Reactor Production and Medical Applications of Radioisotopes

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July 26, 2007

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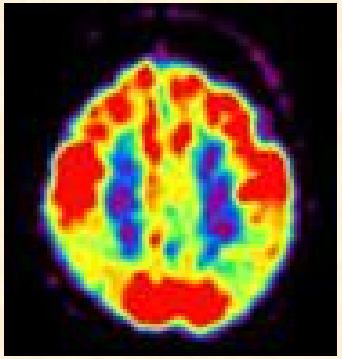
U. S. DEPARTMENT OF ENERGY

Outline

- **Medical applications of radioisotopes**
  - **Diagnostic**
  - **Therapeutic**
- **Production of radioisotopes**
  - **Accelerators/cyclotrons**
  - **Nuclear reactors**

Diagnostic Nuclear Medicine

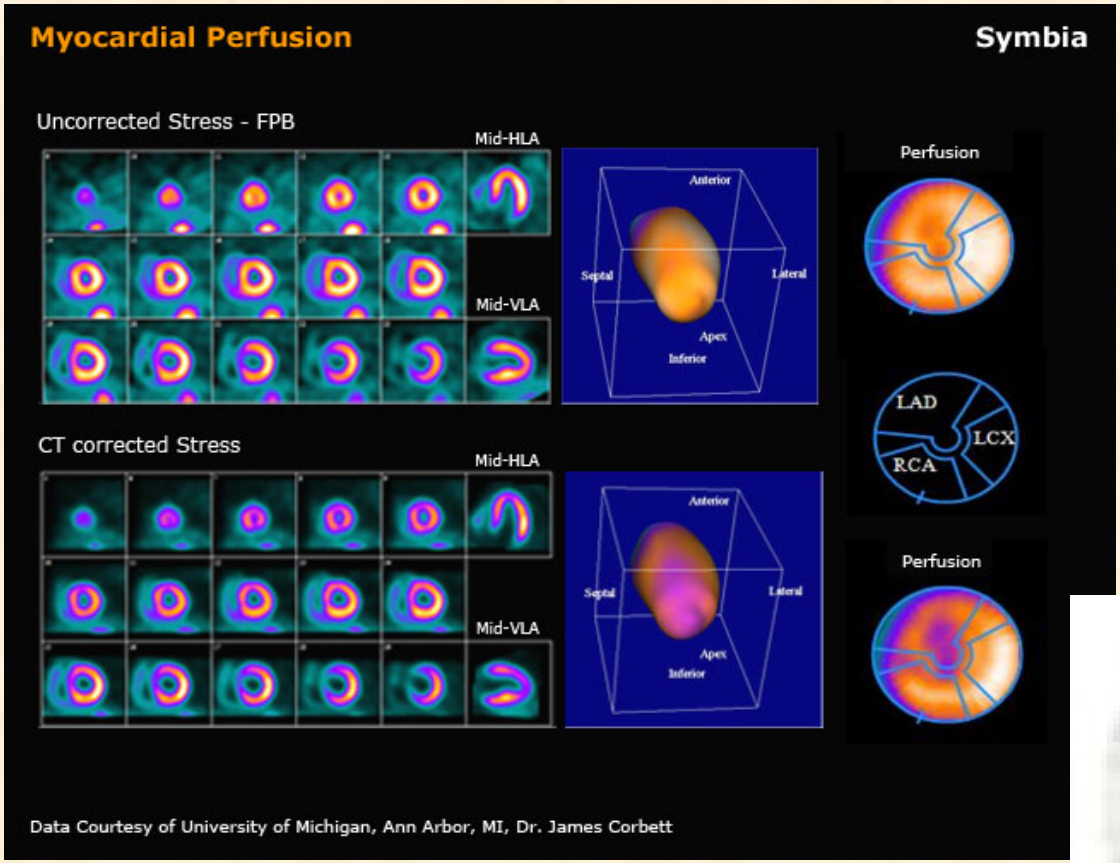
- **Molecular imaging**
  - **Internally administered radiolabeled compounds**
  - **External detectors/signal processing generate image**
  - **Enhanced soft tissue imaging**
  - **Smaller cell cluster imaging**
  - **Study organ functionality**

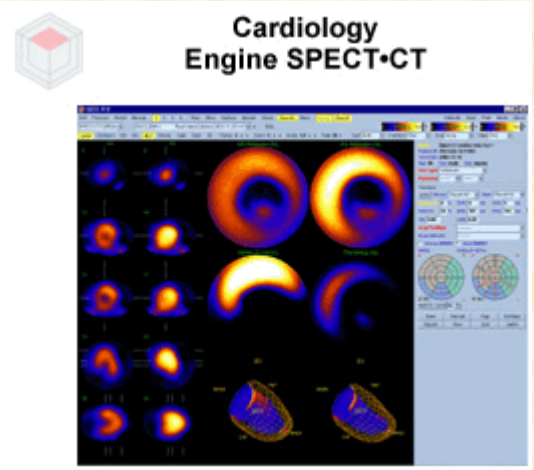


PET Image of Alzheimer's Patient Brain

- **Many devices, e.g.,**
  - **Gamma camera**
  - **Single Photon Emission Computed Tomography (SPECT), SPECT/CT (Computed Tomography)**
  - **Positron Emission Tomography (PET), PET/CT**

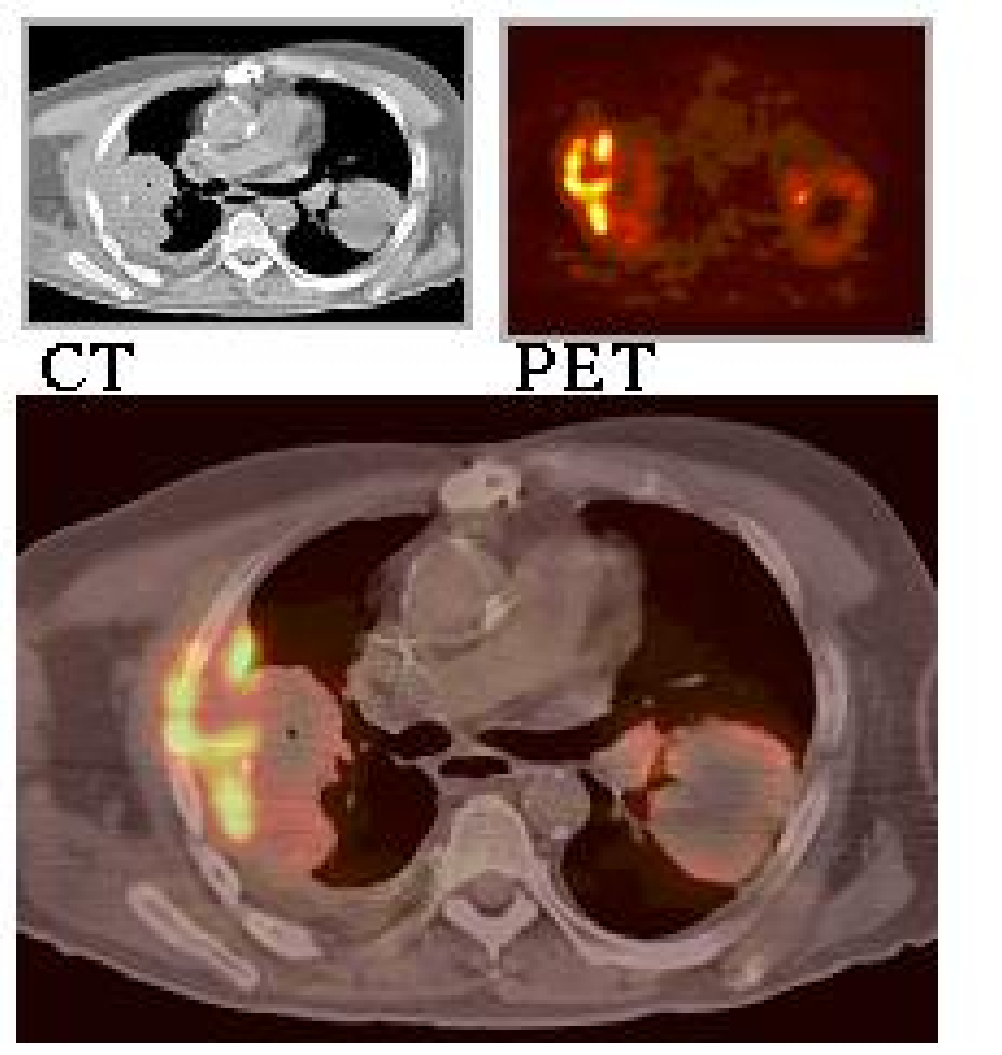
Single Photon Emission Computed Tomography (SPECT)

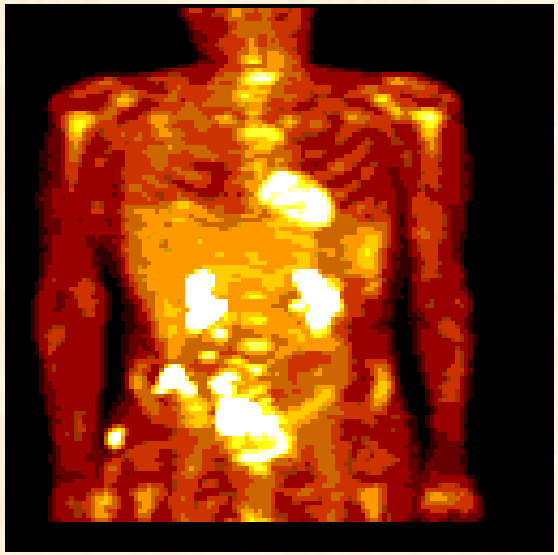




Siemens SPECT/CT

Positron Emission Tomography (PET)

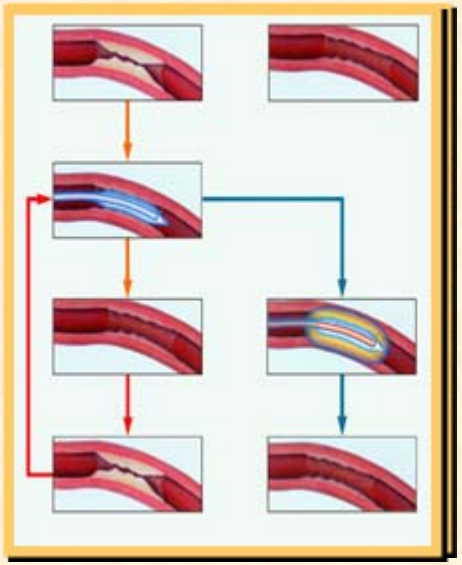




Therapeutic Nuclear Medicine

- **Targeted therapy**
  - α, β, γ **emitters delivered to diseased tissue**
- **Strategies**
  - **Molecular targeting (monoclonal antibodies, peptides, etc.)**
  - **Natural targeting (e.g., iodine/thyroid, strontium/bone)**
  - **Brachytherapy**

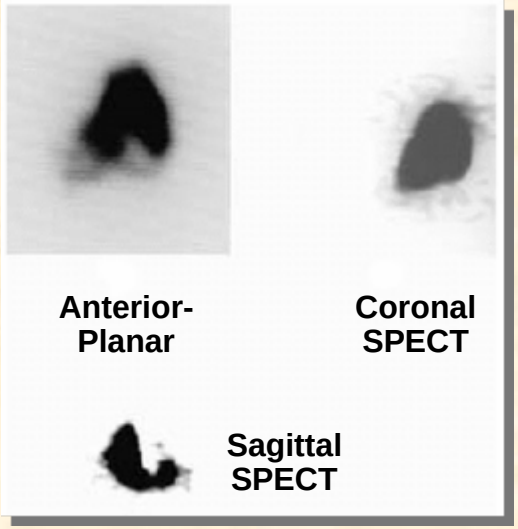
Heart Disease



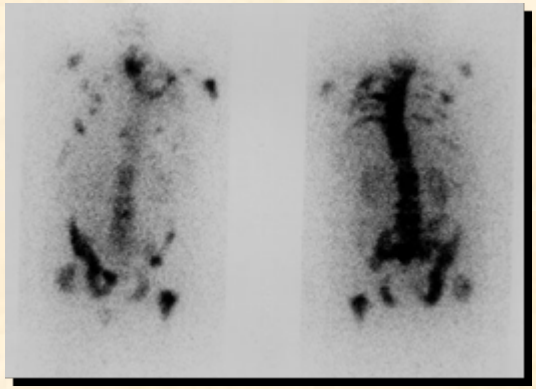
Schwartz et al., Science & Medicine, March-April (1996)

^{188}Re

Arthritis



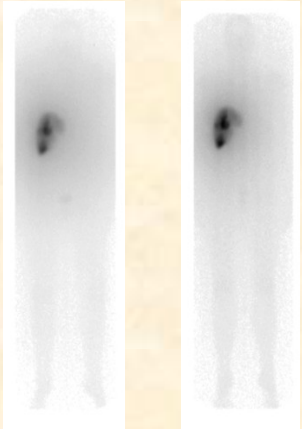
Lee et al., Nucl. Med. Commun., 24, 689 (2003)



