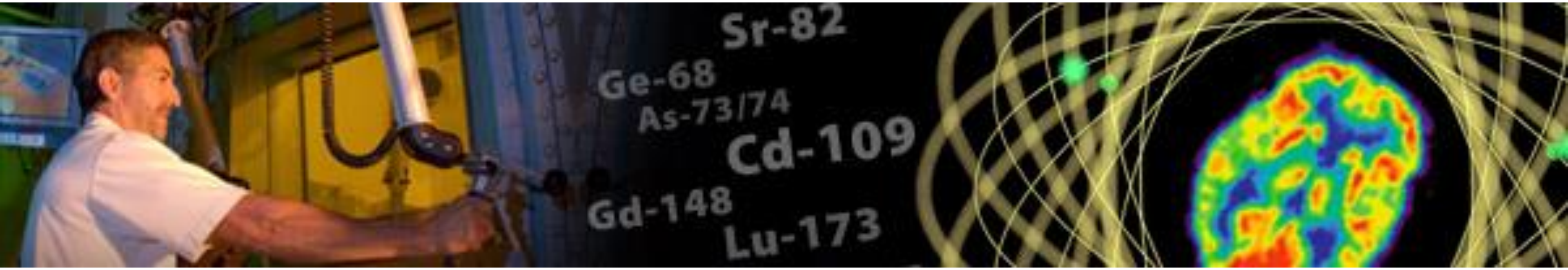
U.S. DEPARTMENT OF ENERGY

OFFICE OF SCIENCE

Radioisotope Power Source Isotope Selection



6th Workshop on Isotope Federal Supply and Demand
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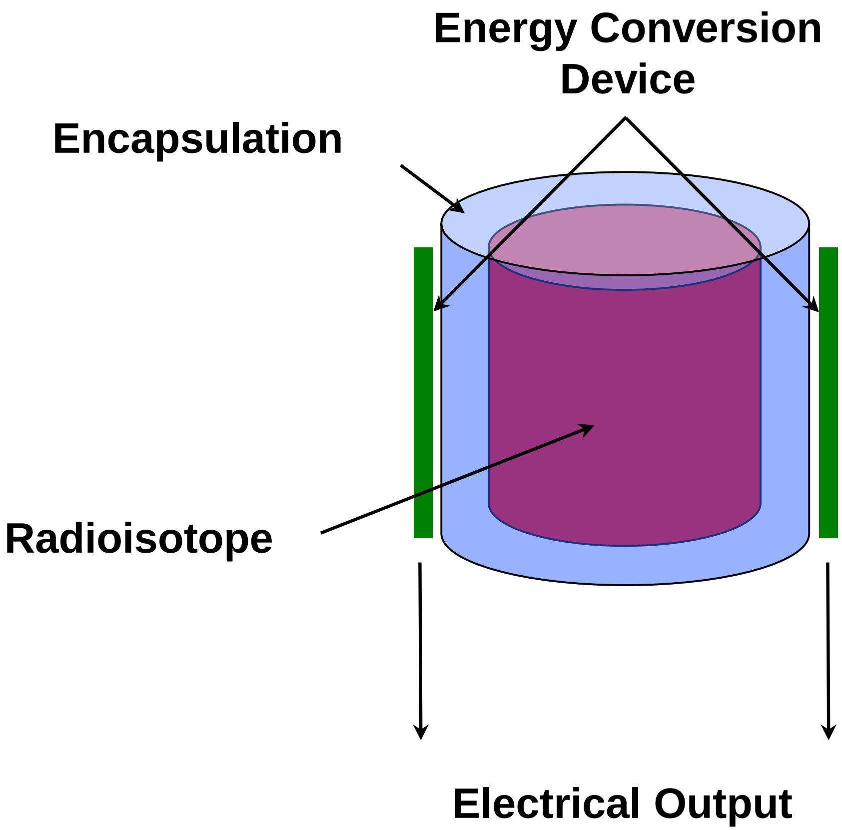
Office of Nuclear Physics, Office of Science, U.S. Department of Energy

What is a radioisotope power source?

