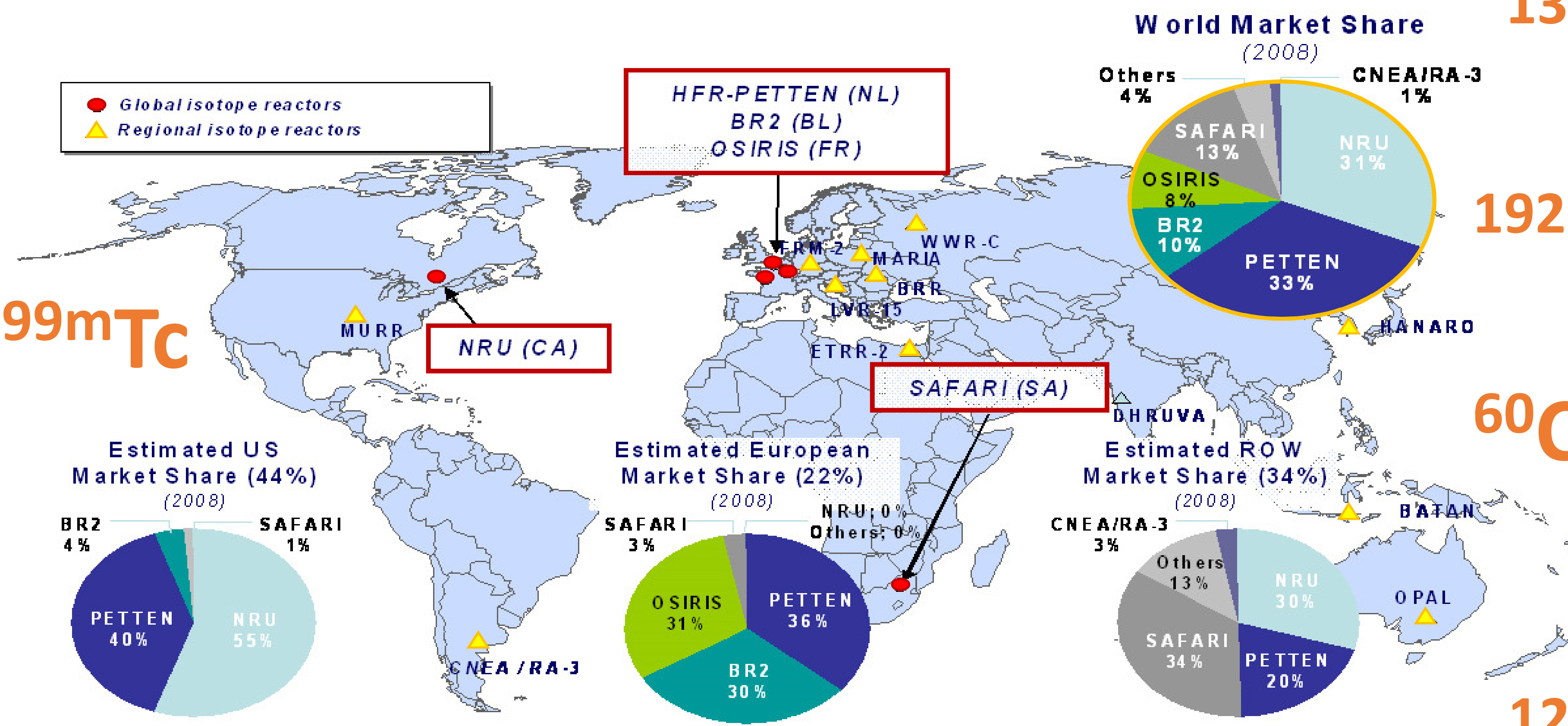
METHODS of RADIONUCLIDE PRODUCTION for MEDICAL ISOTOPE USABILITY

