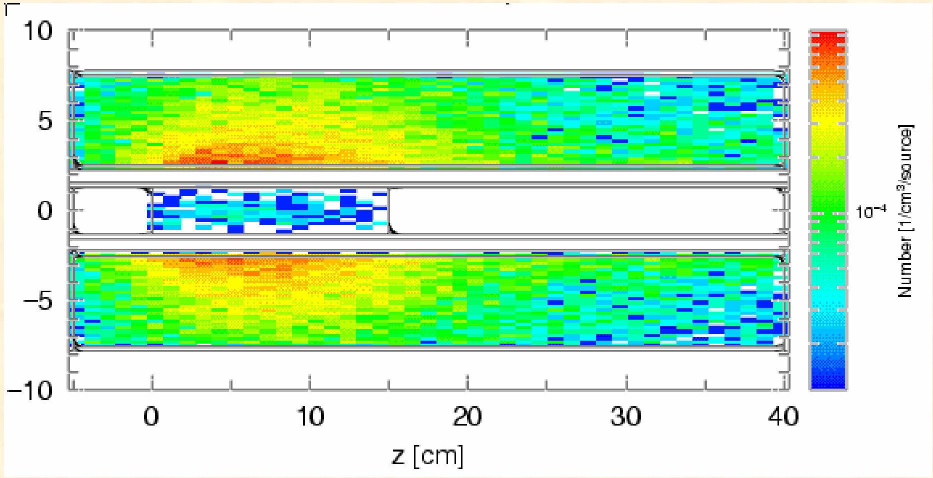


Fission Density Distributions (per Beam Particle)