Courtesy of Prof. H.-J. Biersack and
Dr. H. Palmedo, University Hospital, Bonn

Bone Pain

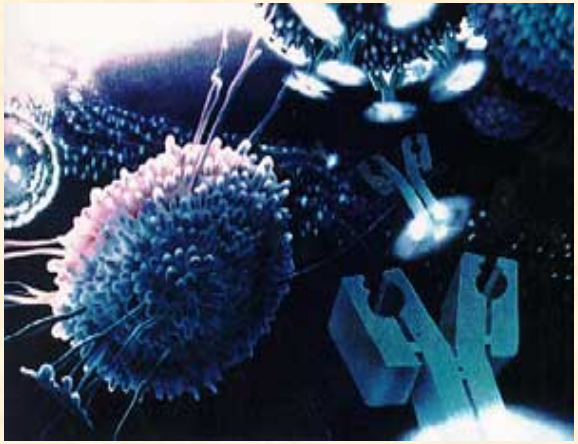
22 h post-therapy



44 h post-therapy

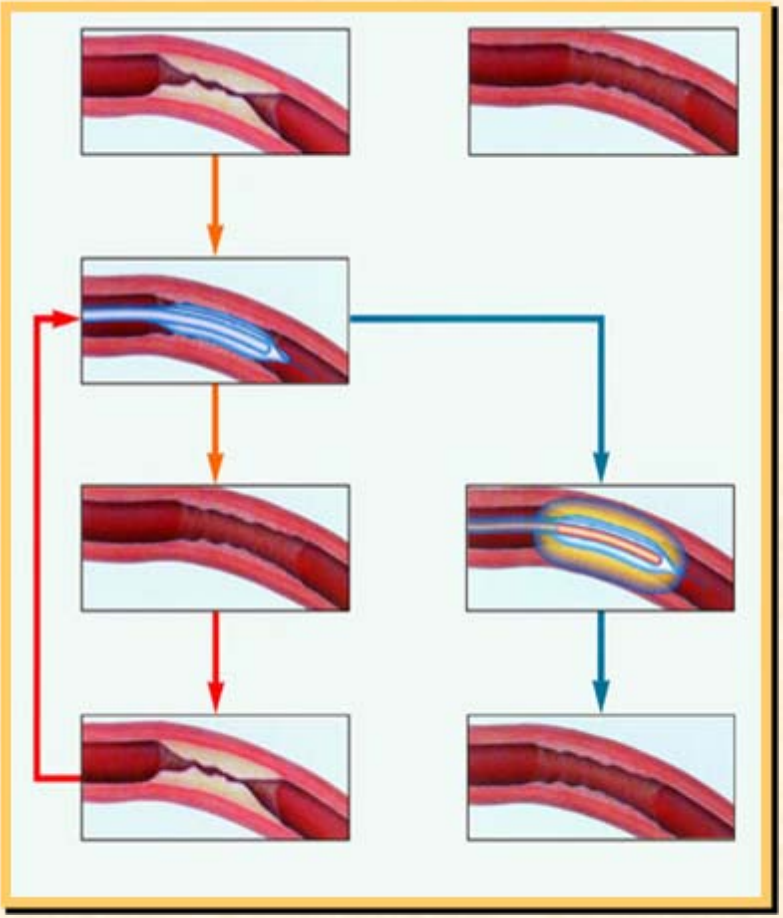
Courtesy of J. Kropp et al., Dresden, Germany

