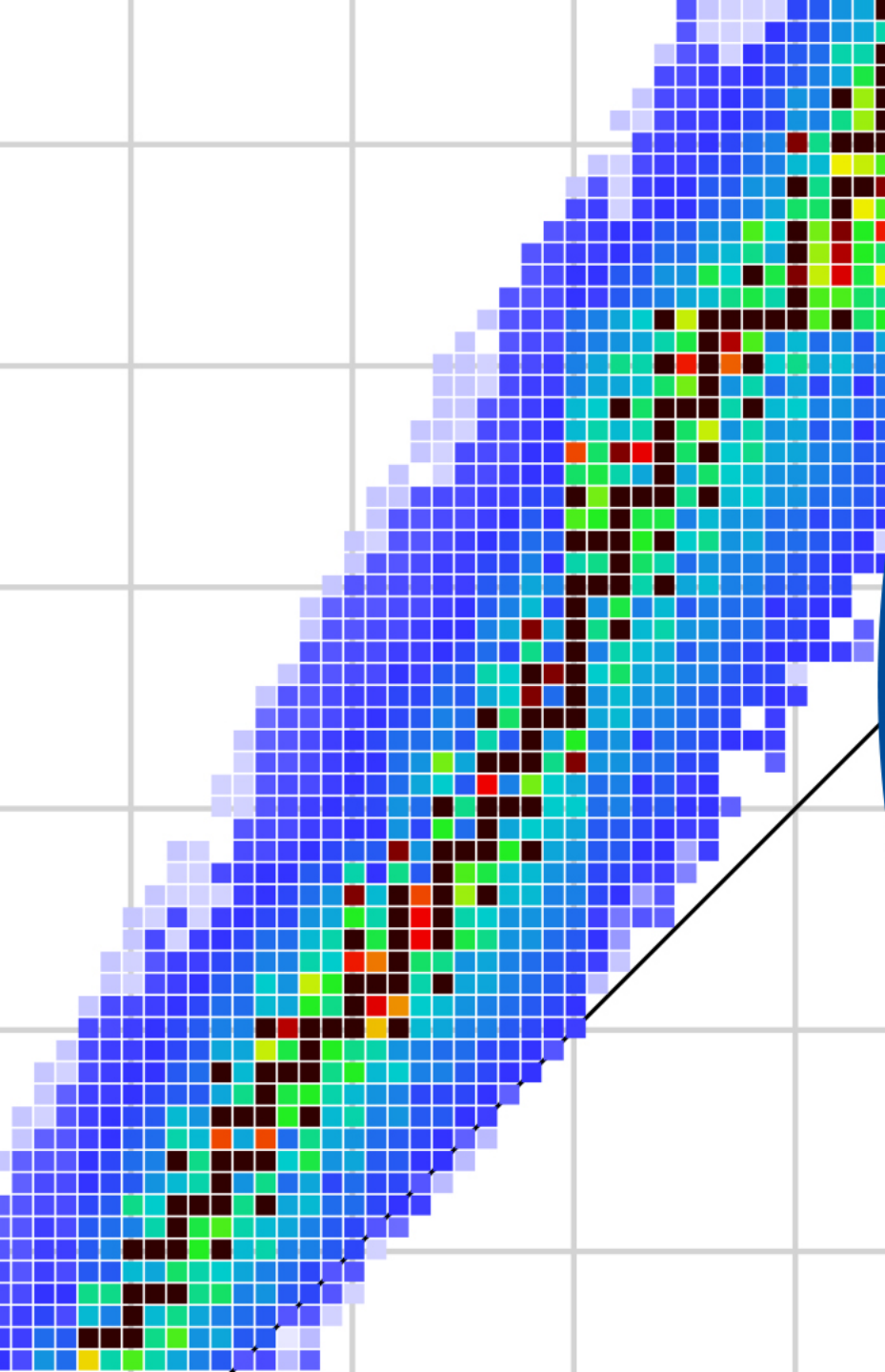


ANS® EDUCATOR TRAINING

Radioisotopes: Nuclear Applications Beyond Energy

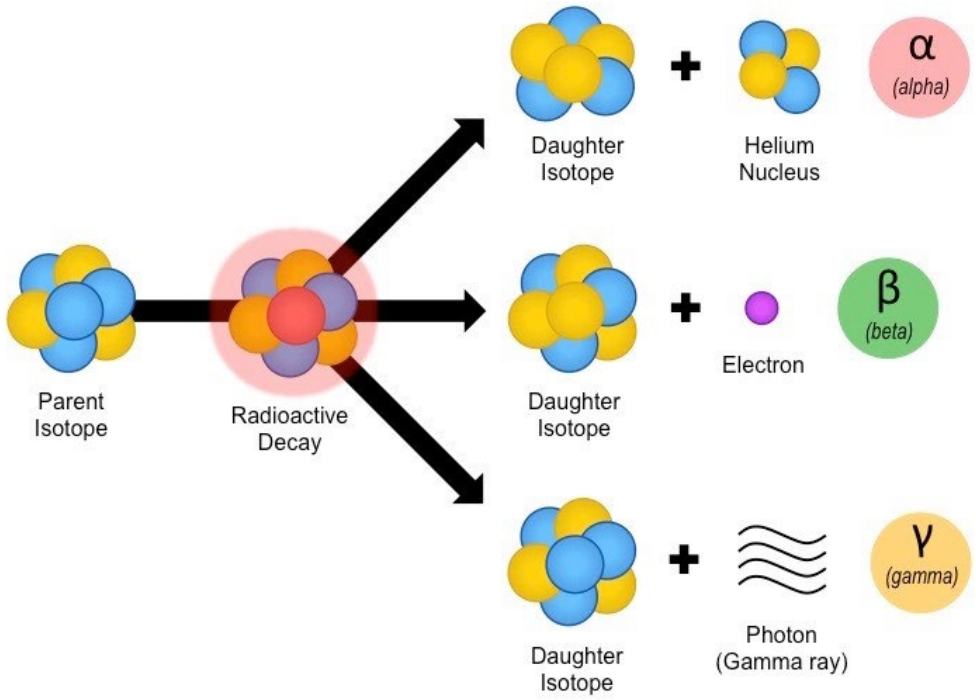
Thursday, October 19

This event is presented by ANS in partnership with the Department of Energy, Office of Nuclear Energy.

Isotopes-what are they good for?

