Applications of Radiation

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with special thanks to

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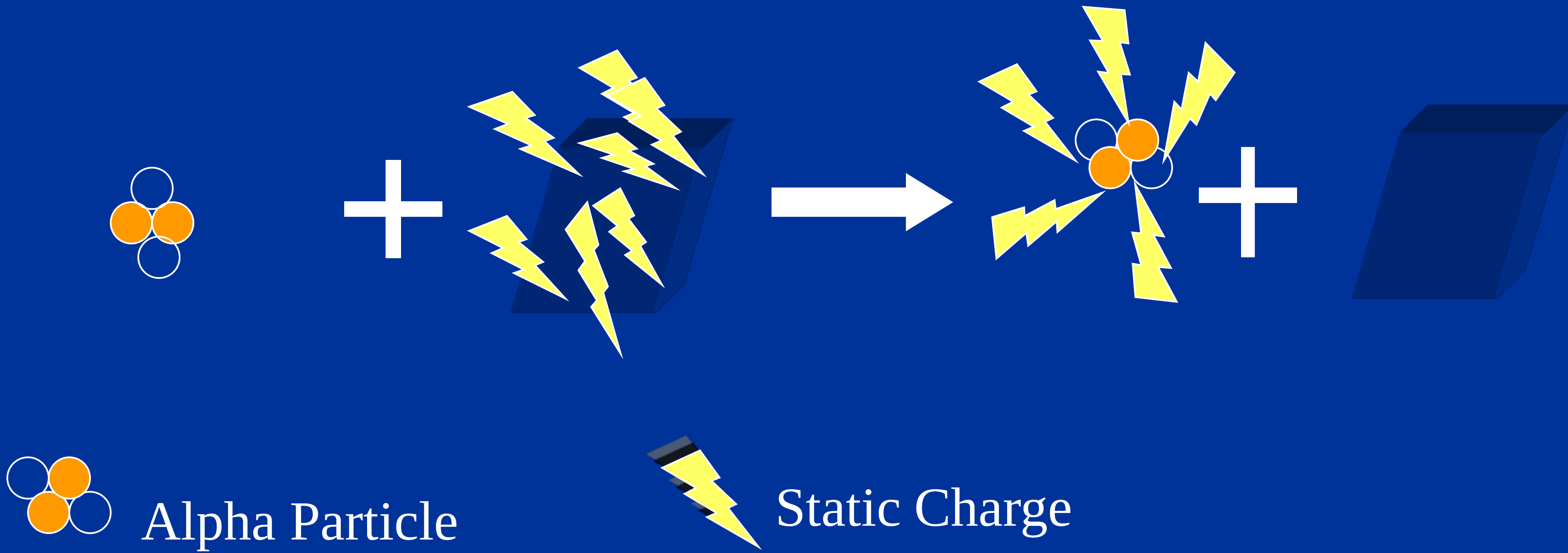
Overview

- General applications by radiation type
- Radiography - process
- Medical Research
- Medical Applications
- Space

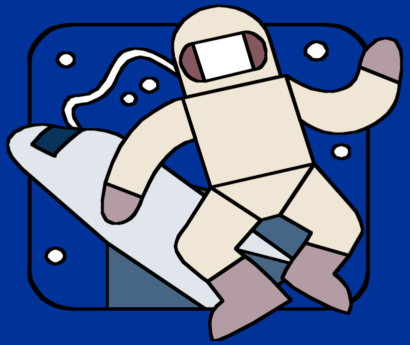
Alpha Radiation α

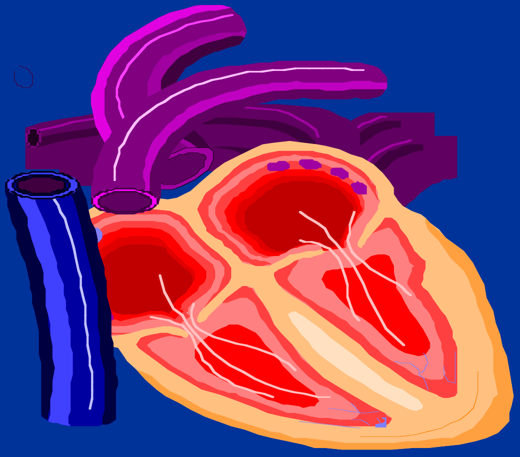
- Highly ionizing
- Removes Static Charge