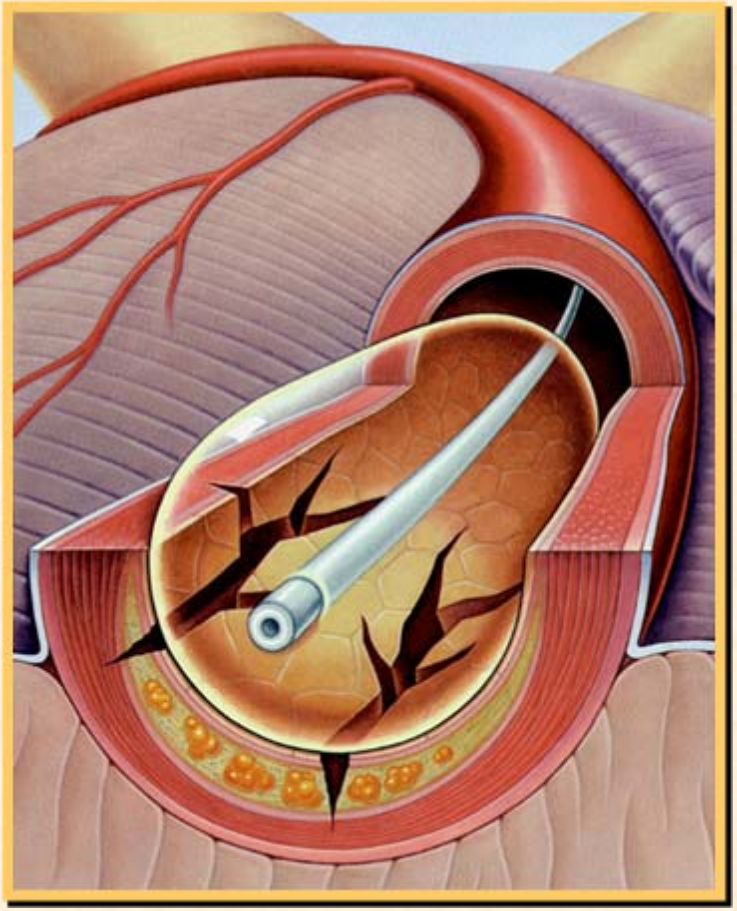
Liver Metastases



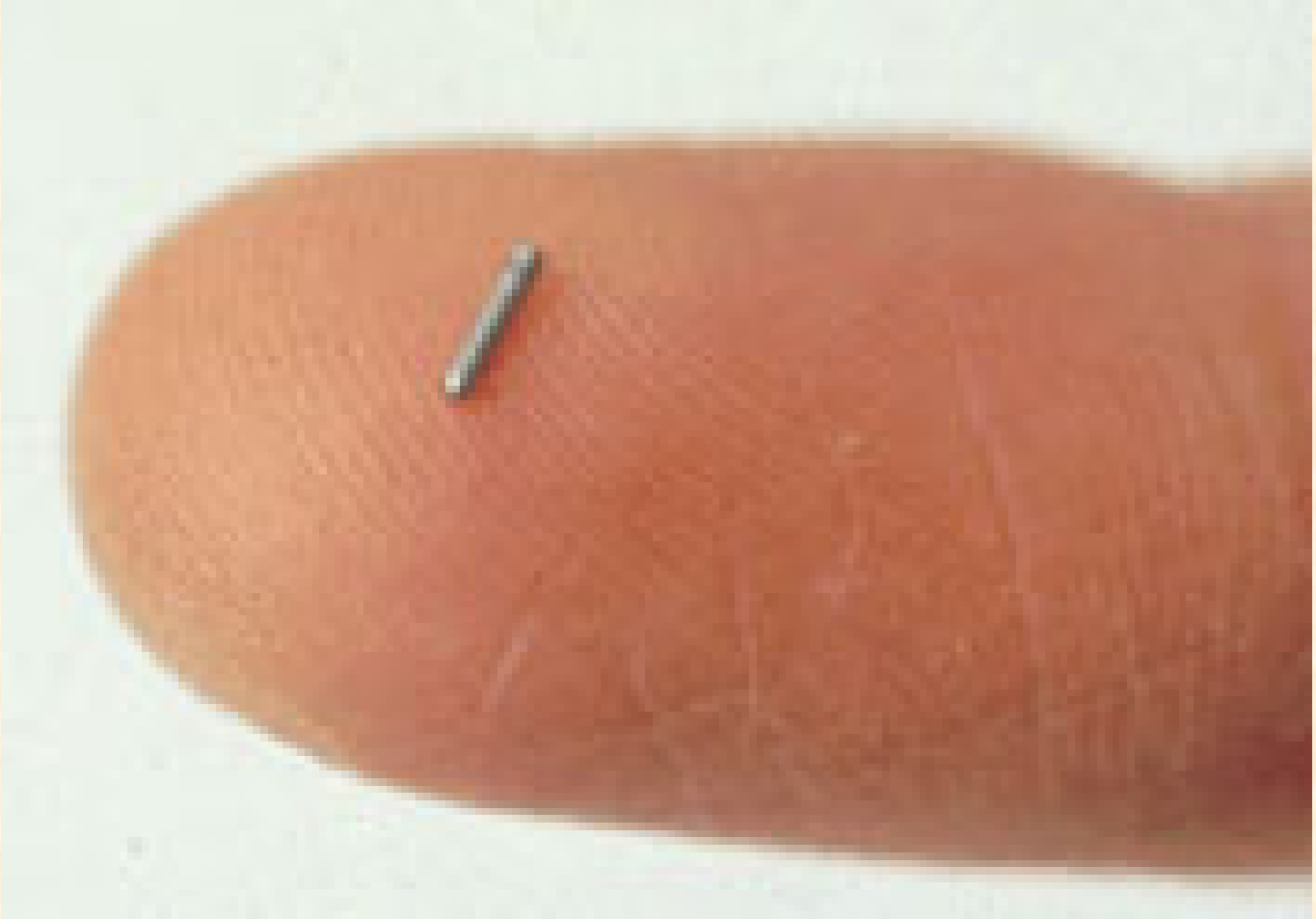
Radioimmunotherapy

Coronary Artery Disease

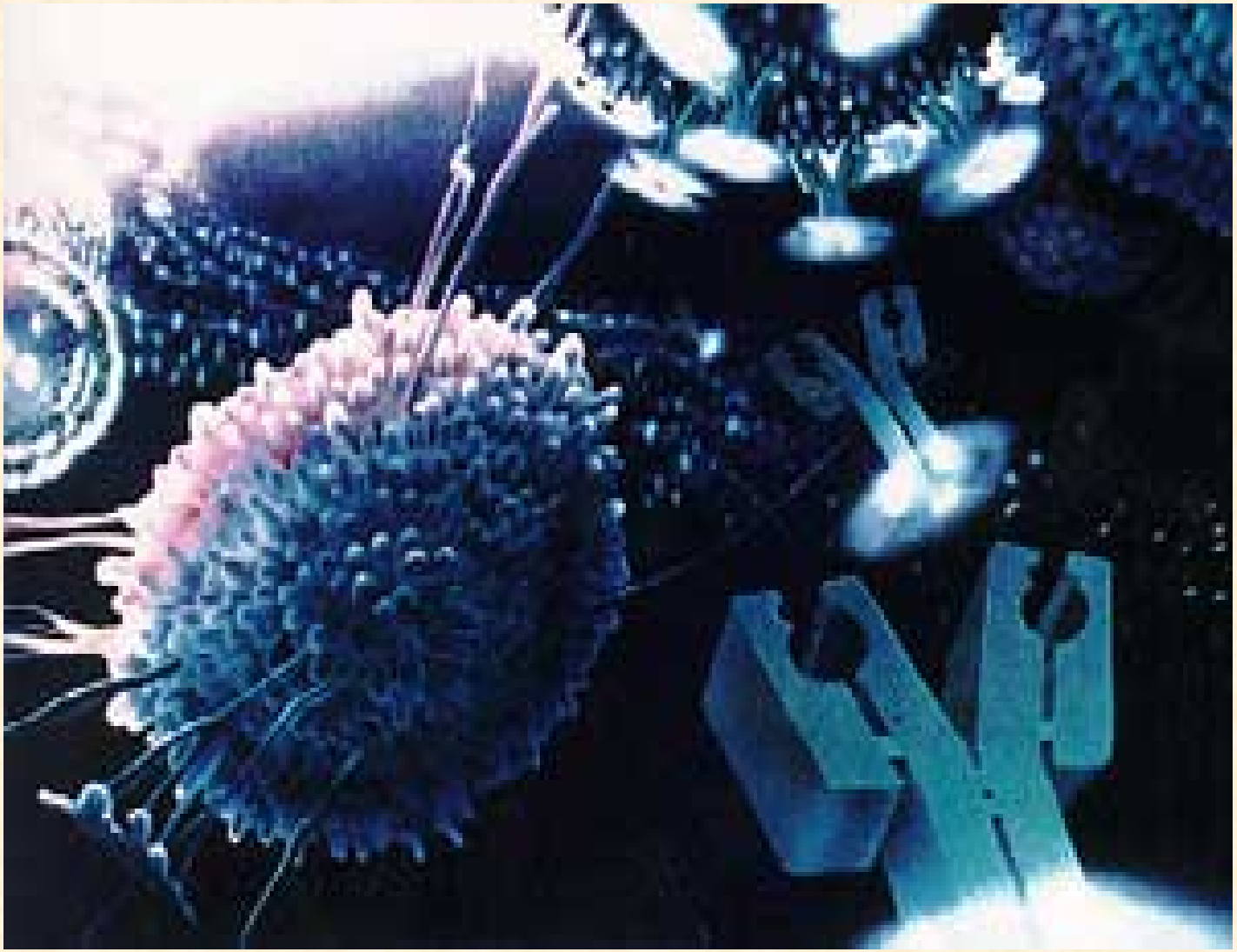




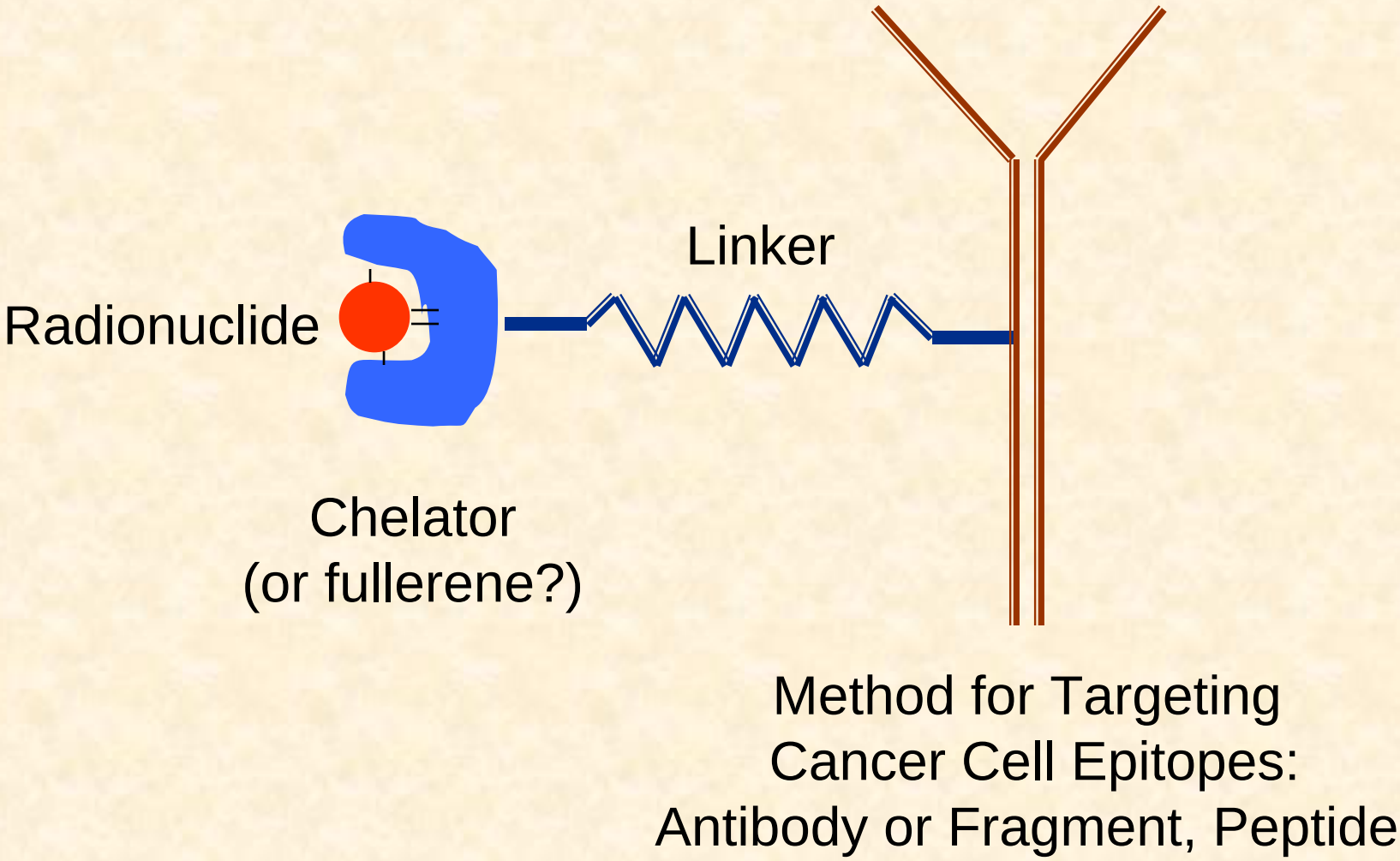
Prostate Cancer Seed (Brachytherapy)



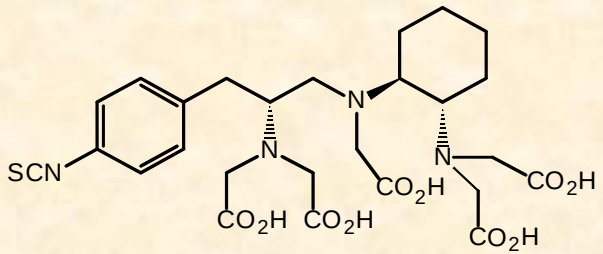
Radioimmunotherapy (RIT)



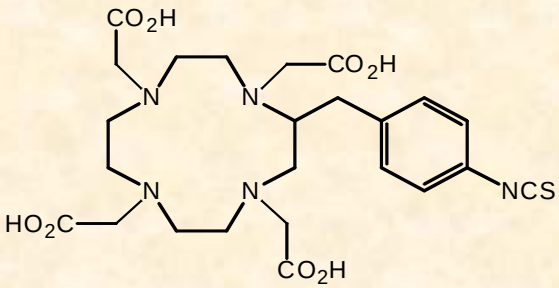
Radioimmunotherapy Concept



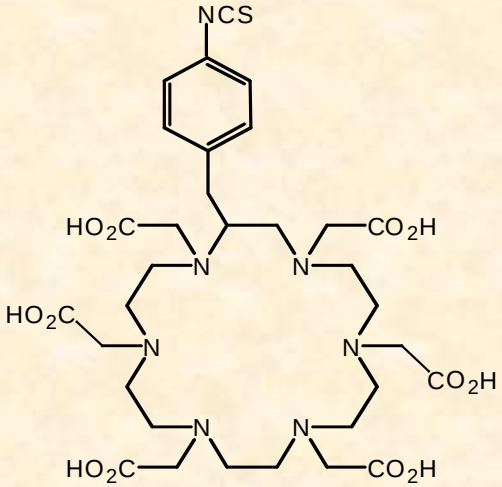
Polyamincarboxylate (PAC) Chelating Ligands and Fullerenes (attach radiometals to monoclonal antibodies)



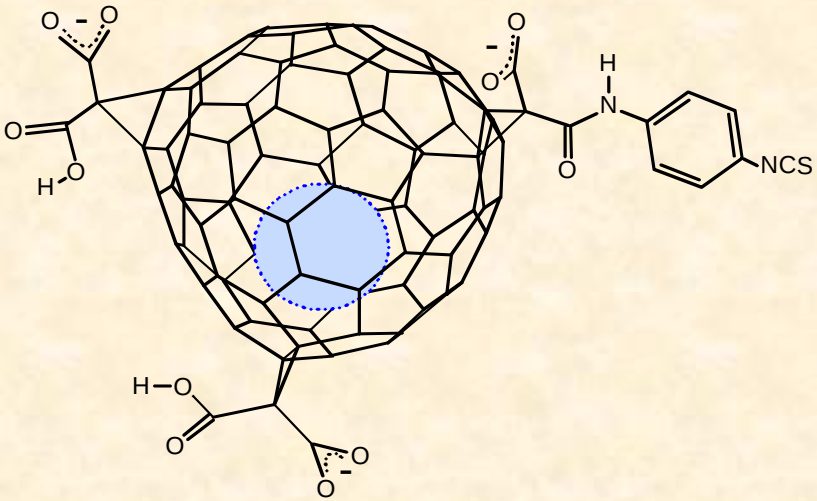
CHX-A'' DTPA



c-DOTA

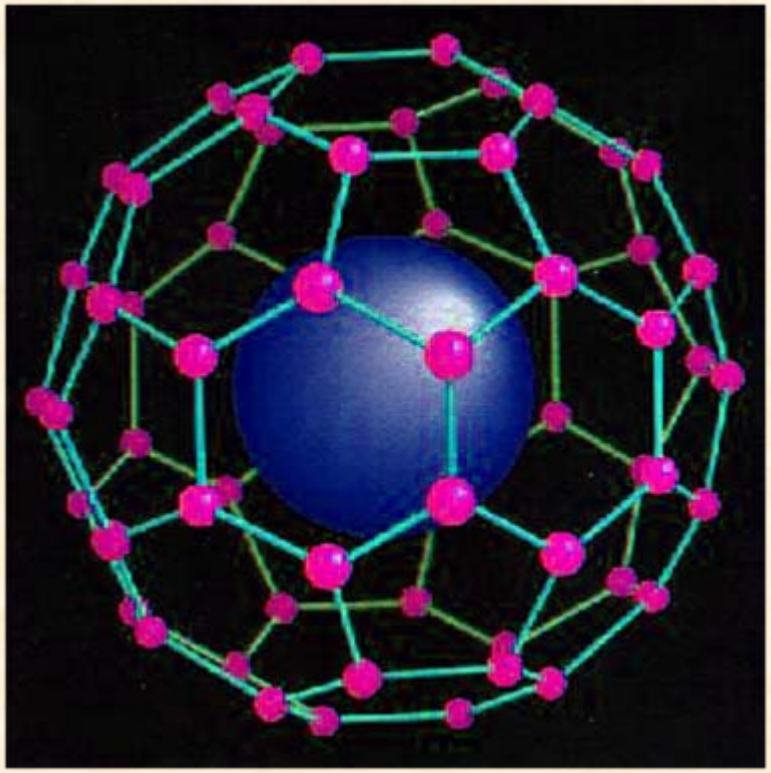


HEHA



C_{82} Carboxymetallofullerene

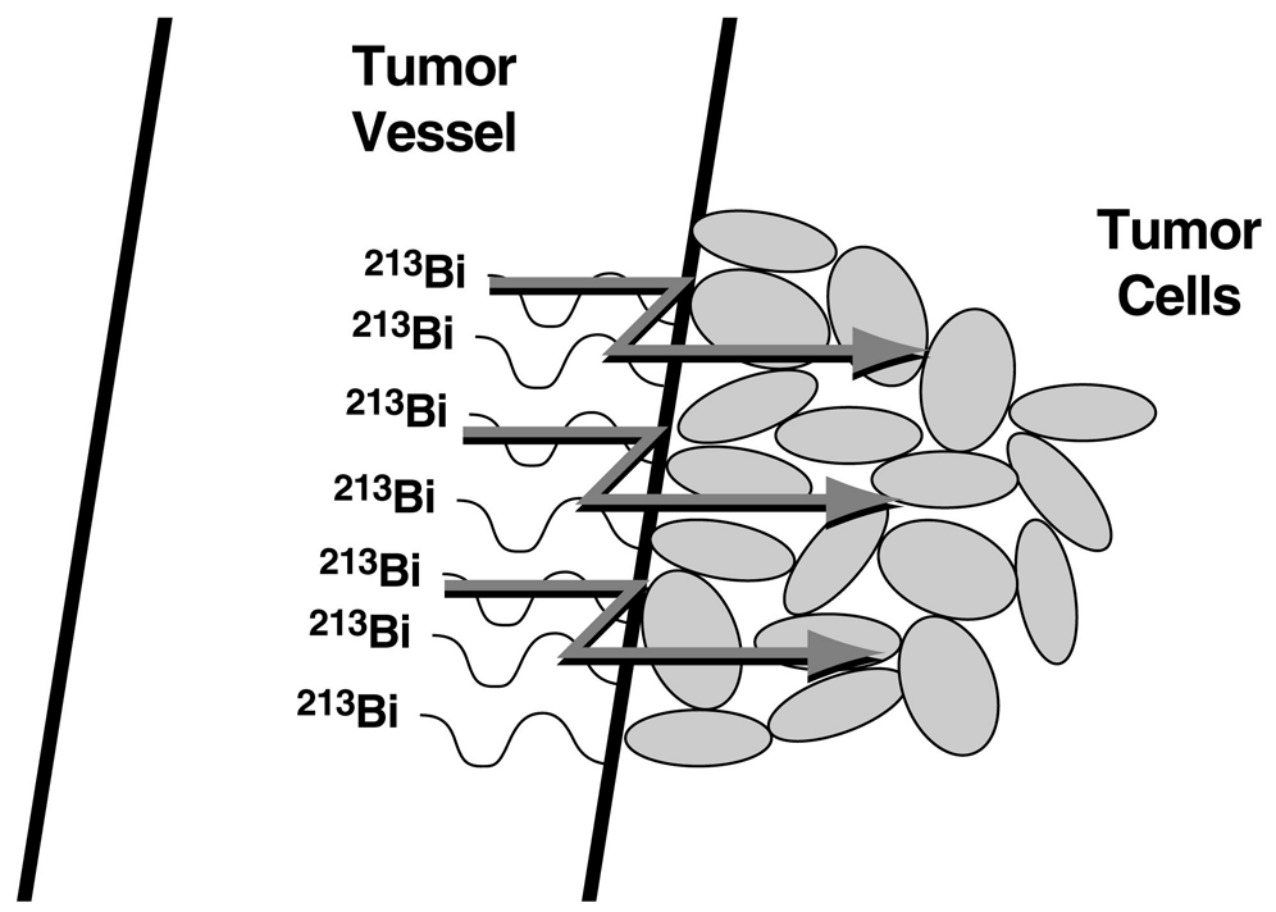
ORNL Research into Radiofullerenes



Representation of a metal atom encapsulated in a simple carbon fullerene buckyball

Metal Ion	Ionic Radius (pm)
Lu^{+3}	86.1
Tm^{+3}	88.0
Ho^{+3}	90.1
$^{213}Bi^{+3}$	103
$^{212}Pb^{+2}$	119
$^{225}Ac^{+3}$	112

