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
- Medical
- Space
- Semiconductors
- Product Development
Nuclear Power

• Overall reactor diagram

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

© Westinghouse. All rights reserved. This content is excluded from our Creative Commons license. For more information, see http://ocw.mit.edu/help/faq-fair-use/.
Nuclear Power

- Pressurized Water Reactor (PWR)

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

© Westinghouse. All rights reserved. This content is excluded from our Creative Commons license. For more information, see http://ocw.mit.edu/help/faq-fair-use/.


© Asian Network for Scientific Information. All rights reserved. This content is excluded from our Creative Commons license. For more information, see http://ocw.mit.edu/help/faq-fair-use/.
How a Reactor Core Works

• Fuel, fission, and energetics

• Control rods

• Coolant and moderation

• Reflection and shielding
A Neat Aside

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

"Advanced Test Reactor" by Argonne National Laboratory

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

• Fuse light nuclei (D + D or D + T) instead
Fusion Reactor Workings

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

\[
\frac{2}{1}D + \frac{3}{1}T \rightarrow \frac{4}{2}He + \frac{1}{0}n
\]

\[
\frac{1}{0}n + \frac{3}{3}Li \rightarrow \frac{3}{1}T + \frac{4}{2}He + \frac{1}{0}n
\]

\[
\frac{1}{0}n + \frac{6}{3}Li \rightarrow \frac{3}{1}T + \frac{4}{2}He
\]
Why Fission and Fusion Work

Fusion releases binding energy

Fission releases binding energy

Can’t gain energy from fission or fusion!

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

2010

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

- Differential absorption (attenuation) of x-rays

![Graphs showing differential absorption of x-rays in tissue and bone.](image)

First x-ray taken by C. Roentgen

1895

2010

Public domain, from U.S. NIST.

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

• Hinges upon absorption of x-rays by tumors
Proton Therapy

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

1. **Cyclotron**
   Using magnetic fields, the cyclotron can accelerate the hydrogen protons to two-thirds the speed of light.

2. **Electromagnets**
   The magnets focus the proton beams toward the gantry.

3. **Gantry**
   The gantry can rotate 360° around the patient to position the nozzle.

4. **Nozzle**
   A 1,000-pound magnet guides the beam to the patient through a nozzle.


MIT 22.01: Intro to Ionizing Radiation

© The New York Times. All rights reserved. This content is excluded from our Creative Commons license. For more information, see [http://ocw.mit.edu/help/faq-fair-use/](http://ocw.mit.edu/help/faq-fair-use/).
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)

Prostate shape
Beam shape dynamically adjusted during exposure to control intensity
A set of tungsten leaves control each beam's shape

Torso cross-section
Rectum

Prostate

© American Academy of Family Physicians. All rights reserved. This content is excluded from our Creative Commons license. For more information, see http://ocw.mit.edu/help/faq-fair-use/.


Image by MIT OpenCourseWare.
Why Protons vs. X-Rays?

- Intensity Modulated Radiation Therapy (IMRT)

![Graph showing dose vs. depth for protons and x-rays.](Image)

Courtesy of Macmillan Publishers Ltd. License CC BY-NC-SA.

Brachytherapy

- Relies on simple radioactive decay
  - Implanted directly into tumor
    - Ir-192 commonly used
    - Short or long range?
    - Short or long half life?
    - Biocompatibility?

Public domain photo. Courtesy of Korea Atomic Energy Research Institute. Used with permission.

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

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

Detected decay energy

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

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

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

Courtesy of Bechara Y. Ghorayeb, MD. Used with permission.
HUGE $^{99}$Mo Shortages!

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

Soon, highly enriched targets will be illegal...

Reprinted by permission of Macmillan Publishers Ltd.
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

Courtesy of Wikipedia User: Stannered. License CC BY.
More Complex Shielding

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

- Long-lived, high power decay heat sources

[Image of RTG components and a 238PuO2 Radiological Thermal Generator (RTG) with a description: This 250 g (3.2 cm diameter) sphere produces 100 Watts (thermal) (without any external energy input - simply as a result of radioactive decay).]

Public domain image.

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

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

• Thrust may be lower, but life is longer!

Public domain image.

http://trajectory.grc.nasa.gov/projects/ntp/
Semiconductor Processing

• VERY precise n-type doping of Si to P

Courtesy of MIT Nuclear Reactor Laboratory. Used with permission.
Accelerator Applications


• Making super thin, scratch-proof iPhone screens

Courtesy of Neutron Therapeutics, Inc. Used with permission.
Accelerator Applications


• Making super thin, scratch-proof iPhone screens

Courtesy of Neutron Therapeutics, Inc. Used with permission.
Accelerator Applications


• Making super thin, scratch-proof iPhone screens

Courtesy of Neutron Therapeutics, Inc. Used with permission.
Accelerator Applications


• Making super thin, scratch-proof iPhone screens

Courtesy of Neutron Therapeutics, Inc. Used with permission.
Other Products

- Betavoltaics – direct usage of *beta particle charge*

- Semiconductor band gap accelerates electron-hole pairs

MIT 22.01: Intro to Ionizing Radiation
Detectors

• Various kinds for different uses

**BF$_3$ neutron detector** –

Courtesy of ORAU Foundation. Used with permission.


<table>
<thead>
<tr>
<th>muon</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>No</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>No</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Yes</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

**High-purity Ge gamma spectrometer** -


© STC RADEK Ltd. All rights reserved. This content is excluded from our Creative Commons license. For more information, see http://ocw.mit.edu/help/faq-fair-use/.

**Two ionization tubes used as a muon coincidence detector** -

https://hackaday.io/project/1700-cosmic-ray-muon-81-9x9-pixel-hodoscope

© Libelium Comunicaciones Distribuidas S.L. All rights reserved. This content is excluded from our Creative Commons license. For more information, see http://ocw.mit.edu/help/faq-fair-use/.

**Transparent Geiger tube** –

22.01 Introduction to Nuclear Engineering and Ionizing Radiation
Fall 2015

For information about citing these materials or our Terms of Use, visit: http://ocw.mit.edu/terms.