<< MEETING THE DEMAND >>

Nathan S. Hicks

Introduction
A Global Crisis

http://www.nrcan.gc.ca/energy/uranium-nuclear/7795



Note: Market shares do not include the impact of the 2008 HFR-Petten shutdown

^{131}I

^{192}Ir

^{99m}Tc

^{60}Co

^{125}I

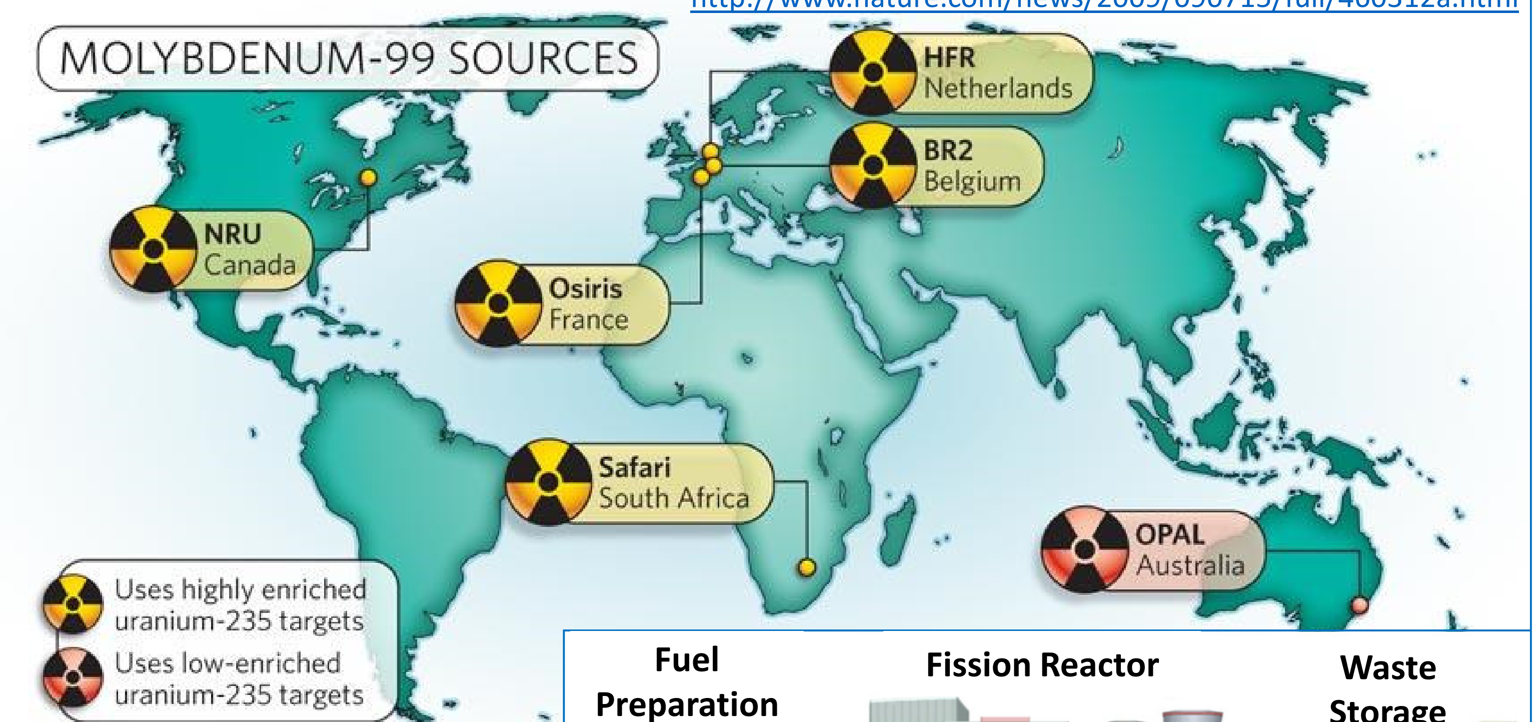
^{177}Lu

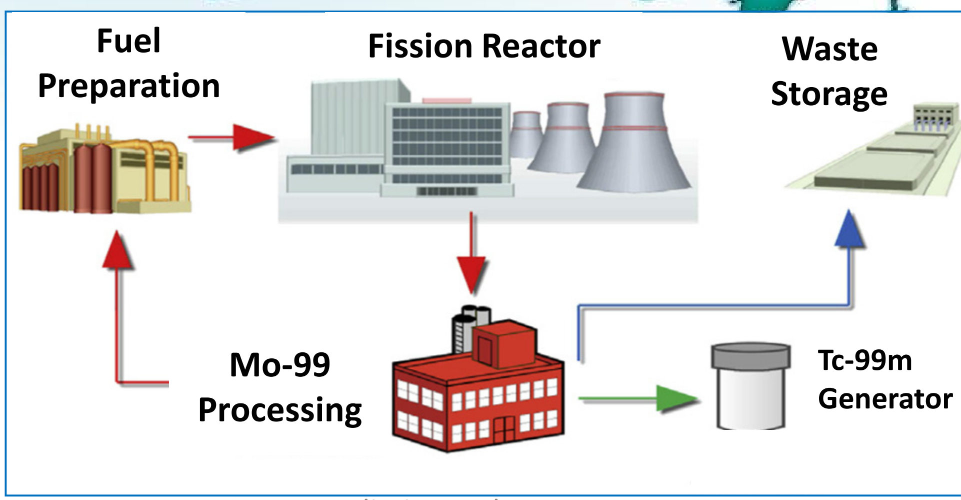
^{166}Ho

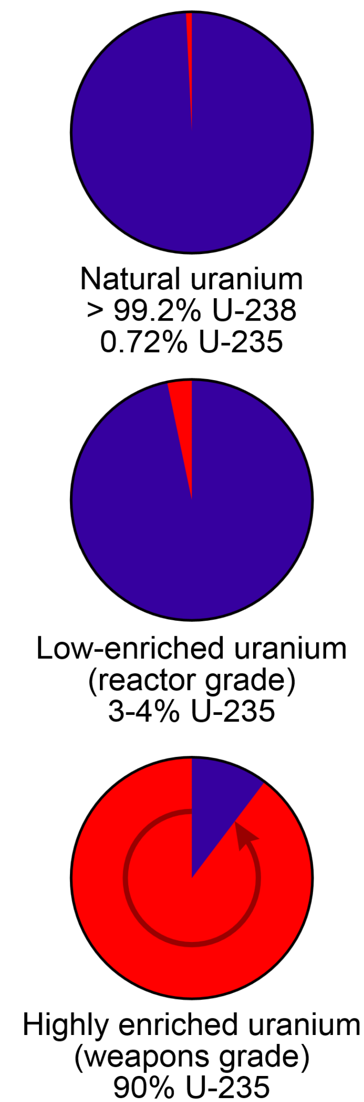
^{133}Xe

Introduction
Existing Infrastructure

http://www.nature.com/news/2009/090715/full/460312a.html







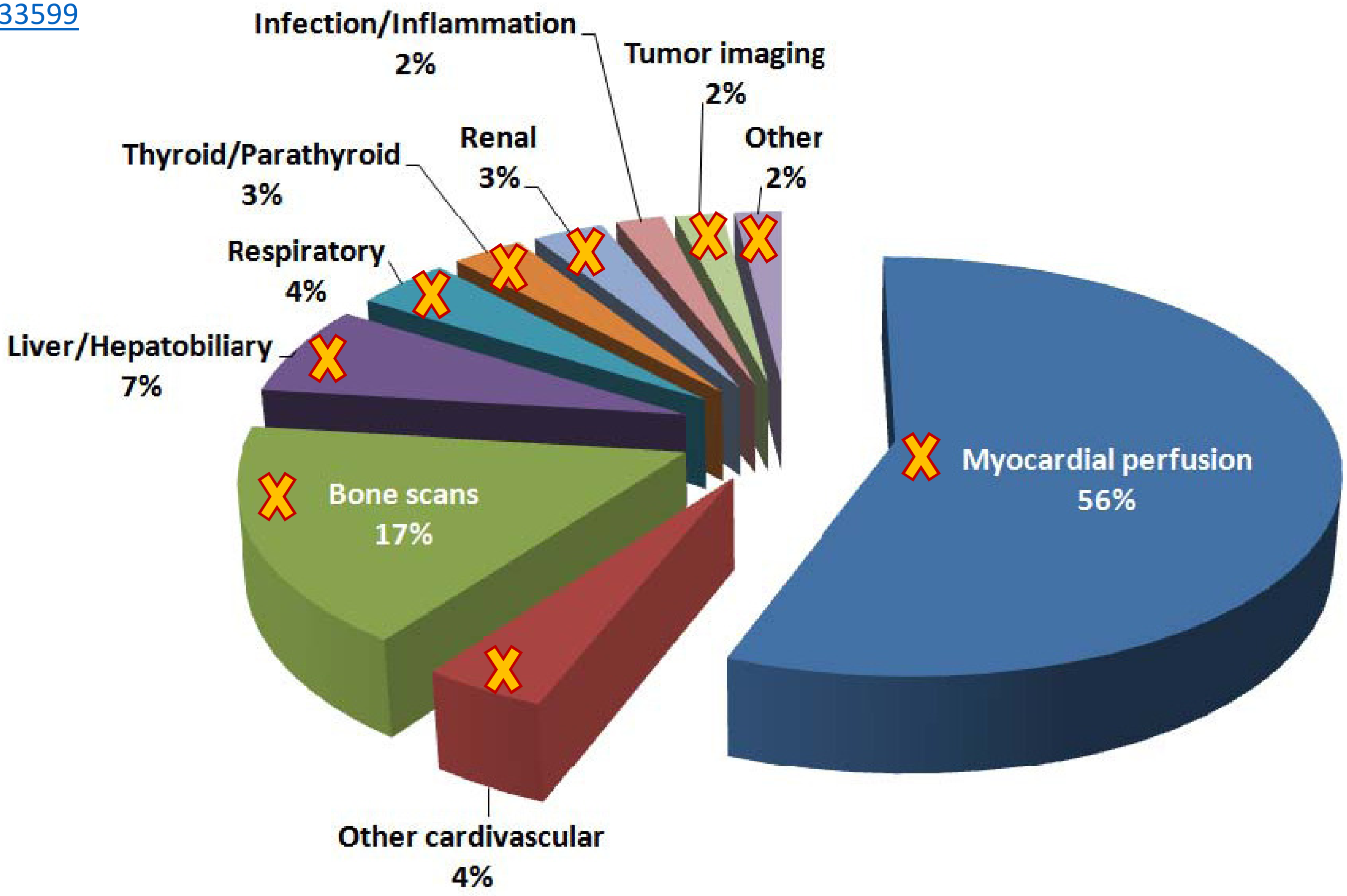
Other Production Methods

- Heterogeneous reactors
- **Accelerators**
- Sub-critical assemblies
- Neutron capture
- Spallation