Julie Ezold, Technical Advisor
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

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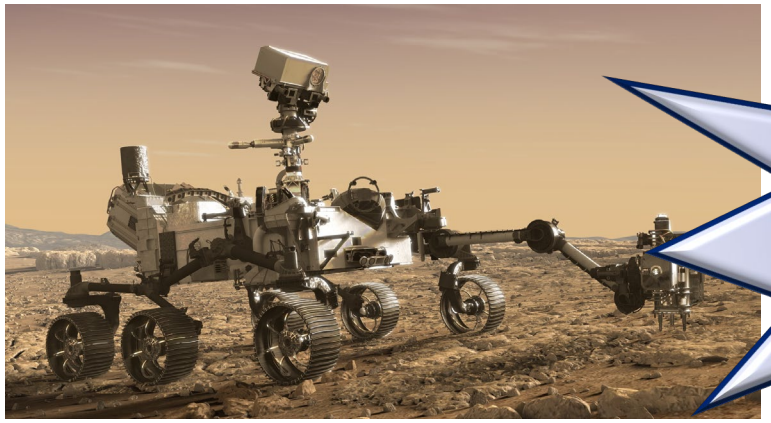
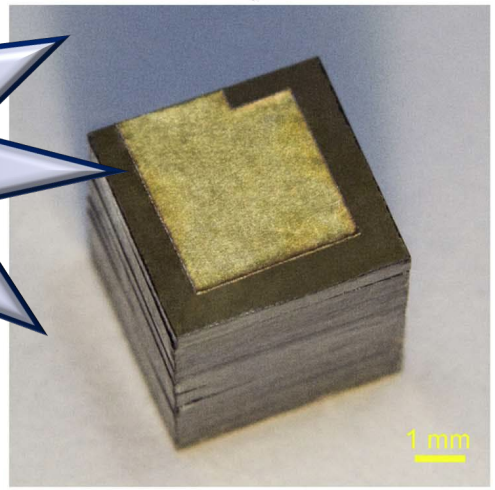


Nuclear batteries

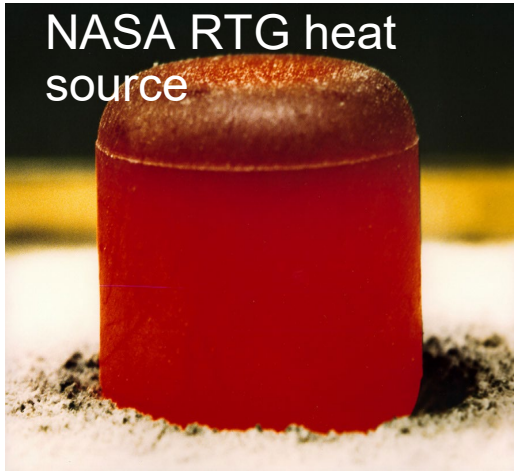
Betavoltaics

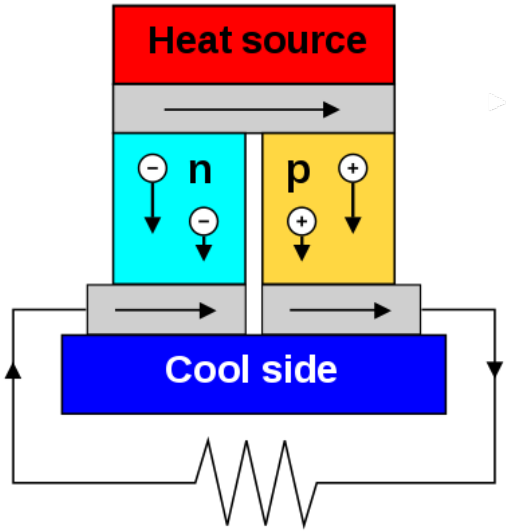


Beta particle source

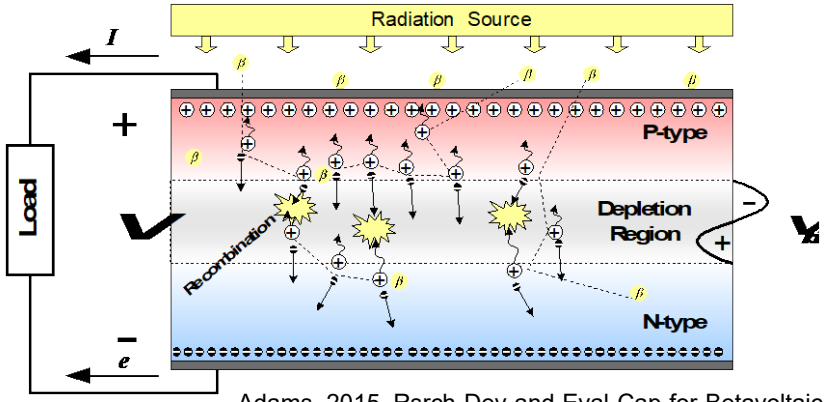
Beta-Photovoltaics

BPVs





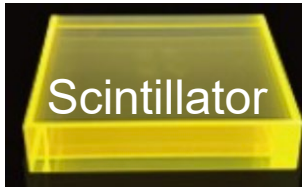
Thermoelectric Transducer



Adams_2015_Rsrch-Dev-and-Eval-Cap-for-Betavoltaic-Pwr-Sources_ ASEE#13983

Semiconductor Transducer

Radio-isotope



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Isotope	Decay	Type	Example size battery
Pu-238	α	RTG	10 W
Am-241	α	RTG	10 W
Sr-90	β	RTG	10 W
Ac-227	α	RTG	10 W
Pm-147	β	BV/BPV	10 mW
Eu-155		BV	3 mW
Ni-63	β	BV	1 mW
H-3	B	BV	100 µW

Sr-90 Example:

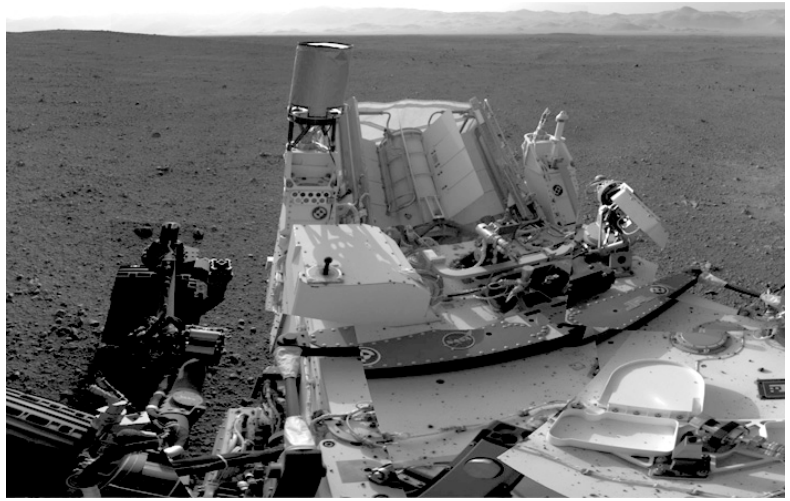
1.13 E 6 eV/decay
1 Ci = 3.7 E 10 decays/sec
1 J = 6.24 E18 eV
1 W = 1J/s

∴149 Ci Sr-90 for 1 W_{th} energy

For 5% efficient RTG:
2,987 Ci Sr90/W_e

NB Type	Energy Source	Transducer	Power Level	Application	Usage
RTG	α, β → Thermal ΔT	TE semiconductors	1-100's W	• Mini-satellites • Maritime Sensing • UAV • Deep earth	High
BV	β → e-h pairs	Voltaic semiconductors	1-1000µW	• Remote wireless sensors • Medical	Low
BPV	β → photons	Luminescent + PV	0.1-10mW	• Hybrid NB-CB systems • Remote wireless sensors	Low

Abbreviation	Definition
RTG	Radioisotope Thermoelectric Generator
BV	Beta Voltaic
BPV	Beta Photo Voltaic
eV	Electron Volt
Ci	Curie
J	Joule
W	Watt