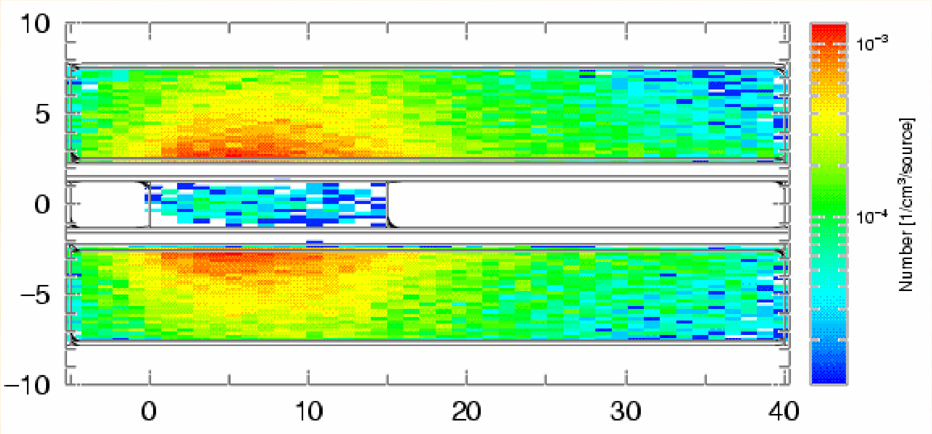
Proton



Deuteron



He-3

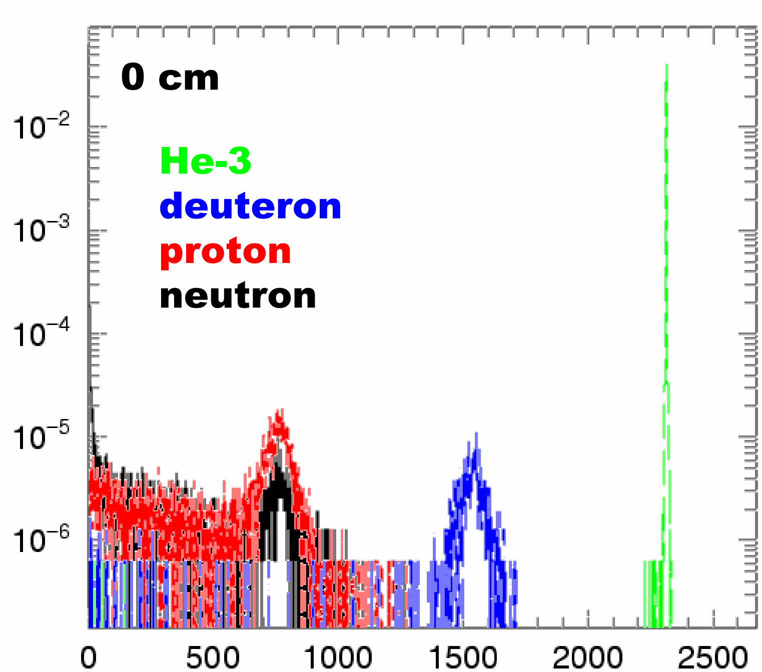


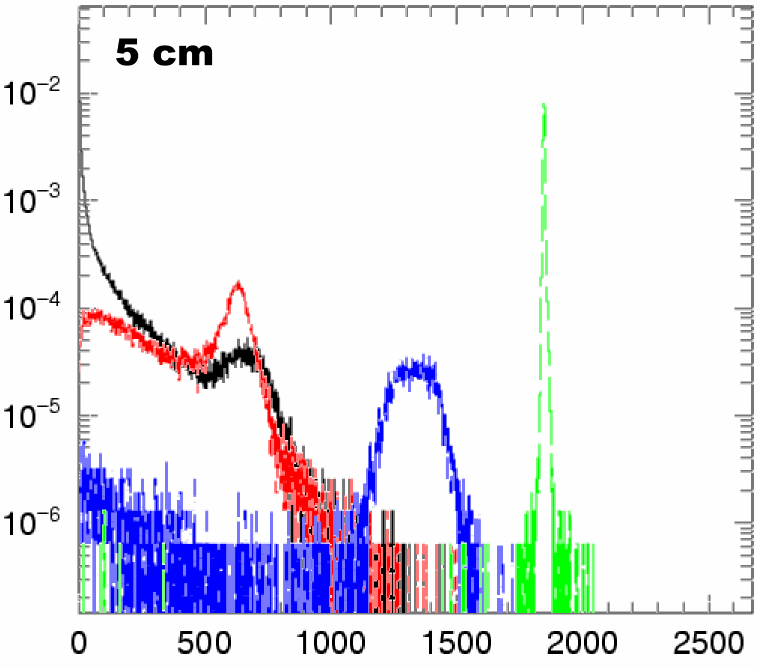
Preliminary Heat Transfer Results

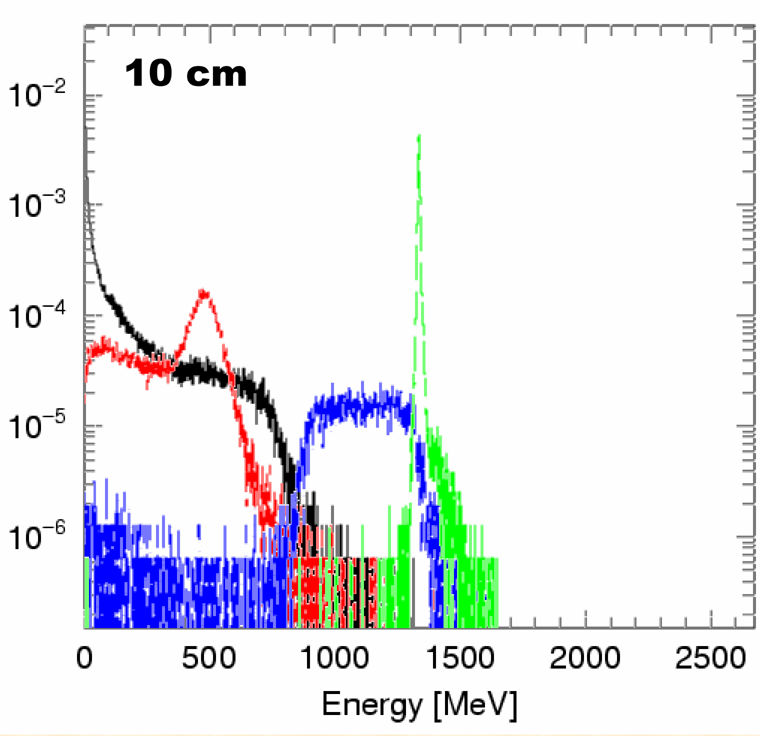
Primary target cooled with water flow

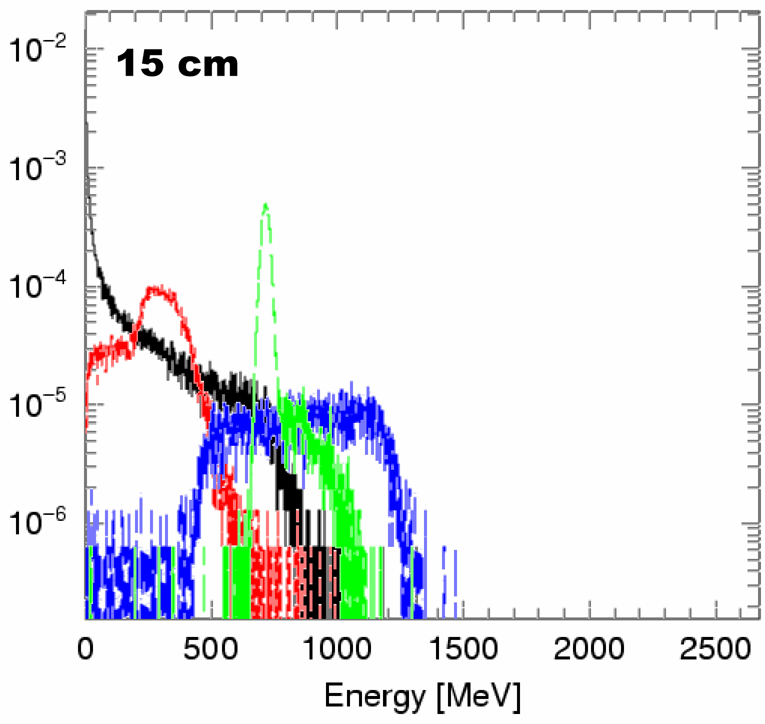
- **Maximum heat load ~ 5kW/cm^3**
- **Water takes up ~20 % of the primary target volume (coolant channel diameter ~1.6 mm, pitch 3.4 mm)**
- **Temperatures:**
  - **Tungsten < 225^{o}C**
  - **Water < 140^{o}C**
- **Water flow of ~ 2 liters/s**
- **Pressure drop ~ 0.7 MPa,**
- **Water velocity ~ 18 m/s**

