Radiation-Utilizing Technology Overview

A survey of critical technologies utilizing radiation

and

How YOU will understand their functions after 22.01

Motivation for Today

- Answer two question in a few ways:
  - How can radiation be used to our benefit?
  - What is the physics behind how it is used?

Types of Technology

- Power
- Space
- Product Development
- Medical
- Semiconductors

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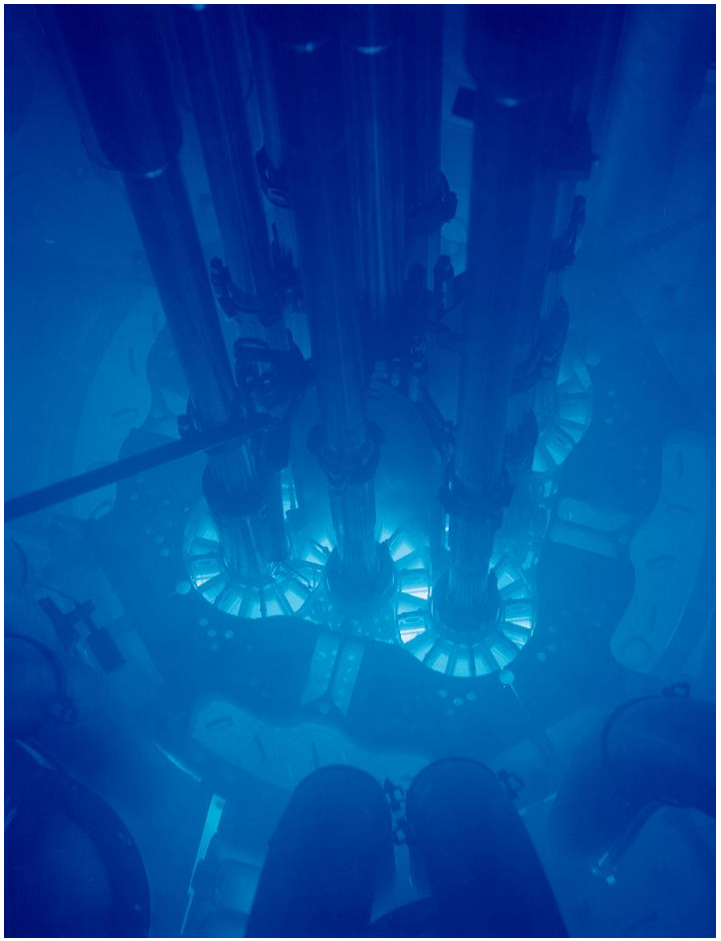
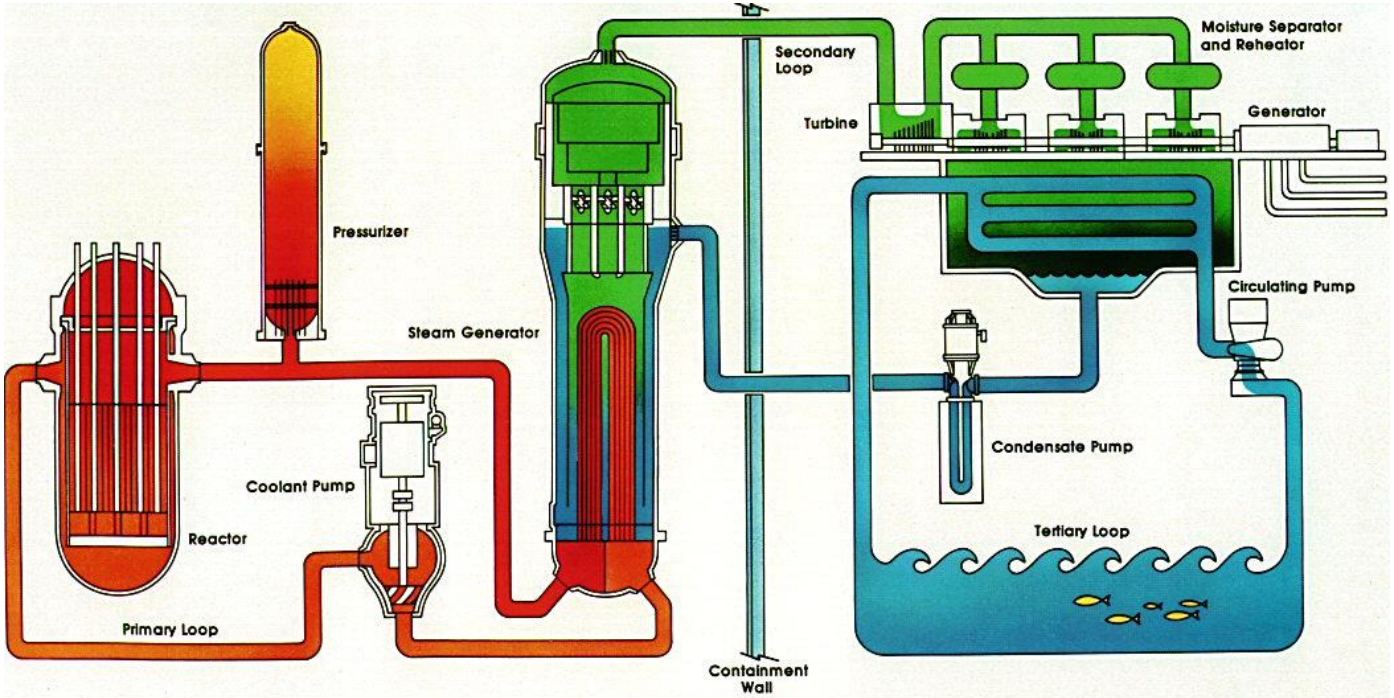


Courtesy of Argonne National Laboratory on Flickr. License CC BY-NC-SA.

Nuclear Power

http://www.nucleartourist.com/type/pwr_cycle.htm

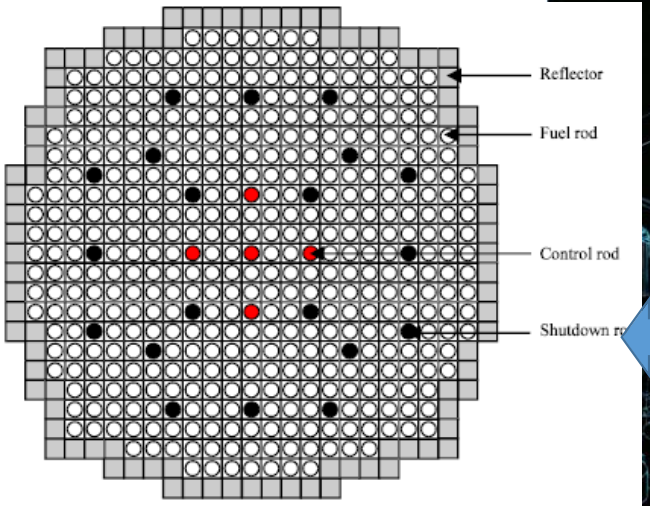
- Overall reactor diagram

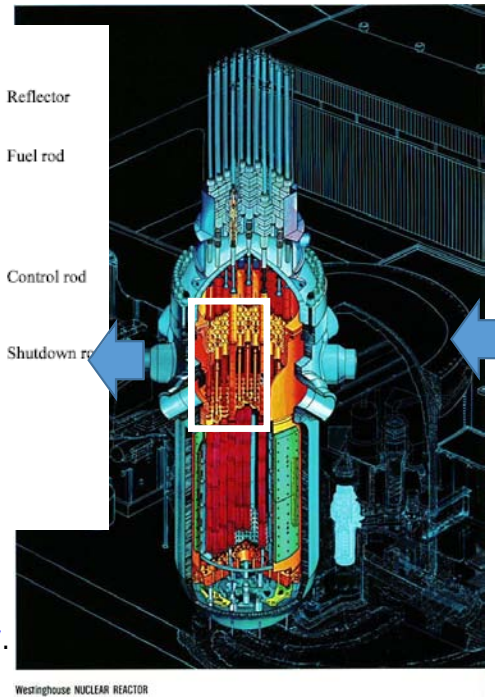


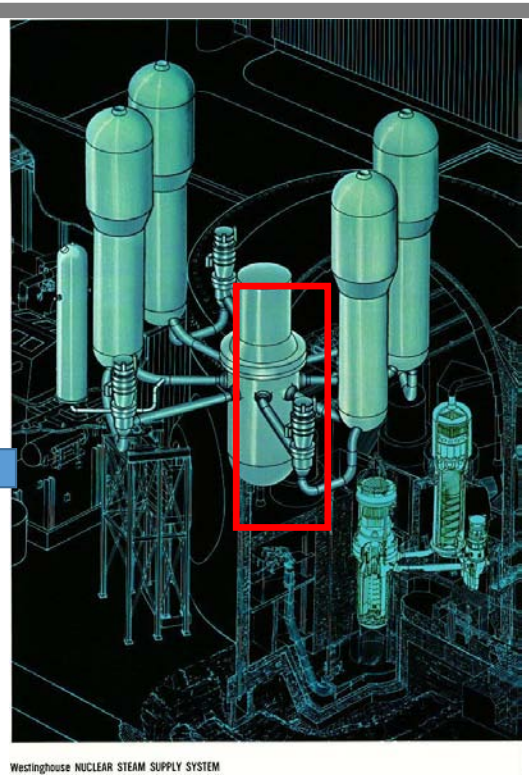
Nuclear Power

http://www.nucleartourist.com/type/pwr_cycle.htm

- Pressurized Water Reactor (PWR)







Source: Hussain, A., and C. Xinrong. "Core Optimization Simulation for a Pressurized Water Reactor." Information Technology Journal 8, no. 2 (2009): 220-225. http://dx.doi.org/10.3923/itj.2009.220.225