https://en.wikipedia.org/wiki/Enriched_uranium

Introduction
The Nuclear Medicine Market

http://www.bbc.com/news/magazine-32833599

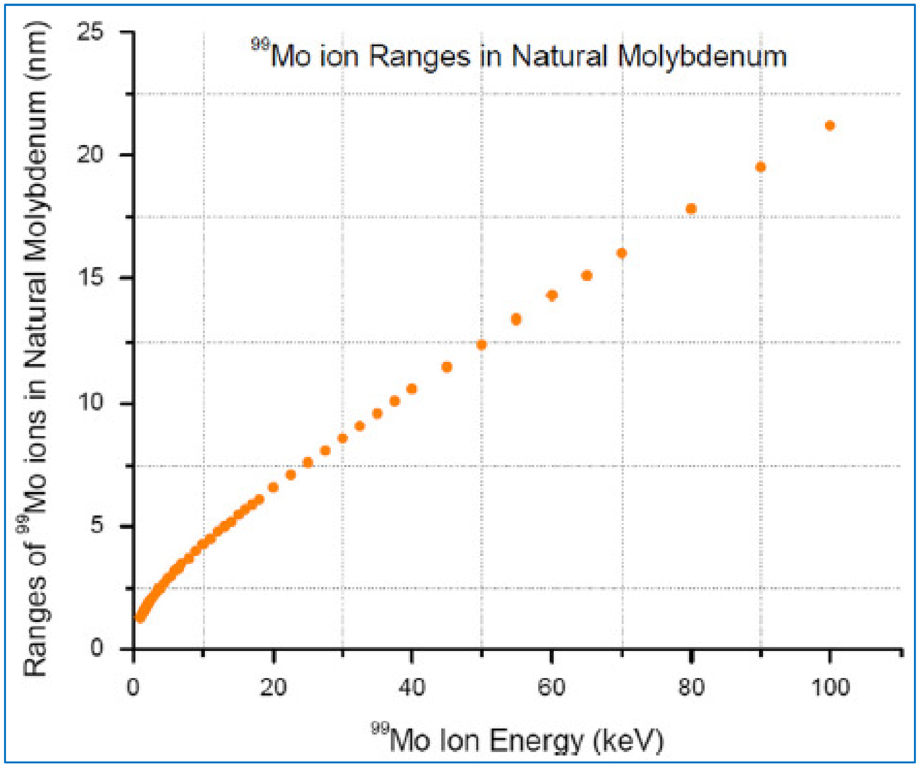


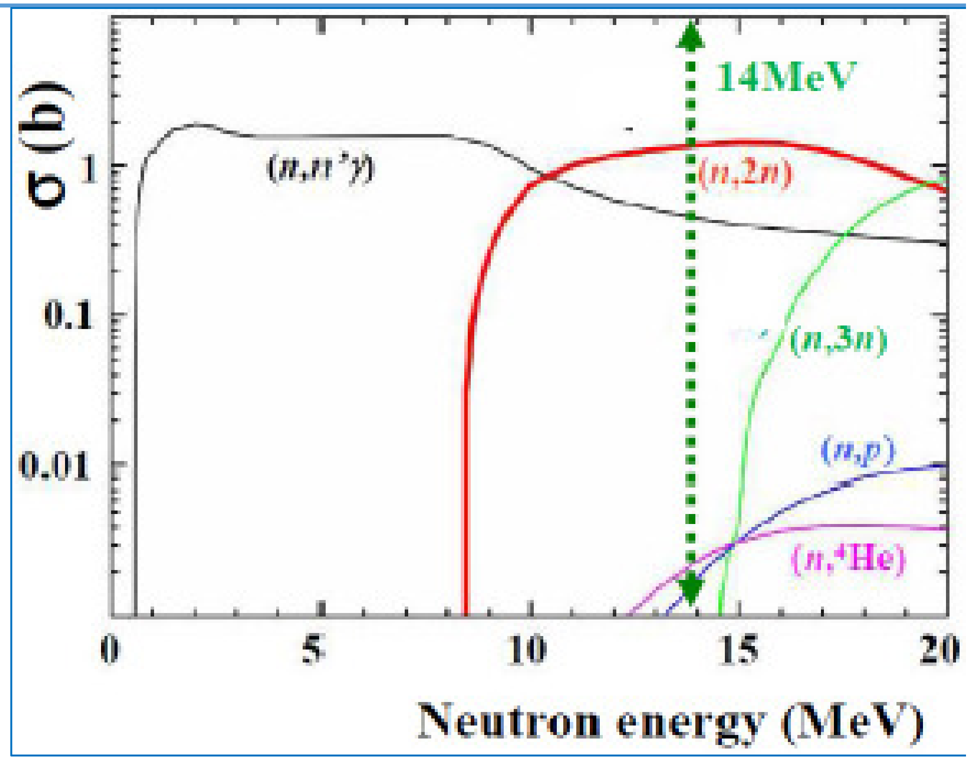
- **Technetium-99m**

  Brain, Thyroid, Parathyroid, Heart, Lungs, Liver, Kidney, Spleen, or Bone Marrow

Cross Sectional Energies
Molybdenum-100 / Molybdenum-99 Conversions

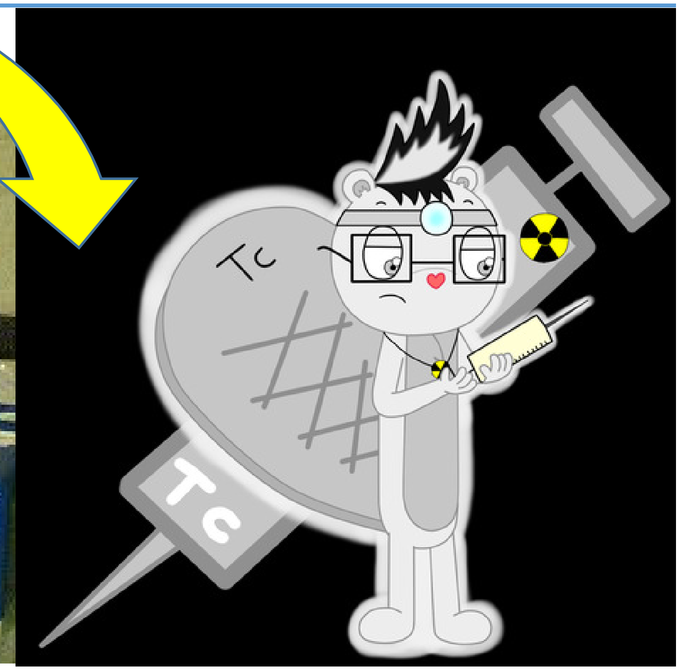
- Neutrons
- Protons
- Deuterons





- Electrons
- Photoneutrons and Photoprotons

Medical Radioisotopes
Technetium-99m from Molybdenum-99



https://en.wikipedia.org/wiki/Technetium-99m_generator

http://www.bbc.com/news/magazine-32833599

nuclide symbol	Z(p)	N(n)	isotopic mass (u)	half-life[n 1]	decay mode(s)[3][n 2]	daughter isotope(s)[n 3]	nuclear spin
	excitation energy						
^{99}Mo[n 6][n 8]	42	57	98.9077119(21)	2.7489(6) d	β^-	^{99m}Tc	1/2+

https://en.wikipedia.org/wiki/Isotopes_of_molybdenum

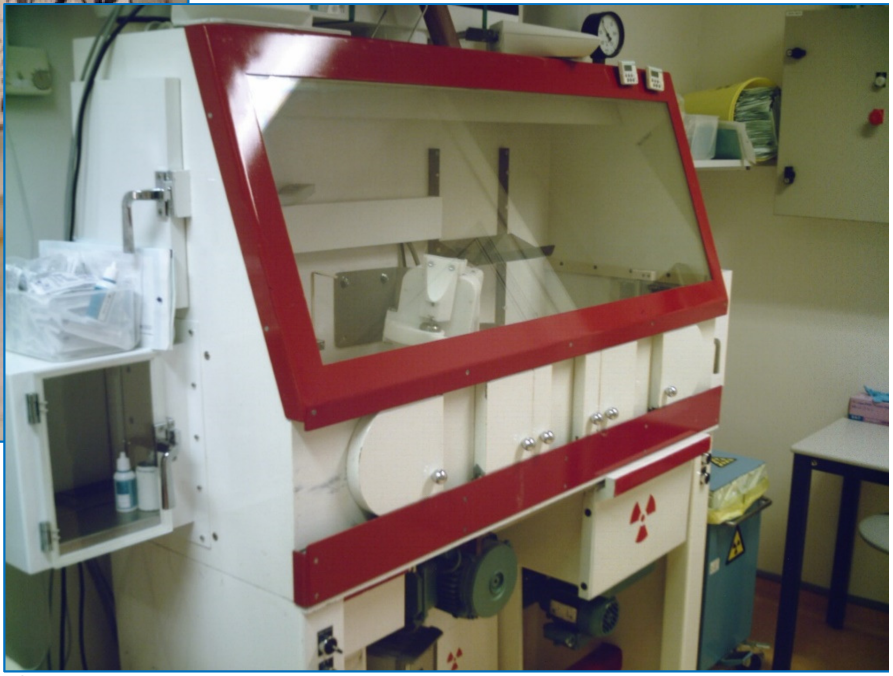
$$^{99m}_{43}\mathrm{Tc} \xrightarrow[6\ \mathrm{h}]{\gamma\ 141\ \mathrm{keV}} {}^{99}_{43}\mathrm{Tc} \xrightarrow[211\ 000\ \mathrm{y}]{\beta^-\ 249\ \mathrm{keV}} {}^{99}_{44}\mathrm{Ru}$$