Particle Current, 777 MeV/u He-3 Beam, W+H_2O Target









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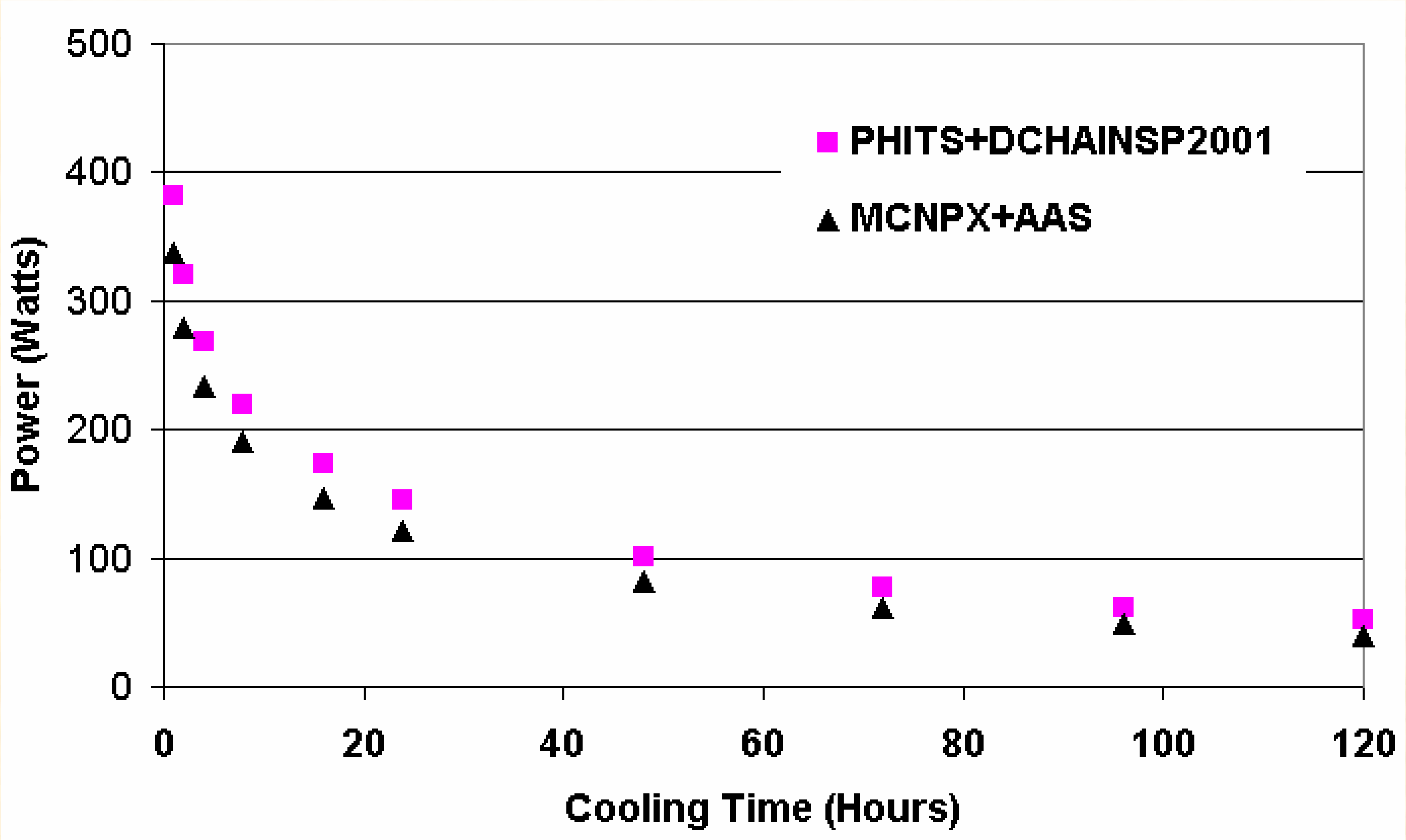
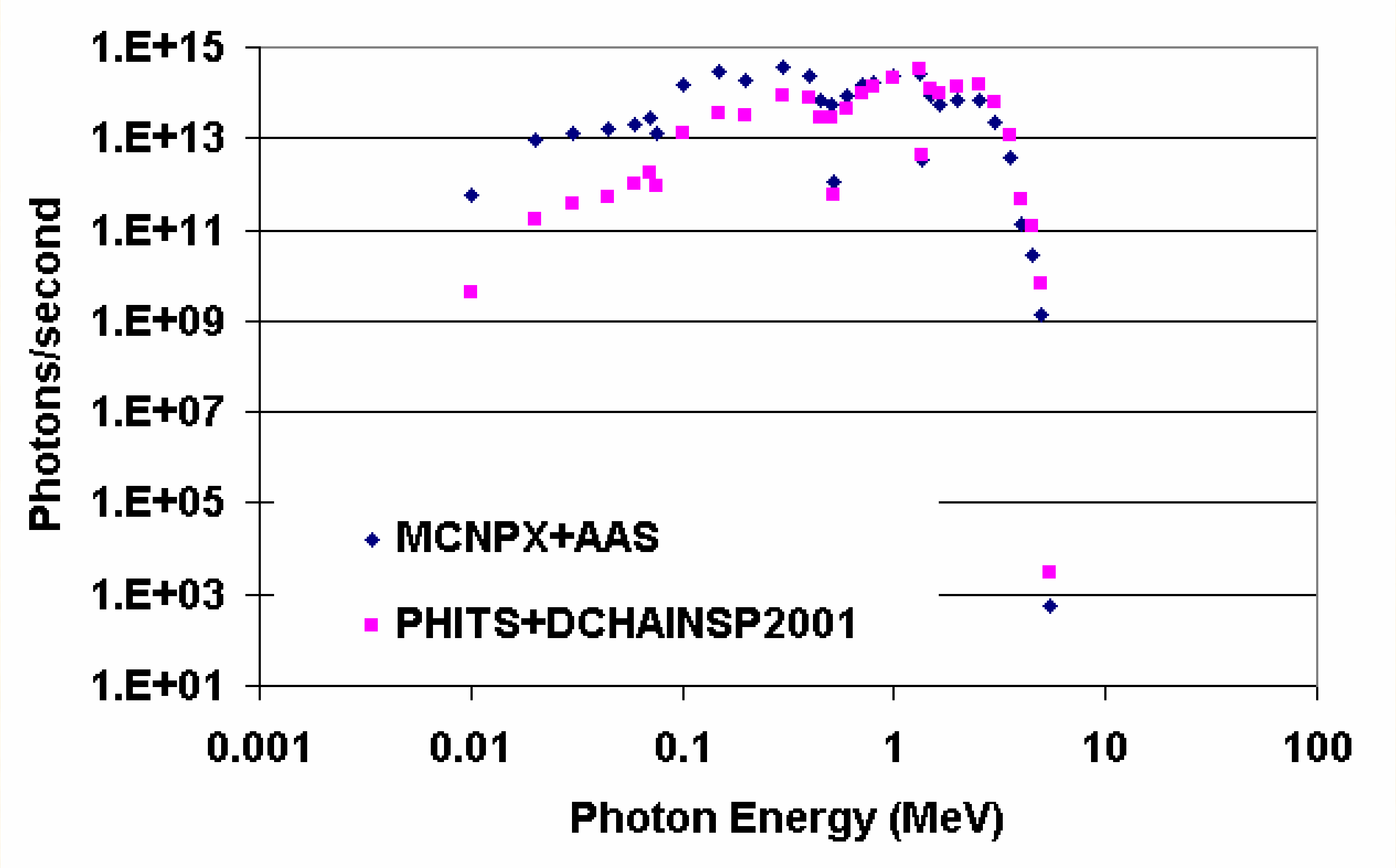
Decay Heat, 0.9 W + 0.1 D_2O, 1-GeV p, After 28 Days of Operation at 400 kW



Photon Emission, After 28 Days of Operation and 1 Hour Cooling Time, 0.9 W + 0.1 D_2O, 1-GeV p Beam at 400 kW



Preliminary Conclusions from Two-Step ISOL Target Simulations

- **A two-step ISOL target for 400 kW beam appears feasible**
- **1-GeV proton and 622-MeV/u deuteron beam are about equivalent**
- **777-MeV He-3 beam produces less fissions and higher heating**
  - **Would probably require > 20% of water (by volume) in the primary for cooling**