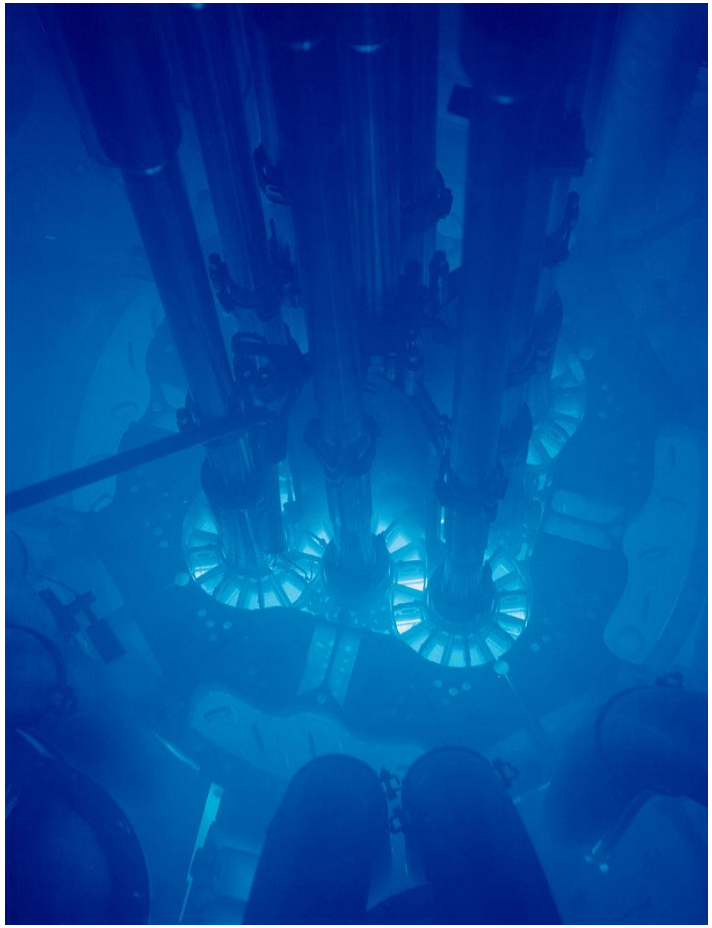
How a Reactor Core Works

- Fuel, fission, and energetics
- Control rods
- Coolant and moderation
- Reflection and shielding

A Neat Aside

"Advanced Test Reactor" by Argonne National Laboratory

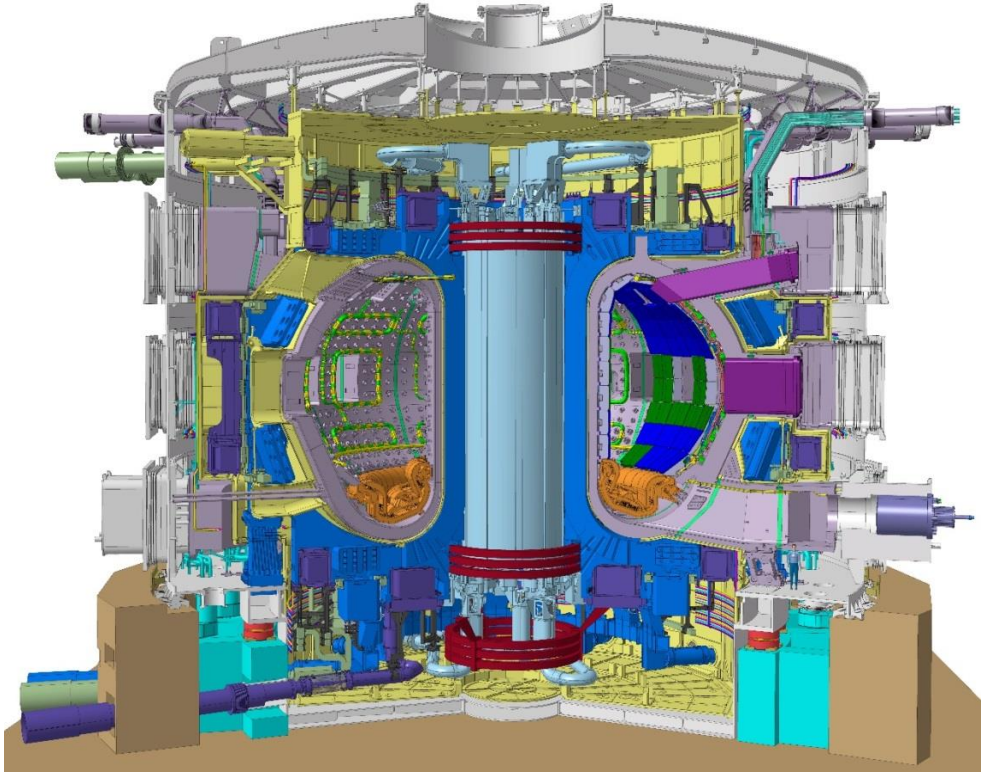
- Cherenkov Radiation
  - Beta particles traveling faster than the speed of light in *water*



Fusion Energy

http://www.iter.org/

- Fuse light nuclei (D + D or D + T) instead



Fusion Reactor Workings

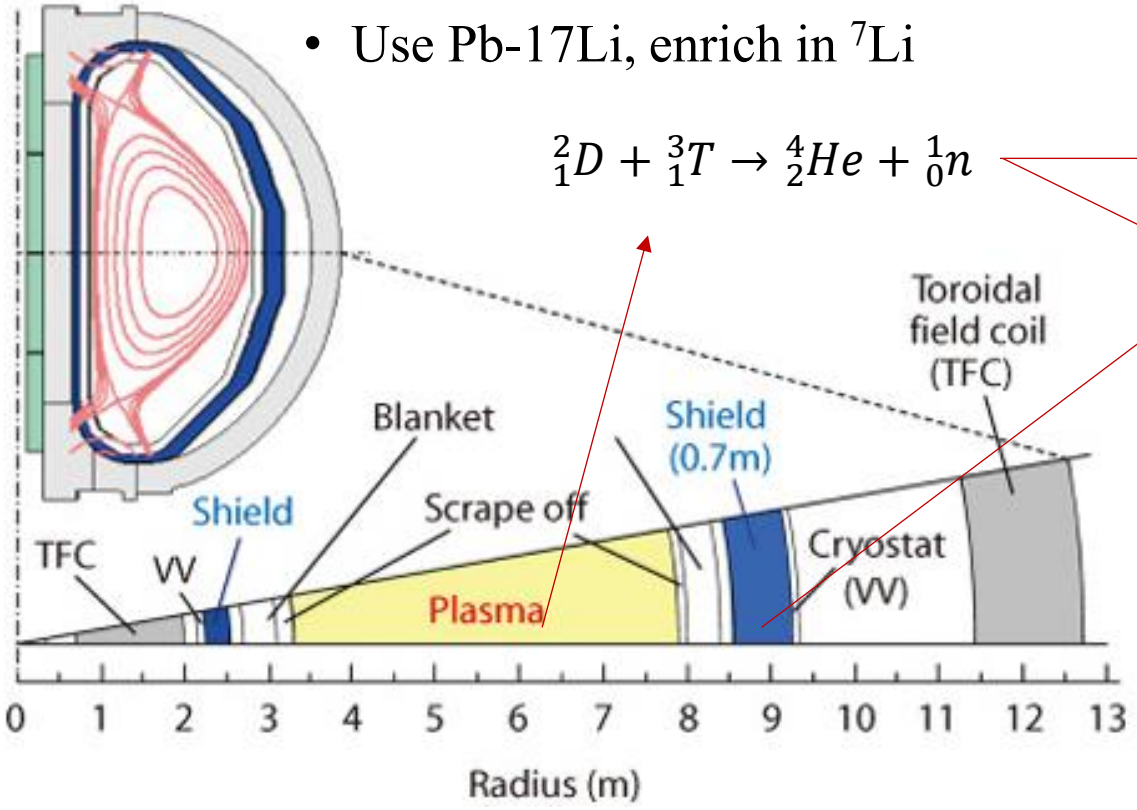
http://jolisfukyu.tokai-sc.jaea.go.jp/fukyu/mirai-en/2006/3_12.html

- Fuse light nuclei, breed fuel from ^{7}Li
  - Use Pb-17Li, enrich in ^{7}Li

$$^{2}_{1}D + ^{3}_{1}T \rightarrow ^{4}_{2}He + ^{1}_{0}n$$

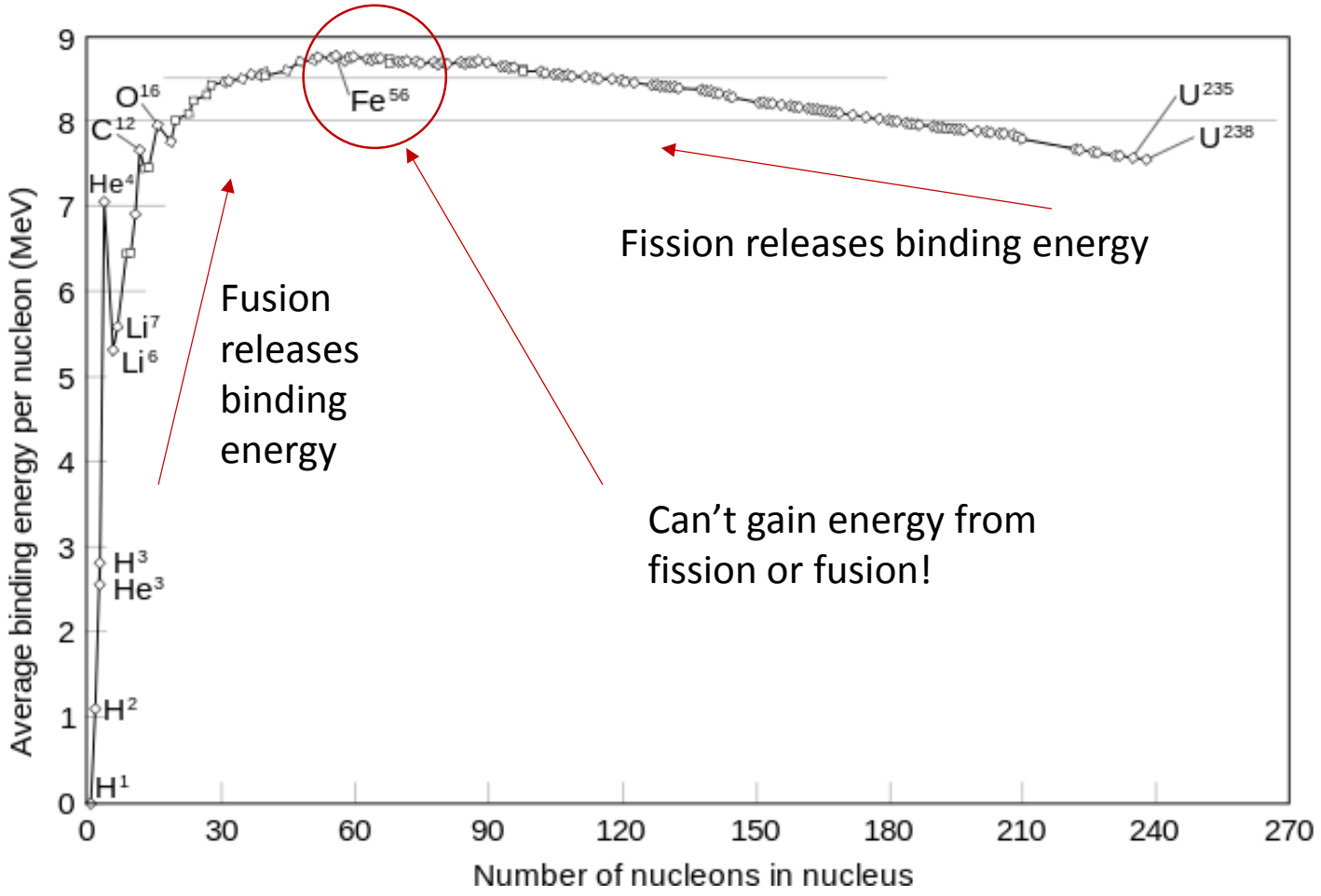
$$^{1}_{0}n + ^{7}_{3}Li \rightarrow ^{3}_{1}T + ^{4}_{2}He + ^{1}_{0}n$$