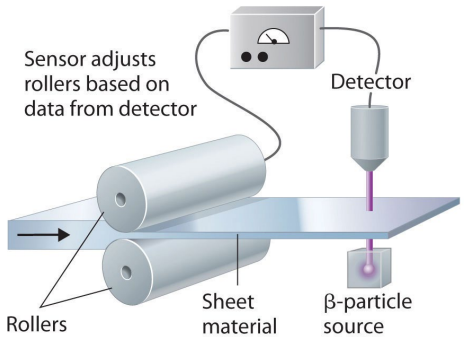


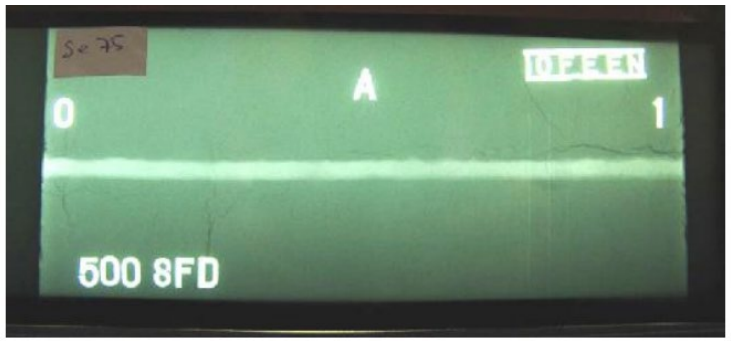
The Mars Science Laboratory rover, Curiosity, took this self portrait, which shows its Radioisotope Thermoelectric Generator (RTG) at center.

Power Sources For Space, underwater

Radioactive Power Sources

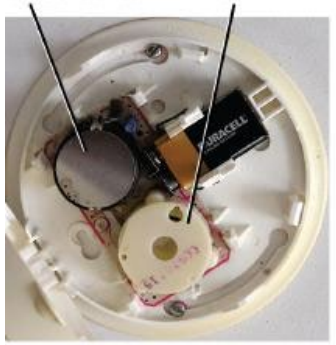
- Radioisotope Thermoelectric Generator
- Multi-Mission Radioisotope Thermoelectric Generator

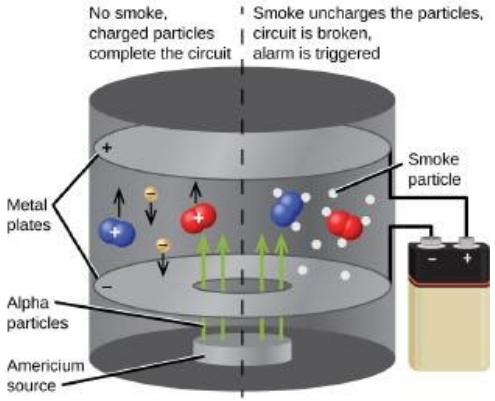


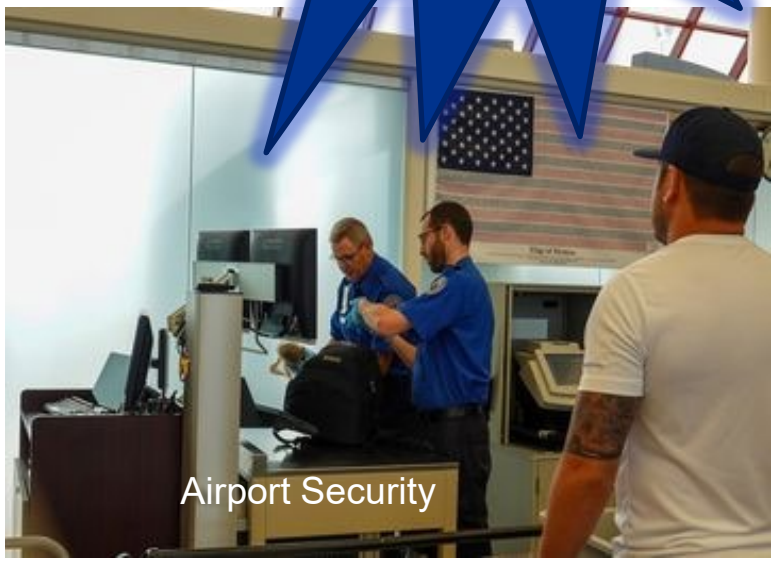


Gamma radiography (Se-75 and Ir-192)

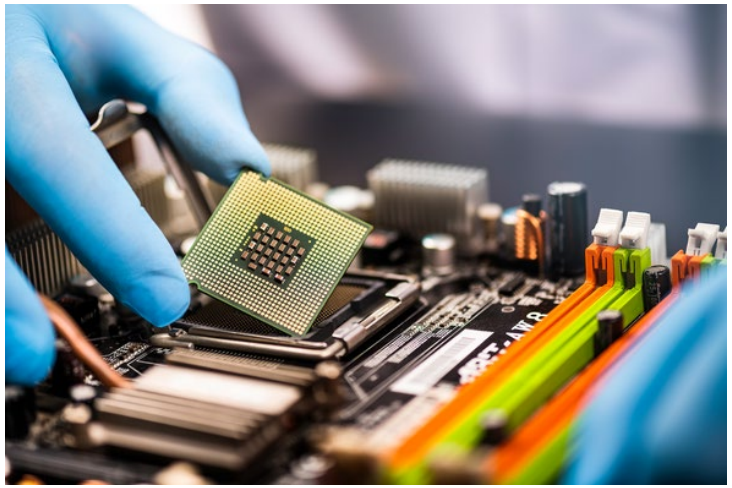
Industrial Applications







Pest Control



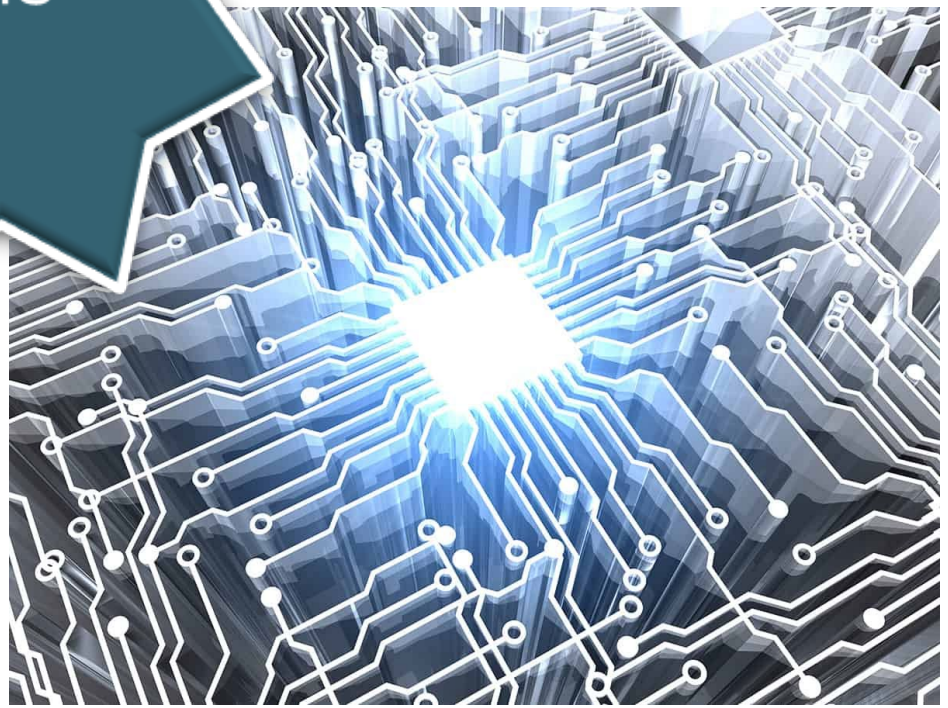
Si-28 for improved heat conduction on computer chips