Uses of Alpha Radiation

- Pacemakers (Older models)
- Airplanes
- Copy Machines
- Smoke Detectors
- Space exploration

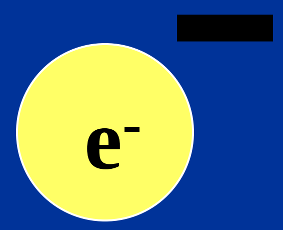




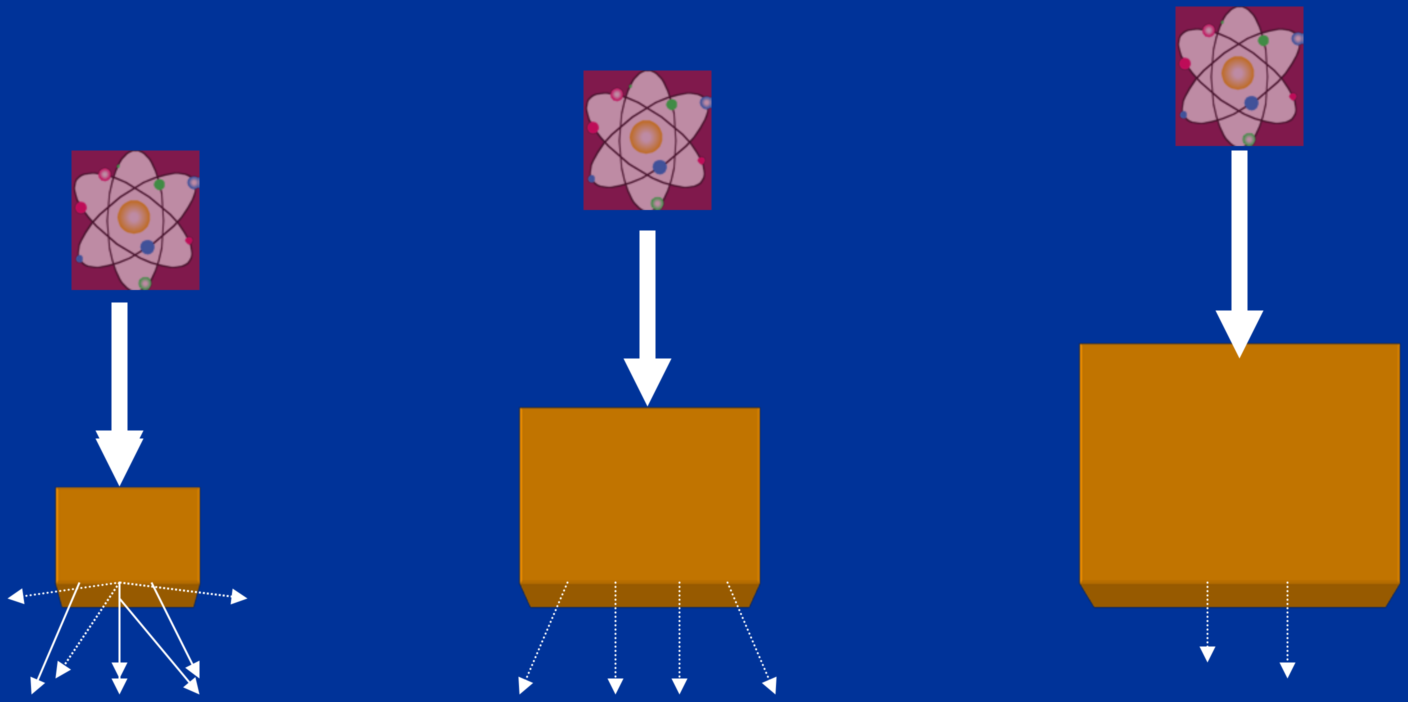
Beta Radiation

- Small electron particle
- More penetrating than alpha

β



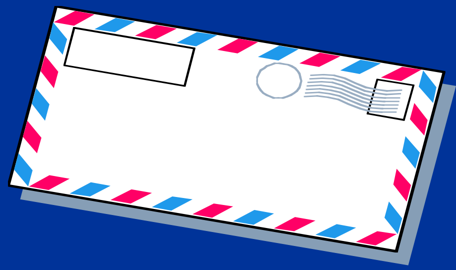
Beta radiation is used in thickness gauging