$$^{1}_{0}n + ^{6}_{3}Li \rightarrow ^{3}_{1}T + ^{4}_{2}He$$



Why Fission and Fusion Work

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



Public domain image.

Medical Uses of Radiation

- Imaging
- X-ray therapy
- Proton therapy
- Brachytherapy
- Radiotracers

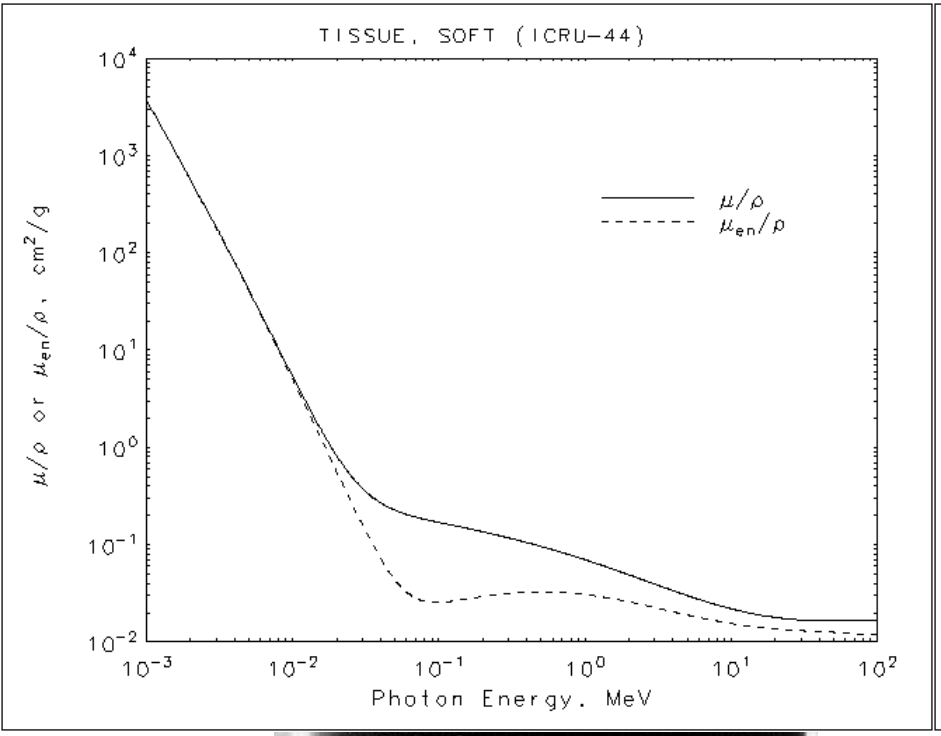
Imaging

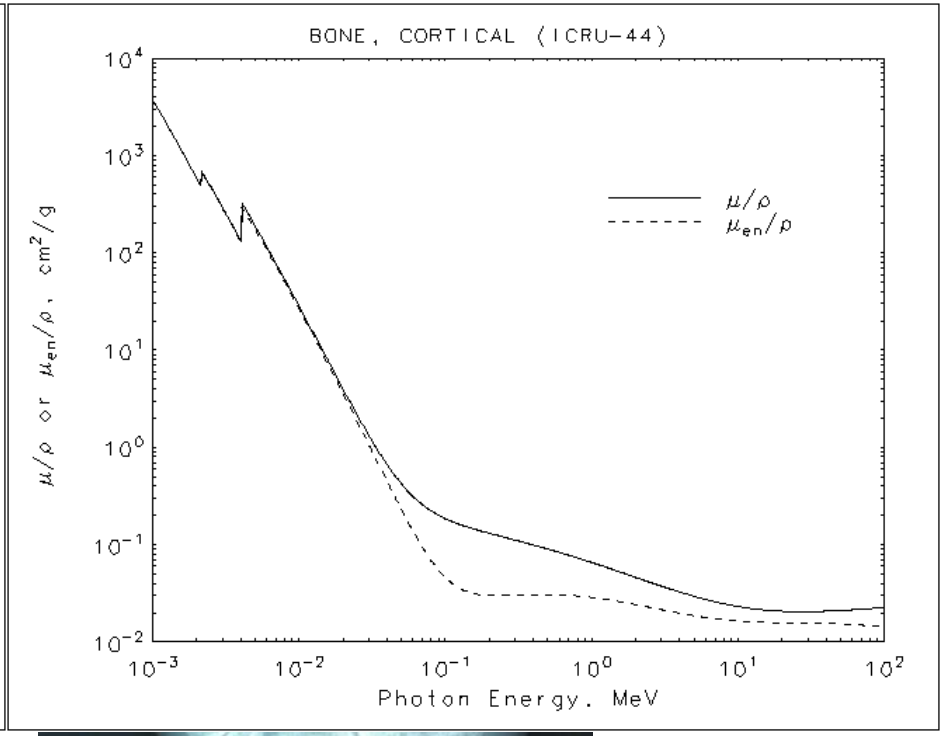
- Differential absorption (attenuation) of x-rays

First x-ray taken by C. Roentgen

Imaging

- Differential absorption (attenuation) of x-rays





First x-ray taken by C. Roentgen

Courtesy of Porcaro Family on Flickr. License CC BY-NC-SA.

Public domain, from U.S. NIST.

X-Ray Therapy

- Hinges upon absorption of x-rays by tumors

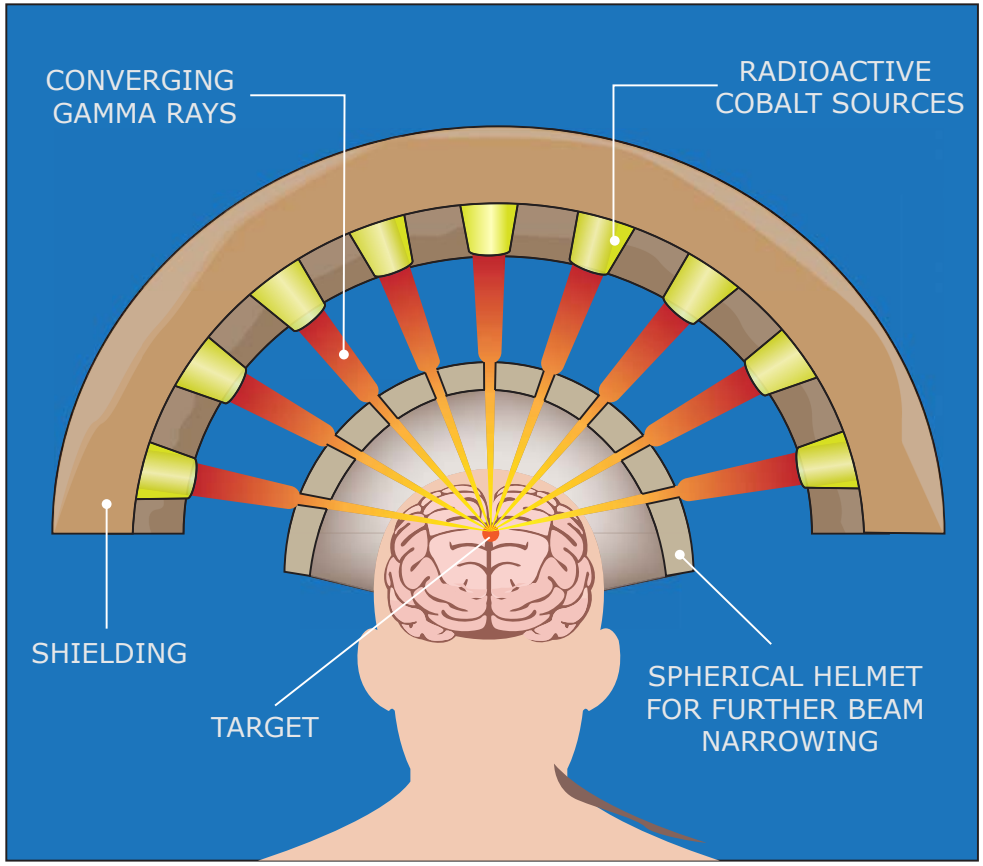
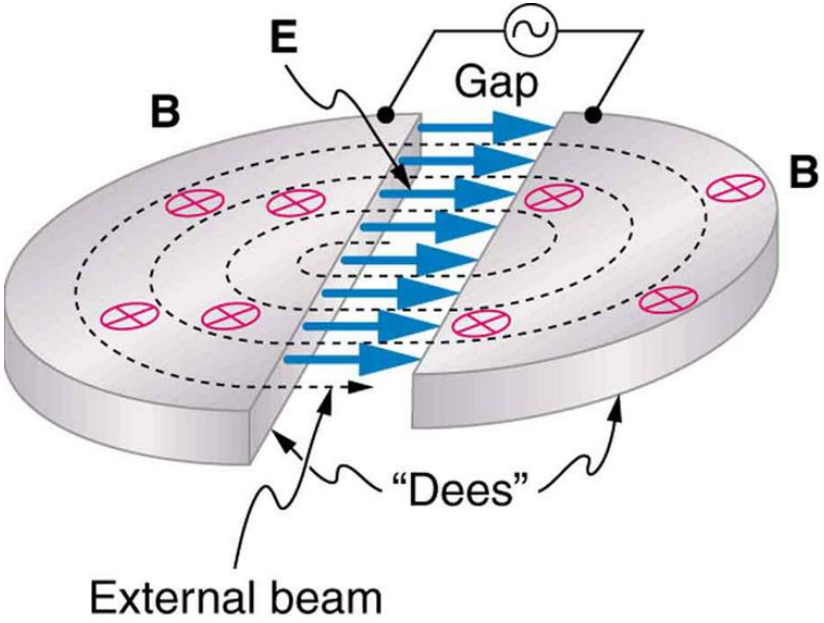


Image by MIT OpenCourseWare.