Fission Reactors
Molybdenum Processing

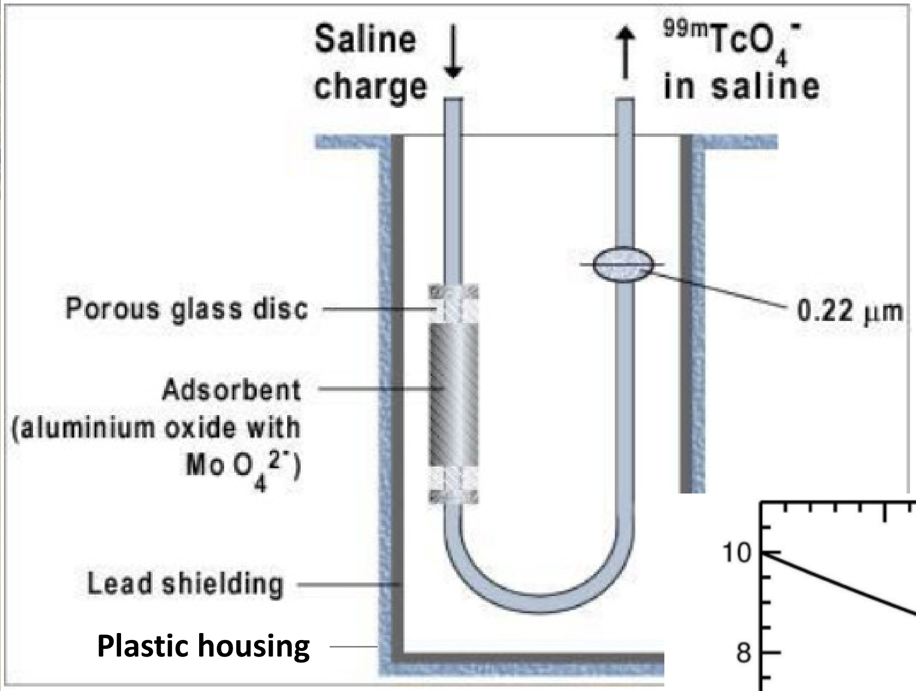
URANIUM

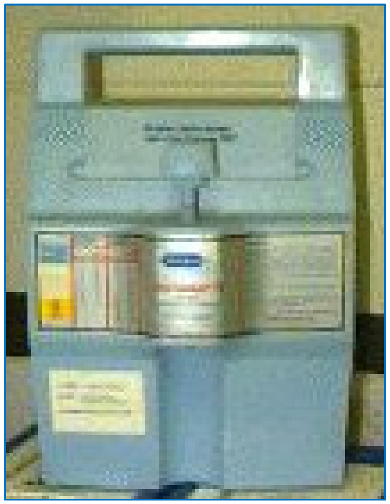
https://en.wikipedia.org/wiki/Uranium-235