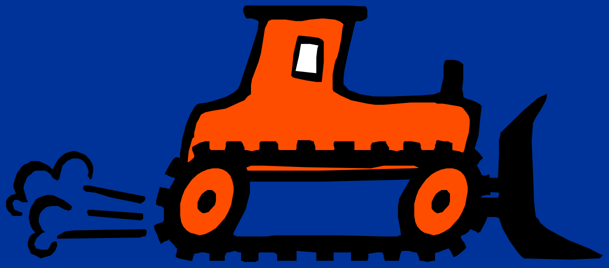


The thicker the material the less radiation will pass through the material.

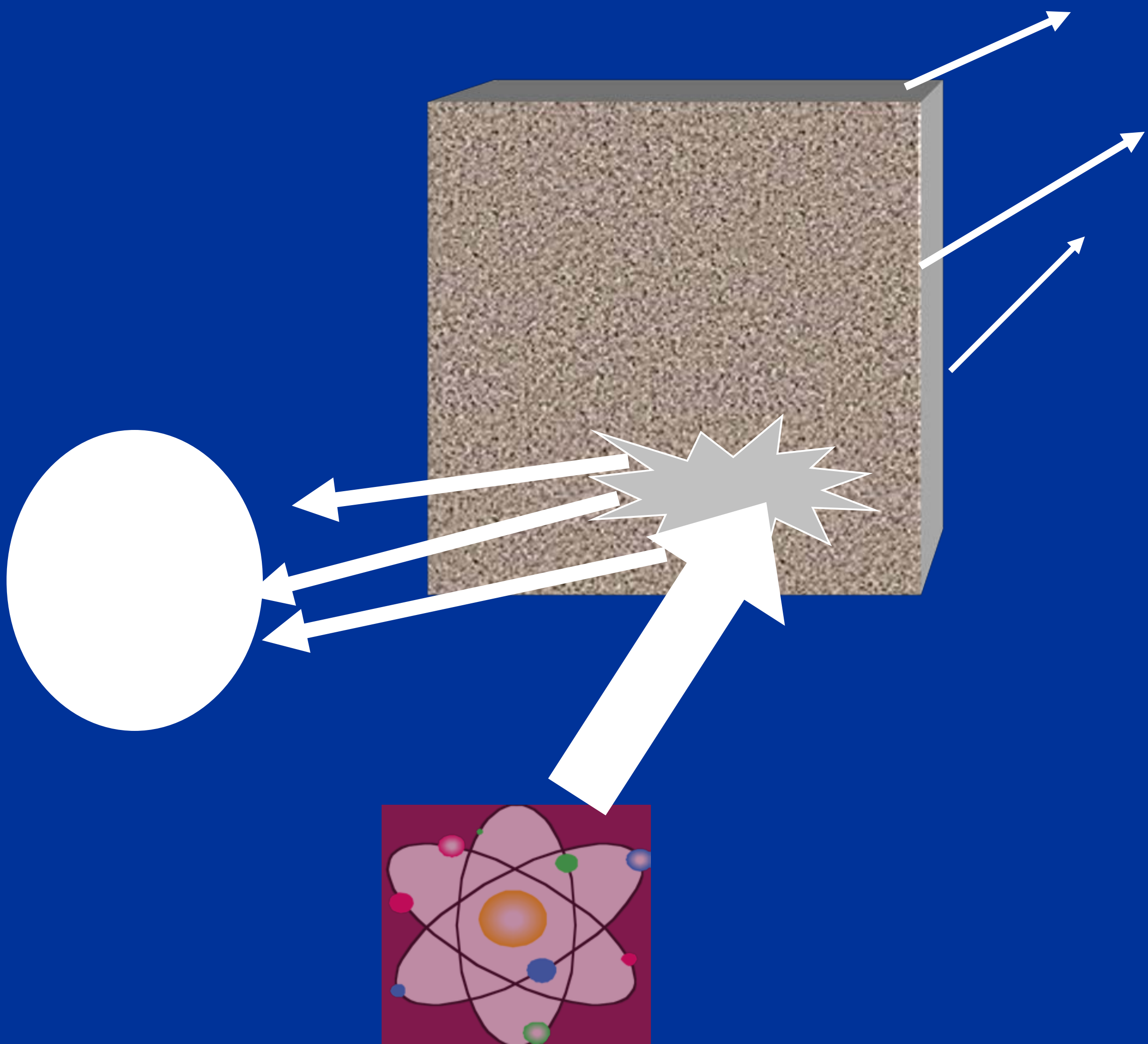
Gauging is used to

- Measure and control thickness of paper, plastic, and aluminum.
- Measure the amount of glue placed on a postage stamp
- Measure the amount of air whipped into ice cream.
- Measure the density of the road during construction.

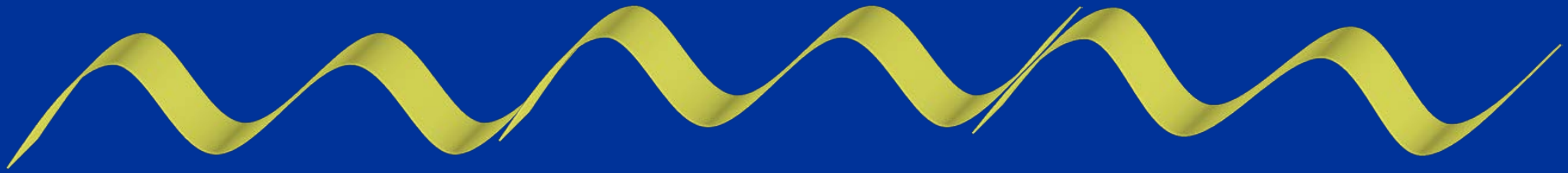




Back Scattering



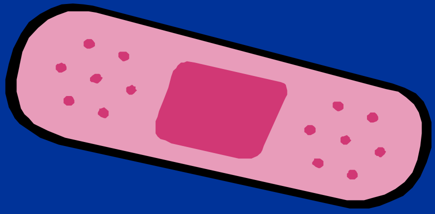
Gamma Radiation γ



A penetrating wave

Uses for Gamma Radiation

- Food irradiation
- Sterilization of medical equipment
- Creation of different varieties of flowers
- Inspect bridges, vessel welds and Statue Of Liberty



What were original uses of mysterious rays?

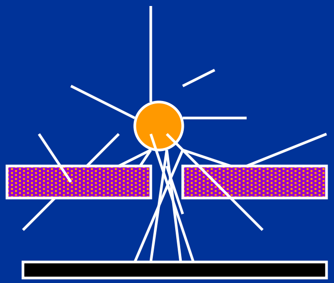
- Becquerel’s discovery
- Roentgen x-ray of wife’s hand
- Marie Curie – WWI – x-ray unit

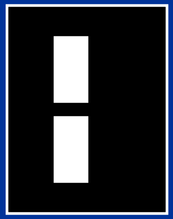
Early X-ray

http://www.uihealthcare.com/depts/medmuseum/galleryexhibits/collectingfrompast/xray/xray.html