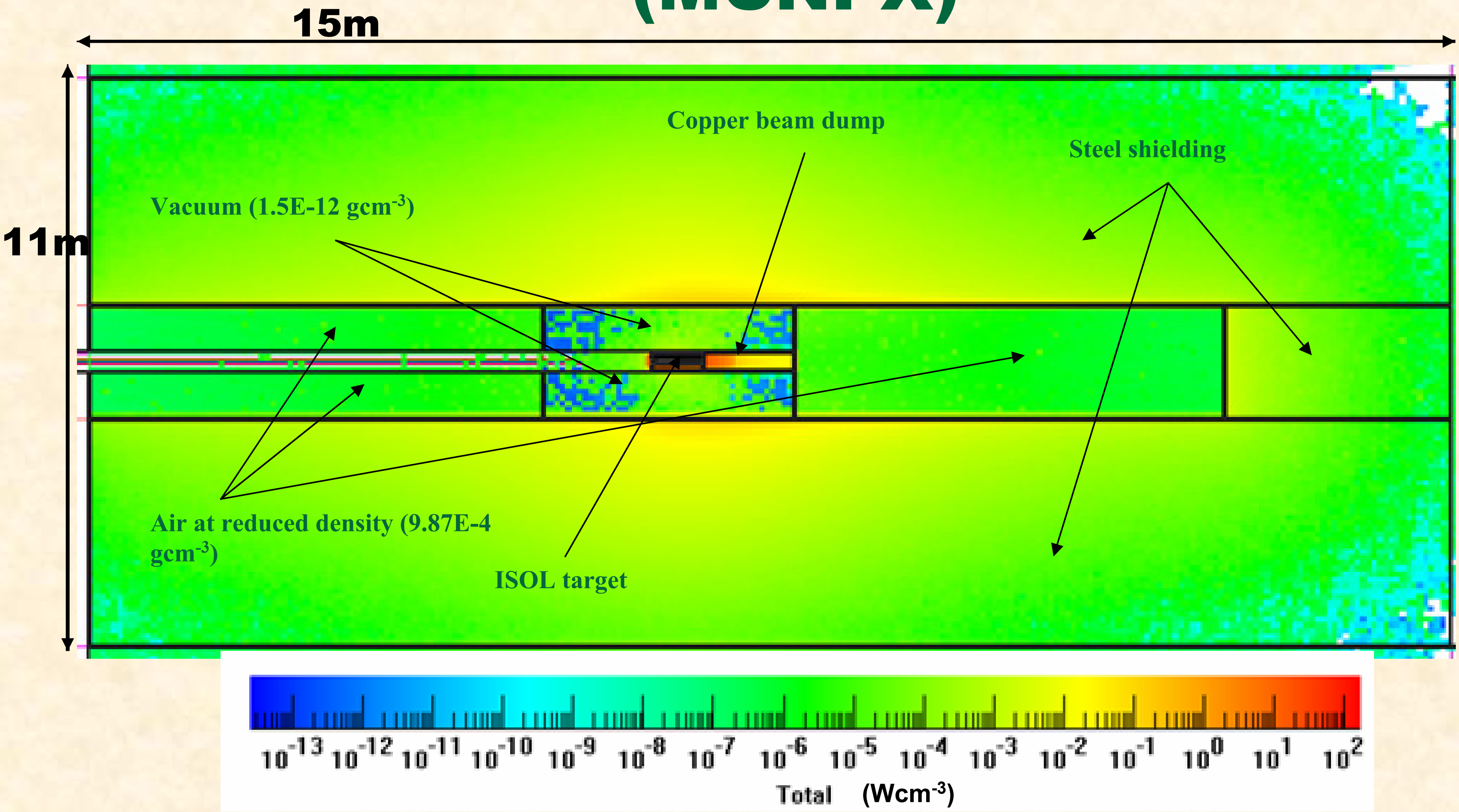
Simulations with “Large-Scale” Models

Simulations were also carried out with large-scale models with the objectives to:

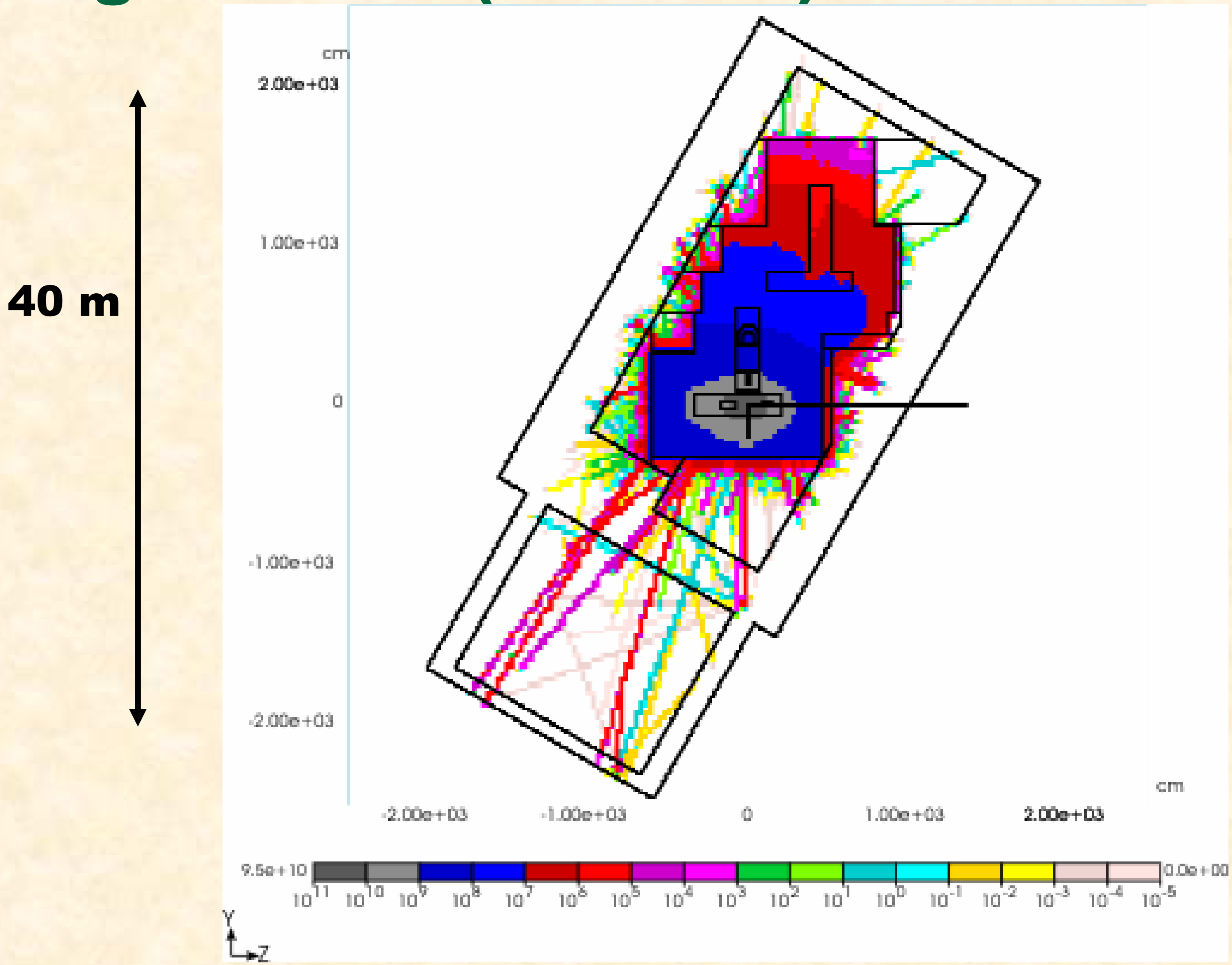
- Study radiation fields
- Determine necessary shielding
- Assess activation of the magnets, beam dumps, and other structures
- Provide input for overall facility design