Betavoltaic power sources for microelectronics

Semi-conductor manufacturing, microelectronics

QIS

Quantum Information System



Isotopically pure isotopes of Si and Ge for quantum dot devices

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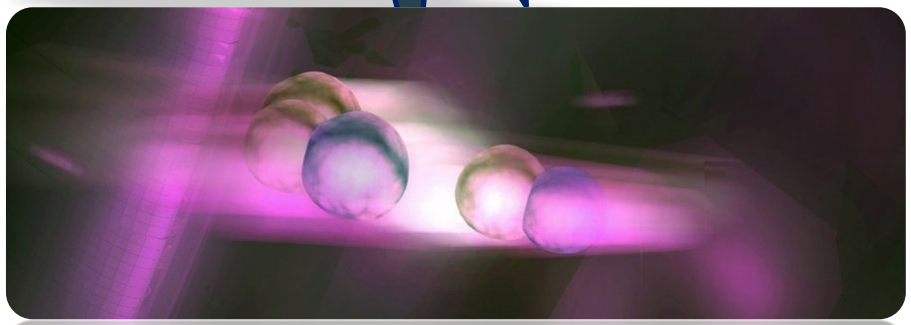
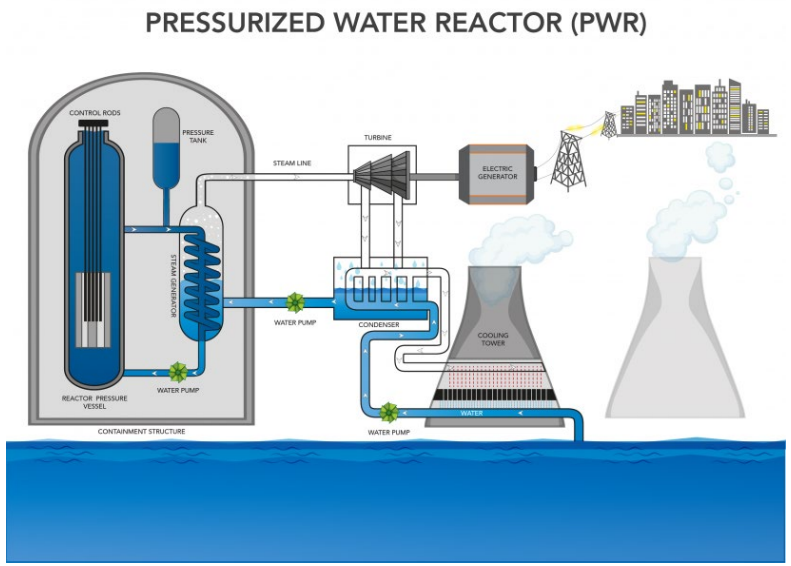
Fusion Reactor



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

Fission Reactor

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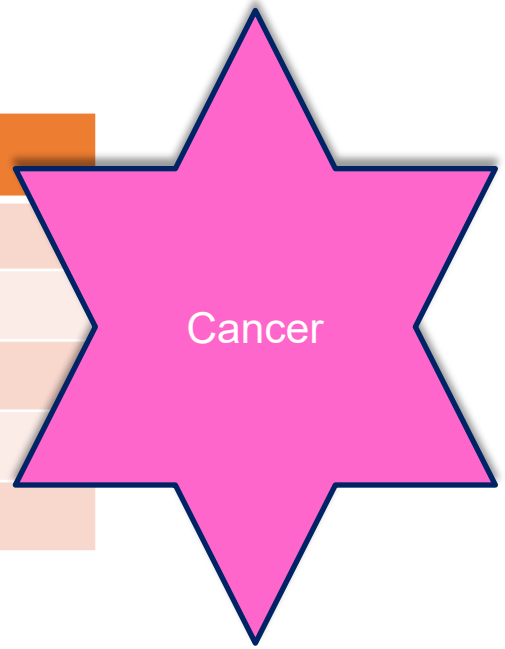
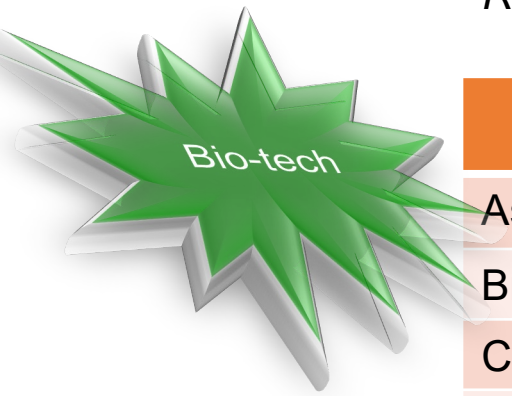
Available Medical Isotopes					
Ac-225 /Bi-213	Co-55	Mn-52g	Rb-83	Sr-90/Y-90	Y-86
Ac-227	Co-60 HSA	Pb-212 /Bi-212	Se-72	Th-227	Y-88
As-73	Fe-52	Pm-147	Sn-177m	Th-228/ Ra-224	Zn-65
At-211	He-3	Ra-223	Sr-85	V-48	
Au-199	Lu-177 c.a.	Ra-226	Sr-89	W-188/Re-188	



*Radio-isotopes in **blue** available soon.*



Under development					
As-72 /Se-72	**Ce-134**	Mn-54	Pt-191,193m/195m	Sc-43, Sc-44	**Ti-44/Sc-44**
Br-76, Br-77	Co-57	Nb-90	**Ra-226**	Sc-47	Tm-170
C-14	**Cu-67**	Pb-203	Re-186 /189	Tb-161	U-230/Th226
Cd-109	Fe-59	Pb-205 /Pb-202	Ru-106	Te-119m	
Ce-139	Lu-177 (nca)	Pd-103	**Sb-119**	Th-229	

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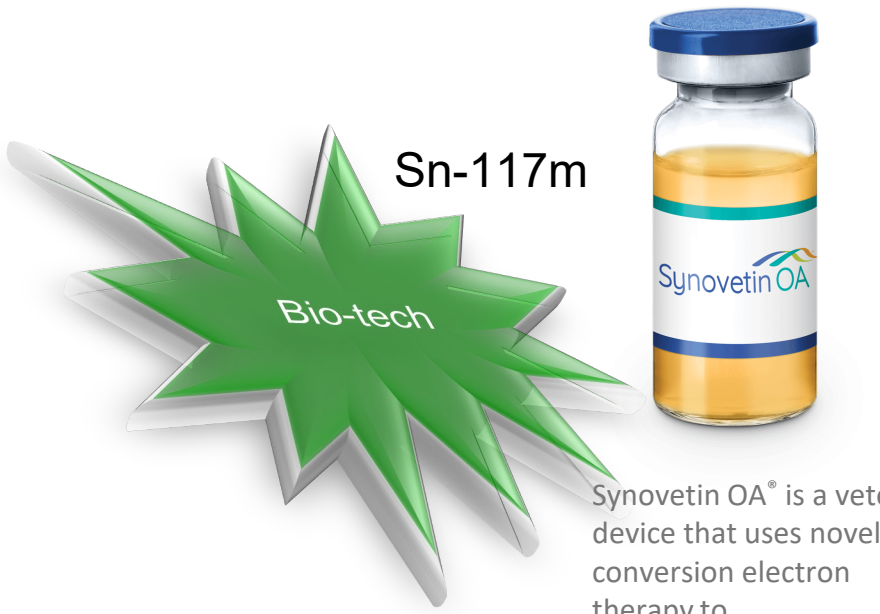
Theranostics = diagnostics + treatment