Radiographs

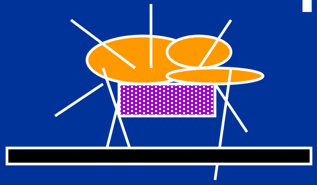
X-ray

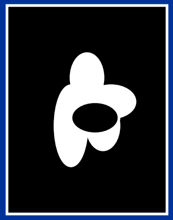




- Radiograph - radiation energy passes through object

Photo-Film



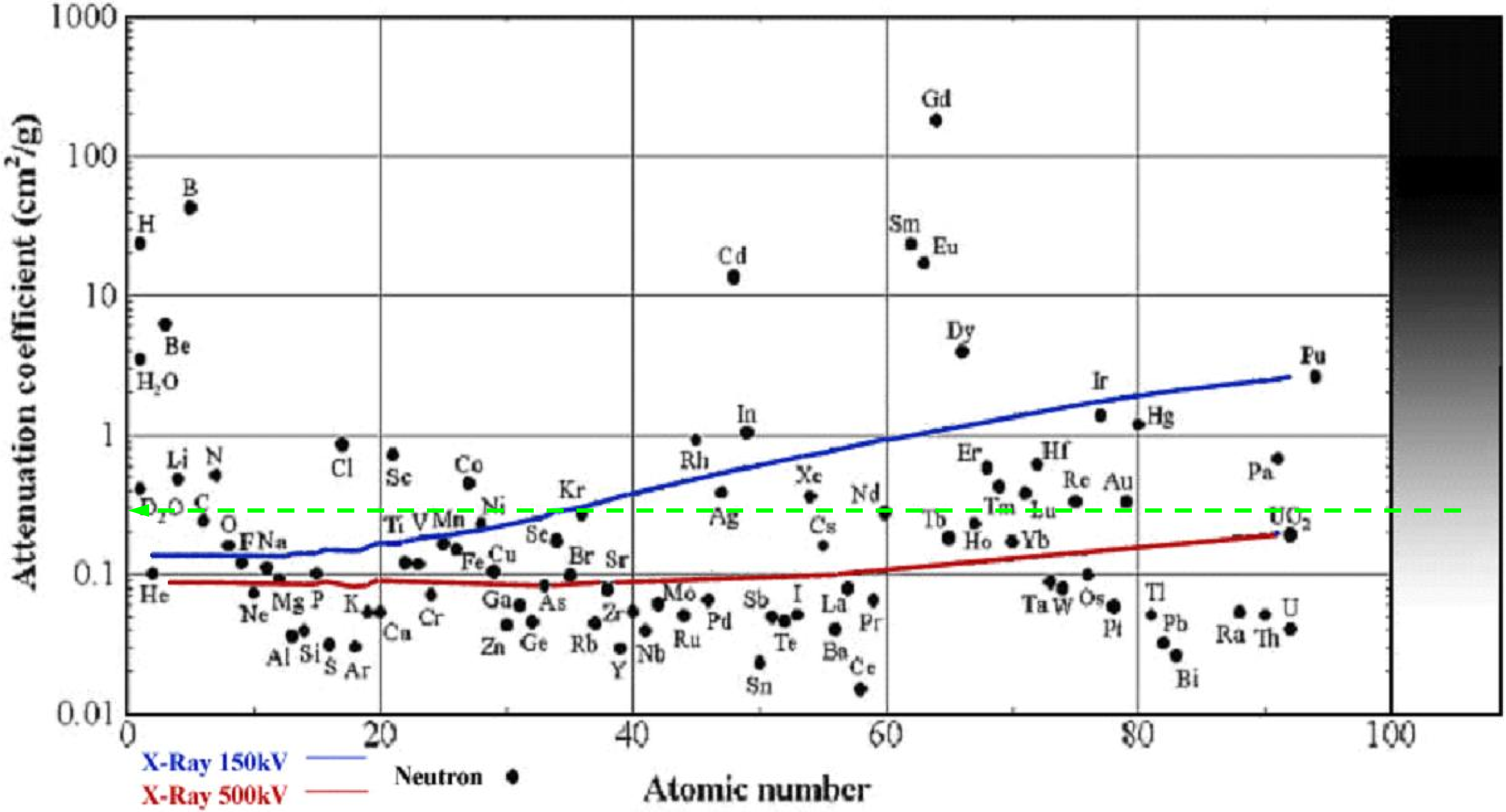


- Autoradiograph - use radiation from object itself

Radiography

- Let's explore two different methods of using radiation to capture images
  - X—rays
  - Neutrons
- The next graph shows attenuation of the radiation vs. atomic number. The shading on the right shows how much radiation is blocked – black indicates completely blocked.