Examples of these analyses are given in the following slides

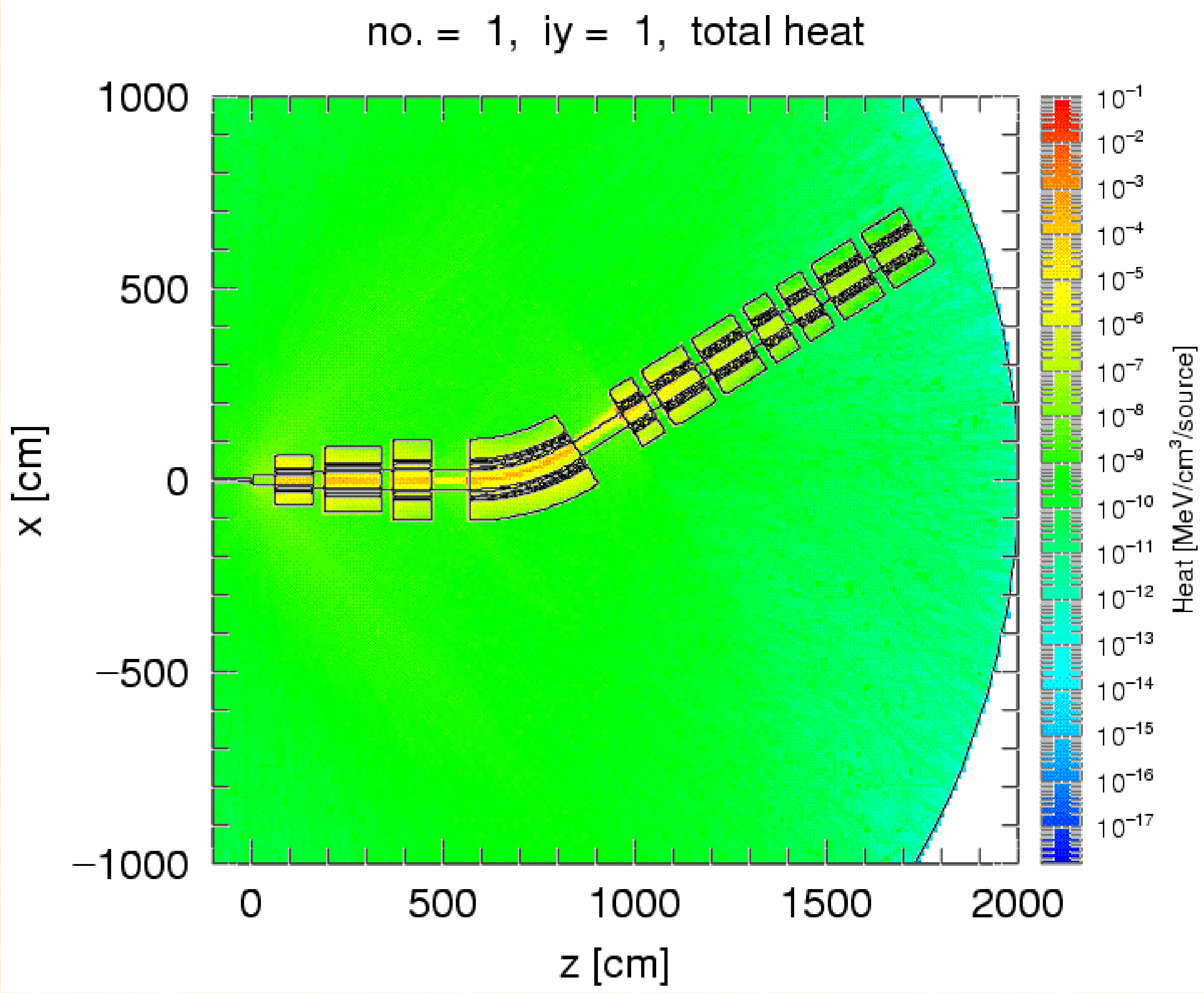
Heating Rates Around ISOL Target (MCNPX)



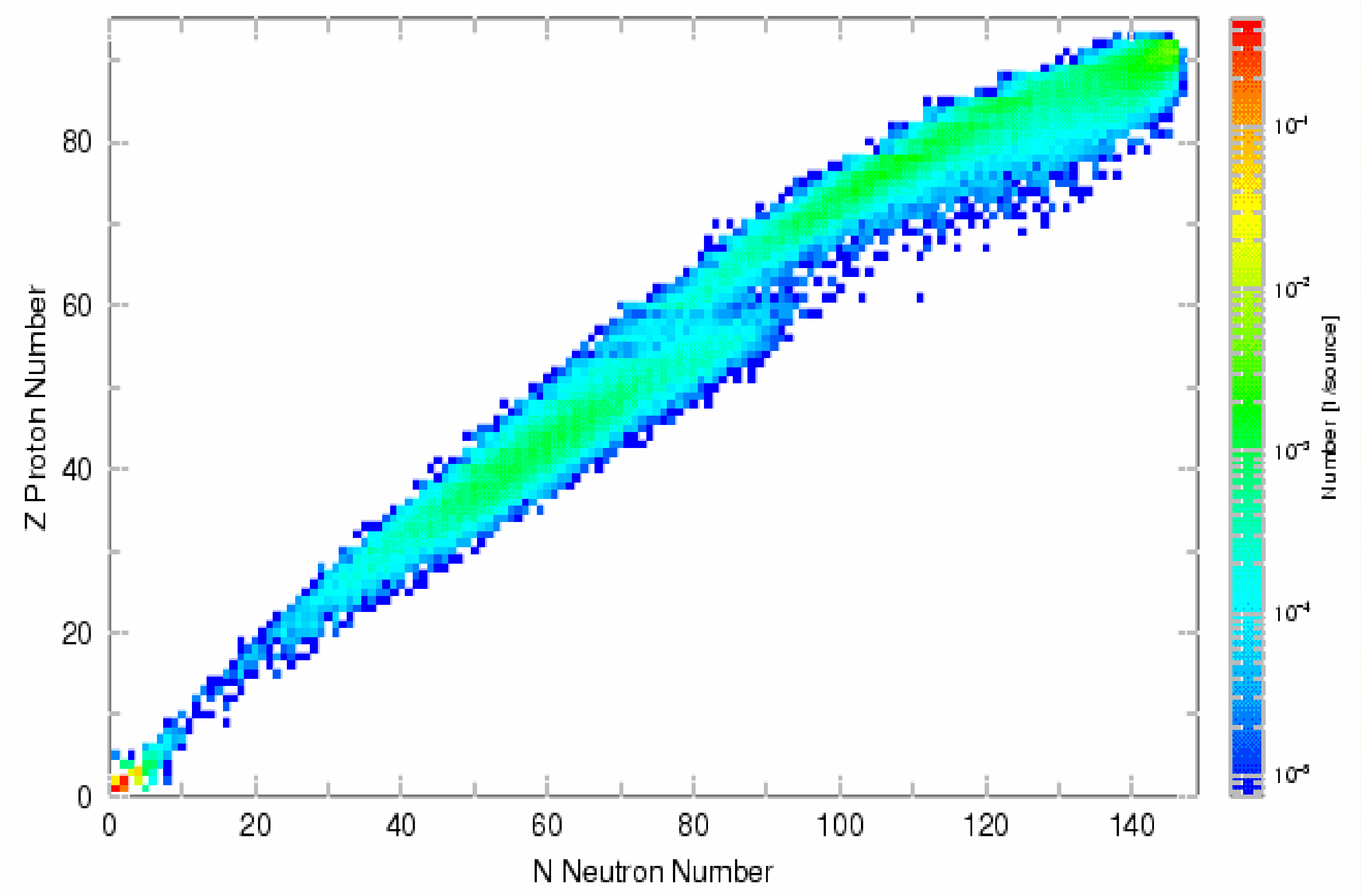
Neutron Flux Distribution in Large ISOL Target Model (MARS15)