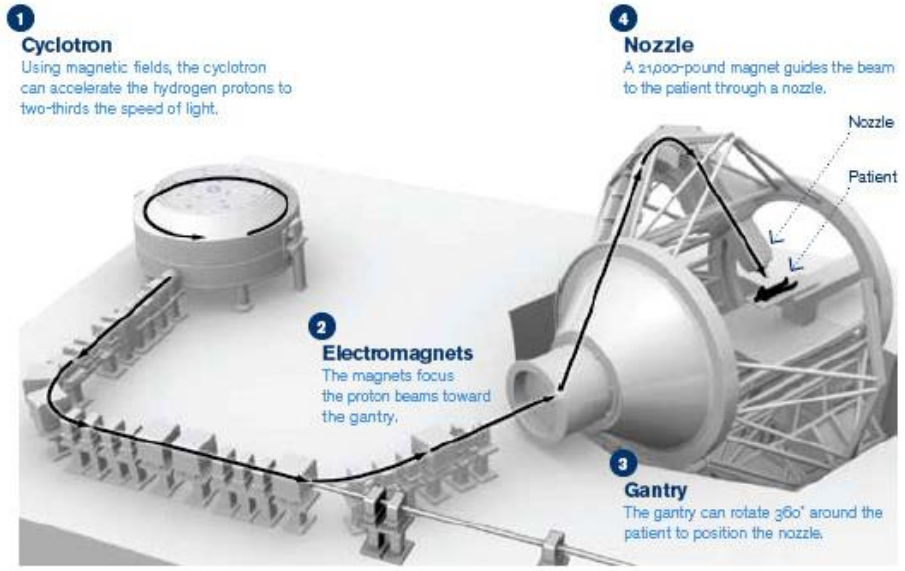
Proton Therapy

- Use an accelerator (cyclotron) to accelerate protons, fire them into the tumor!



Courtesy of Vietnam Open Educational Resources. License CC BY.

http://voer.edu.vn/m/accelerators-create-matter-from-energy/389d856b



See http://www.symmetrymagazine.org/article/december-2008/the-power-of-proton-therapy

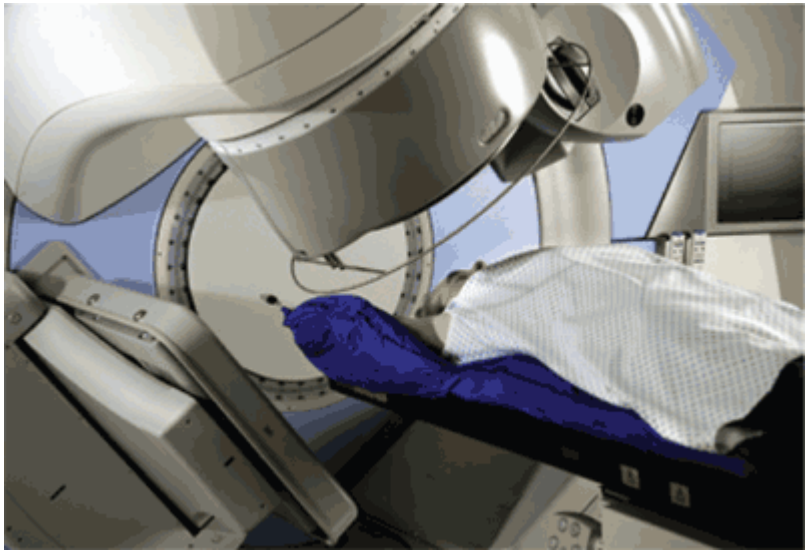
Why Protons vs. X-Rays?

- Highly controllable range vs. just attenuation

Run SRIM live as demo

Why Protons vs. X-Rays?

- Intensity Modulated Radiation Therapy (IMRT)



http://www.aafp.org/afp/2008/1201/p1254.html

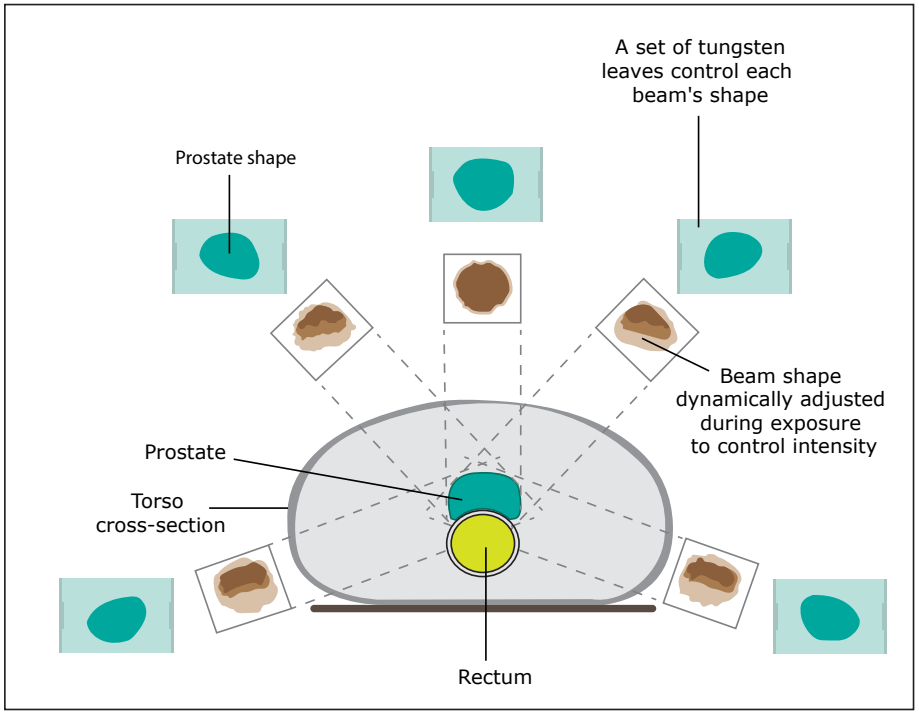
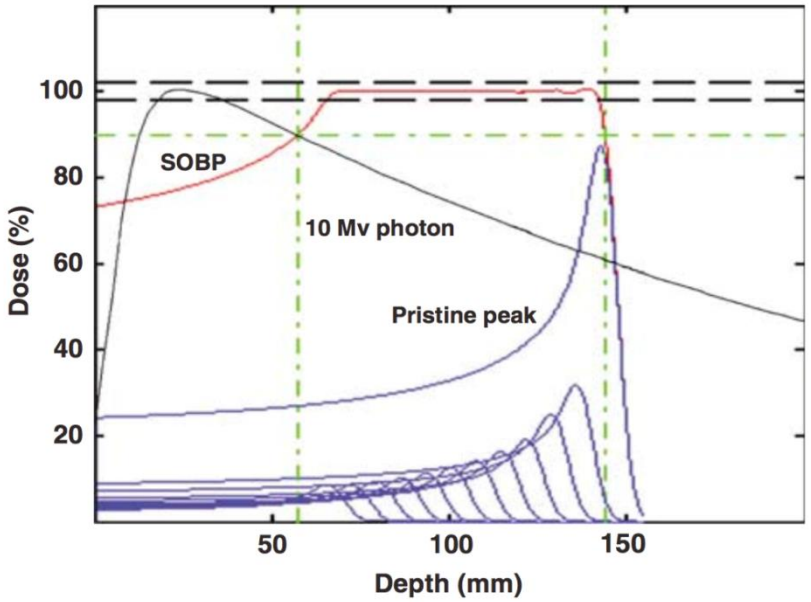


Image by MIT OpenCourseWare.

Why Protons vs. X-Rays?

- Intensity Modulated Radiation Therapy (IMRT)



Source: W. P. Levin et al. "Proton beam therapy." *British J. Cancer*, 93(8):849-854 (2005).

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Brachytherapy

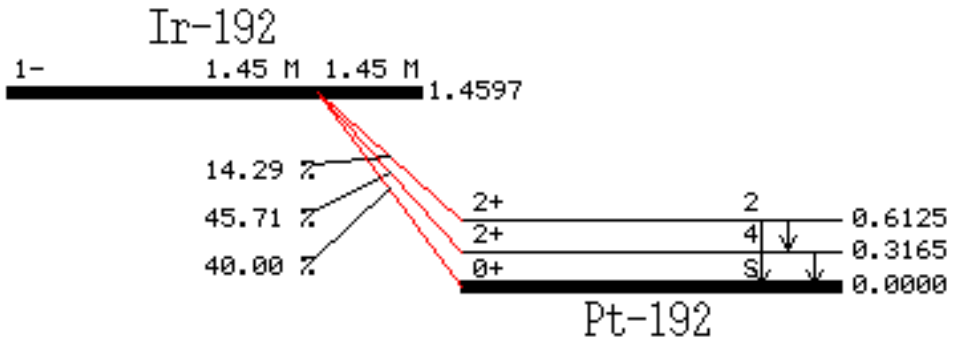
https://en.wikipedia.org/wiki/Brachytherapy

- Relies on simple radioactive decay
  - Implanted directly into tumor

Brachytherapy "seeds'

Public domain photo.