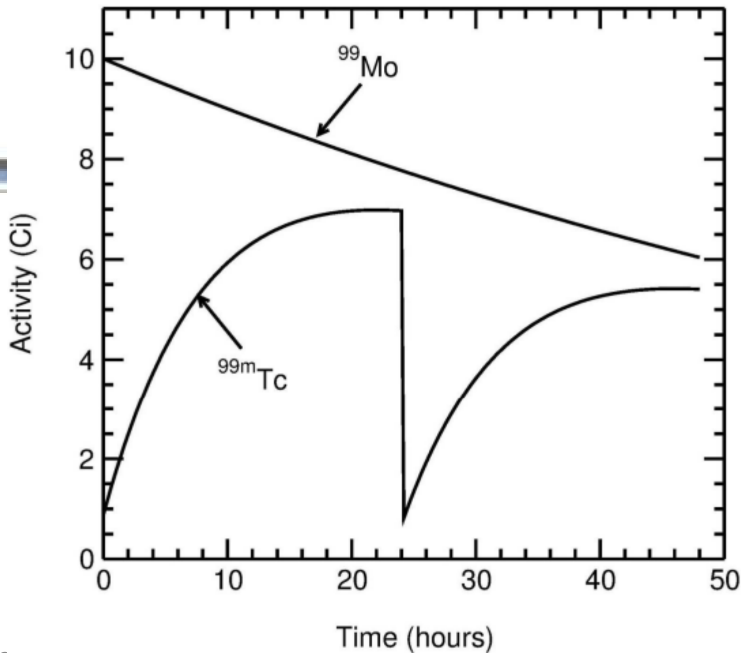
https://en.wikipedia.org/wiki/Hot_cell



Fission Reactors
Technetium Processing



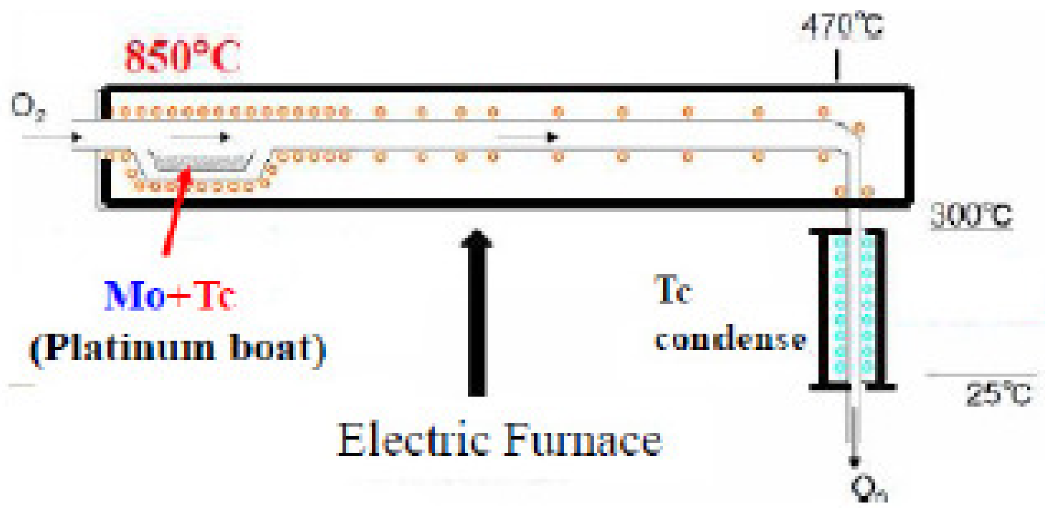




<u>**Specific Activity**</u>

$$A = \phi \cdot n \cdot \sigma \cdot (1 - e^{-\lambda t})$$

Accelerator Reactors
Technetium-99m Separation



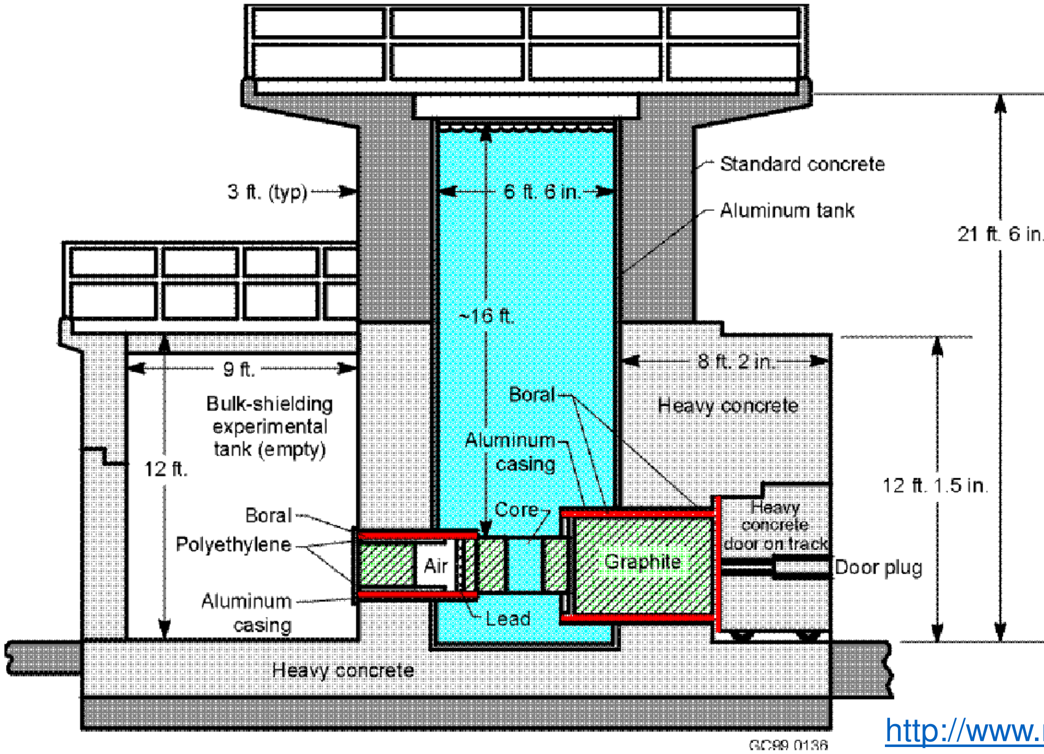
https://en.wikipedia.org/wiki/Technetium-99m

- **Elution of pertechnetate solution** (1958).
- **Thermal Chromatographic Separation** via vapor pressure.
- **Organic Solvent Extraction (MEK Process)** via aqueous solution.
- **Chromatographic Column (ABEC)** via immiscible liquids.
- **Nuclear kinetic recoil** via photonuclear reactions.

Accelerator Reactors
Technetium-99m Separation - Commercialization

http://www.northstarnm.com/radiogenix-technology

Fission Reactors
General Overview – Typical Construction



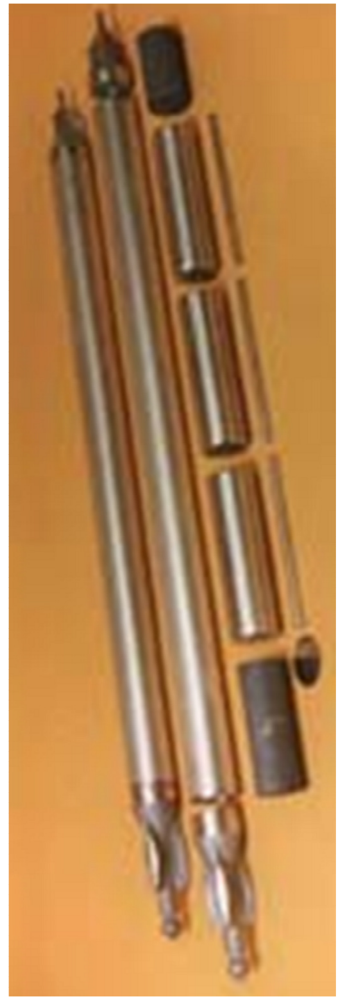
http://www.rcp.ijs.si/ric/description-a.html

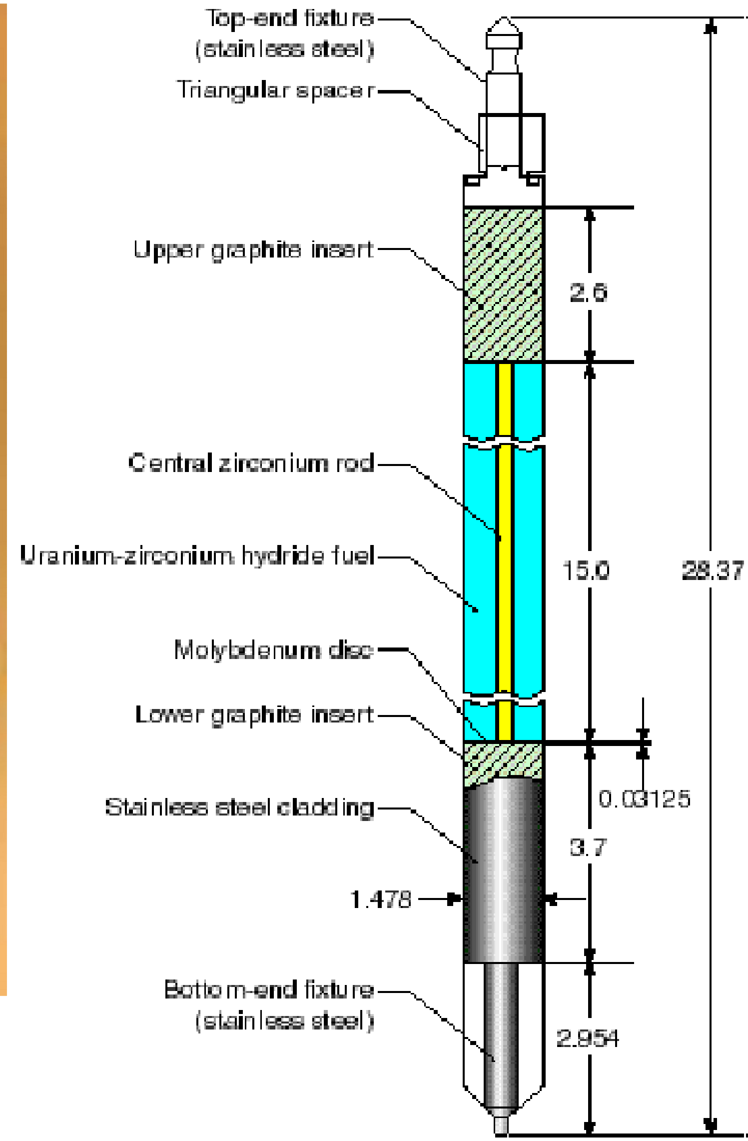
<u>High flux reactors (TRIGA)</u>

energies > 1.10^{14} neutrons/cm^2/s

- Research
- Operational purposes
- Radioisotope production

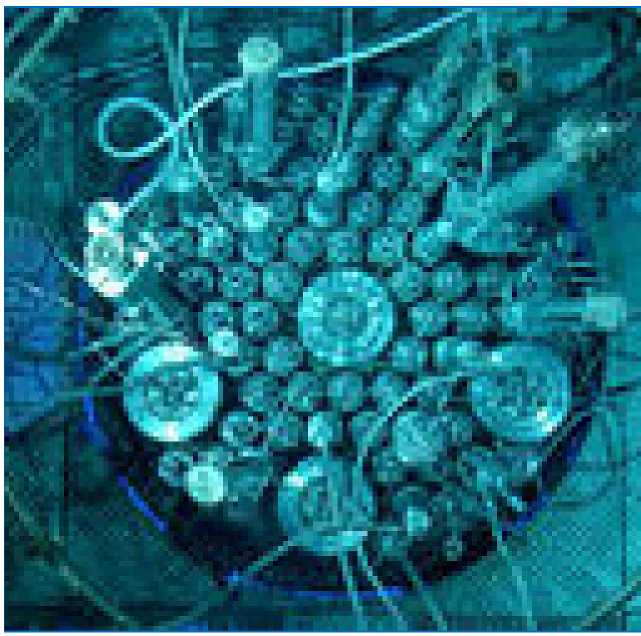
Fission Reactors
General Overview – Fuel Rods