Convert Energy from Radioactive Decay to Electricity

- Radioisotope
  - Energy of radioactive decay
  - Determines output of device (independent of load)
- Encapsulation
  - Containment and shielding for radioactive material
- Energy Conversion Device
  - Several commonly used methods to convert radiant energy to electricity
  - Can be coupled with energy storage device to minimize radioisotope requirements



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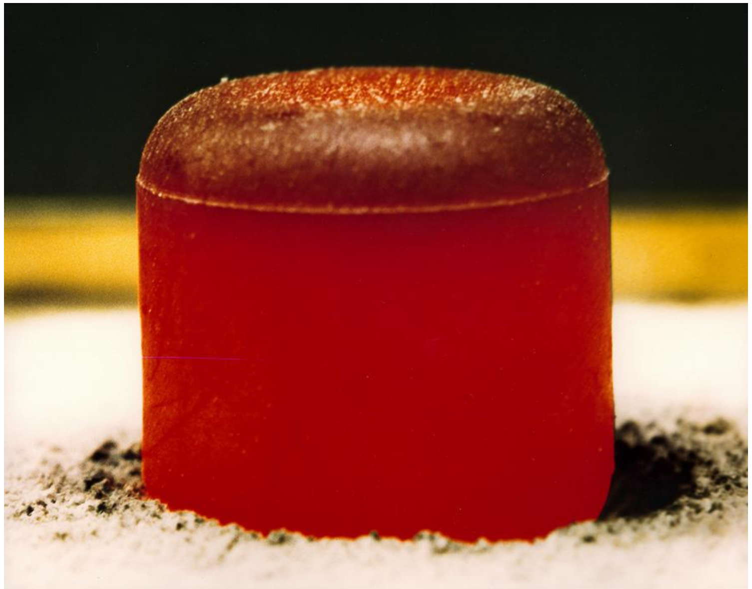
Benefits of radioisotope power sources: High energy density

	Energy Density (MJ/kg)
^{2}H-^{3}H fusion	337,000,000
^{235}U fission	88,250,000
^{238}Pu decay	2,230,000
LH_2*	143
Methane*	55.6
Gasoline*	46.4
Ethanol*	30
Coal*	14 – 19
Wood*	6
TNT	4.6
Li ion battery	0.5 – 2.7
H fuel cell	1.6
Flywheel	0.5
NiMh battery	0.22
NiCd battery	0.14 – 0.22
Lead acid battery	0.09 – 0.11
Ultra capacitor	0.02
Super capacitor	0.01
Capacitor	0.002
100 m dam	0.001



*excludes oxidizer

Benefits of radioisotope power sources: Long life

Nuclide	Half-Life (y)
^{210}Po	0.38
^{147}Pm	2.6
^{60}Co	5.3
^{3}H	12.3
^{90}Sr	28.8
^{238}Pu	87.7
^{63}Ni	101.2
^{241}Am	432.6

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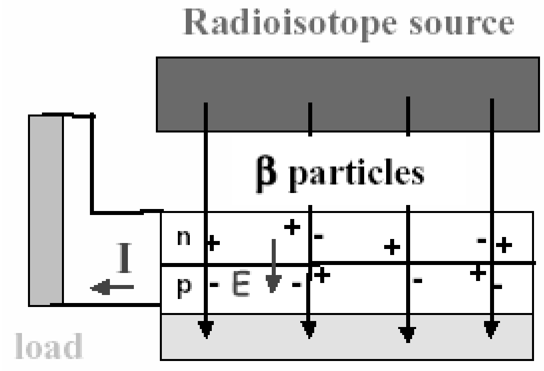
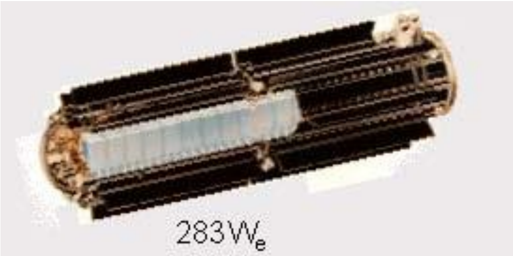
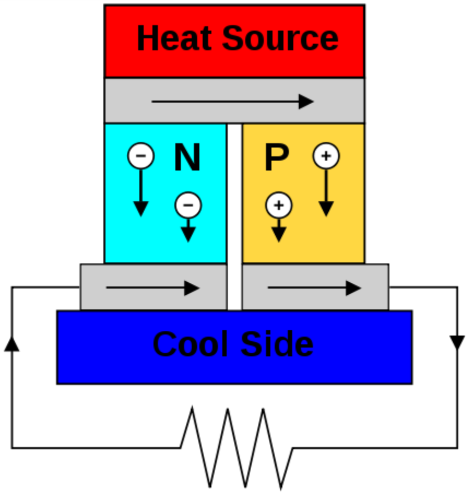
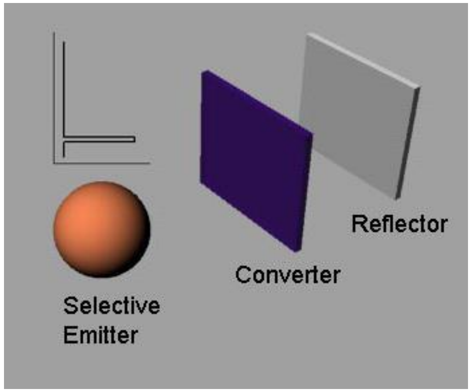
Examples of Radioisotope Power Conversion Methods