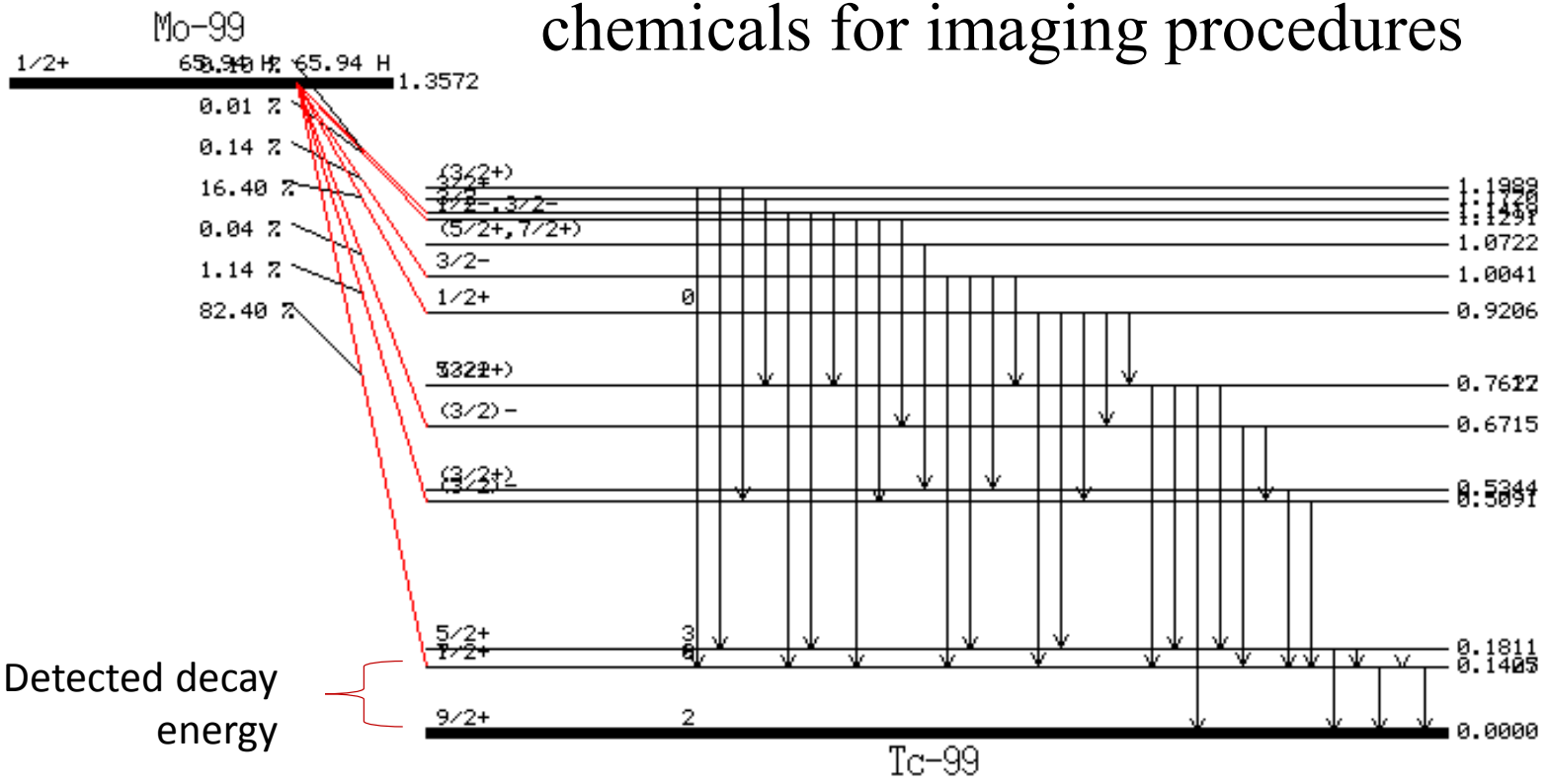
- Ir-192 commonly used
- Short or long range?
- Short or long half life?
- Biocompatibility?



Courtesy of Korea Atomic Energy Research Institute. Used with permission.

Radiotracers

- Typically $^{99}Mo \rightarrow {}^{99m}Tc$, attached to other chemicals for imaging procedures

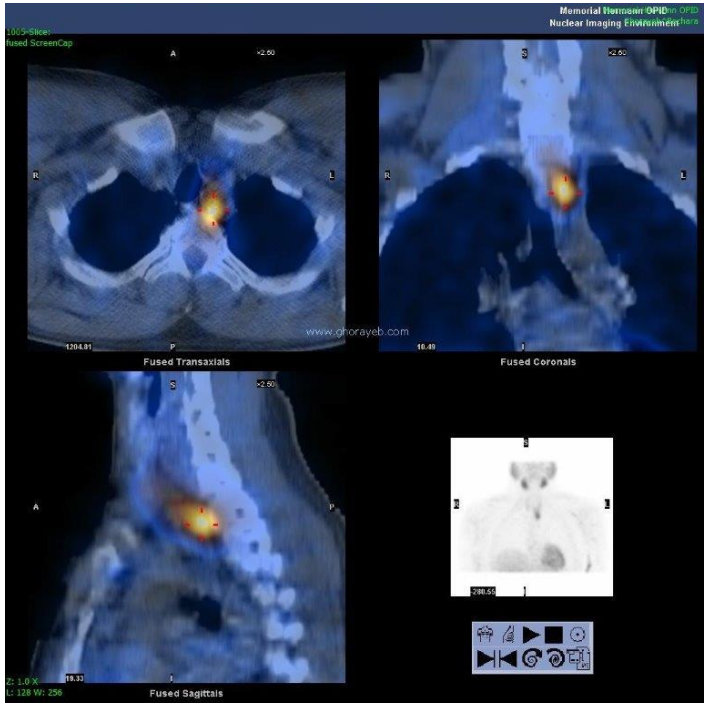


Courtesy of Korea Atomic Energy Research Institute. Used with permission.

Radiotracers

http://www.ghorayeb.com/ParathyroidSestamibisSPECT.html

- Typically $^{99}Mo \rightarrow {}^{99m}Tc$, attached to other chemicals for imaging procedures



Courtesy of Bechara Y. Ghorayeb, MD. Used with permission.

HUGE ^{99}Mo Shortages!

Nature 460, 312-313 (2009), doi:10.1038/460312a

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Source: Gould, Paula. "Medical isotope shortage reaches crisis level." *Nature* 460, 312-313 (2009).

Soon, highly enriched targets will be illegal…

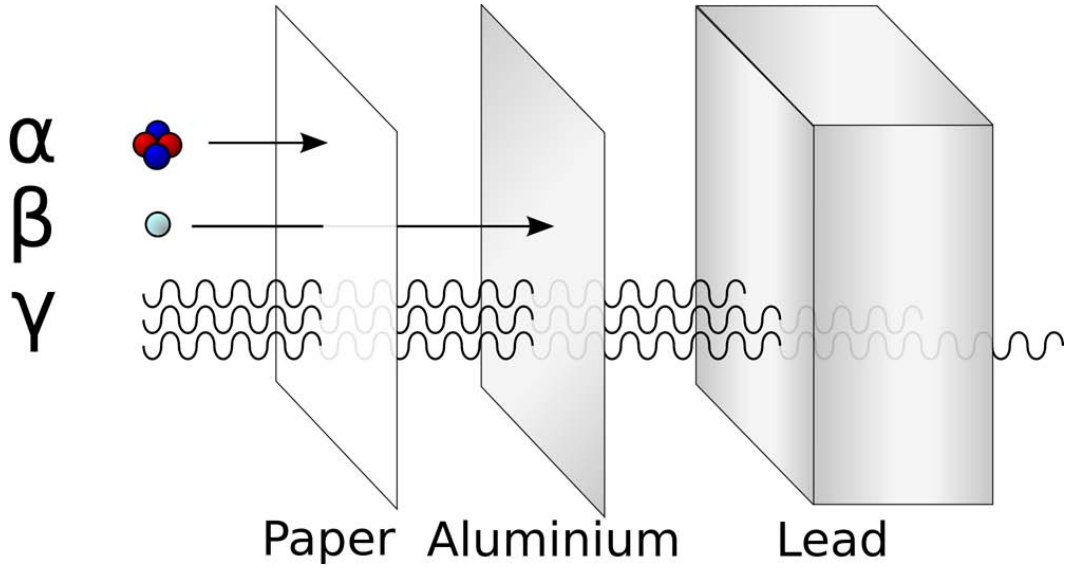
Space Applications

- Astronaut Shielding
- Radioisotope Thermoelectric Generators (RTGs)
- Nuclear Rockets