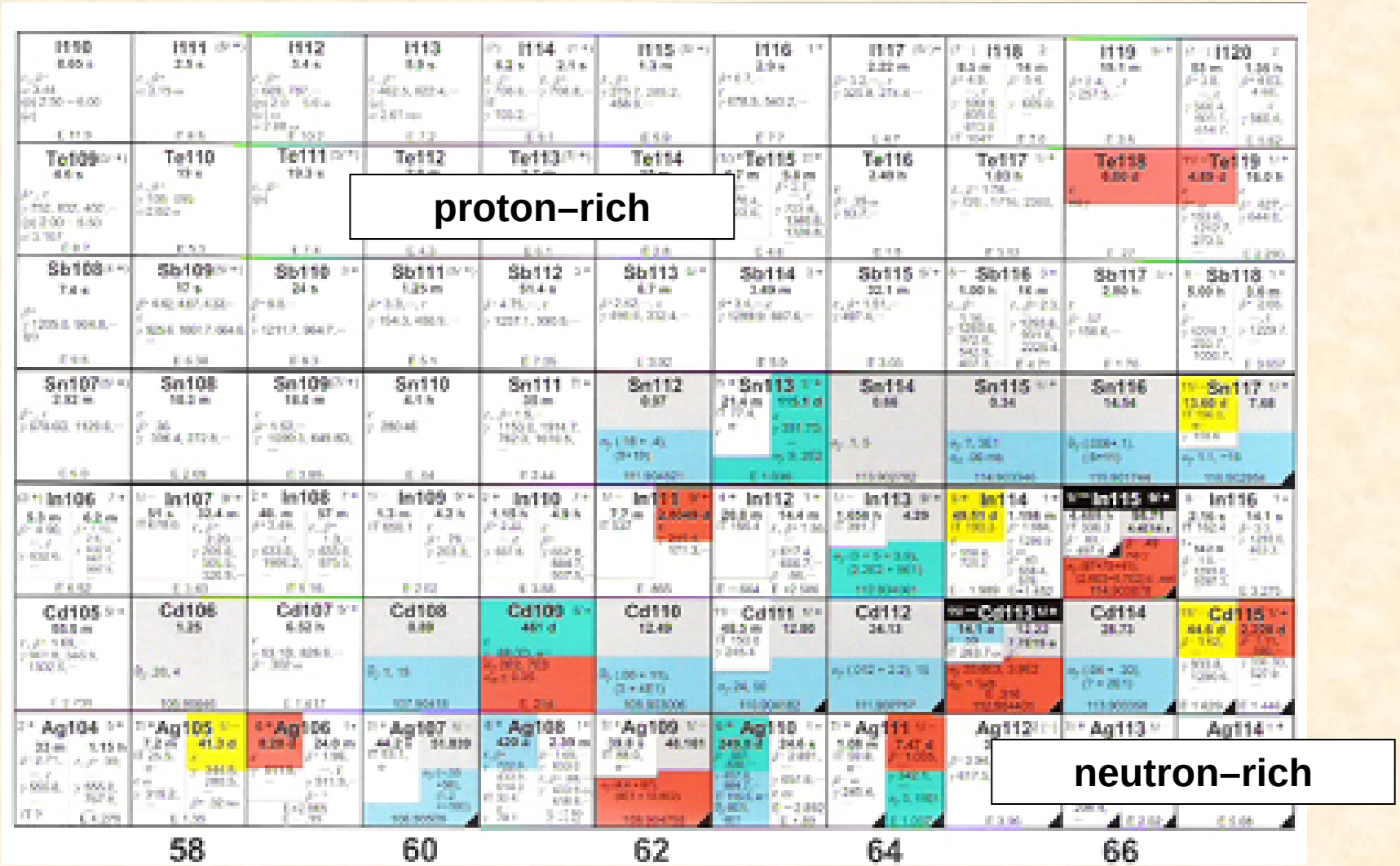
Vascular-targeted Radioimmunotherapy



Medical Isotope Production

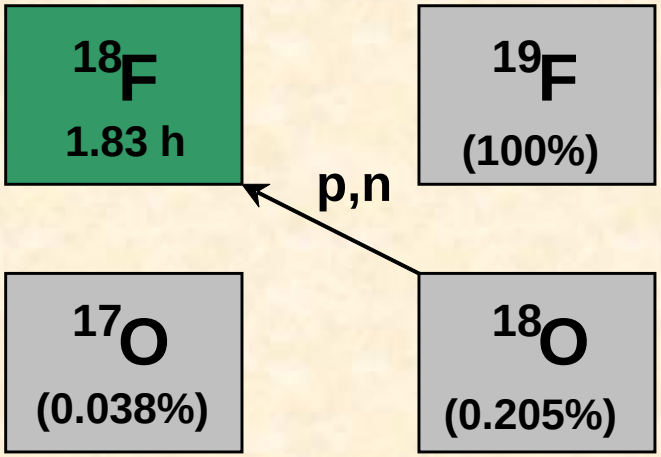
- **Diagnostic**
  - **Gamma emitters**
  - **Positron emitters**
- **Therapeutic**
  - **Beta emitters**
  - **Alpha emitters**
- **Facilities**
  - **Accelerators/cyclotrons**
  - **Nuclear reactors**

Chart of the Nuclides



Charged Particle Reactions

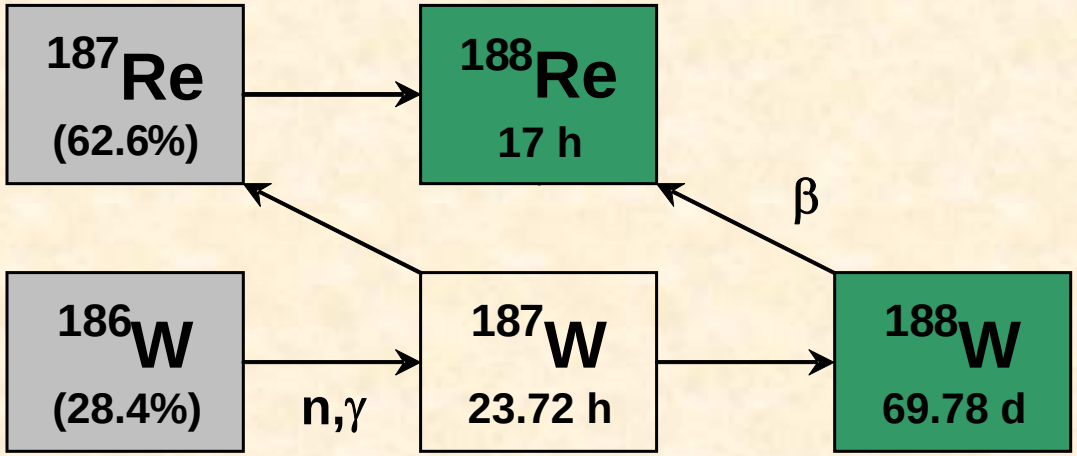
$^{18}O(p,n)^{18}F \Rightarrow$ Positron Emission Tomography