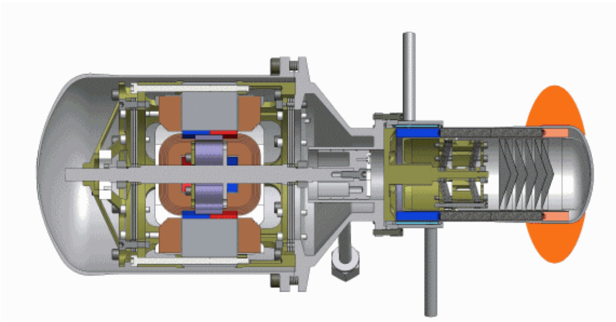
- Alpha/betavoltaic
  - Charged particles passing through a semiconductor create electron-hole pairs to produce electricity
- Thermal Electric
  - Seebeck Effect – Conversion of temperature differences to electricity
- Thermophotovoltaic
  - Radiant heat causes emitter to emit photons that are converted to electricity by a photovoltaic cell
- Mechanical
  - Stirling engine – Conversion of heat energy to mechanical work





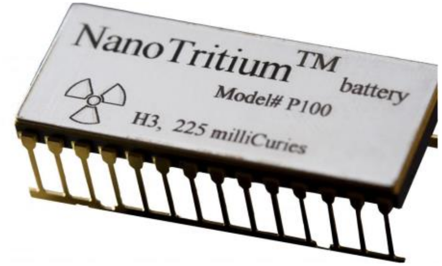






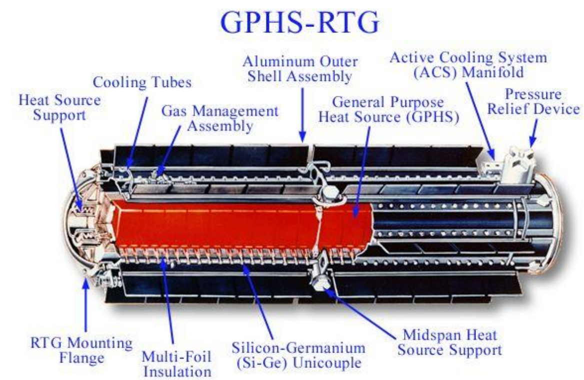
Examples of Radioisotope Power Sources Applications of Interest