Thermal neutron and X-ray mass attenuation coefficients for the elements

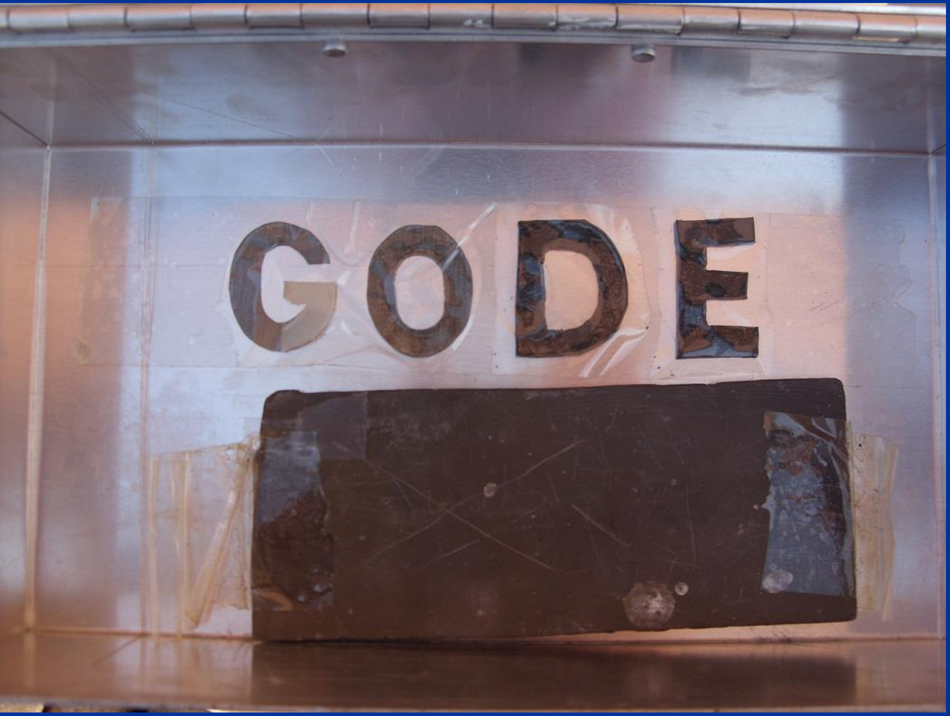


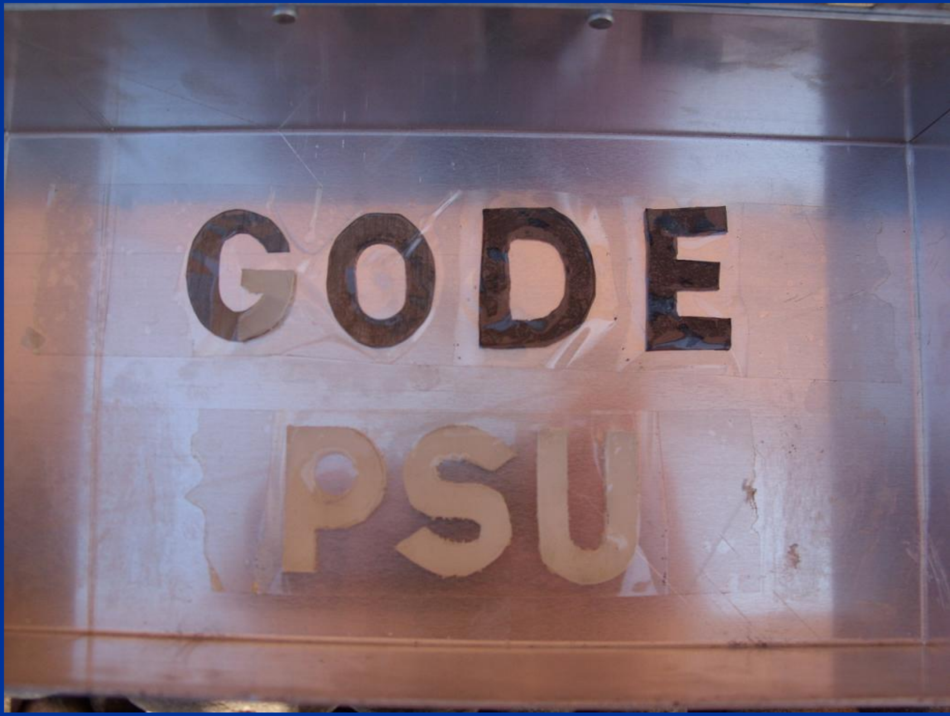
Comparing Different Materials

- **Cadmium (Cd)**
- **Lead (Pb)**