Heating Rates Along Fragmentation Line, 400 MeV/u U-238 Beam on Li Target (PHITS)



Yields for 400-MeV/u U-238 Beam on Li target (PHITS)



Conclusions

- RIA target areas R&D is proceeding utilizing a successful multi-institution effort
- A variety of codes are being used to perform the various simulations; more will be added
  - Some inter-comparisons were performed with encouraging results; more will be needed (benchmarking)
- A two-step ISOL target with water cooled tungsten primary and UC secondary target appears viable for beam powers up to 400 kW
  - Optimization analyses are needed
- For a two-step ISOL target, primary beams of 1-GeV protons or 622-MeV/u deuterons give ~equal fission rates and heating
  - 777 MeV/u He-3 beam results in less fissions and higher heating
  - Two-step ISOL targets are likely to use proton beams only

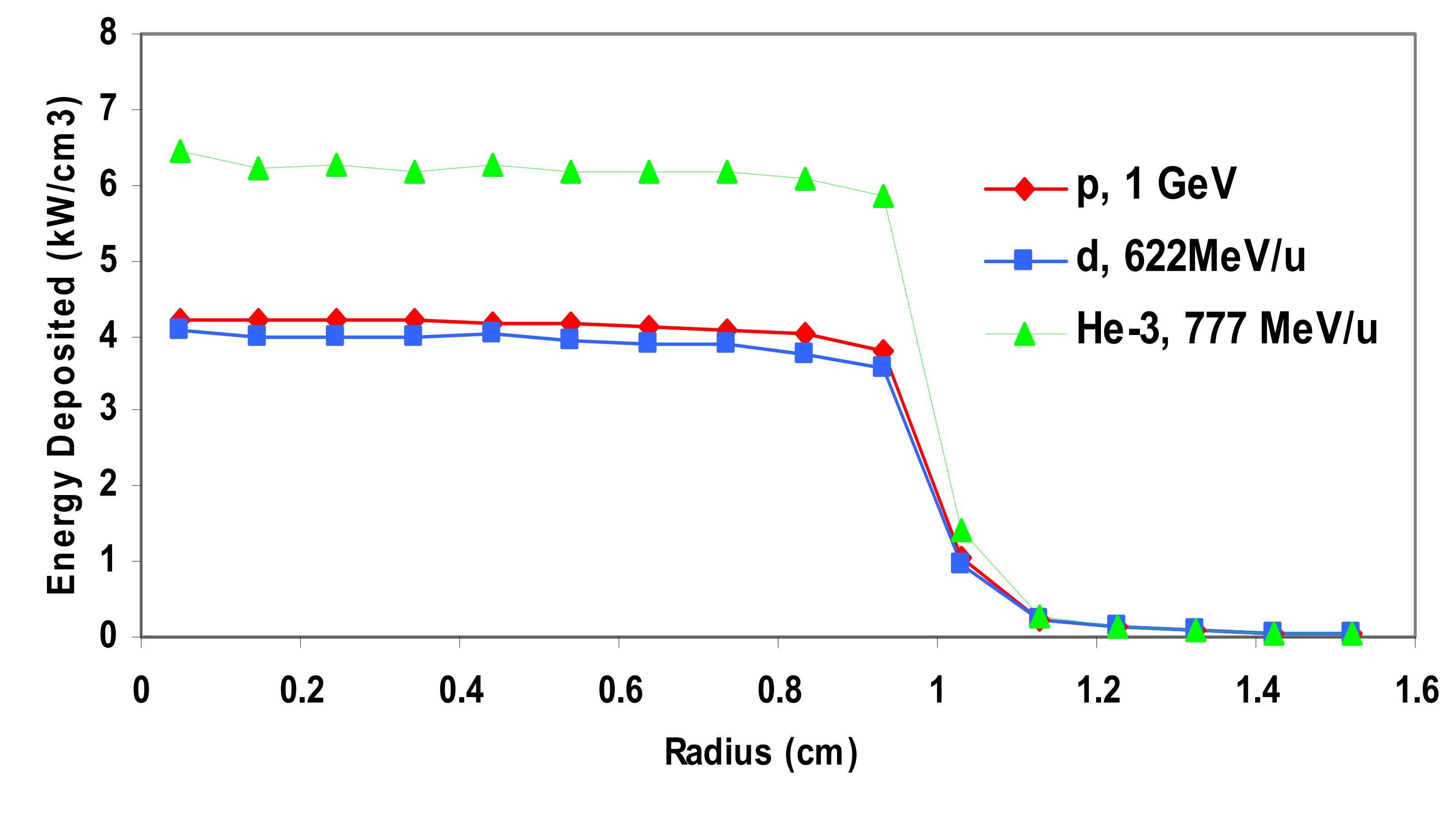
Supplementary Slides

Comparisons per Beam Particle

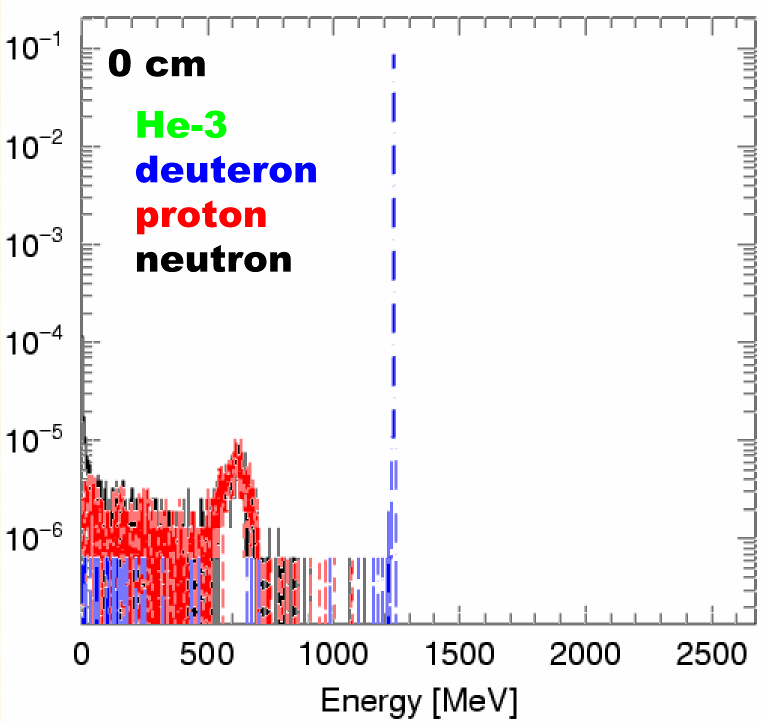
	Number of fissions in UC			Energy deposited in primary		
	Hg	0.9 W + 0.1 H_2O	0.9 W + 0.1 D_2O	Hg	0.9 W + 0.1 H_2O	0.9 W + 0.1 D_2O
p, 1 GeV	1.00	1.03	1.03	1.00	1.19	1.19
d, 622 MeV	1.23	1.30	1.30	1.23	1.49	1.49
He-3, 777 MeV	1.98	2.00	2.00	3.37	4.00	4.00