Shielding

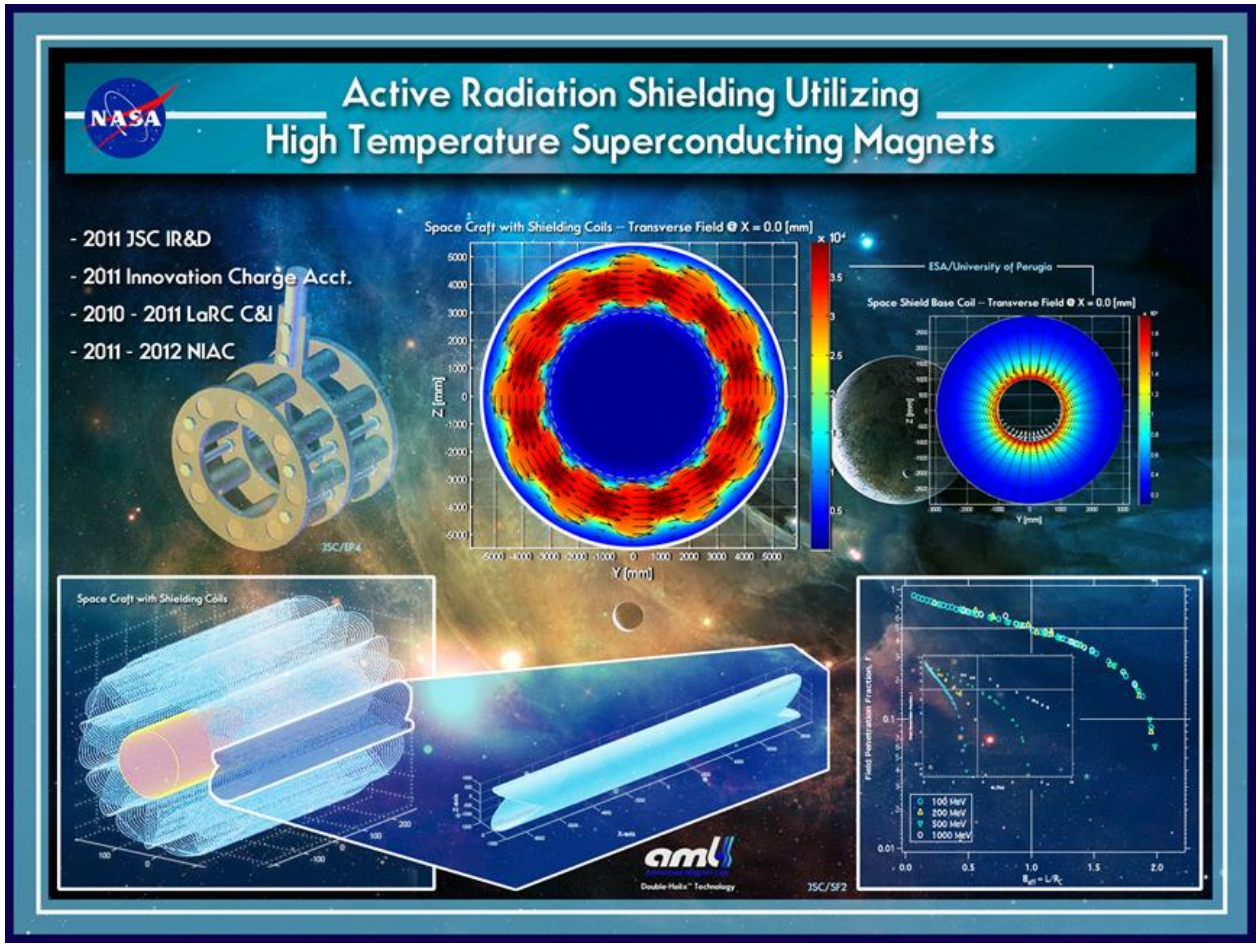
- Must know basic principles of shielding vs.
  - Density
  - Material
  - Energy

https://commons.wikimedia.org/wiki/File:Alfa_beta_gamma_radiation_penetration.svg



More Complex Shielding

http://www.nasa.gov/offices/oct/early_stage_innovation/niac/westover_radiation_protection.html



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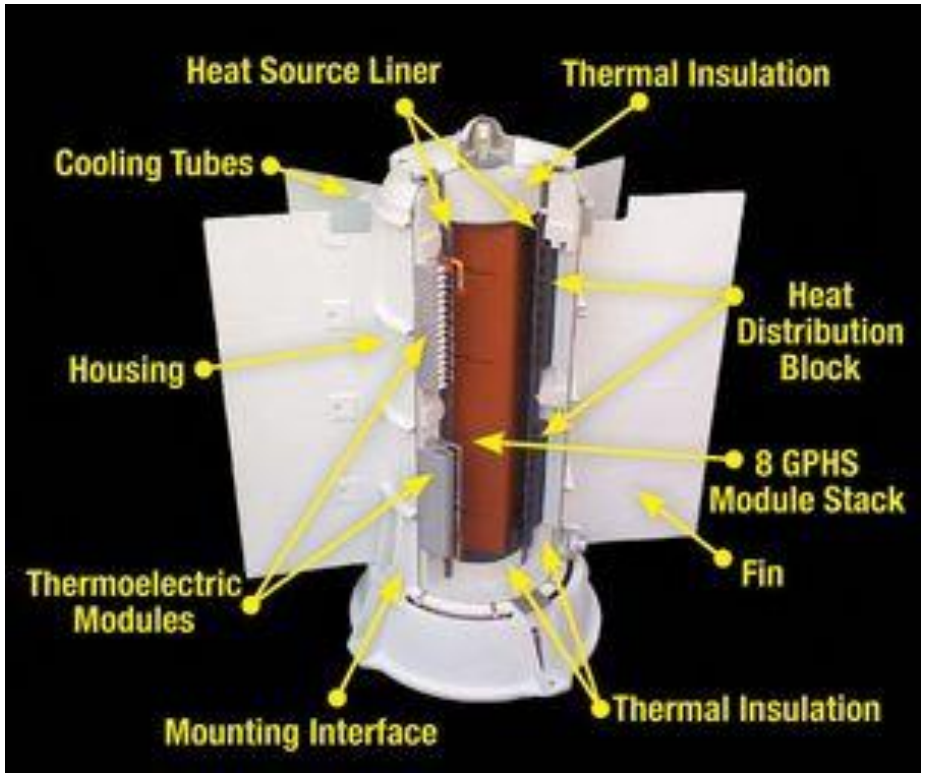
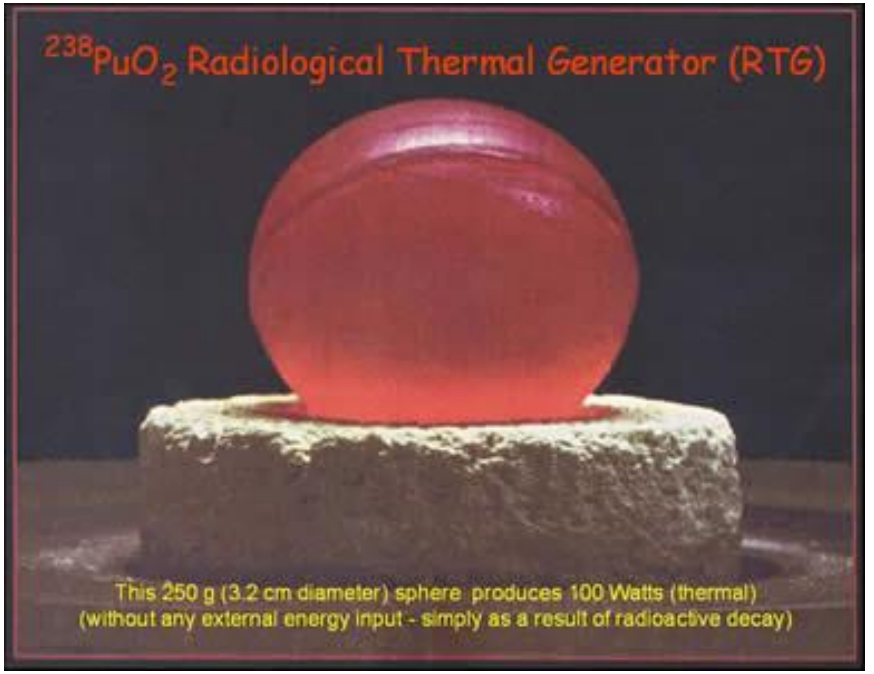
RTGs

- Long-lived, high power decay heat sources





Public domain image.

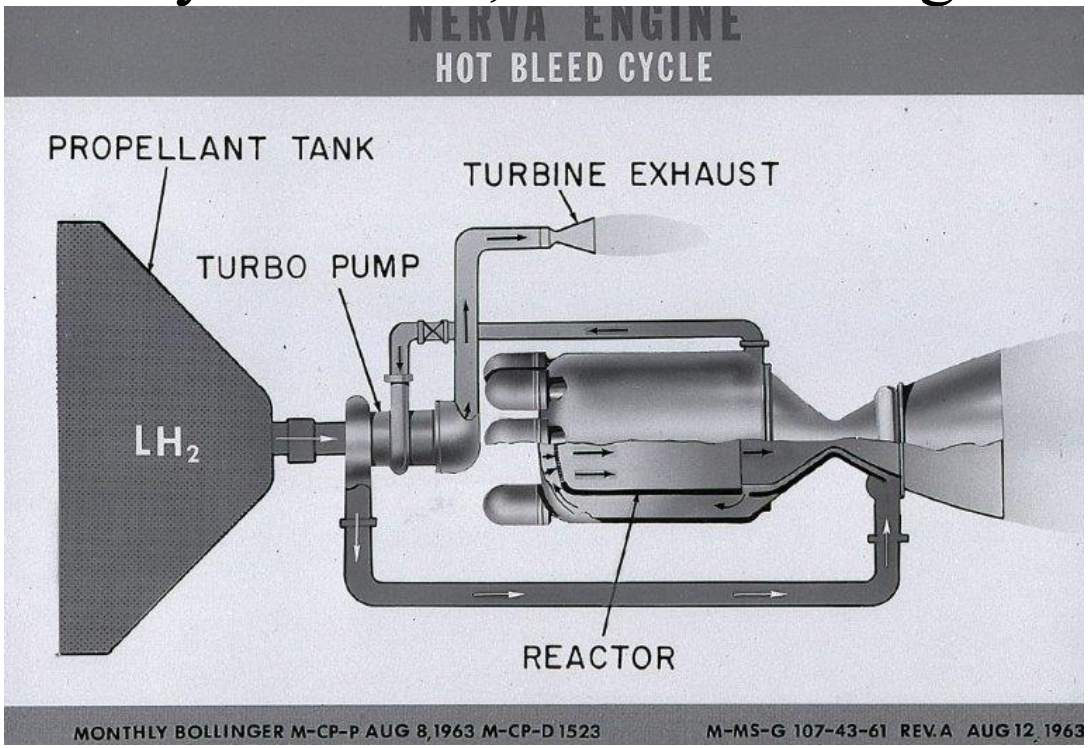
https://radio.chem.wsu.edu/why/

http://solarsystem.nasa.gov/rps/docs/MMRTGfactsFeb_2010.pdf

Nuclear Rockets

http://motherboard.vice.com/blog/should-we-worry-about-a-nuclear-future-in-space

- Thrust may be lower, but life is longer!

