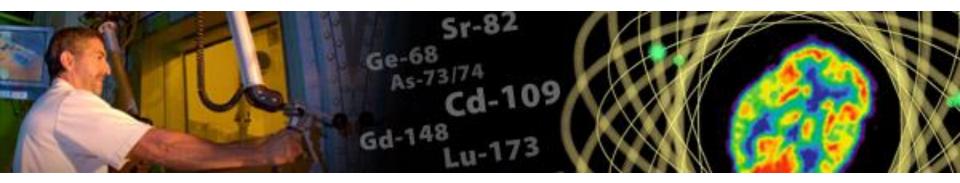




Radioisotope Power Source Isotope Selection



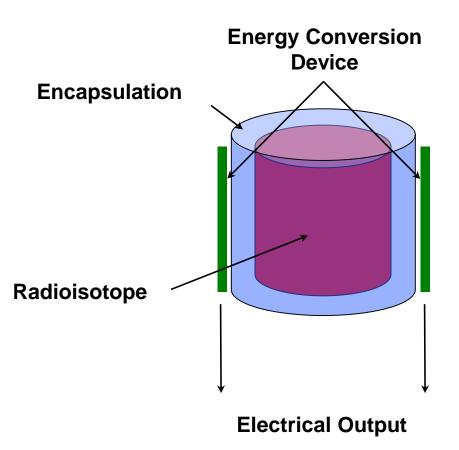
6th Workshop on Isotope Federal Supply and Demand November 15, 2018

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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





Office of 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

Science



*excludes oxidizer



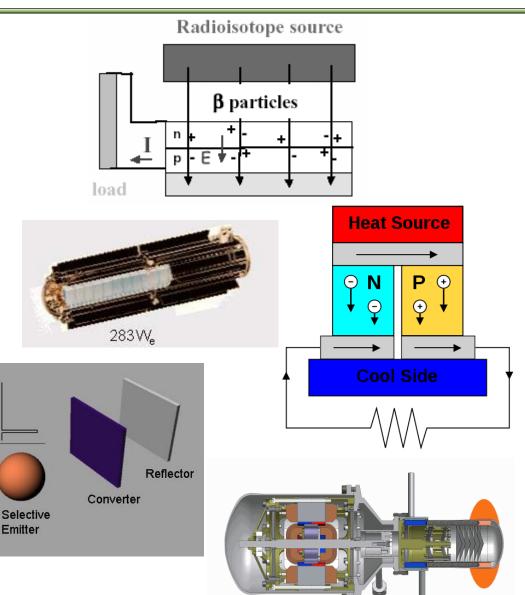
Office of Benefits of radioisotope power sources: Science Long life

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



f 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

battery

Nano TritiumTM

H3, 225 milliCuries

Model# P100

Support

RTG Mounting

Flange

Multi-Foil

Insulation

- Remote sensors
- Implantable medical devices
- Power for applications where logistics of battery replacement are difficult

GPHS-RTG Active Cooling System Aluminum Outer (ACS) Manifold Shell Assembly **Cooling Tubes** Pressure Heat Source General Purpose Gas Managemen **Relief** Device Heat Source (GPHS Assembly

Silicon-Germanium

(Si-Ge) Unicouple

Midspan Heat

Source Support

Microscale devices





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

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		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		<u> </u>
	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



- 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



- Power source developers involve people knowledgeable in isotope characteristics and utilization
- Submit requests for desired isotopes through the DOE Isotope Program catalog at <u>www.isotopes.gov</u>
- Sign up for the DOE Isotope Program mailing list at <u>www.isotopes.gov</u> 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