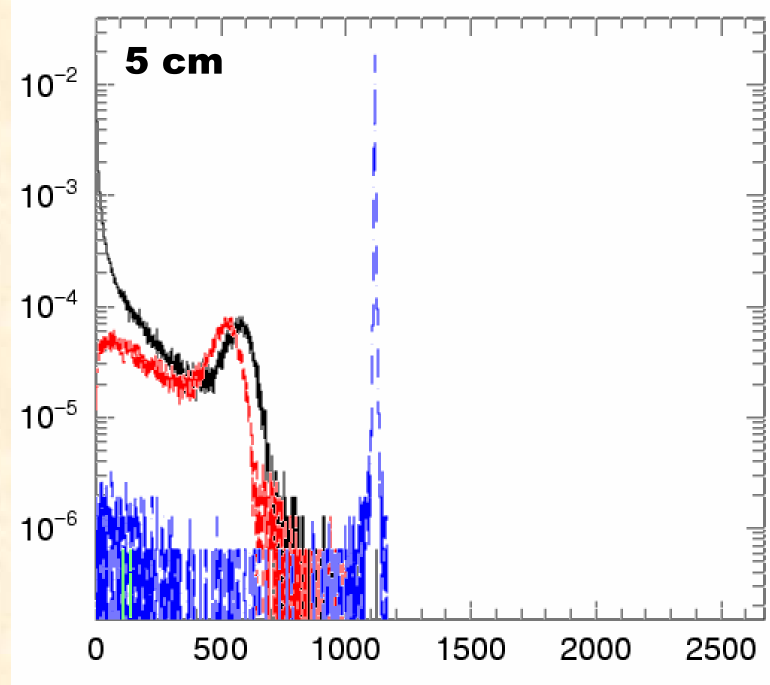
Note that results are normalized to p-on-Hg-target results.

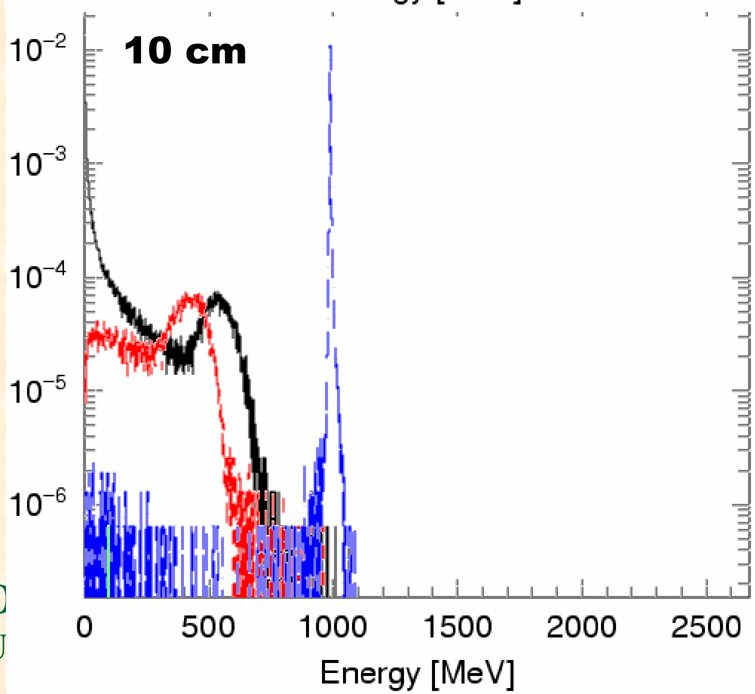
Heating Profiles at Target Face, Pencil Beam with 1-cm Radius