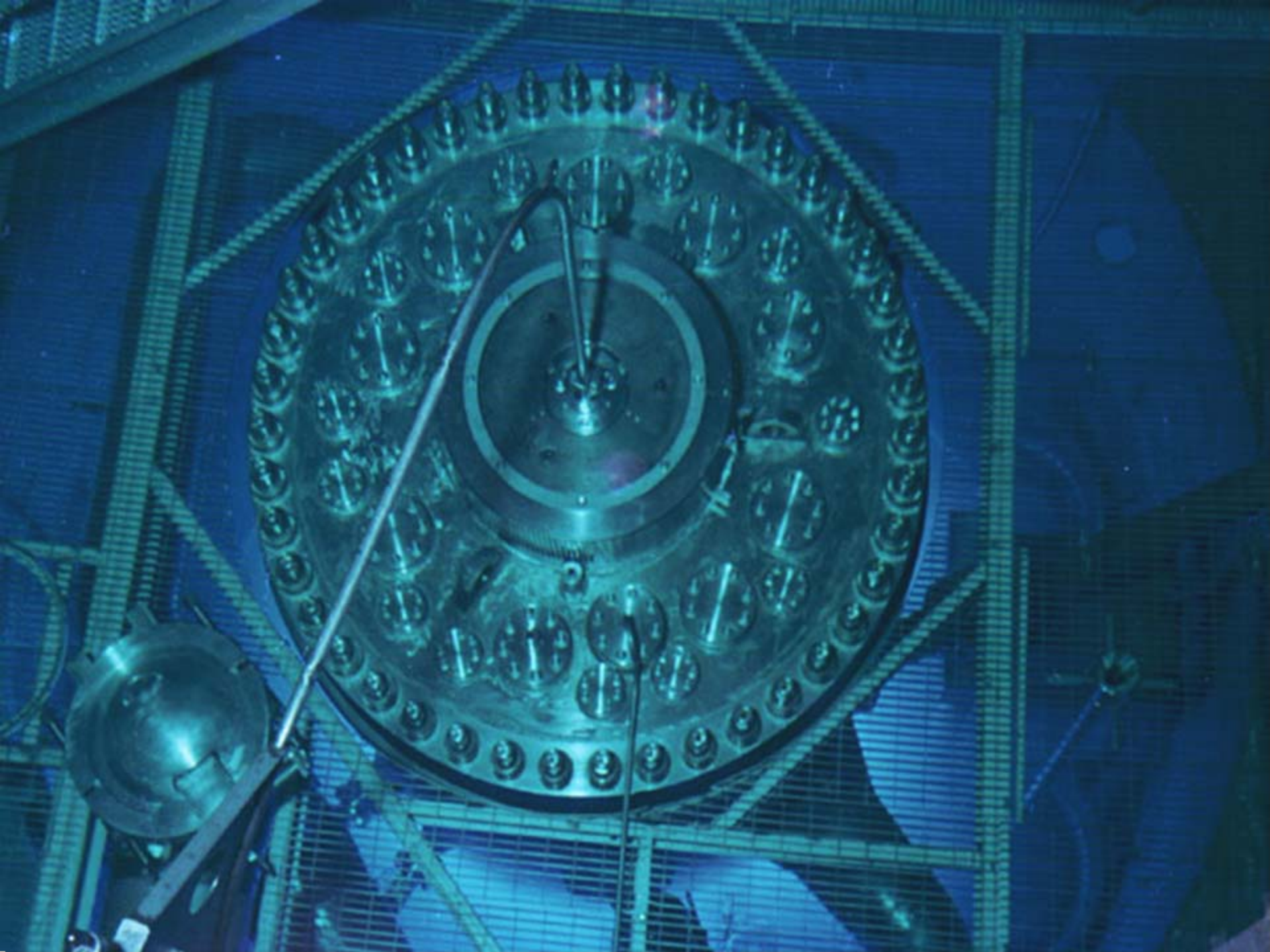


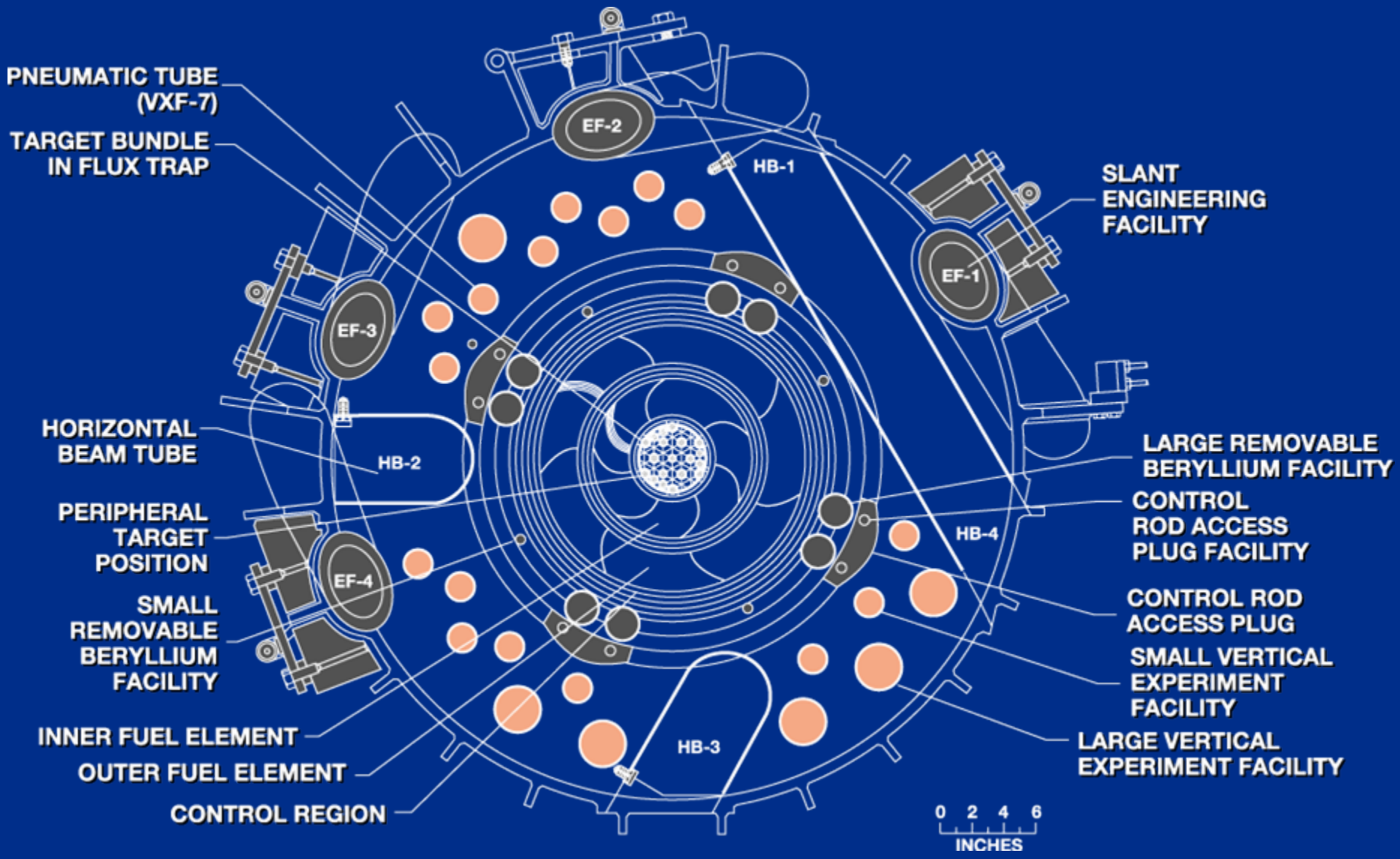
Reactor Production of Radioisotopes

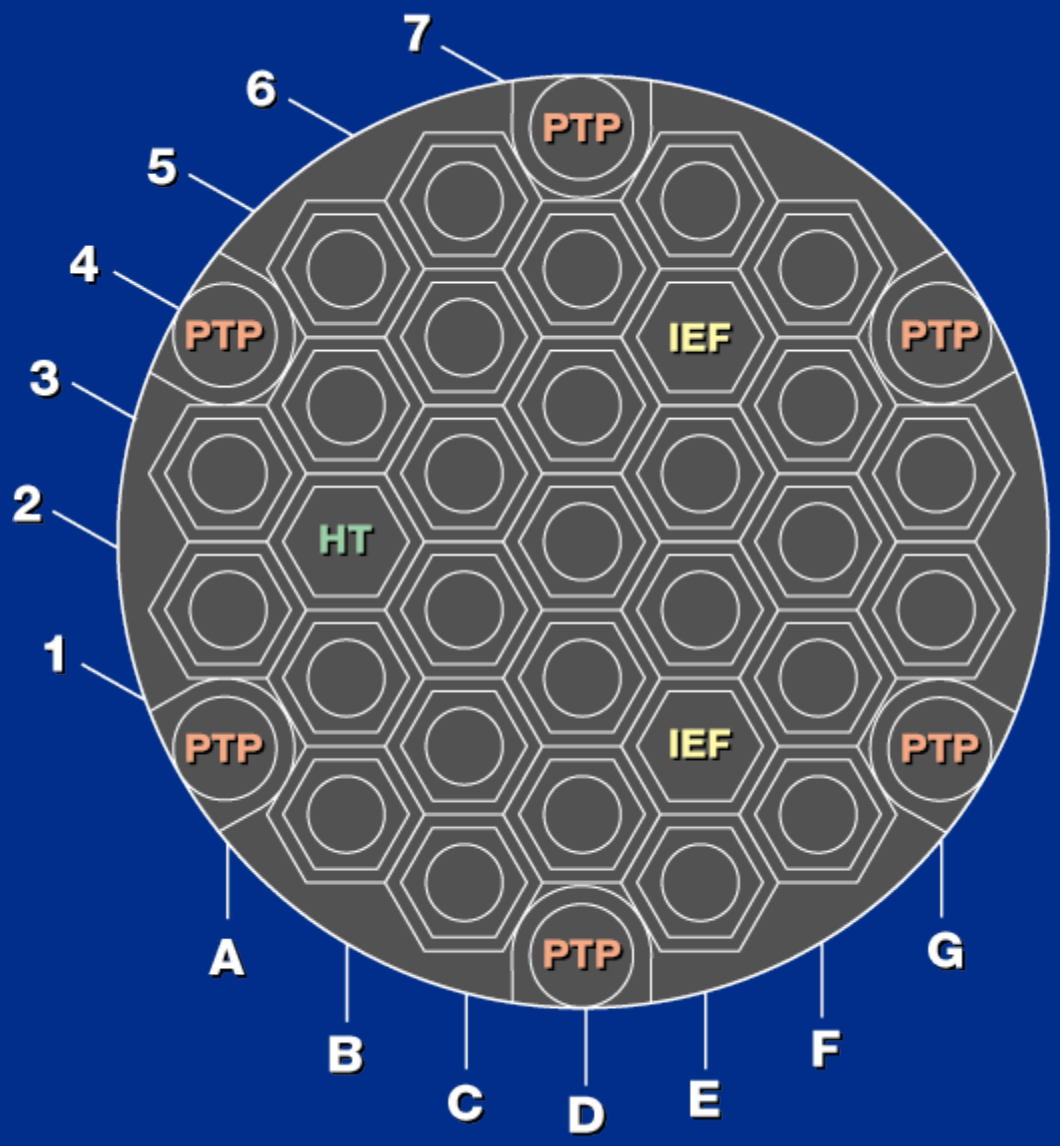
- **Typically produce neutron – rich isotopes**
- **Radiative capture (n,γ) predominates at low neutron energies (thermal reactor)**

$$^{187}Re(n,\gamma)^{188}Re \Rightarrow \text{Cancer Therapy, etc.}$$



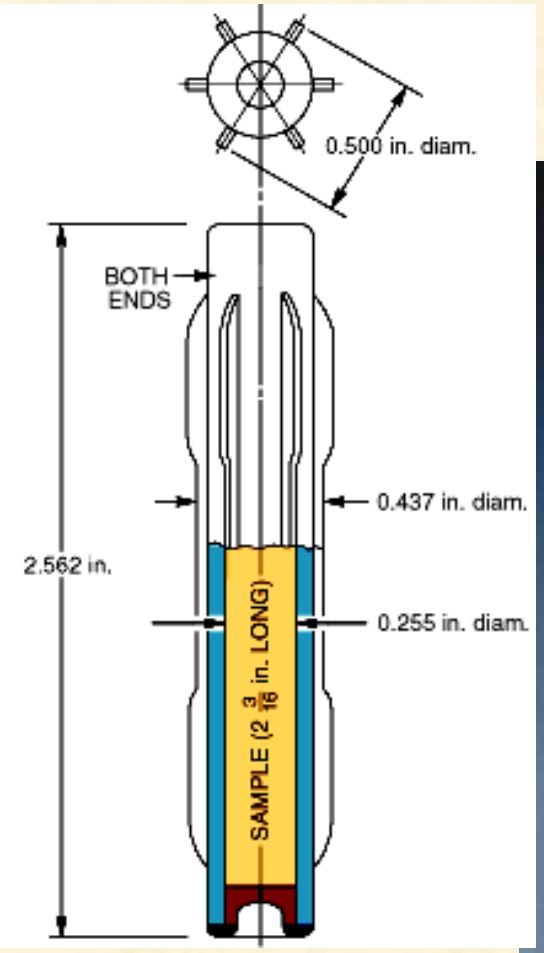



PNEUMATIC TUBE (VXF-7)
TARGET BUNDLE IN FLUX TRAP
HORIZONTAL BEAM TUBE
PERIPHERAL TARGET POSITION
SMALL REMOVABLE BERYLLIUM FACILITY
INNER FUEL ELEMENT
OUTER FUEL ELEMENT
CONTROL REGION
EF-1
EF-2
EF-3
EF-4
HB-1
HB-2
HB-3
HB-4
SLANT ENGINEERING FACILITY
LARGE REMOVABLE BERYLLIUM FACILITY
CONTROL ROD ACCESS PLUG FACILITY
CONTROL ROD ACCESS PLUG
SMALL VERTICAL EXPERIMENT FACILITY
LARGE VERTICAL EXPERIMENT FACILITY
0 2 4 6
INCHES

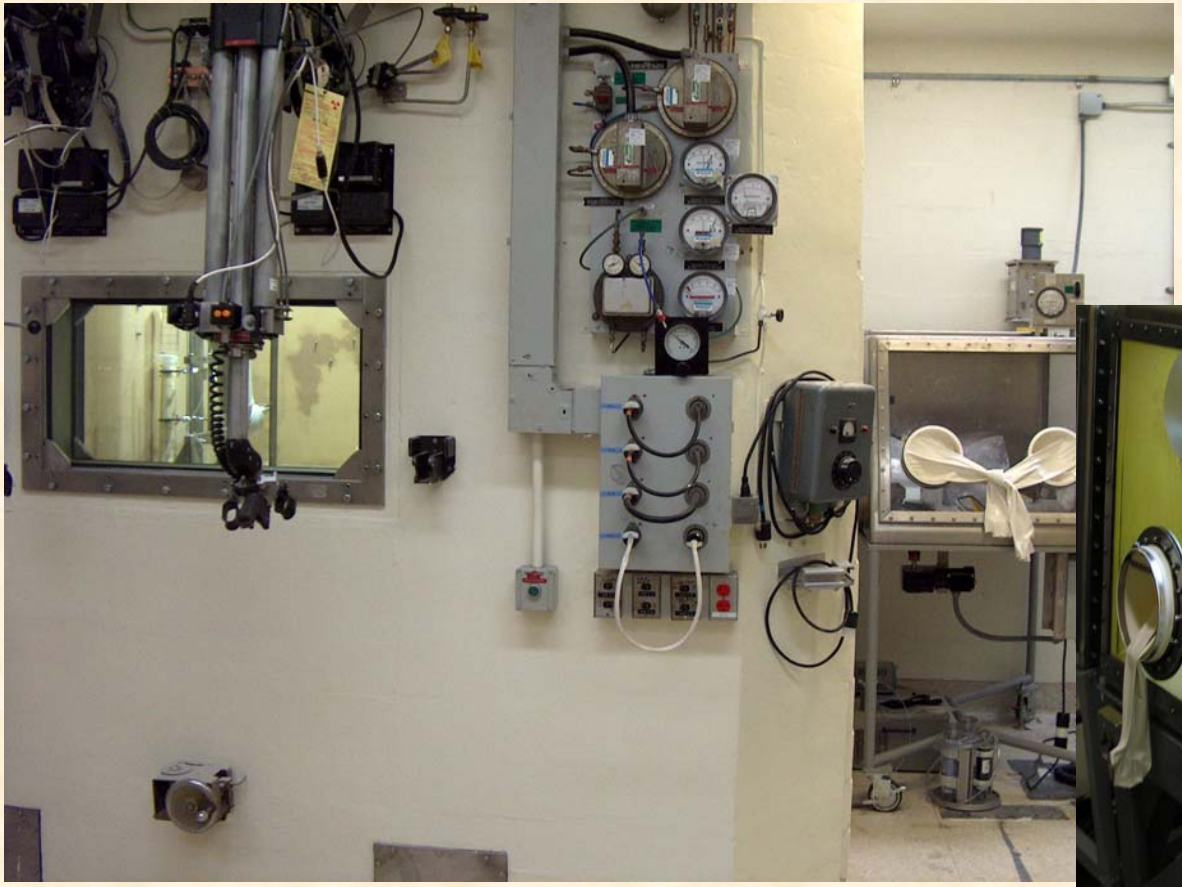


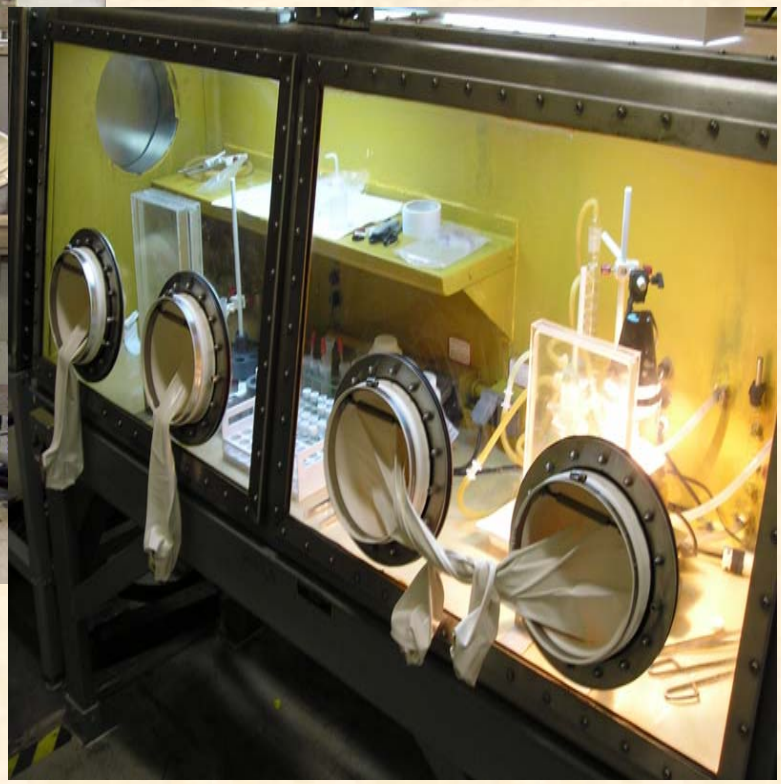
HT HYDRAULIC TUBE
PPT PERIPHERAL TARGET POSITIONS
IEF INSTRUMENTED EXPERIMENT FACILITIES