- Remote sensors

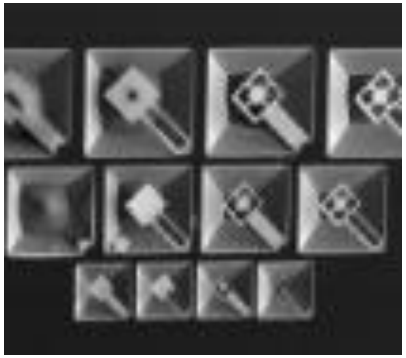


- Implantable medical devices

- Power for applications where logistics of battery replacement are difficult



- Microscale devices



Isotope Selection Considerations

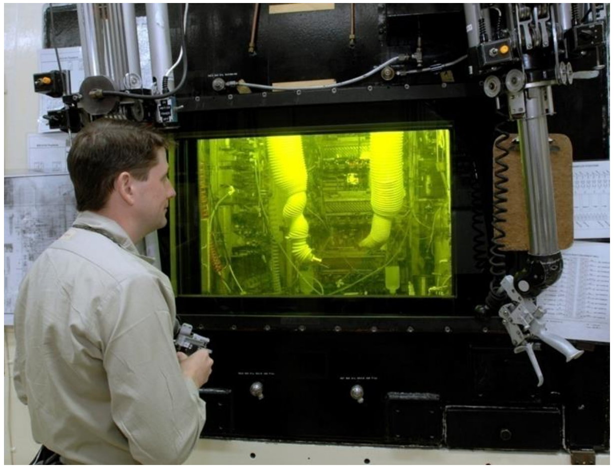
Design Requirement	Isotope/System Considerations
Mission Duration	Half-life
Power Requirement Continuous or Intermittent	Power/Energy Density Combine with Energy Storage
Size	Power/Energy Density
Radiation Dose	Decay Emissions/Shielding
Application/Use of Power Source	Licensing of Facilities/Possession Nuclear Regulatory Commission Transportation Dept. of Transportation Disposal Nuclear Regulatory Commission

POLITICS AND TERRORISM

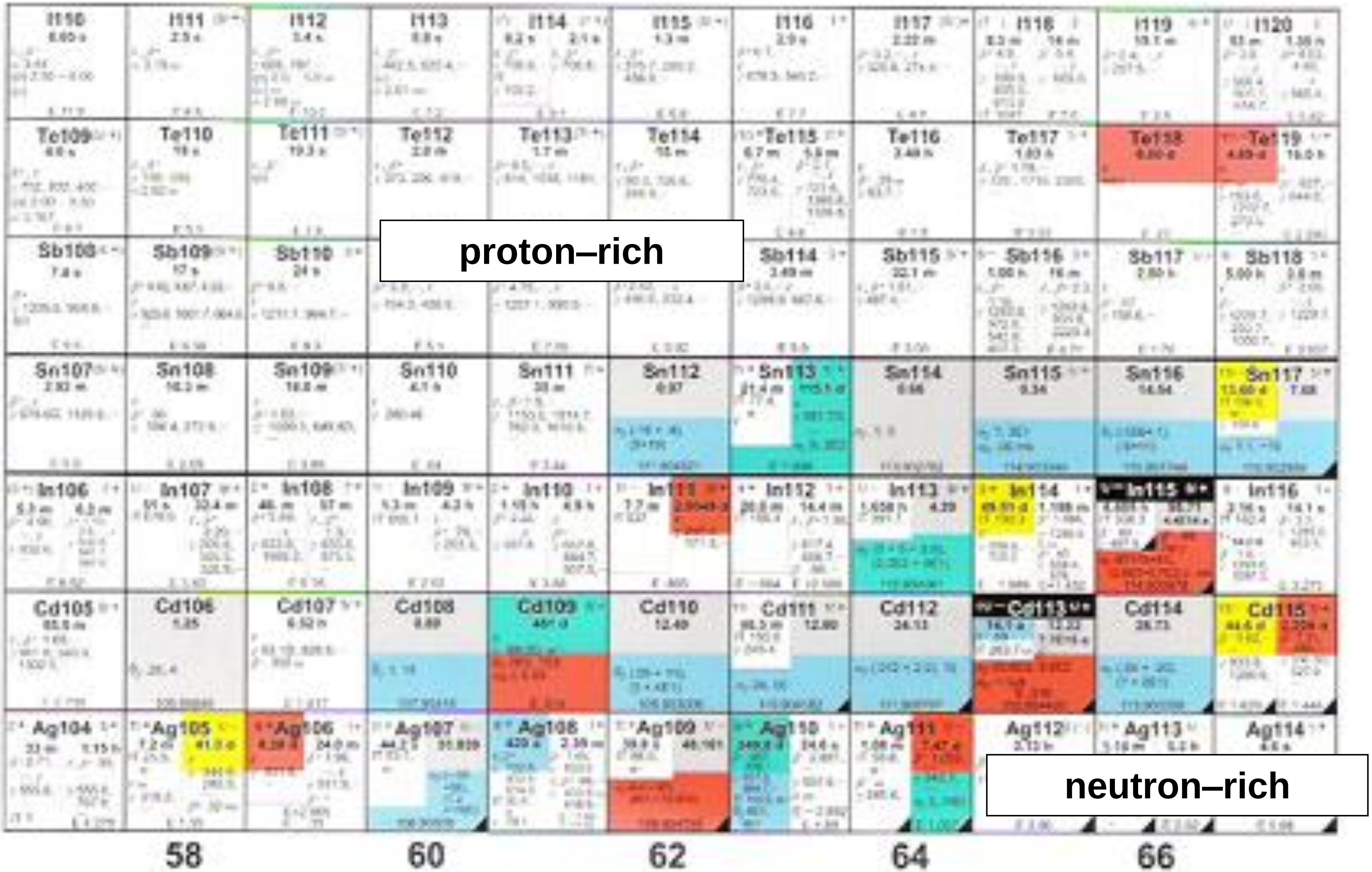
Isotope Production Cost Drivers and Availability

