Radioisotopes: Nuclear Applications Beyond Energy
Thursday, October 19

This event is presented by ANS in partnership with the Department of Energy, Office of Nuclear Energy.
Isotopes—what are they good for?

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Department of Energy Isotope Program
Radioisotopes

- Radioisotopes are alternate forms of an element with the same number of protons, but different number of neutrons.
- They are unstable and decay into a more stable daughter by alpha, beta or gamma ray emission.
- Radioisotopes can be found in nature as well as made in reactors, particle accelerators, and generators (where a radioisotope decays into another radioisotope daughter of interest).
Endless Possibilities

- Nuclear batteries
- QIS
- Bio-tech
- Semi-conductor manufacturing, microelectronics
- Industrial Apps
- Power Sources for Space, underwater
- Cancer
- Fusion Reactor
- Fission Reactor
- Discovery Research
American Nuclear Society

Adams_2015_Rsrch-Dev-and-Eval-Cap-for-Betavoltaic-Pwr-Sources_ASEE#13983

Beta-Photovoltaics
BPVs

Radio-isotope

NASA RTG heat source

Beta particle source

Scintillator

PV

Thermoelectric Transducer

Semiconductor Transducer

Heat source

Cool side

Nuclear batteries
<table>
<thead>
<tr>
<th>Isotope</th>
<th>Decay</th>
<th>Type</th>
<th>Example size battery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pu-238</td>
<td>α</td>
<td>RTG</td>
<td>10 W</td>
</tr>
<tr>
<td>Am-241</td>
<td>α</td>
<td>RTG</td>
<td>10 W</td>
</tr>
<tr>
<td>Sr-90</td>
<td>β</td>
<td>RTG</td>
<td>10 W</td>
</tr>
<tr>
<td>Ac-227</td>
<td>α</td>
<td>RTG</td>
<td>10 W</td>
</tr>
<tr>
<td>Pm-147</td>
<td>β</td>
<td>BV/BPV</td>
<td>10 mW</td>
</tr>
<tr>
<td>Eu-155</td>
<td>β</td>
<td>BV</td>
<td>3 mW</td>
</tr>
<tr>
<td>Ni-63</td>
<td>β</td>
<td>BV</td>
<td>1 mW</td>
</tr>
<tr>
<td>H-3</td>
<td>β</td>
<td>BV</td>
<td>100 µW</td>
</tr>
</tbody>
</table>

**Sr-90 Example:**

1.13 E 6 eV/decay  
1 Ci = 3.7 E 10 decays/sec  
1 J = 6.24 E18 eV  
1 W = 1J/s

∴ 149 Ci Sr-90 for 1 W,<sub>th</sub> energy

**For 5% efficient RTG:**  
2,987 Ci Sr90/<sub>W</sub><sub>e</sub>

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<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
</tr>
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<tbody>
<tr>
<td>RTG</td>
<td>Radioisotope Thermoelectric Generator</td>
</tr>
<tr>
<td>BV</td>
<td>Beta Voltaic</td>
</tr>
<tr>
<td>BPV</td>
<td>Beta Photo Voltaic</td>
</tr>
<tr>
<td>eV</td>
<td>Electron Volt</td>
</tr>
<tr>
<td>Ci</td>
<td>Curie</td>
</tr>
<tr>
<td>J</td>
<td>Joule</td>
</tr>
<tr>
<td>W</td>
<td>Watt</td>
</tr>
</tbody>
</table>

**Abbreviation Definition**

- **RTG**: Radioisotope Thermoelectric Generator
- **BV**: Beta Voltaic
- **BPV**: Beta Photo Voltaic
- **eV**: Electron Volt
- **Ci**: Curie
- **J**: Joule
- **W**: Watt
Radioactive Power Sources

- Radioisotope Thermoelectric Generator
- Multi-Mission Radioisotope Thermoelectric Generator
Gamma radiography (Se-75 and Ir-192)

Airport Security

Pest Control
Si-28 for improved heat conduction on computer chips
Betavoltaic power sources for microelectronics
Isotopically pure isotopes of Si and Ge for quantum dot devices

Quantum Information System

Semi-conductor manufacturing, microelectronics
Fuels: deuterium, tritium, He-3, B-11
Blankets: Li-6

Th-232, U-235 for fuel
U-234 for monitoring flux levels
B-10 neutron absorption
# Available Medical Isotopes

| Radio-isotopes in blue available soon. |

<table>
<thead>
<tr>
<th>Under development</th>
</tr>
</thead>
<tbody>
<tr>
<td>As-72 /Se-72</td>
</tr>
<tr>
<td>Br-76, Br-77</td>
</tr>
<tr>
<td>C-14</td>
</tr>
<tr>
<td>Cd-109</td>
</tr>
<tr>
<td>Ce-139</td>
</tr>
</tbody>
</table>
Theranostics = diagnostics + treatment
- Isotopes that aid in diagnostic imaging include Ga-68, Y-86, Sr-82, Cd-109, Fe-52, Se-72, Te-123m, and Xe-129

Co-60:
- Sterilization of single-use medical devices
- Food irradiation
- External beam therapy

Diagnostic demonstration of Cu-67 in living mice, in collaboration with University of Alabama-Birmingham
Alpha and beta emitters approved by the world regulatory bodies (FDA, EMA, etc.)