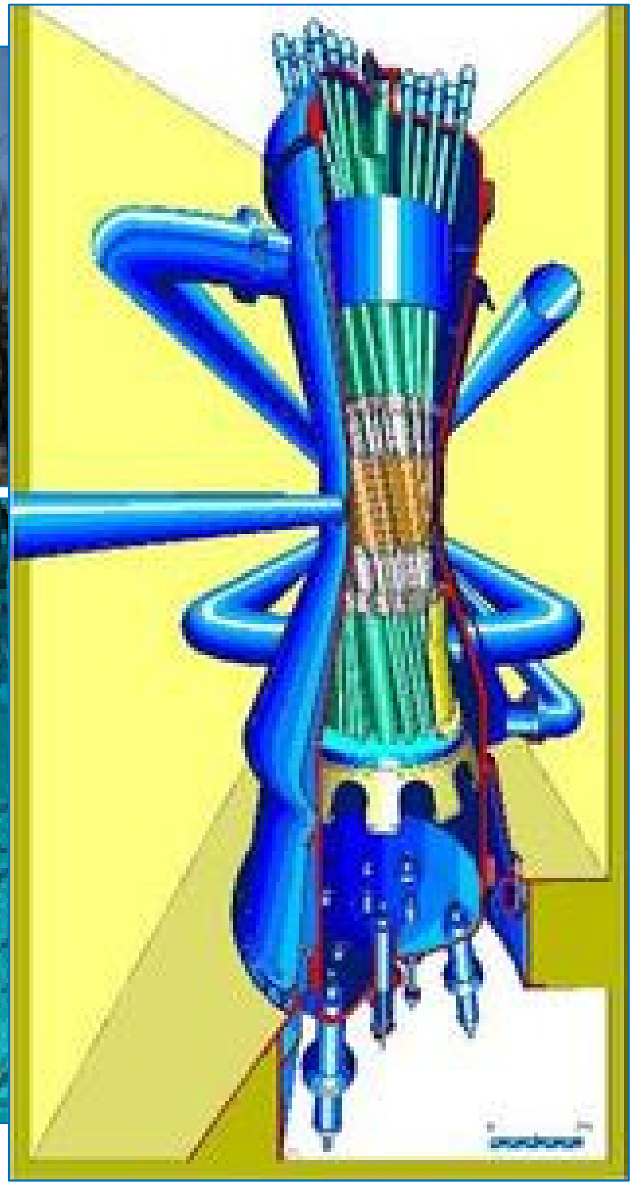




Fission Reactors
Radioisotope Production

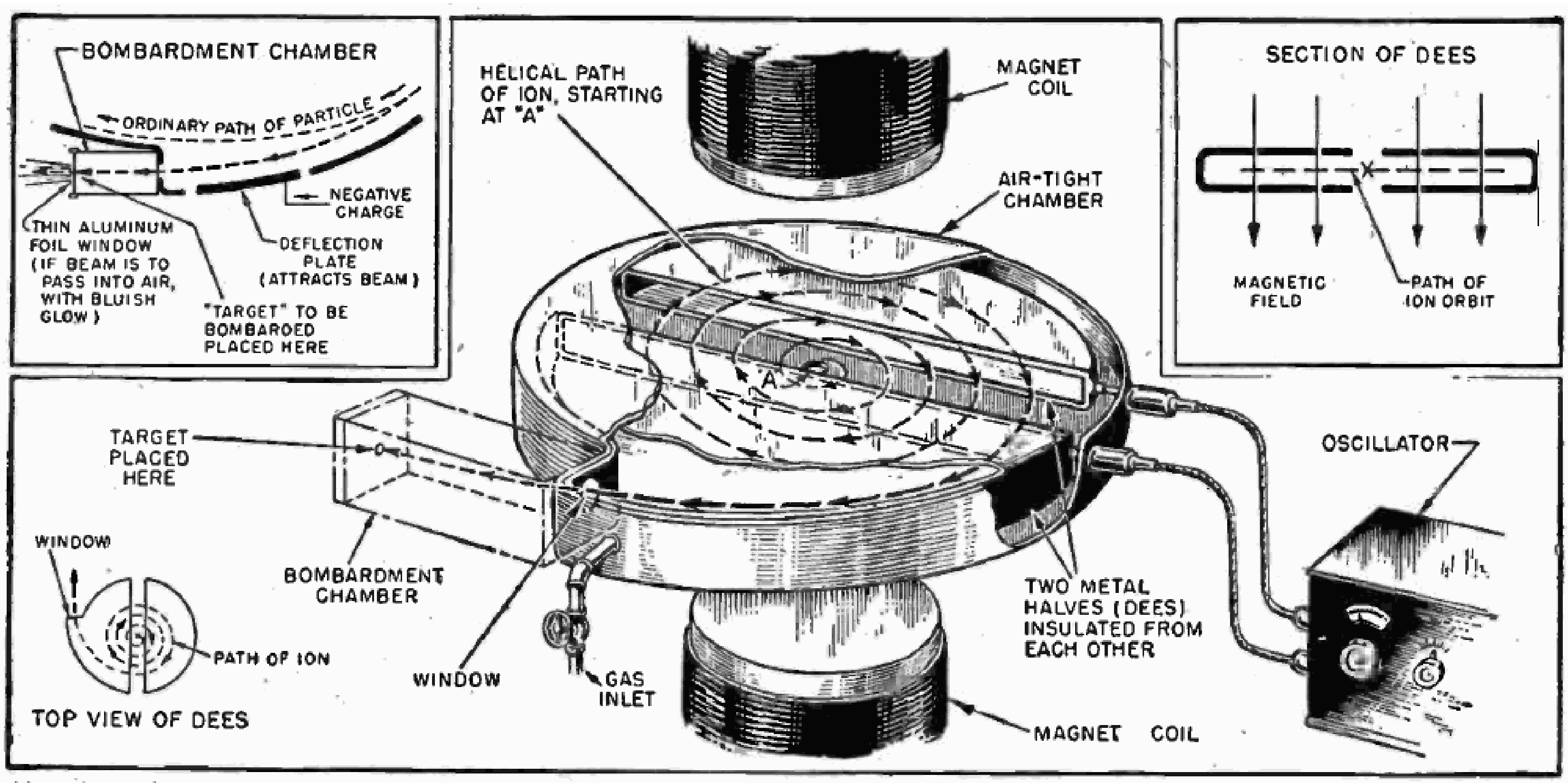
http://science.sckcen.be/en/Facilities/BR2