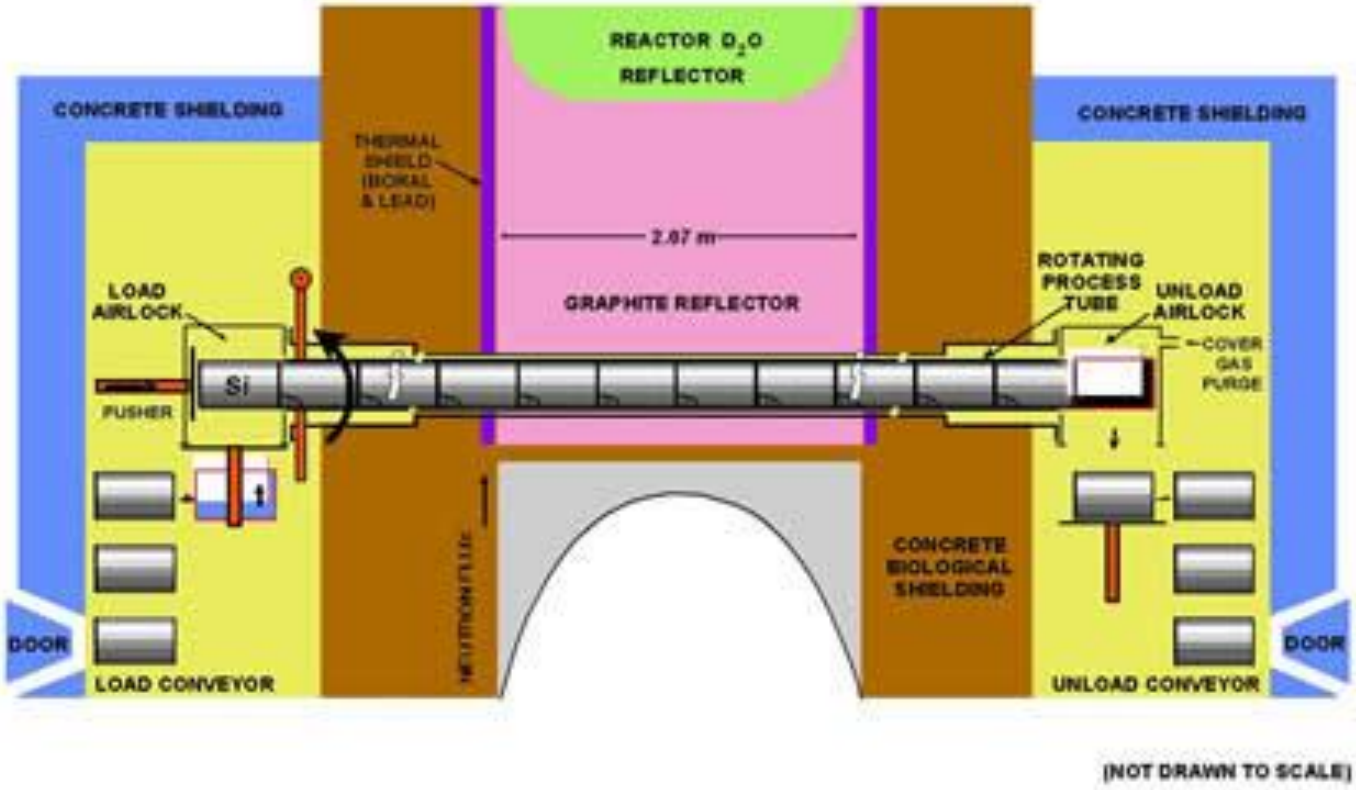


Public domain image.
http://trajectory.grc.nasa.gov/projects/ntp/

Semiconductor Processing

http://nrl.mit.edu/facilities/ntds

- VERY precise n-type doping of Si to P

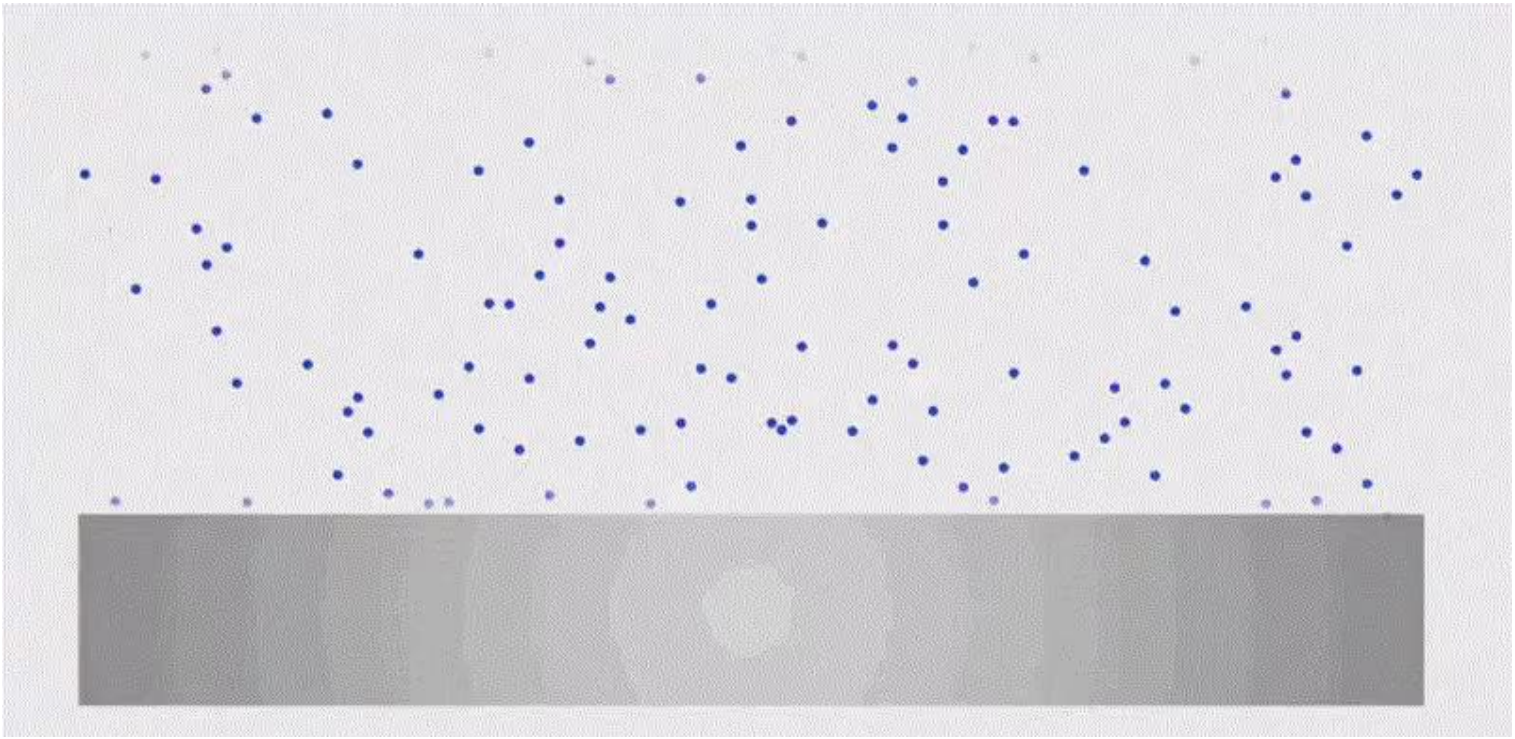


Courtesy of MIT Nuclear Reactor Laboratory. Used with permission.

Accelerator Applications

see animation at http://www.businessinsider.com/how-sapphire-glass-screens-are-made-2014-9

- Making super thin, scratch-proof iPhone screens



Courtesy of Neutron Therapeutics, Inc. Used with permission.

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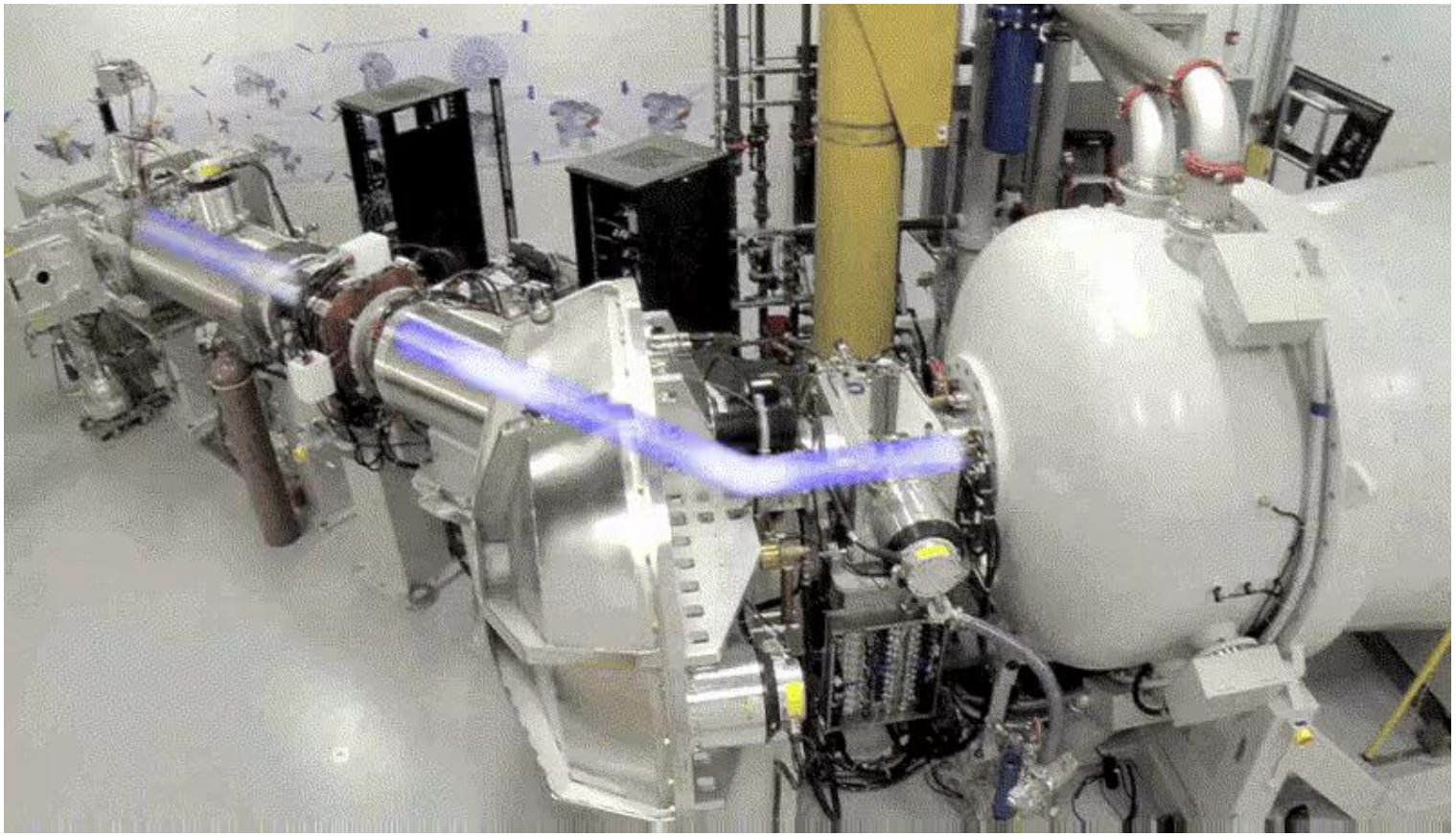