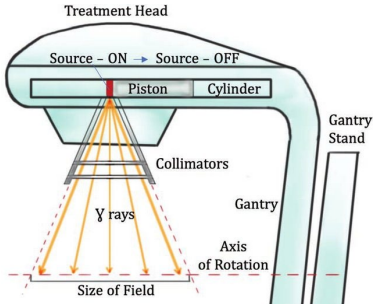
- Isotopes that aid in diagnostic imaging include Ga-68, Y-86, Sr-82, Cd-109, Fe-52, Se-72, Te-123m, and Xe-129

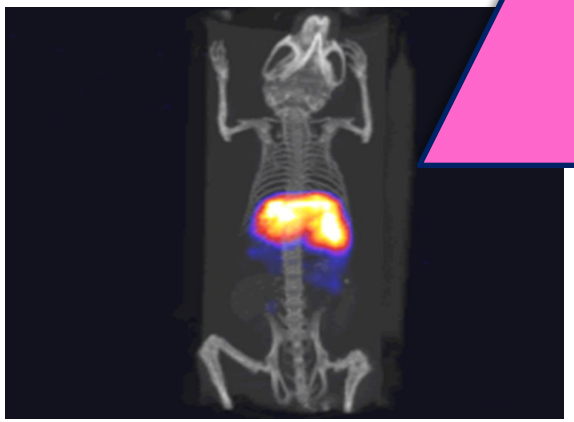


Synovetin OA® is a veterinary device that uses novel, conversion electron therapy to target macrophages and synoviocytes in the injected joint.

Co-60:

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





Cancer

Diagnostic demonstration of Cu-67 in living mice, in collaboration with University of Alabama-Birmingham

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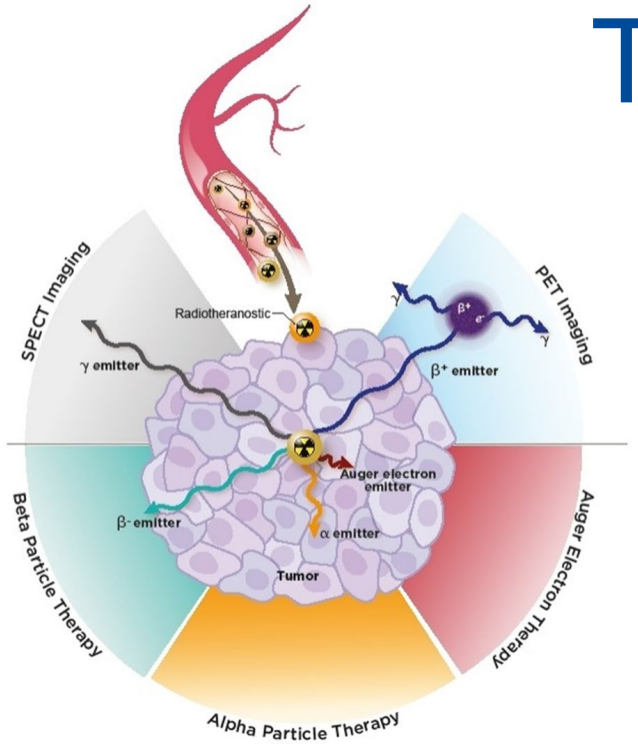
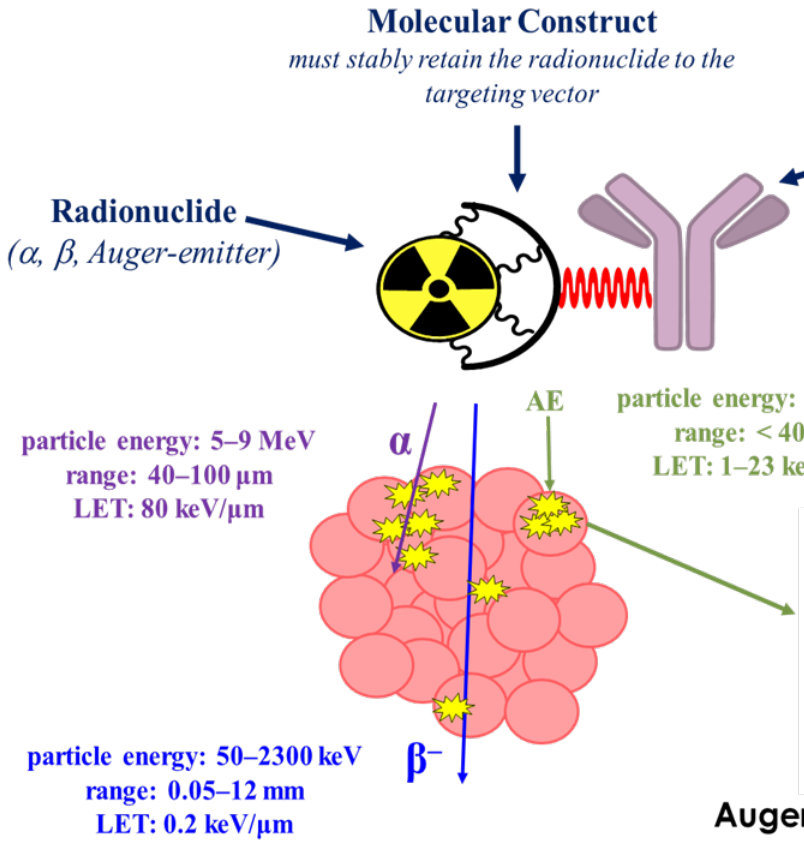
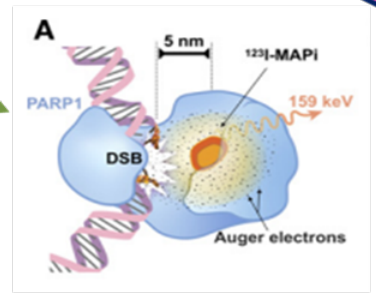
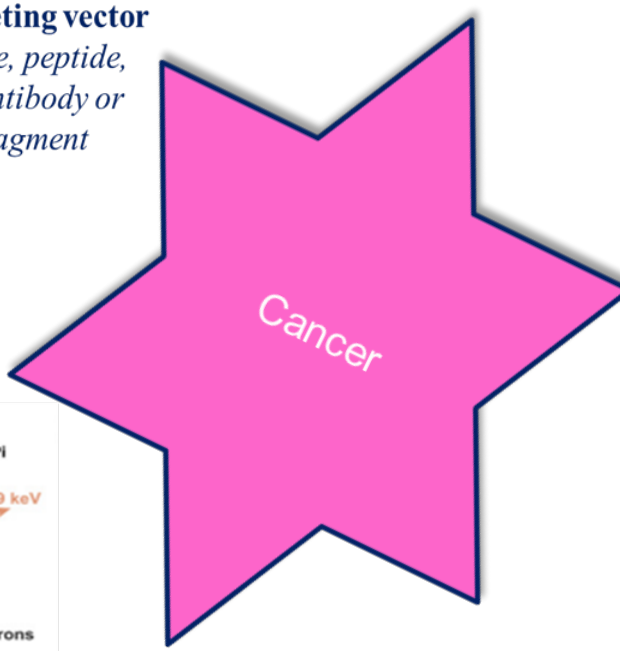
Targeted Radiotherapy