HFIR Targets

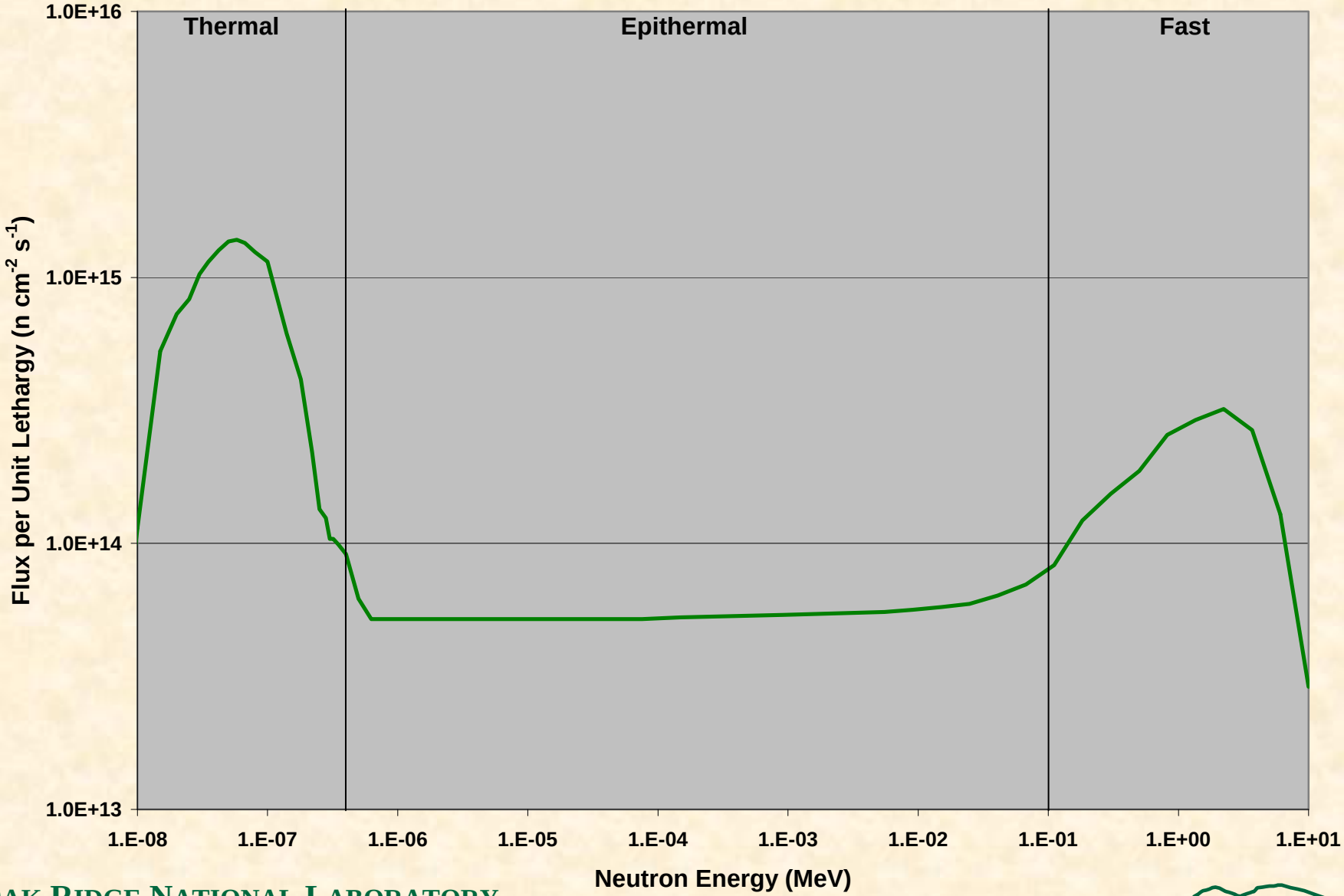


Target Processing

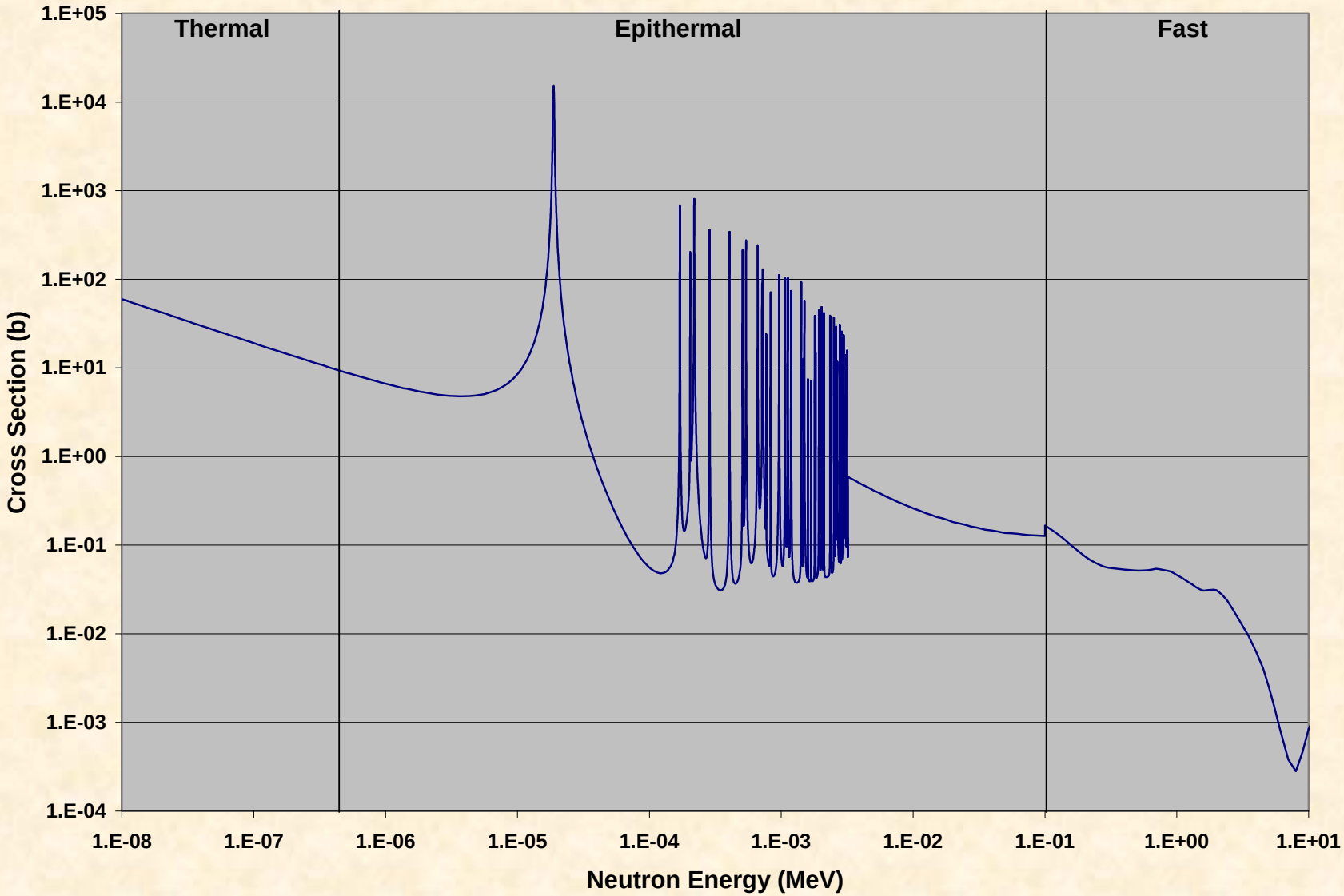




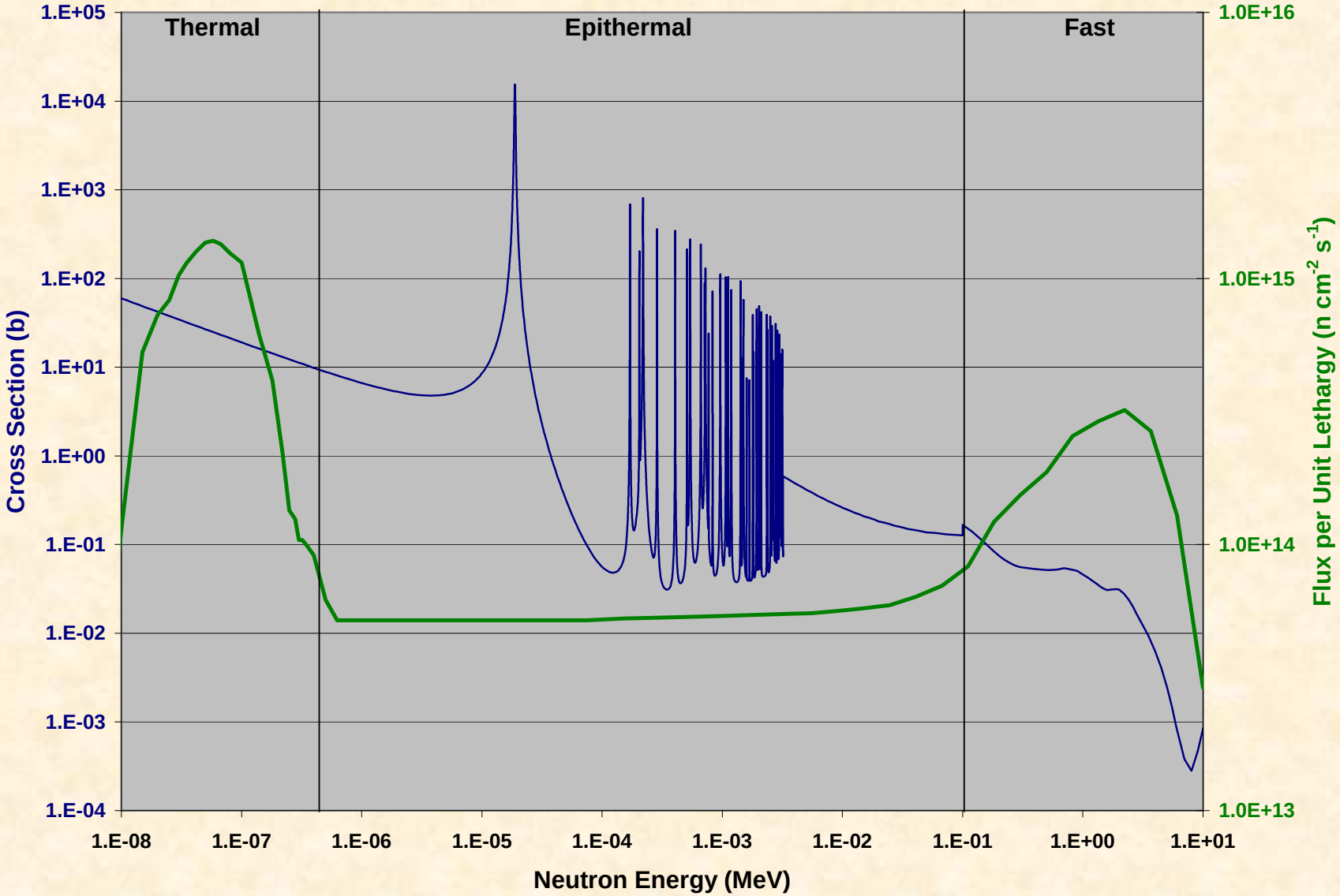
HFIR Neutron Flux Spectrum



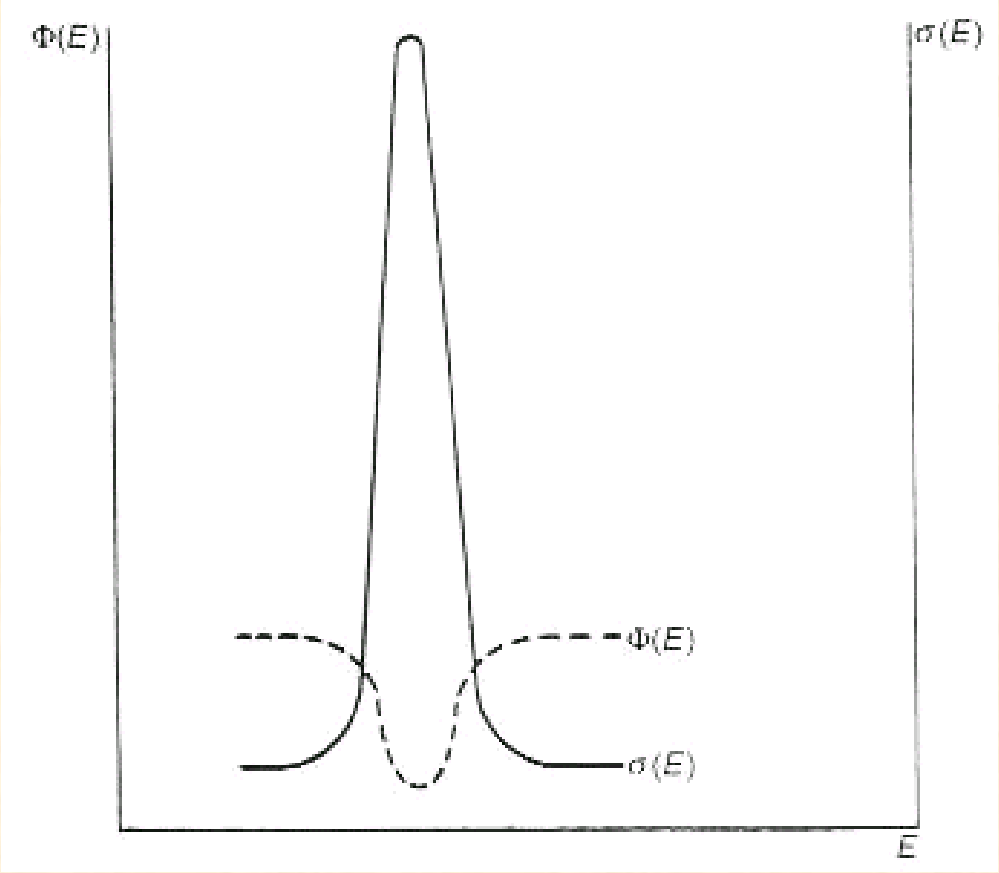
$^{186}W(n,\gamma)^{187}W$ Cross Section