- **Polyethylene [$(CH_3)_n$]**

CODE Box at Penn State

Student Project to Demonstrate X-Ray/Neutron Radiography





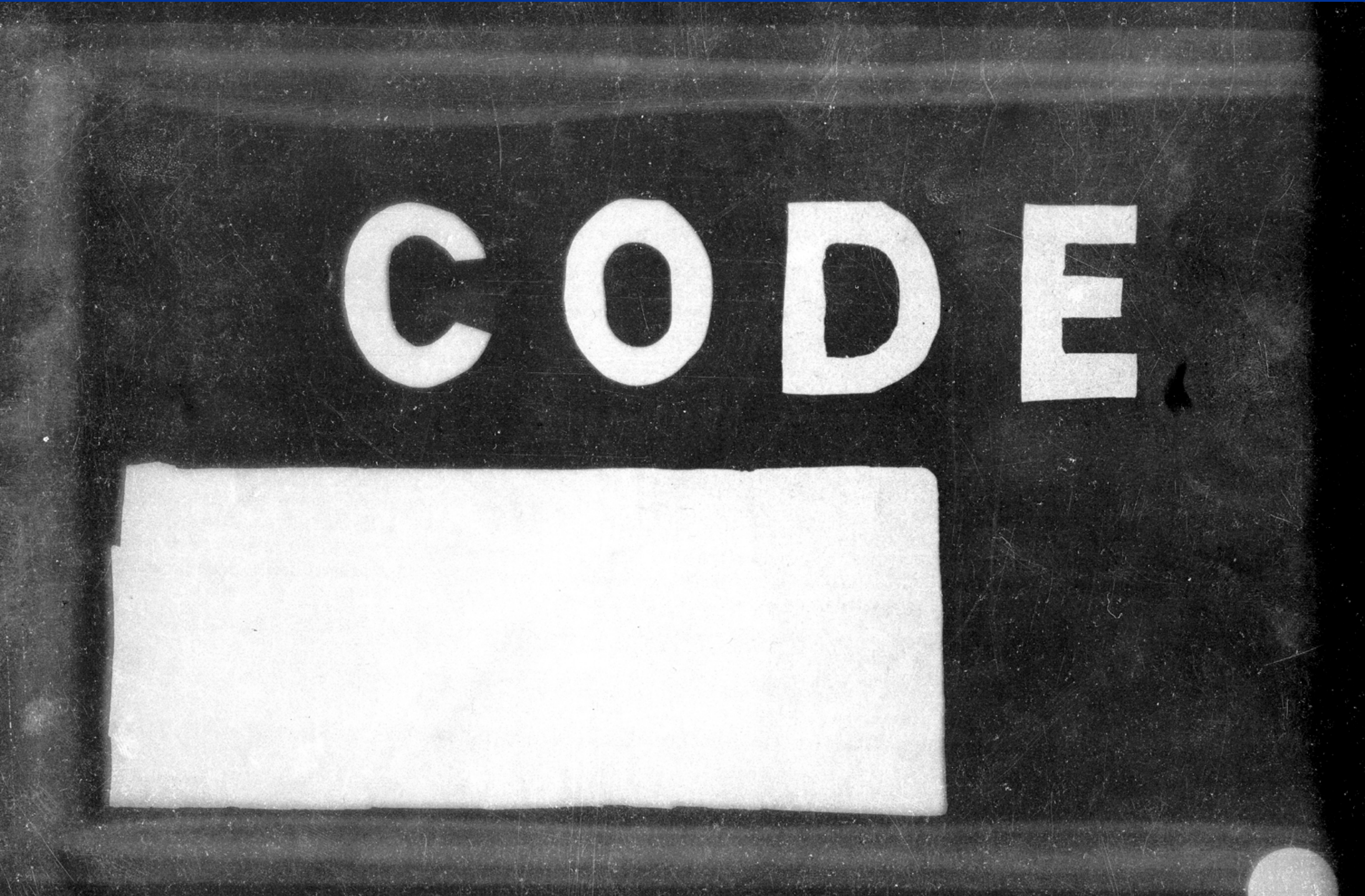
Was originally in cardboard shoe box,
but was replaced by more durable aluminum.