Auger emitters act inside the cell

CLINICAL CANCER RESEARCH | PRECISION MEDICINE AND IMAGING Targeted Brain Tumor Radiotherapy Using an Auger Emitter A C Giacomo Pirovano, Stephen A. Jannetti, Lukas M. Carter, Ahmad Sadique, Susanne Kossatz, Navjot Guru, Paula Demetrio De Souza Fran ca¸ Masatomo Maeda, Brian M. Zeglis, Jason S. Lewis, John L. Humm, and Thomas Reiner

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7299758/

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Alpha and beta emitters approved by the world regulatory bodies (FDA, EMA, etc.)

All (β-emitters)

Established Radioisotopes for therapy (all beta emitters)

I-131 thyroid cancer

Y-90 SIR-Spheres®, Liver cancer

Y-90, non-Hodgkins lymphoma (ZEVALIN®, ibritumomab tiuxetan)

Sr-89, bone palliation (METASTRON™, Strontium-89 Chloride injection)

Ho-166, Liver cancer (QuiremSpheres® - Microspheres)

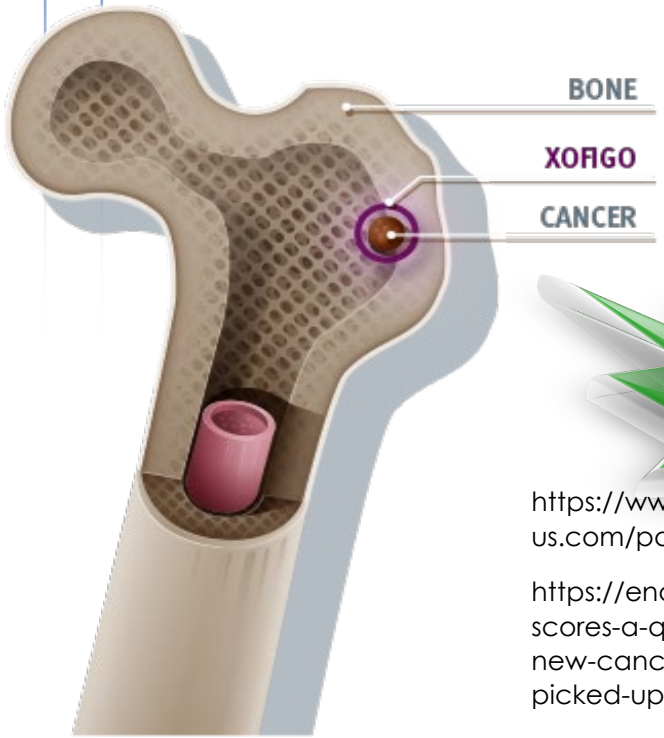
Lu-177 (β-emitter)

January 26, 2018 *Lutathera*® (Lutetium **Lu-177**, dotatate) **approved by the FDA**

Cancer

Ra-223 (α-emitter)

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



Bio-tech

https://www.xofigo-us.com/patient

https://endpts.com/novartis-scores-a-quick-fda-ok-for-its-new-cancer-drug-lutathera-picked-up-in-4b-buyout/

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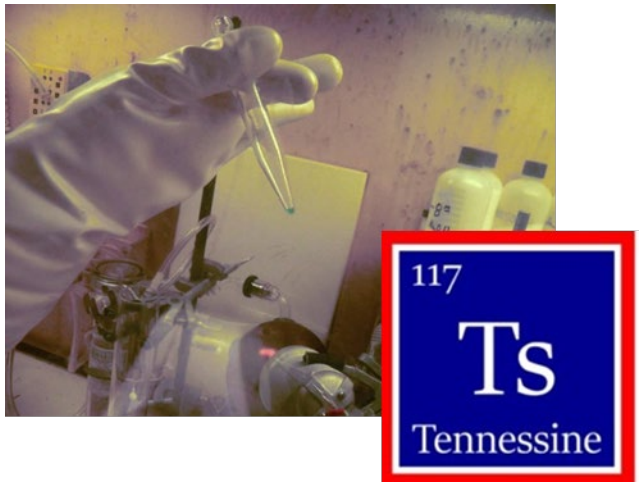
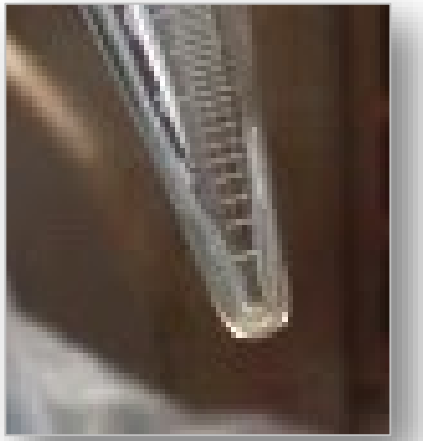
New Elements



Archeology

Nuclear Physics

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



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

^{244}Pu, 15 mg >99% reaction
mechanism studies

Discovery
Research

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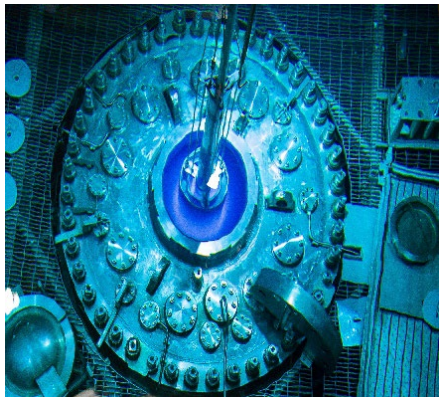
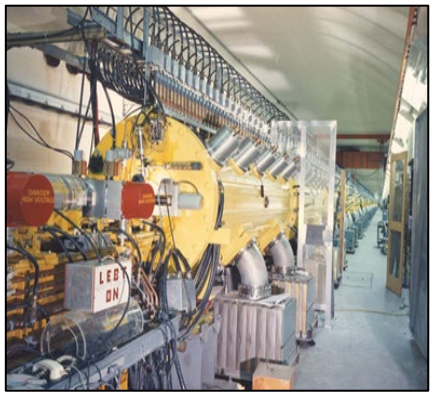
If not found in nature, then what?