<table>
<thead>
<tr>
<th>All (β-emitters)</th>
<th>Lu-177 (β-emitter)</th>
<th>Ra-223 (α-emitter)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Established Radioisotopes for therapy (all beta emitters)</td>
<td>January 26, 2018 Lutathera® (Lutetium Lu-177, dotatate) approved by the FDA</td>
<td>May 15, 2013 Xofigo® (Ra-223 dichloride) approved by the FDA</td>
</tr>
<tr>
<td>I-131 thyroid cancer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Y-90 SIR-Spheres®, Liver cancer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Y-90, non-Hodgkins lymphoma (ZEVALIN®, ibritumomab tiuxetan)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sr-89, bone palliation (METASTRON™, Strontium-89 Chloride injection)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ho-166, Liver cancer (QuiremSpheres® - Microspheres)</td>
<td></td>
<td></td>
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Lu-177 (β-emitter):
- **January 26, 2018**
- Lutathera® (Lutetium Lu-177, dotatate) approved by the FDA

Ra-223 (α-emitter):
- **May 15, 2013**
- Xofigo® (Ra-223 dichloride) approved by the FDA

Additional Links:
- [https://www.xofigo-us.com/patient](https://www.xofigo-us.com/patient)
New Elements

- 117 Ts, Tennessine

- 9 mg of $^{248}$Cm, (>95%)

Archeology

- Discovery Research

Nuclear Physics

- $^{254}$Es, 0.5 μg experiments on fission mechanisms

- $^{244}$Pu, 15 mg >99% reaction mechanism studies
If not found in nature, then what?

- Production pathways
  - Transmutation (accelerator or nuclear reactor)
  - Radiochemistry (separation, generators)
  - Harvesting (FRIB, recovery)

Powerful and state-of-the-art accelerators and reactors within the national laboratory complex can play unique and significant roles in the provision of isotopes.
Transmutation – Particle Accelerator

<table>
<thead>
<tr>
<th>n = neutron</th>
<th>p = proton (H)</th>
<th>d = deuteron (2H; [pn])</th>
<th>t = triton (3H); [p2n]</th>
<th>$^3$He = [2pn]</th>
<th>$\alpha$ = alpha particle (4He); [2p2n]</th>
</tr>
</thead>
</table>

\[
T \left( p_i, x p_e \right) P \\
T + p_i \rightarrow P + x p_e + Q
\]
Transmutation – Nuclear Reactor

\[ n = \text{neutron} \]
\[ p = \text{proton (H)} \]
\[ \beta^- = \text{beta particle} \]
\[ \beta^+ = \text{positron} \]
\[ \varepsilon = \text{electron capture} \]
Radiochemistry

Generators:
• Using chemical differences of parent and decay products to continue generation of desired isotope

Separations:
• Mass separation for isotopes
• Chemical differences of elements
  - Ion Exchange resins
  - Solvent Extraction
Harvesting
Cool Isotope Resources

http://www.periodicvideos.com/

Periodic Table Song

Animated Periodic Table Song
Navigating Nuclear Isotope-related Resources

- Measuring Radiation
- Planting the Seeds for a Better Future for Cancer Patients
- Realities of Radiation
- Radiopharmaceuticals
- Decoding Decay
- Exploring the Present and Future of Radioactive Decay
- Making Mosquitoes SIT!
Additional ANS K-12 Programs

- Educator Training
  - In-person and virtual professional development opportunities, such as webinars and workshops to gain confidence and teaching strategies
- Nuclear Ambassadors
  - ANS members specially trained in classroom interaction
- Pathways to Nuclear
  - Virtual and in-person events inspiring students to careers in nuclear science and technology
More sites to visit

- DOE Isotope R&D and Production
- Applied Nuclear Chemistry
- Quantum Information Science
- Microelectronics
- Nuclear Fusion
- ITER

- Electron-hole Pair in Semiconductors
- Review – Betavoltaic Cell: The Past, Present, and Future
- Photovoltaic effect
- Introduction to Transducers
- Radioisotope Power System
- Radioisotope Power video NASA DOE
- MMRTG Pull-apart Animation