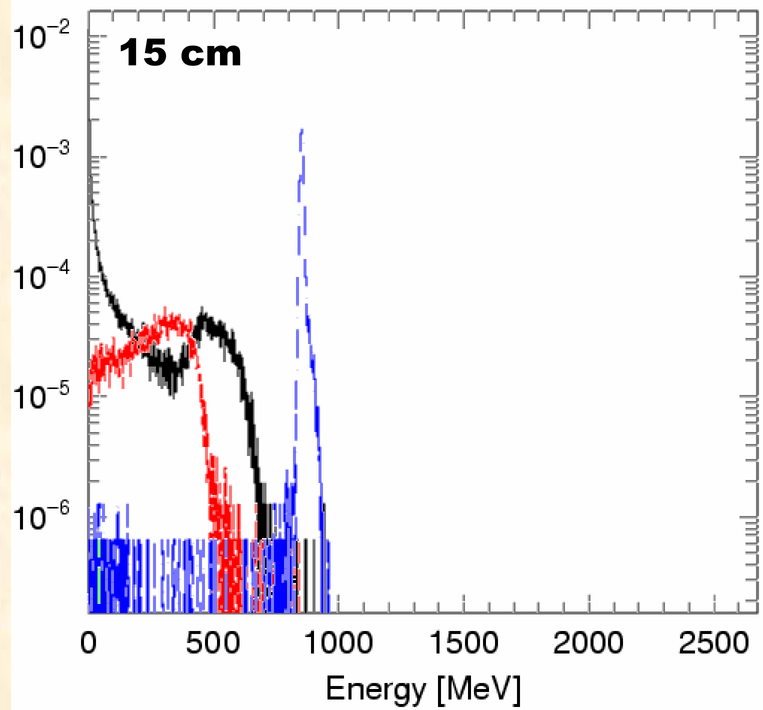


Particle Current,622 MeV/u d Beam, W+H_2O Target

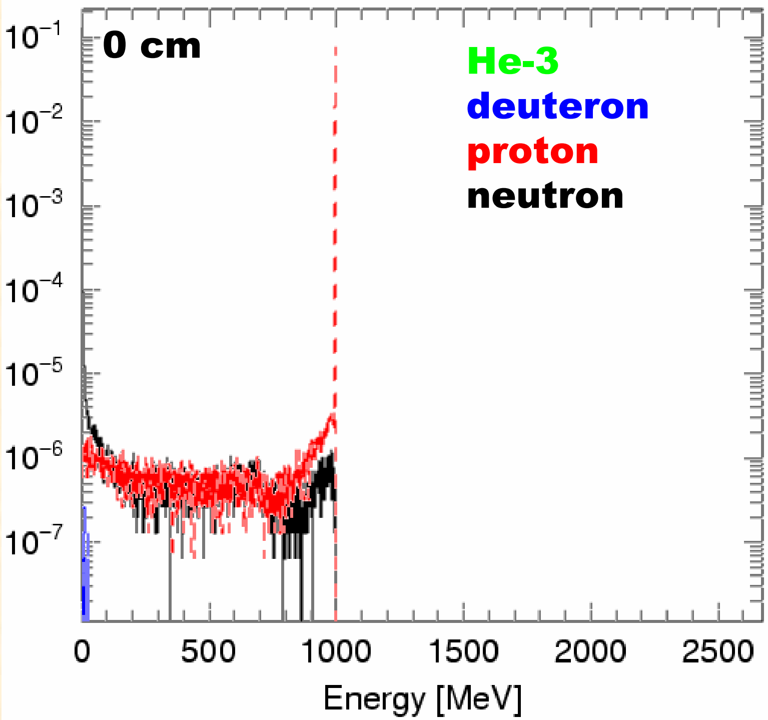


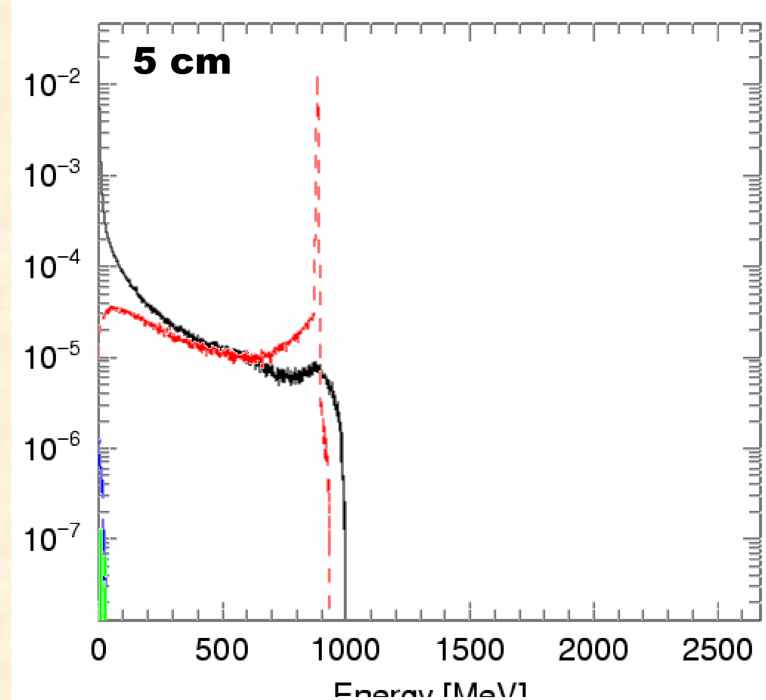


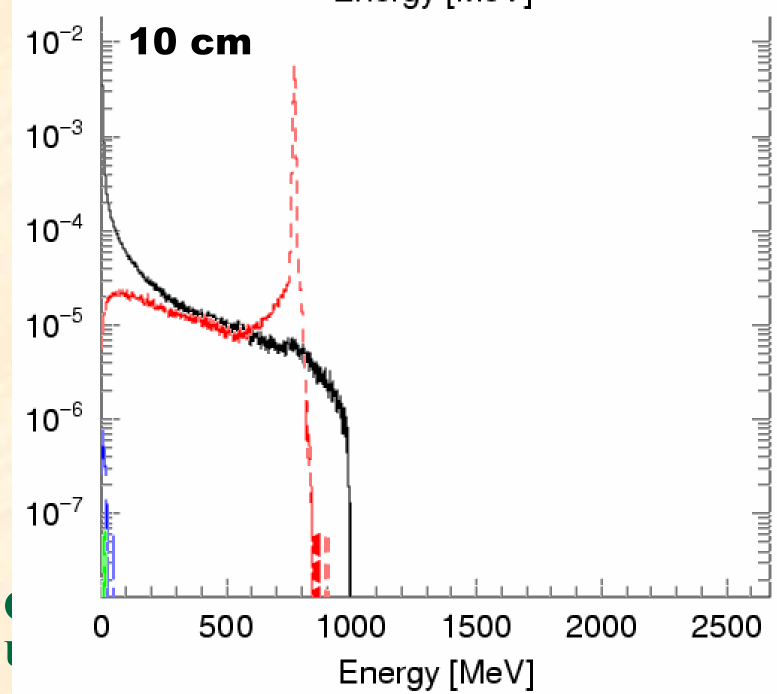


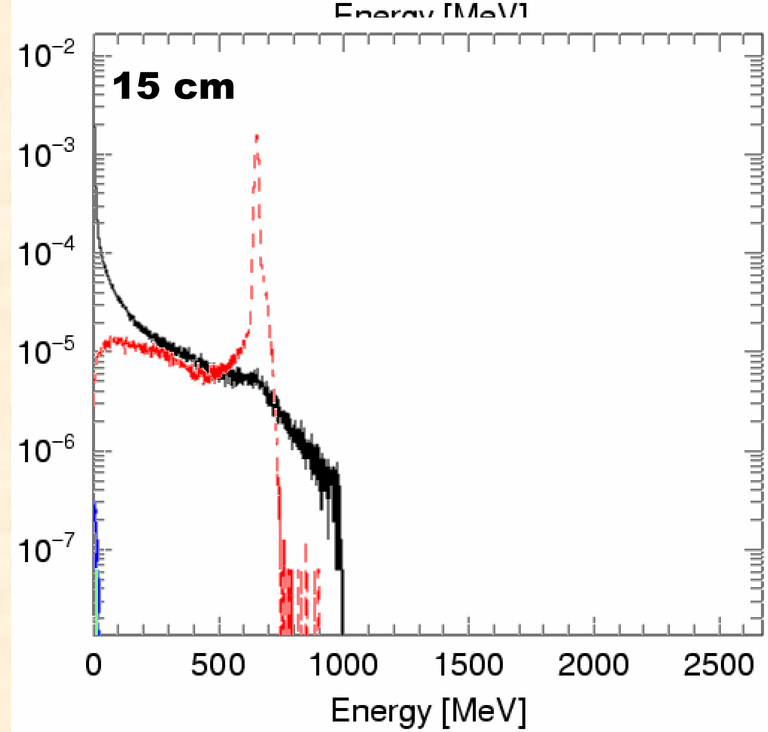


Particle Current, 1000 MeV p Beam, W+H_2O Target









Comparisons at Equal Beam Power

	Number of fissions in UC			Energy deposited in Secondary		
	Hg	0.9 W + 0.1 H_2O	0.9 W + 0.1 D_2O	Hg	0.9 W + 0.1 H_2O	0.9 W + 0.1 D_2O
p, 1 GeV	1.00	1.03 (1.00)*	1.03 (1.00)*	1.00	1.02 (1.01)*	1.03 (1.01)*
d, 622 MeV	0.99	1.05	1.05	0.96	1.01	1.01
He-3, 777 MeV	0.85	0.86	0.86	0.87	0.85	0.85

*For 0.8 W + 0.2 H_2O or D_2O

Note that results are normalized to p-on-Hg-target results.

RIA Targets Conceptual Design

Performance & operation requirements:

- Optimize performance for production of rare isotopes
- Minimize target change-out time
- Ensure safe and reliable operation
- Maintain flexibility to implement new target concepts
- Minimize radioactive waste and hazards associated with the operation