Flux and Cross Section Curves

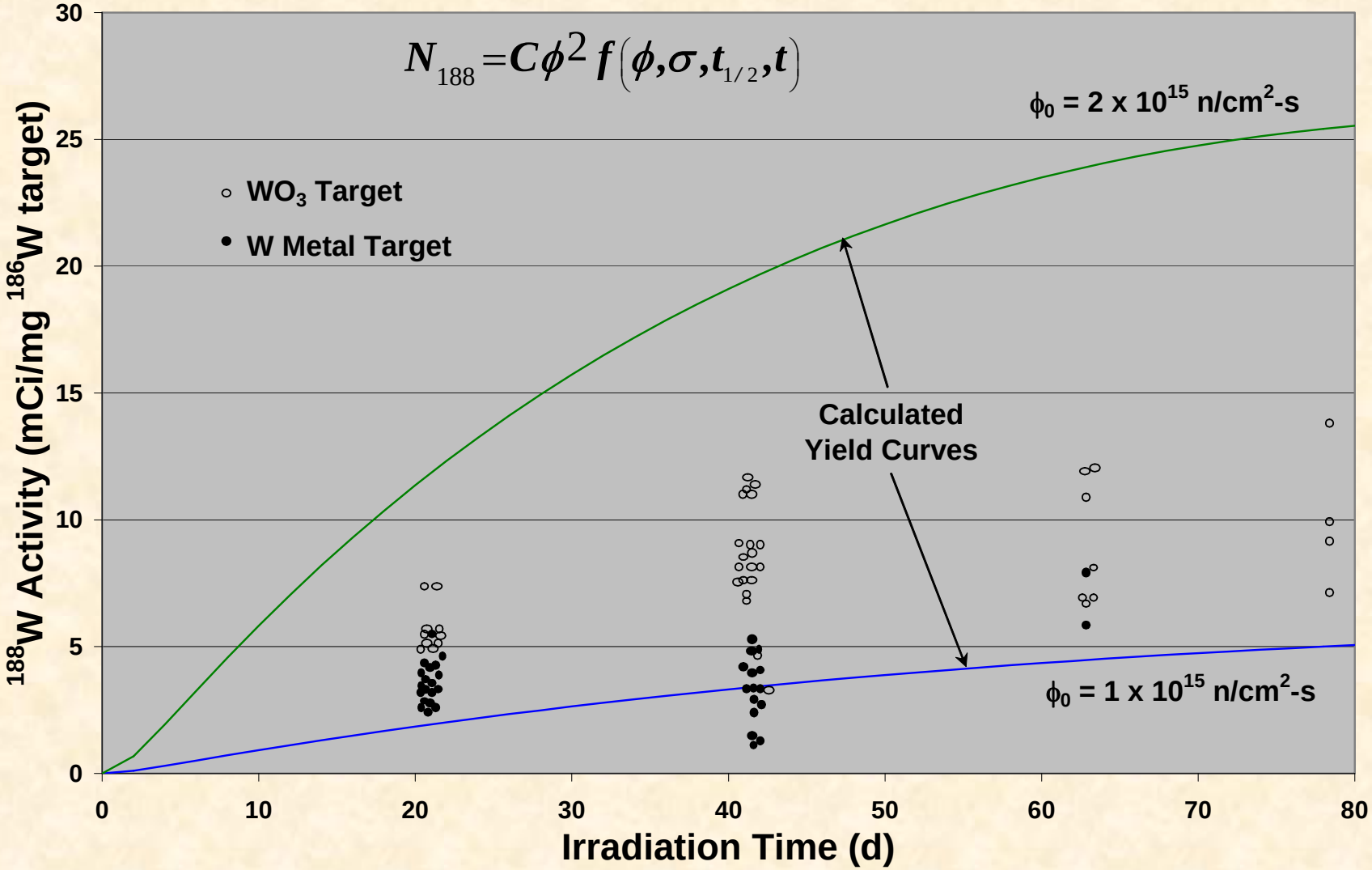


Neutron Self-shielding

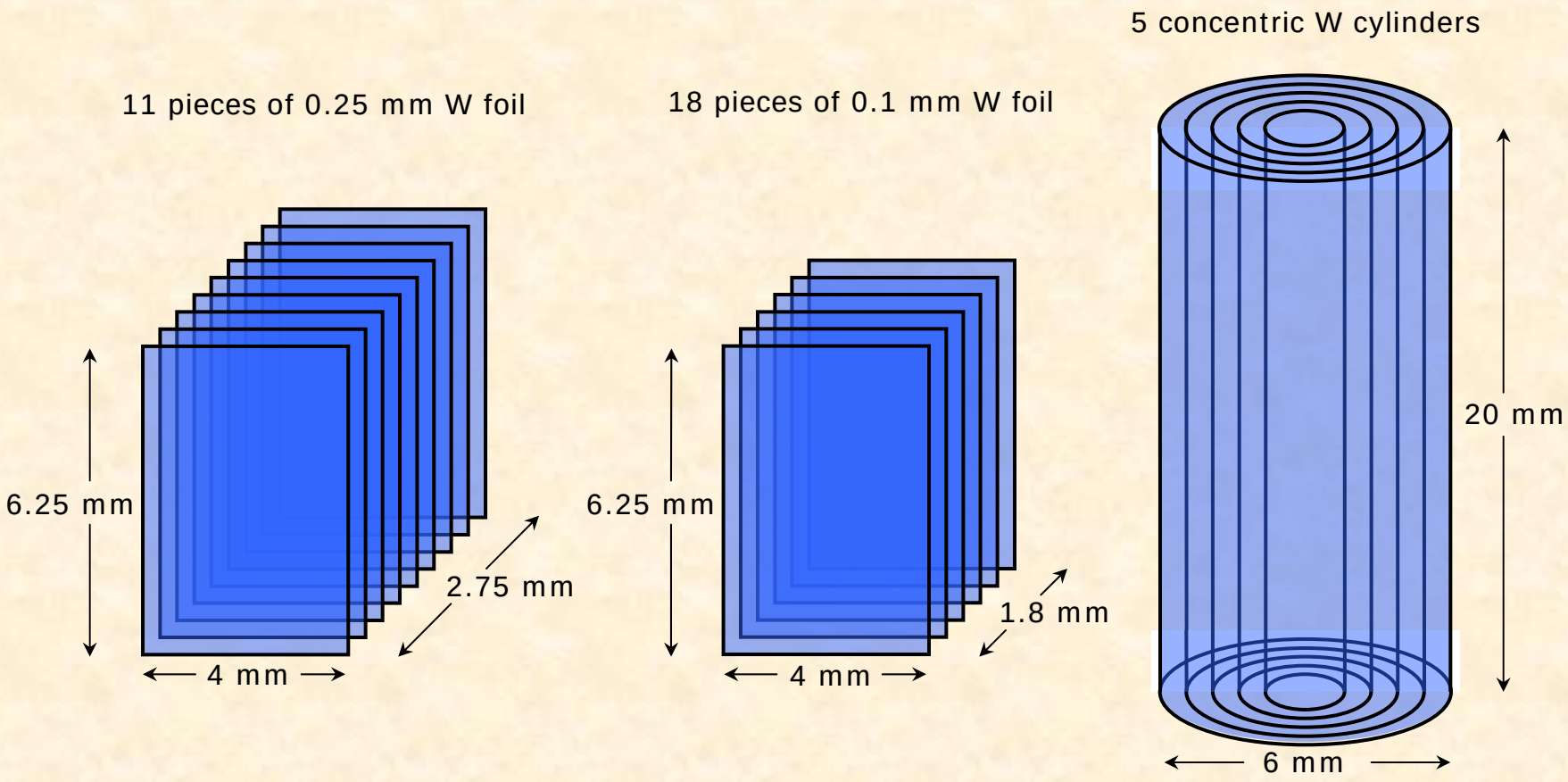


Nuclear Science and Engineering **6**, 100, 1959

^{188}W Production in HFIR

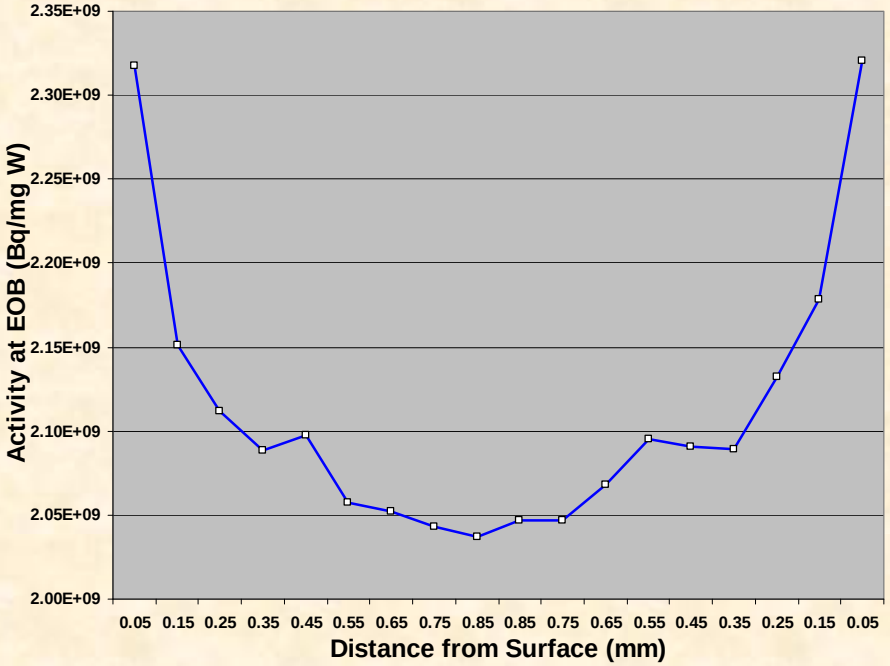


Tungsten Experiments

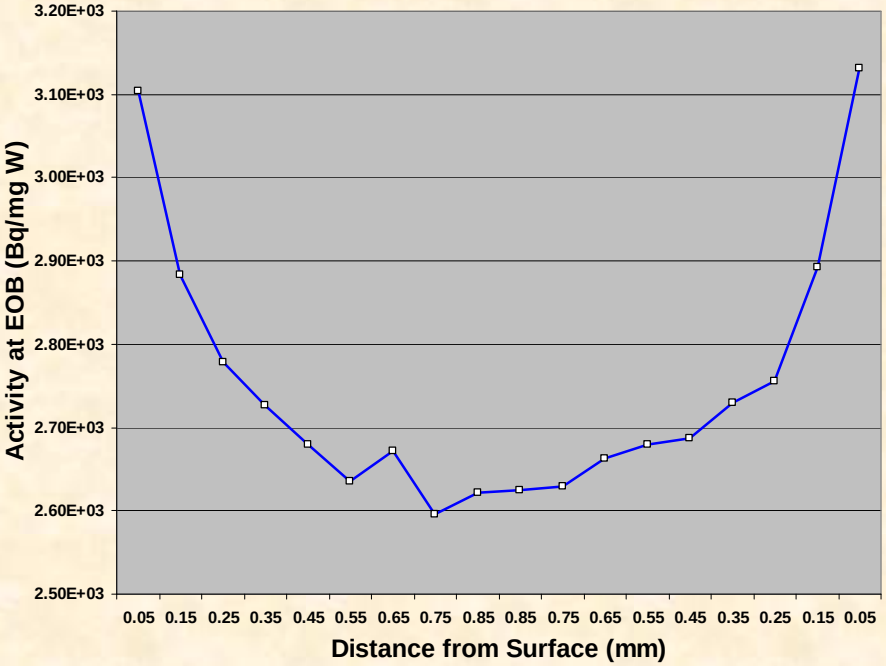


Activity at EOB (0.1 mm Foil)

^{187}W



^{188}W



Neutron Attenuation

$$\phi_x = \phi_0 e^{-N\sigma x}$$

$$N = \frac{19.3\ \mathbf{g/cm^3}}{183.84\ \mathbf{g/mole}} \times 6.02 \times 10^{23}\ \mathbf{at/mole}$$

$$= 6.32 \times 10^{22}\ \mathbf{at/cm^3}$$

$$\sigma \approx \sigma_a + \frac{1}{r} I_a$$

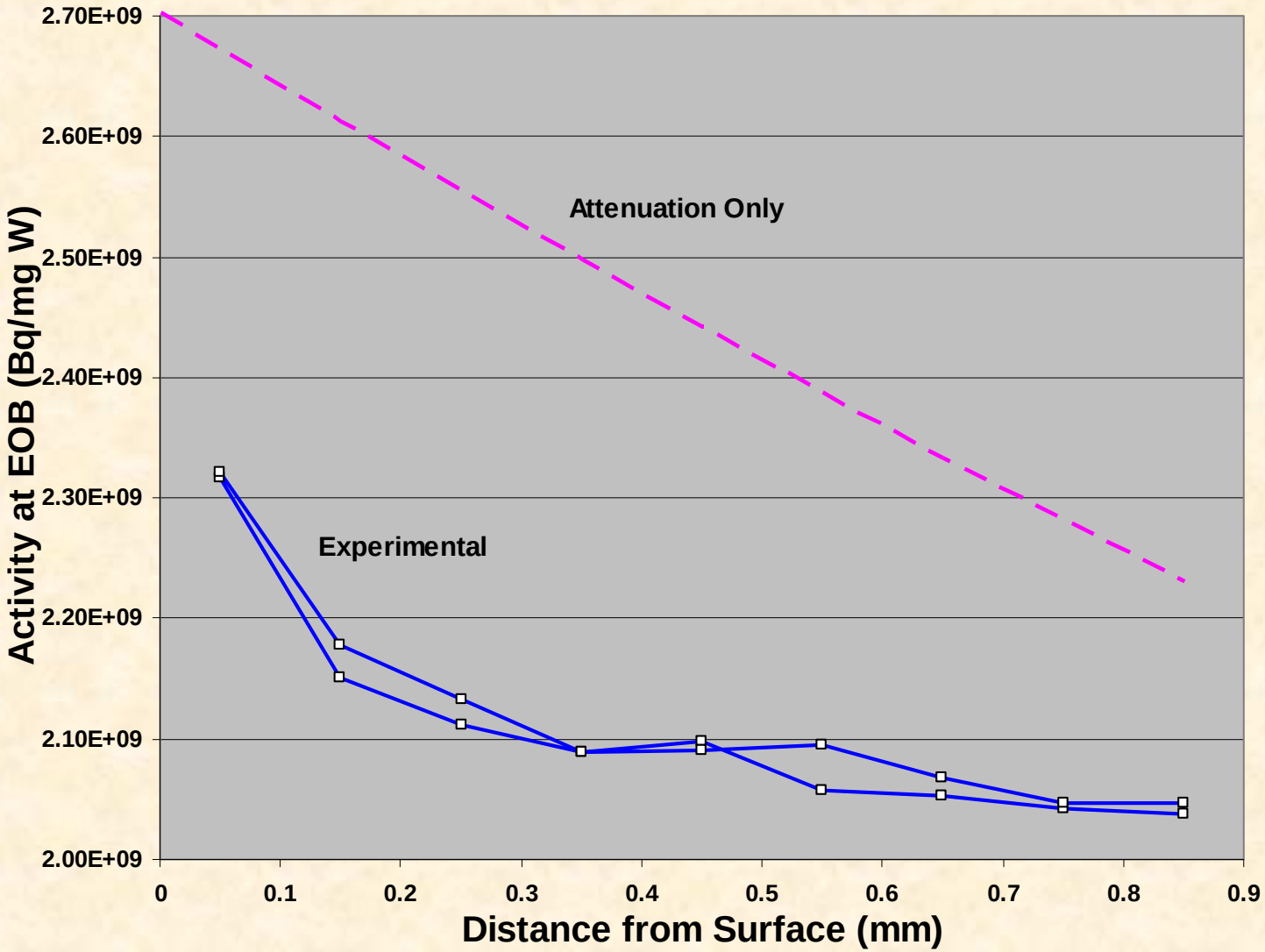
$$= 18.2 + \frac{1}{20} 350 = 35.7\ \mathbf{b}$$

$$\phi(0.01\ \mathbf{cm}) = \phi_0 e^{-6.32 \times 10^{22} \times 5.7 \times 10^{-24} x}$$