http://www.ansto.gov.au/AboutANSTO/OPAL/DevelopmentofOPAL/index.htm

Accelerator Reactors
Cyclotron Production

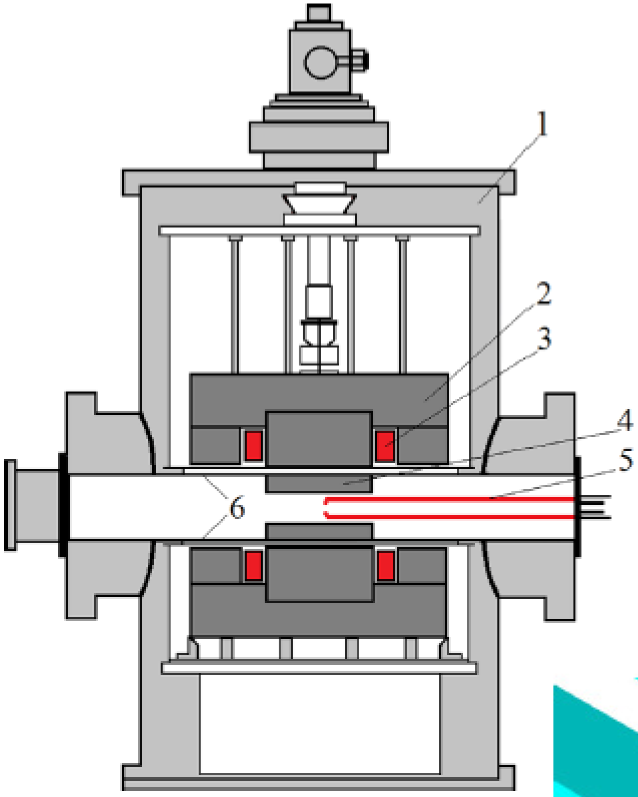


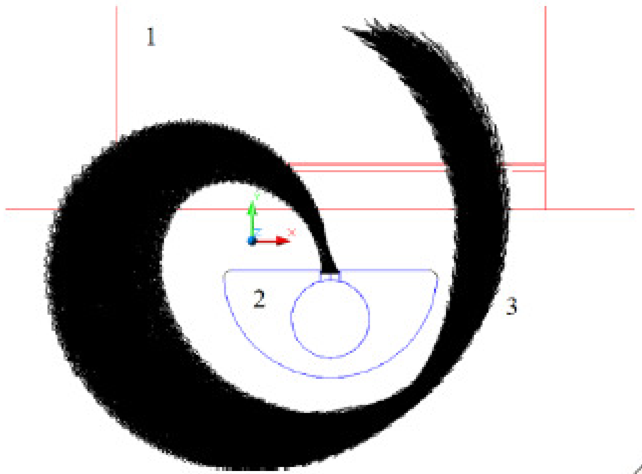
https://en.wikipedia.org/wiki/Cyclotron

Medium flux reactors

energies between 1.10^{12} and 1.10^{14} neutrons/cm^2/s

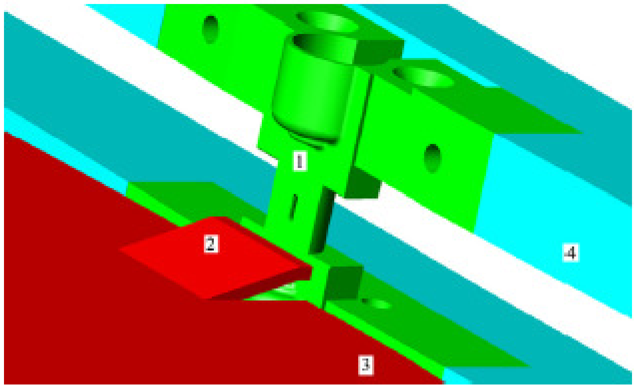
Accelerator Reactors
Cyclotron Production – Compact Designs

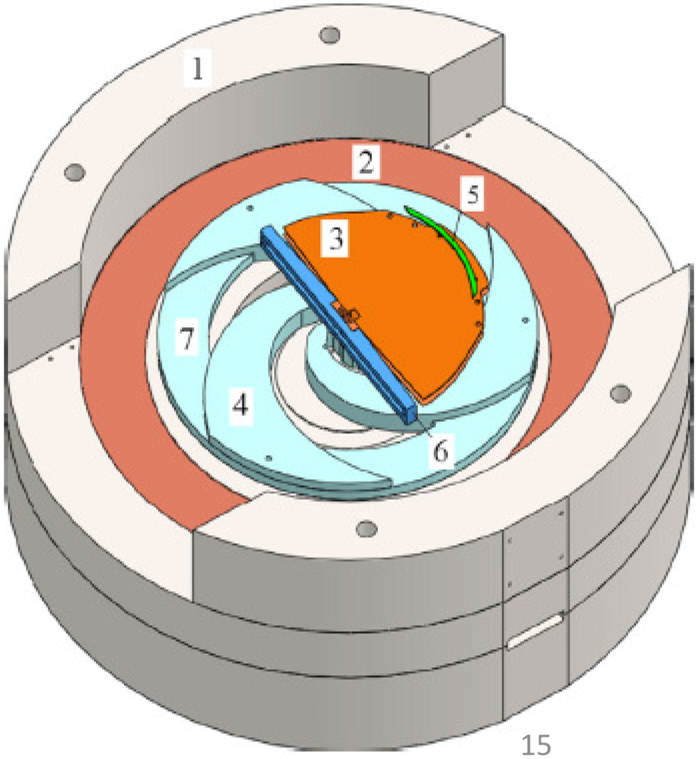




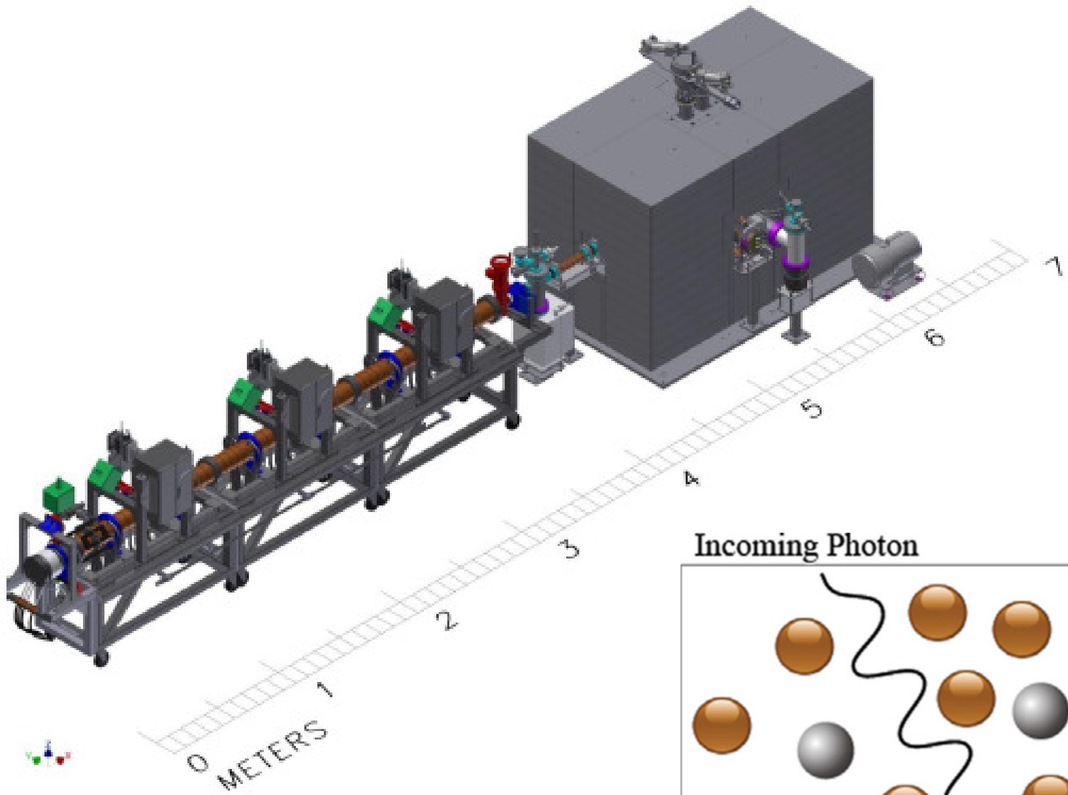
Lorentz Force

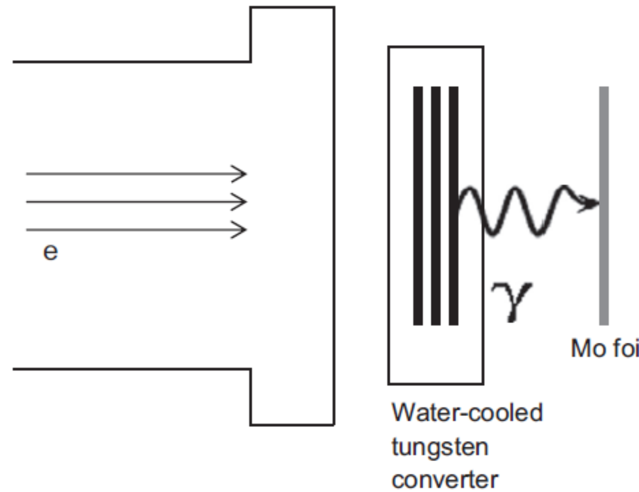
$$\mathbf{F} = q[\mathbf{E} + (\mathbf{v} \times \mathbf{B})]$$