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



Reactors



Cyclotrons/
Accelerators

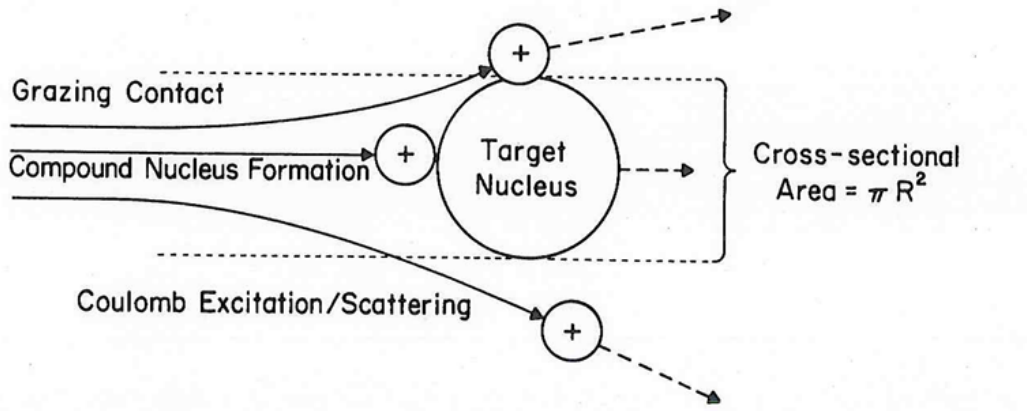
Generators

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

	α,3n	α,2n ^{3}He, n	α, n	
p,2n	p,n	d,n ^{3}He, np	t,n α,np ^{3}He,p	
	p,pn n,2n	**Original Nucleus Z,N**	d,p n,γ t,np	t,p
p,α	n,t d,α n,nd	n,np p,2p n,d	n,p t,^{3}He	
	n,α n,n^{3}He	n,^{3}He n,pd		

n = neutron
p = proton (H)
d = deuteron (^{2}H; [pn])
t = triton (^{3}H); [p2n]
^{3}He = [2pn]
α= alpha particle (^{4}He); [2p2n]

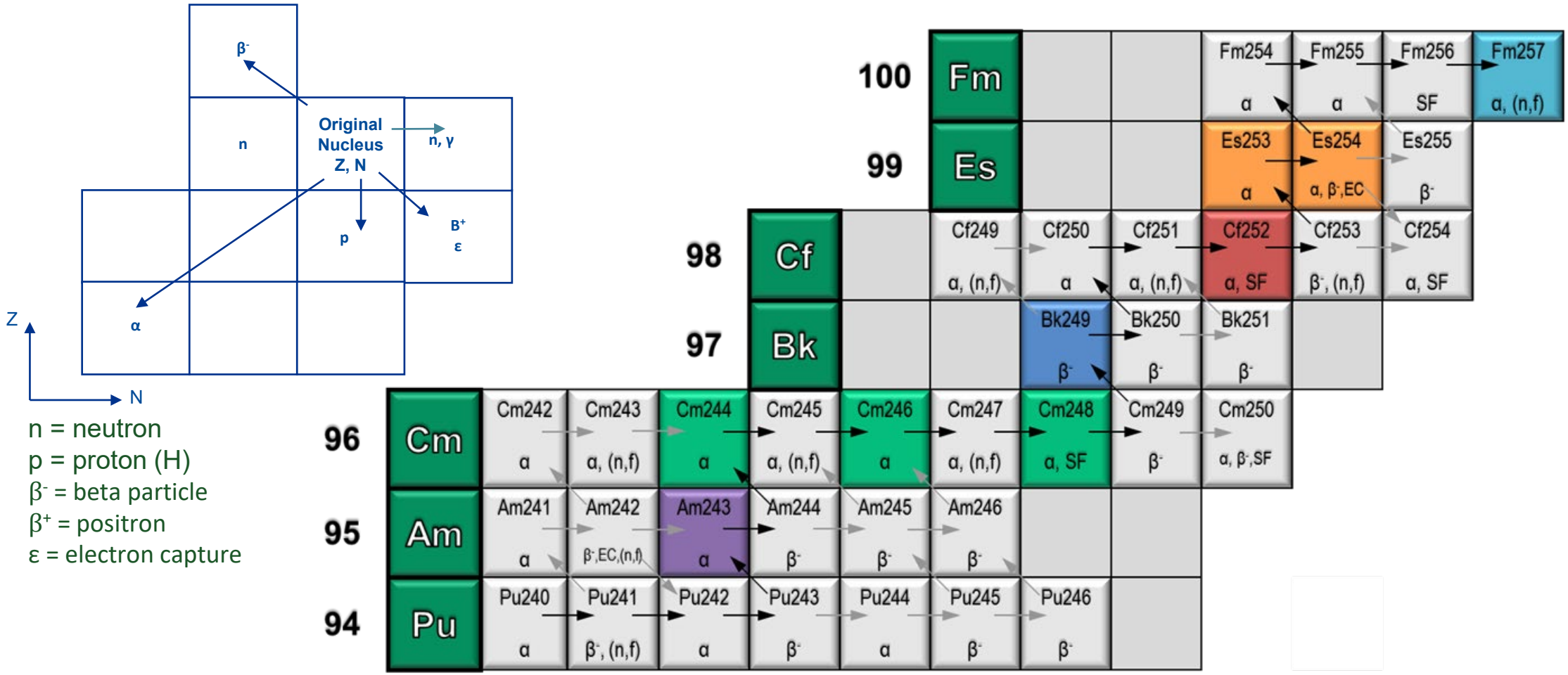


target nucleus (incident particle, exit particle(s)) product nucleus

$$T\ (p_i\ ,\ x\ p_e)\ P$$

$$T + p_i \rightarrow P + x\ p_e + Q$$

Transmutation – Nuclear Reactor



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Radiochemistry

Generators:

- Using chemical differences of parent and decay products to continue generation of desired isotope

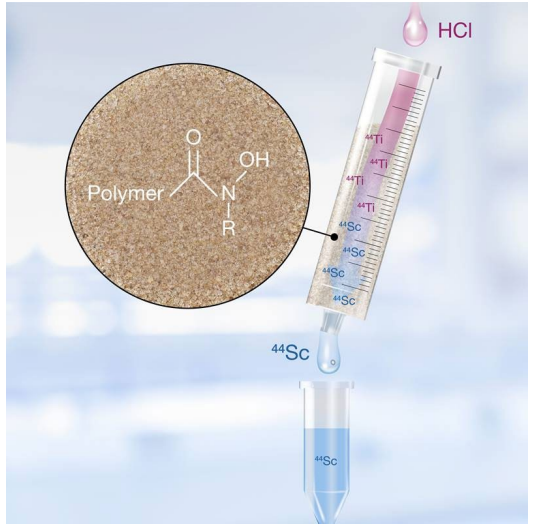


Image courtesy of Brookhaven National Laboratory

Separations:

- Mass separation for isotopes
- Chemical differences of elements
  - Ion Exchange resins
  - Solvent Extraction