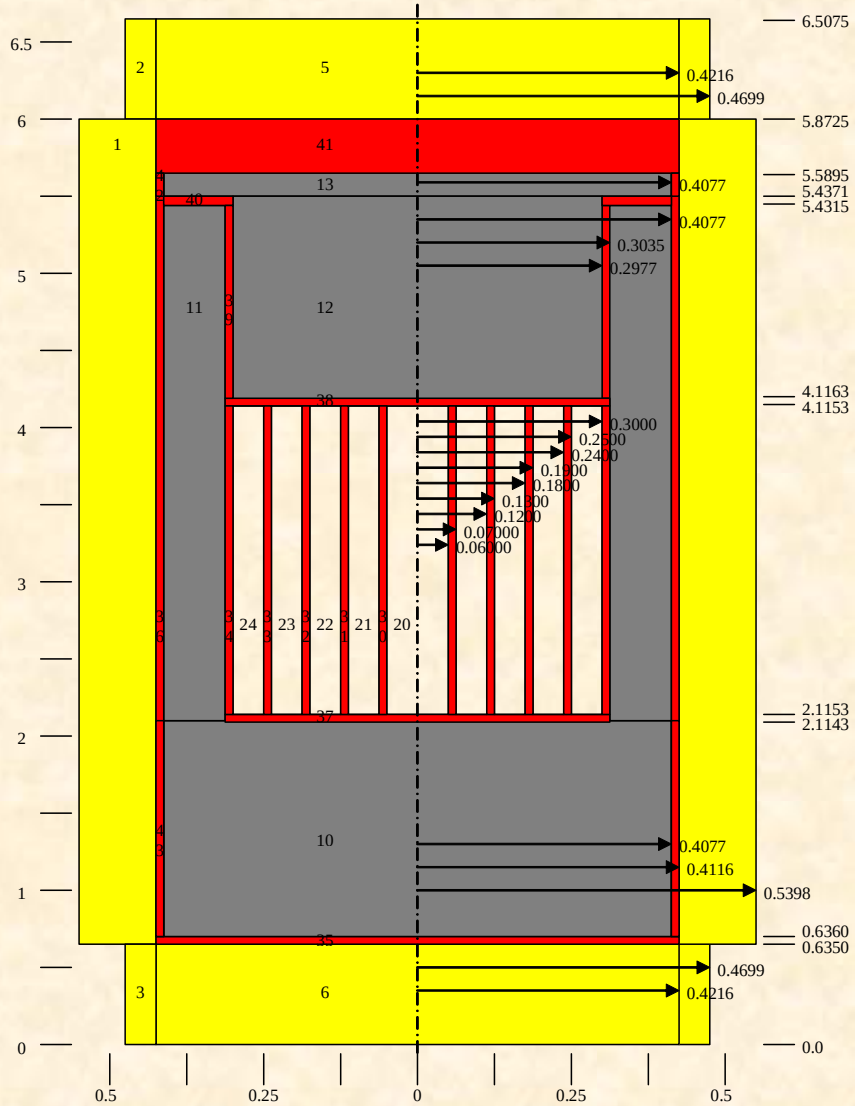
$$= \phi_0 e^{-2.26x}$$

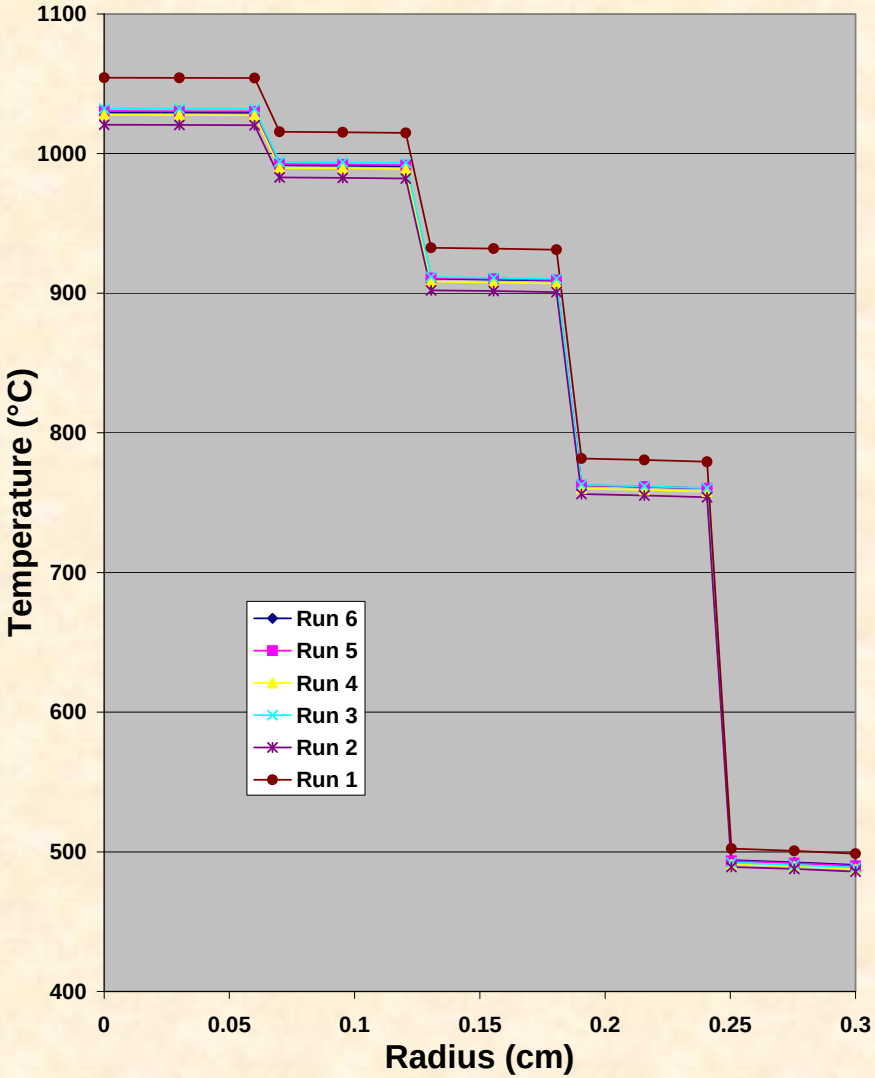
$$= 0.98\phi_0$$

^{187}W Activity at EOB (0.1 mm Foil)

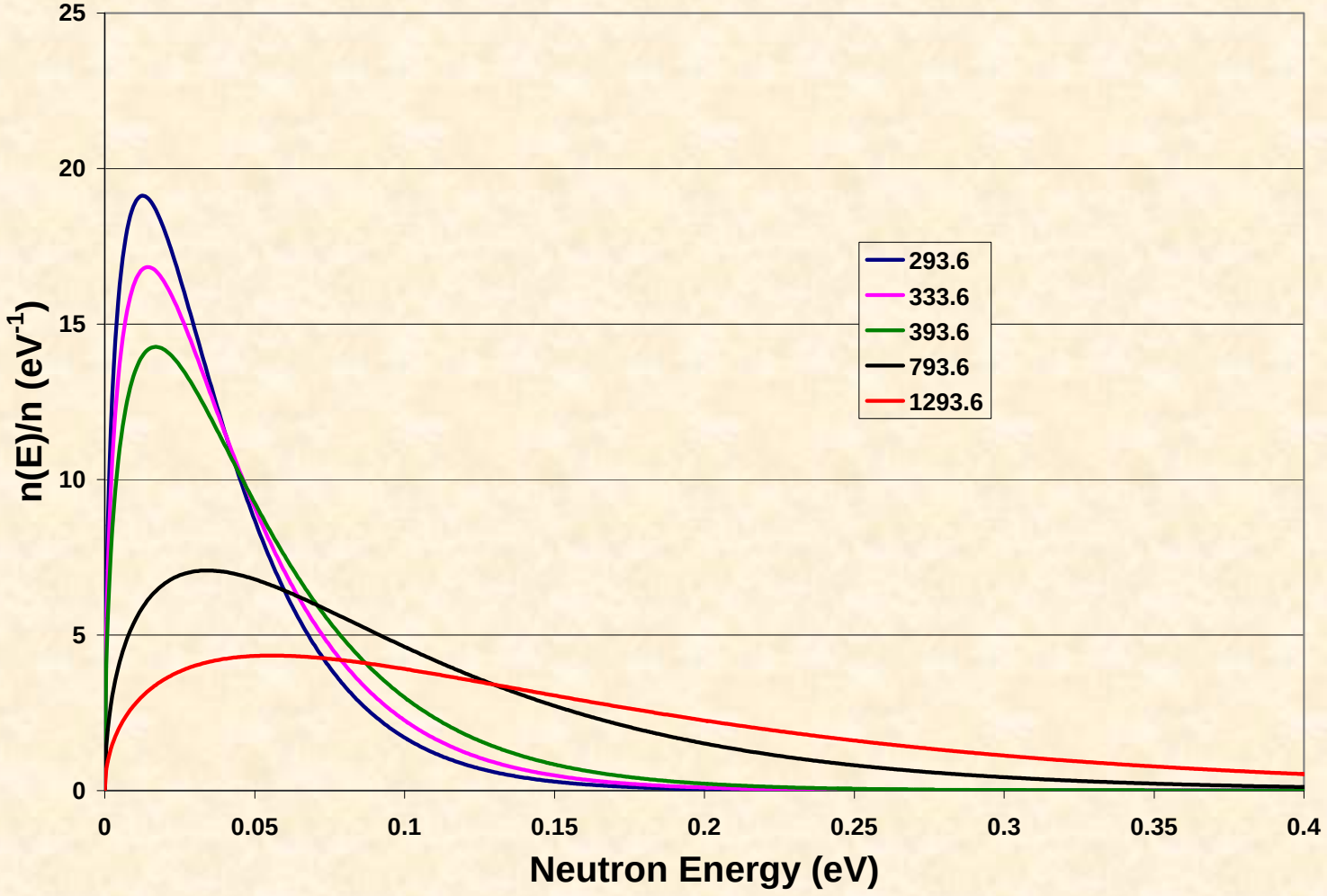


Tungsten Cylinder Temperatures



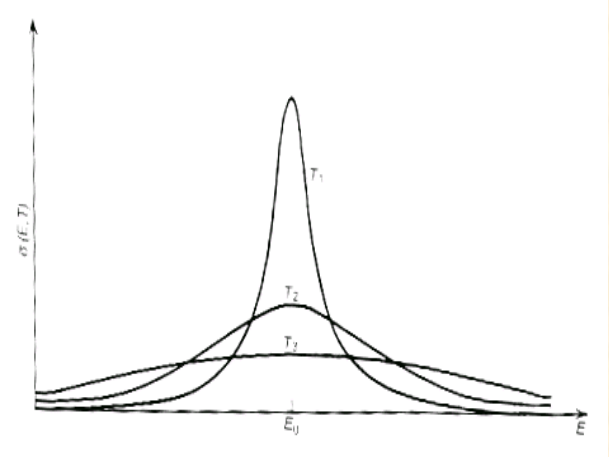


Thermal Neutron Energy Distribution



Temperature Effects within Target

Cross sections



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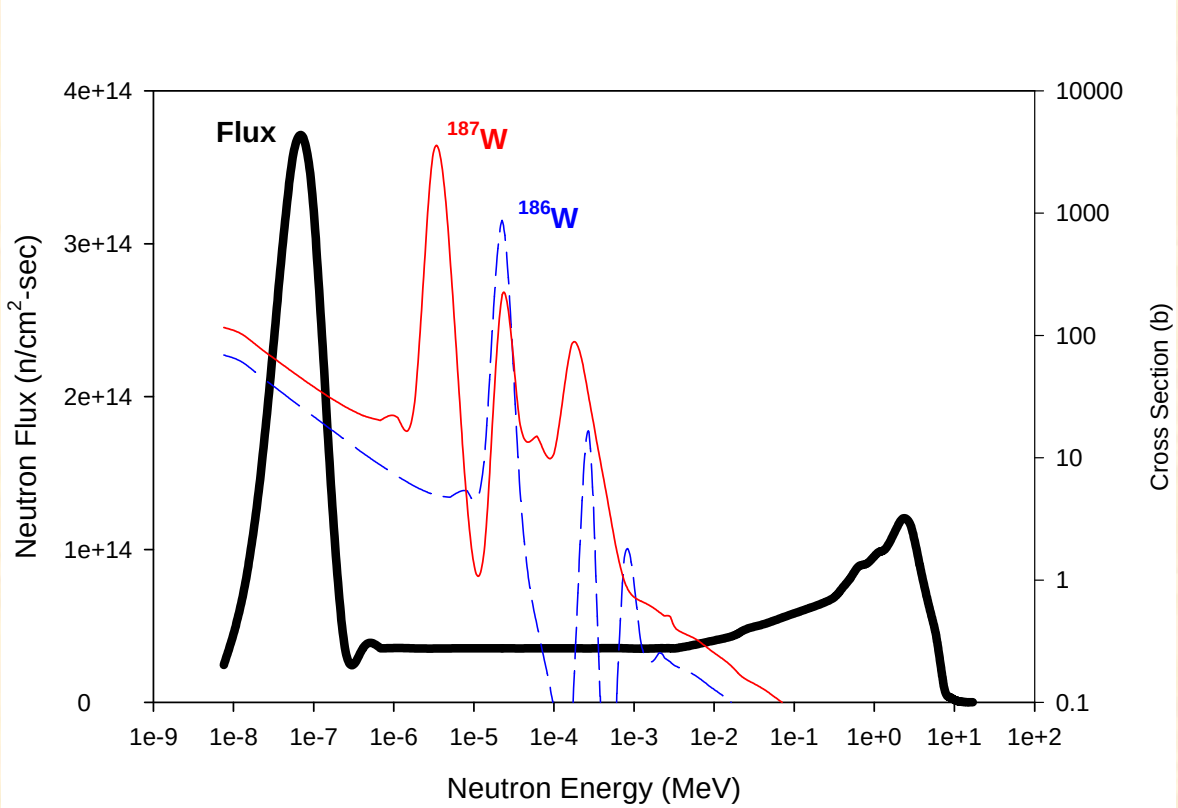
Neutron energies



The End

- **Questions?**