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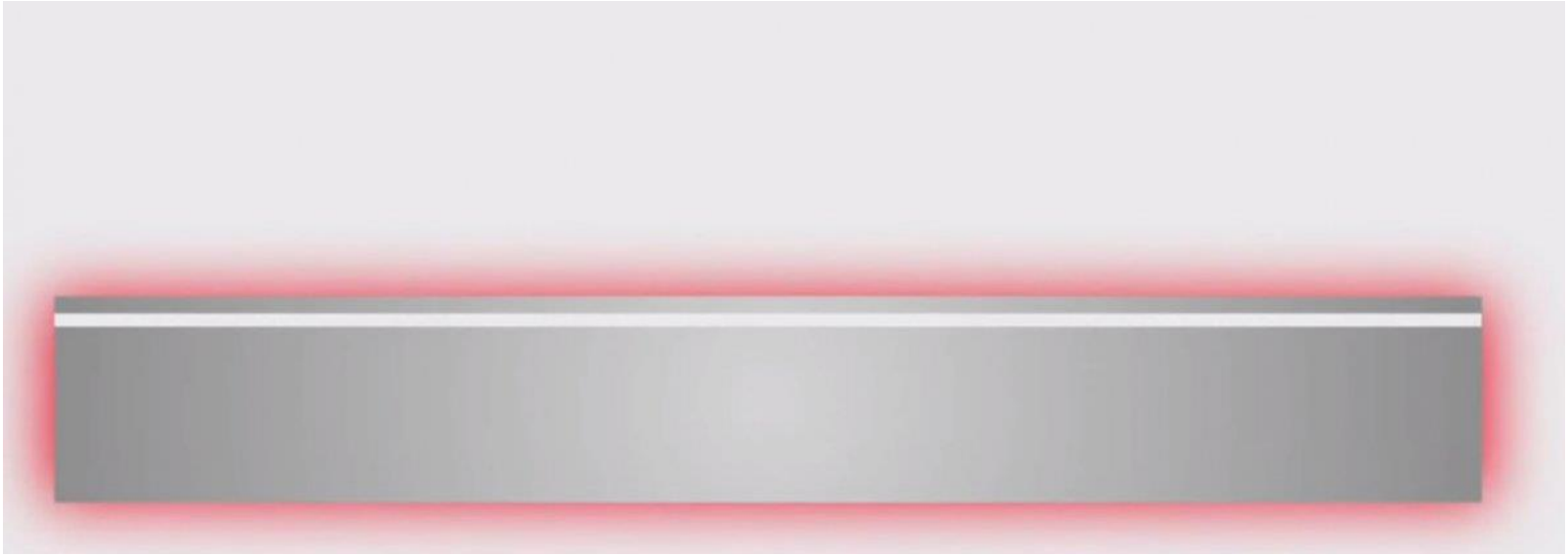

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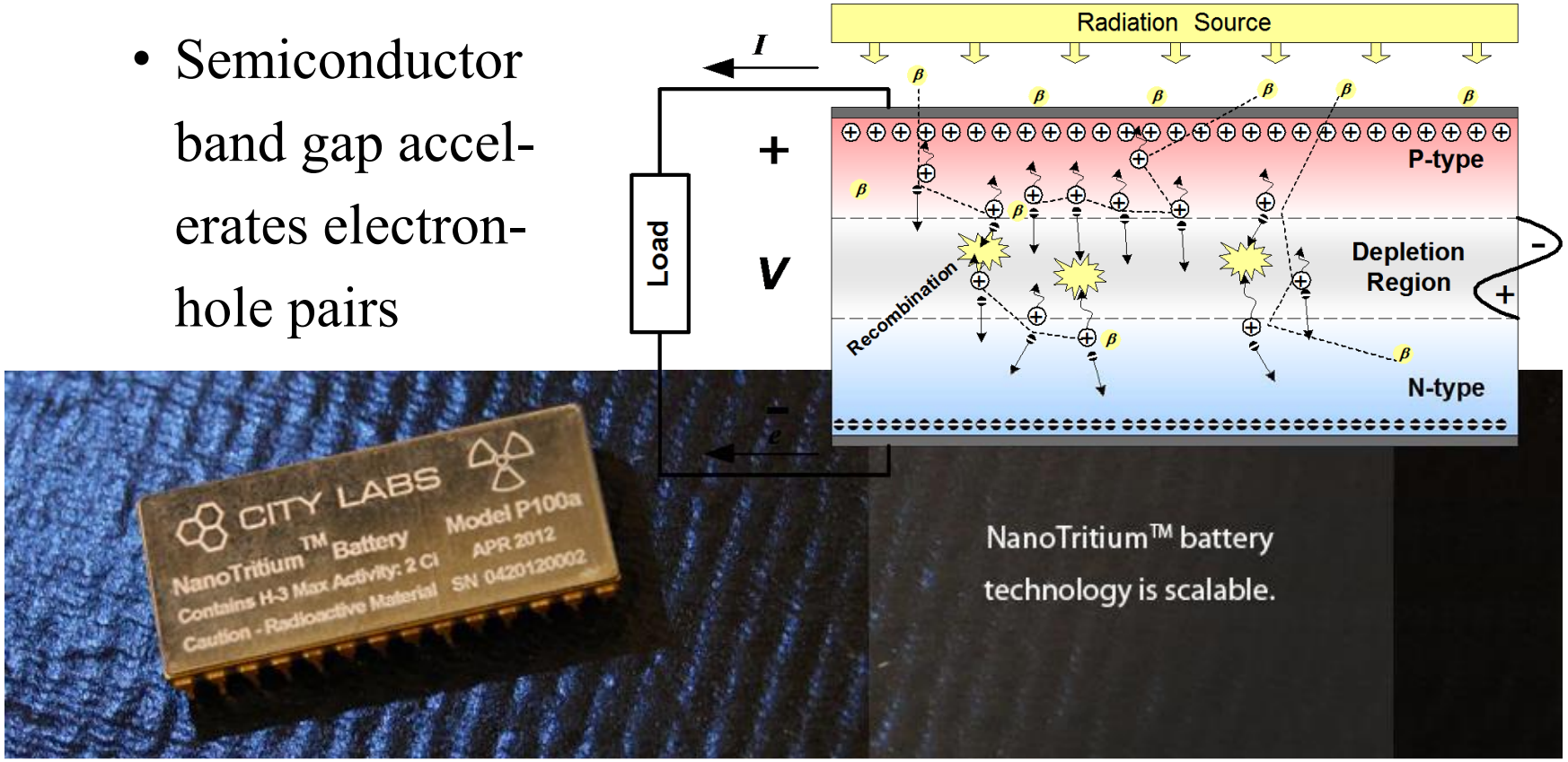
Courtesy of Neutron Therapeutics, Inc. Used with permission.

Other Products

http://www.citylabs.net/

- Betavoltaics – direct usage of *beta particle charge*
  - Semiconductor band gap accel-erates electron-hole pairs



Courtesy of City Labs, Inc. Used with permission.

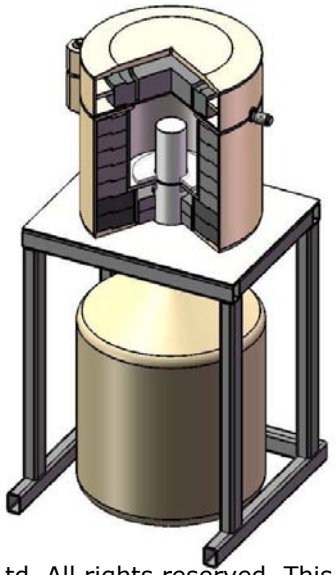
Detectors

- Various kinds for different uses

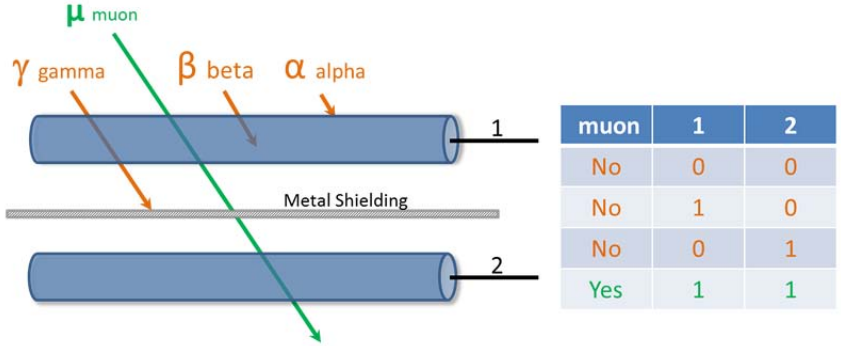
BF_3 neutron detector –

Courtesy of ORAU Foundation. Used with permission.

http://www.orau.org/ptp/collection/proportional%20counters/nucchicago205bf3.htm



High-purity Ge gamma spectrometer - http://www.radek.ru/en/product/Spectrometers-and-radiometers-of-radiation/49/



muon	1	2
No	0	0
No	1	0
No	0	1
Yes	1	1

Courtesy of Robert Hart. Used with permission.

Two ionization tubes used as a muon coincidence detector - https://hackaday.io/project/1700-cosmic-ray-muon-81-9x9-pixel-hodoscope

Transparent Geiger tube – https://www.cooking-hacks.com/documentation/tutorials/geiger-counter-radiation-sensor-board-arduino-raspberry-pi-tutorial/

22.01 Introduction to Nuclear Engineering and Ionizing Radiation
Fall 2015