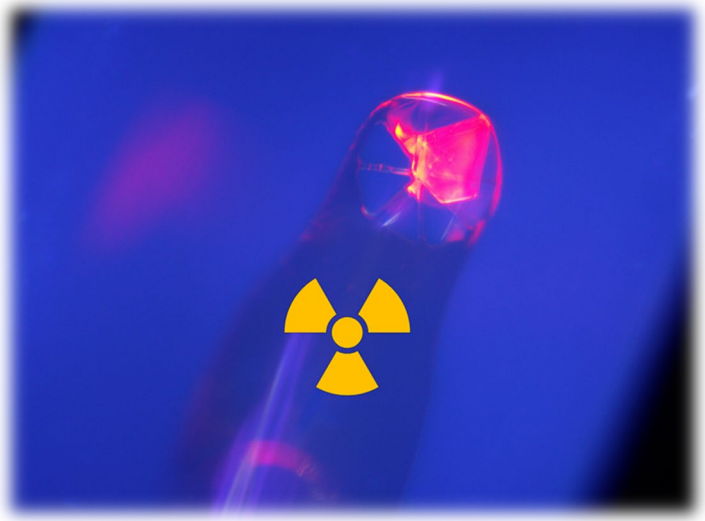
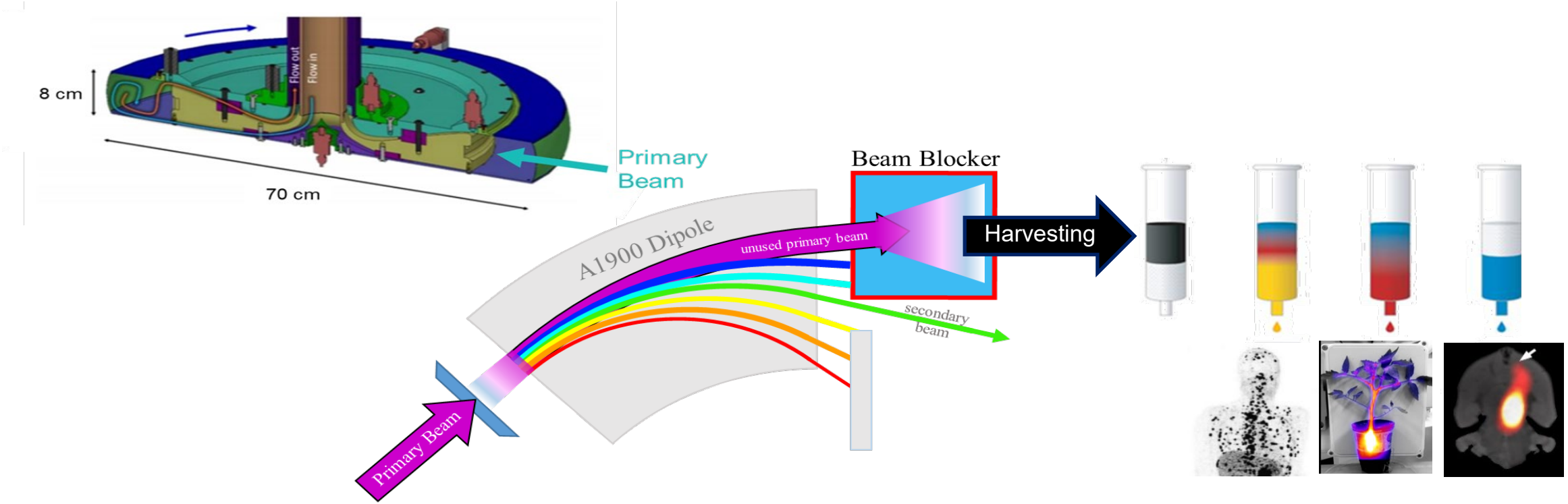
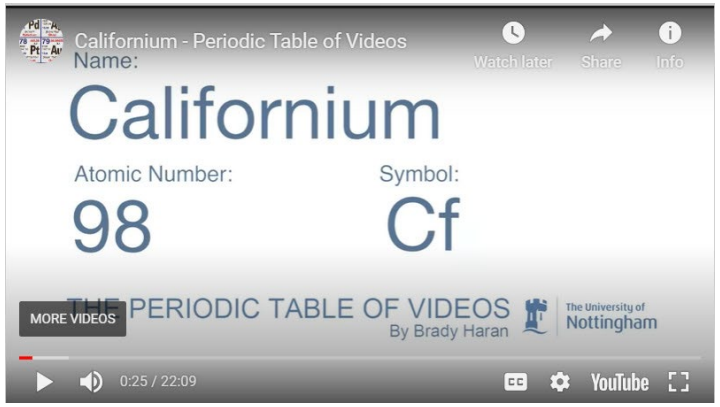


Image courtesy of Gauthier Deblonde, Lawrence Livermore National Laboratory

Harvesting

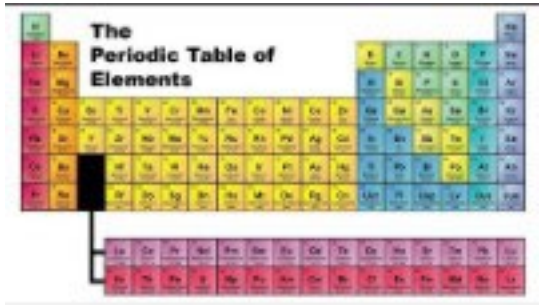

8 cm
Flow out
Flow in
70 cm
Primary Beam
Beam Blocker
A1900 Dipole
unused primary beam
secondary beam
Primary Beam
Harvesting

Cool Isotope Resources



http://www.periodicvideos.com/

Periodic Table Song



Animated Periodic Table Song

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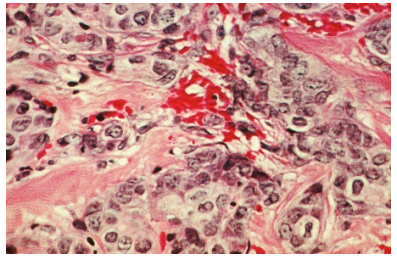
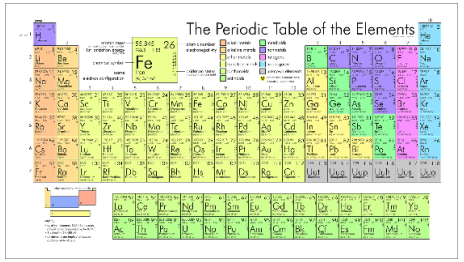
Navigating Nuclear Isotope-related Resources

Measuring Radiation



Planting the Seeds
for a Better Future for
Cancer Patients

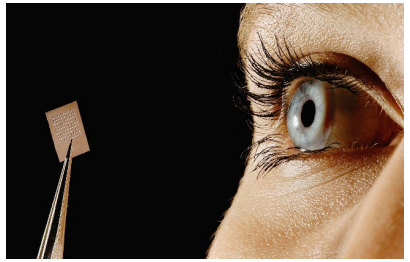
Realities of Radiation



Decoding Decay

Radiopharmaceuticals

Decay Detectives:
Art Forgery or Masterpiece?



Exploring the Present
and Future of
Radioactive Decay

Making Mosquitoes SIT!

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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

ANS®

More sites to visit

DOE Isotope R&D and Production

Applied Nuclear Chemistry

Quantum Information Science

Electron-hole Pair in Semiconductors

Microelectronics

Review – Betavoltaic Cell: The Past, Present, and Future

Photovoltaic effect

Nuclear Fusion

Introduction to Transducers

ITER

Radioisotope Power System

Radioisotope Power video NASA DOE

MMRTG Pull-apart Animation