Isotopes are not cheap!

- Reactor and Accelerator Production
  - Target Material
  - Target Fabrication
  - Target Irradiation
  - Target Processing/Isotope Purification
  - Waste Disposal
- Legacy Isotopes
  - Long-lived Isotopes Available from Historic Production
    - E.g., strontium-90
  - Fission Products from Reactor Fuel Reprocessing
    - Fuel reprocessing not performed in the United States
    - “Piggy-back” on nuclear waste disposal



Isotope Selection



Isotope Decay Energy/Power

		Half-Life (y)	Half-Life (s)	Activity (Bq/g)	Specific Activity (Ci/g)	Particle Energy (MeV)	Intensity	Energy Release (MeV/dis.)	Power Density (W/g)	Material Required (Ci/W)	
Ni	63	100.1	3.16E+09	2.10E+12	57	0.01743	1	0.017425	0.006	9682	β
Co	60	5.27	1.66E+08	4.18E+13	1131	0.09577	0.9988	0.09565508	0.64		β
	60	5.27	1.66E+08	4.18E+13	1131	0.6259	0.0012	0.00075108	0.01		β
	60	5.27	1.66E+08	4.18E+13	1131	1.173	0.9985	1.1712405	7.85		γ
	60	5.27	1.66E+08	4.18E+13	1131	1.332	0.9998	1.3317336	8.92		γ
	60	5.27	1.66E+08	4.18E+13	1131				17.42	65	

DOE Isotope Program Initiatives for Isotopes of Interest for Power Sources

- Strontium-90
  - Legacy material from plutonium production at Hanford
  - Hundreds of Ci available
  - Possible availability of MCi quantities
  - >30 years old (specific activity ~25 Ci/g)
- Nickel-63
  - DOE produces hundreds of Ci per year at high specific activity (>13 Ci/g)
- Americium-241
  - DOE re-established production from plutonium wastes
  - Gram quantities can be available for research
  - Large quantities can be available from industrial consortium established by DOE
- Plutonium-238
  - Small quantities available for research
  - DOE production being established by funding from NASA (managed by DOE-NE)
  - Additional production would require significant investment

DOE Isotope Program Initiatives for Isotopes of Interest for Power Sources

- Cobalt-60
  - DOE produces kCi quantities of high specific activity Co-60 (>250 Ci/g)
  - Available from DOE customers that buy and process irradiated targets
- Promethium-147
  - Currently available as fission product from fuel reprocessing in Russia
    - Contains Pm-146 and Pm-148m which can be problematic radiologically
  - DOE developing reactor production using neodymium-146 target
    - Much lower (or no) Pm-146 and Pm-148m content
    - Much more expensive
- Commercially available isotopes
  - H-3 (tritium)
  - Polonium-210

Next Steps for Isotope Selection for Power Sources

- Power source developers involve people knowledgeable in isotope characteristics and utilization
- Submit requests for desired isotopes through the DOE Isotope Program catalog at www.isotopes.gov
- Sign up for the DOE Isotope Program mailing list at www.isotopes.gov to receive notices of isotope availability and isotope production initiatives
- Workshop to bring together power source developers, isotope producers, and regulatory agencies to inform decisions on isotopes appropriate for power sources