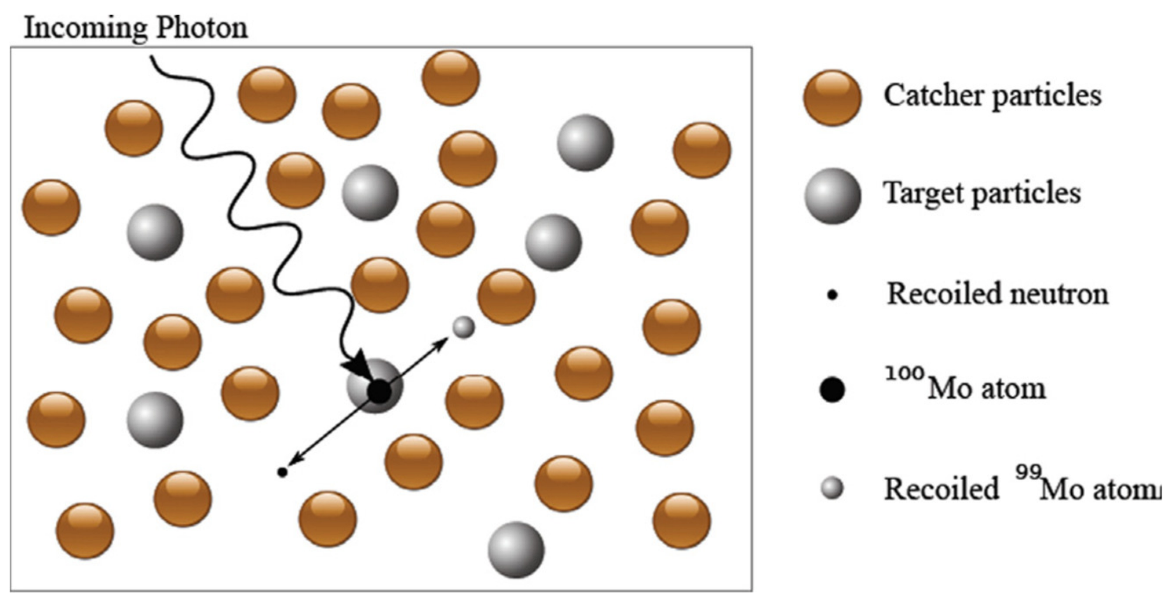




Accelerator Reactors
Linear Particle Accelerator Production







Comparison
Fission vs. LINAC Produced Isotopes

Comparison shows nearly identical diagnostic images.

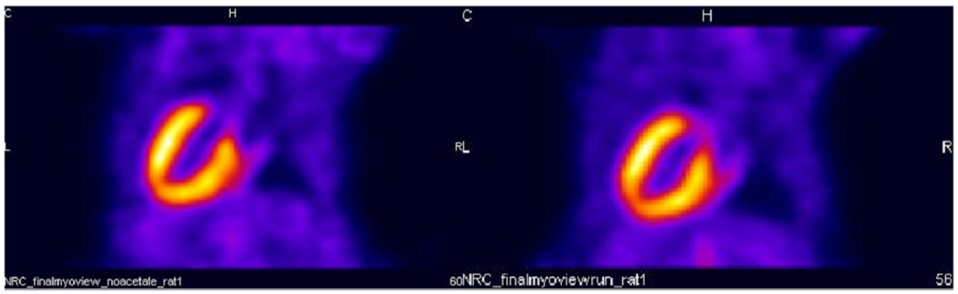


Fig. 1. Cardiac SPECT images of a rat injected with LINAC-Tc-99m (left) and fission-Tc-99m (right) for the same rat.

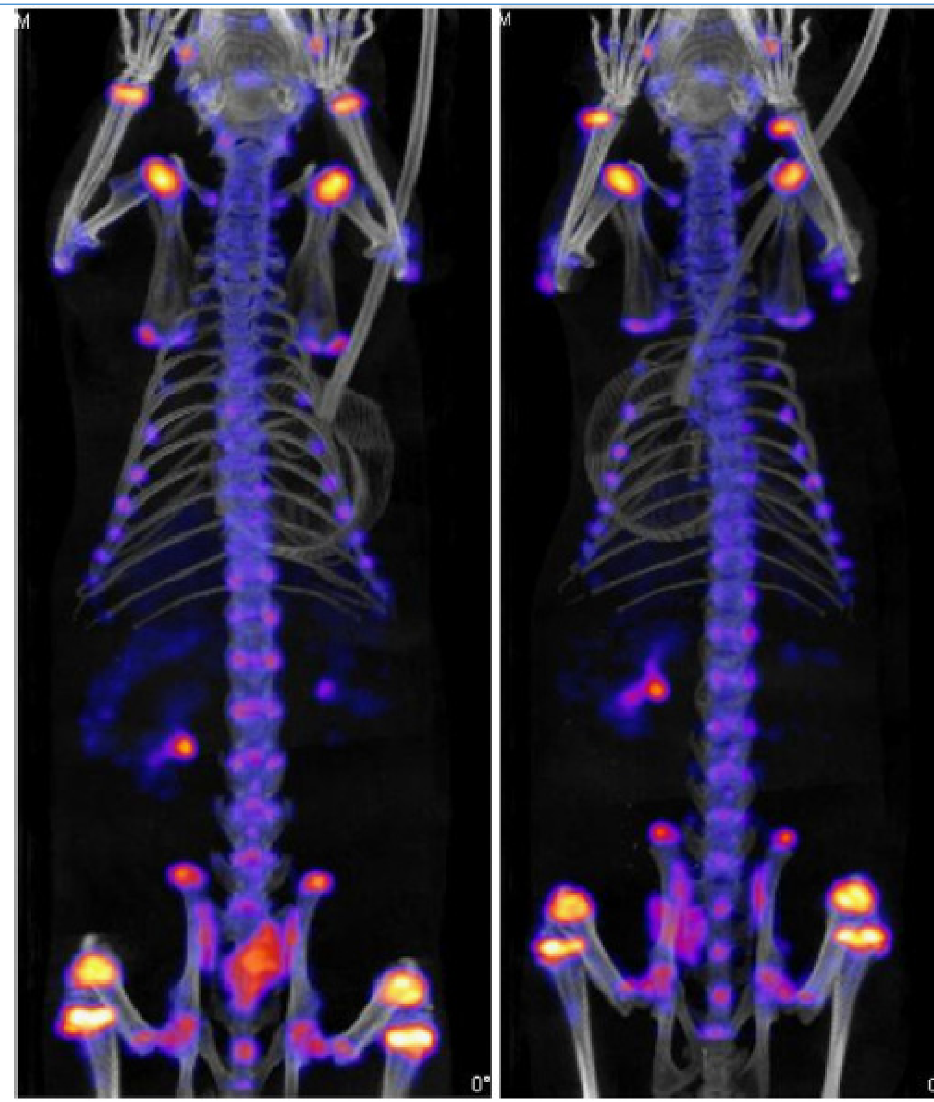


Fig. 2. Bone SPECT images of a rat injected with LINAC-Tc-99m (left) and fission-Tc-99m (right) for the same rat.

Meeting Global Demand
New Models for Technetium Supply

http://www.northstarnm.com/streamlined-distribution

Molybdenum

The Answer to the Ultimate Question of Life, the Universe, and Everything…?

V·T·E **Isotopes of the chemical elements** [hide]

1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 **Mo**	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	*	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	**	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Uut	114 Fl	115 Uup	116 Lv	117 Uus	118 Uuo
	*	57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu	
	**	89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr	

Table of nuclides · Categories: Isotopes · Tables of nuclides · Metastable isotopes · Isotopes by element

https://en.wikipedia.org/wiki/Isotopes_of_molybdenum

Citations

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(http://arxiv.org/ftp/arxiv/papers/1506/1506.08065.pdf)

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