Cadmium = red

Lead = white

CODE

X-Ray Image



Cadmium = red

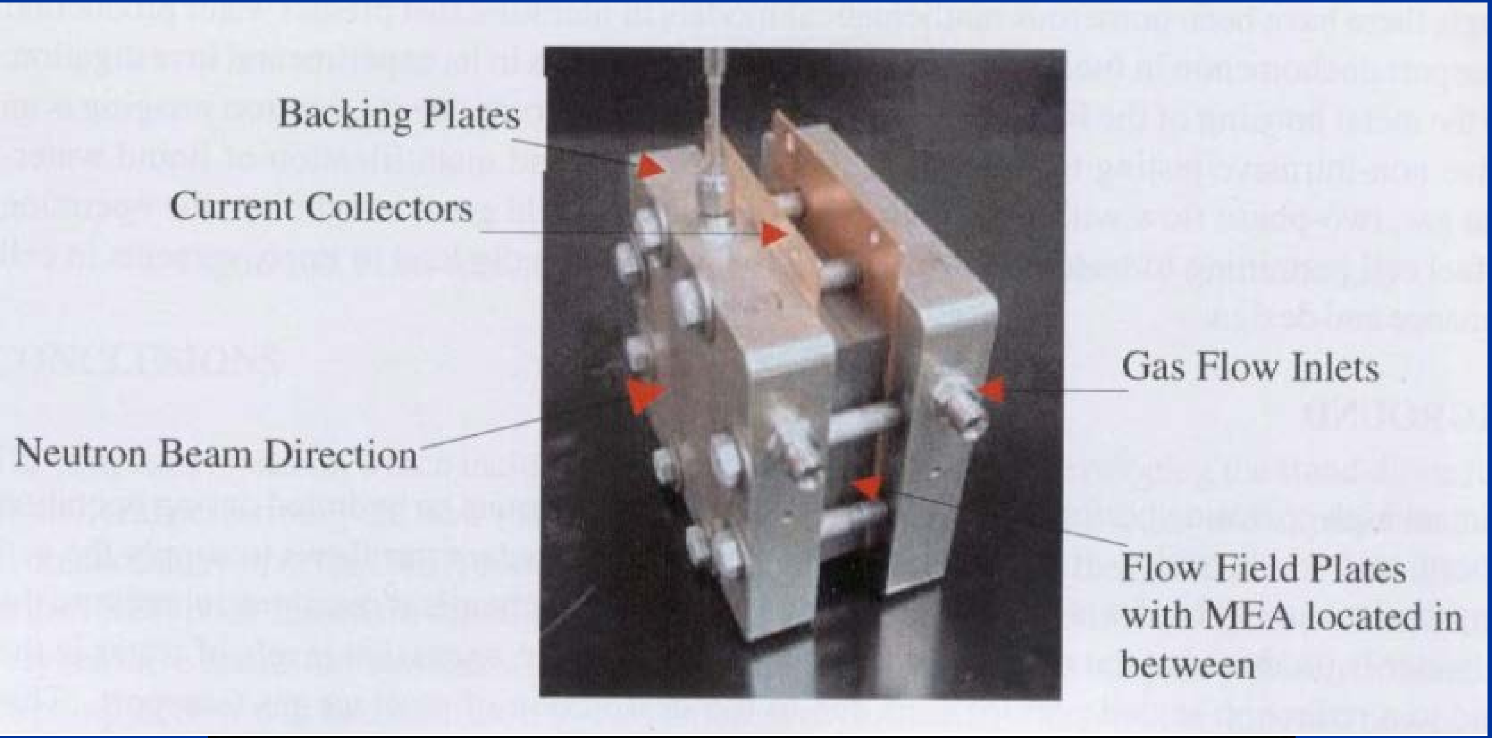
Lead = white

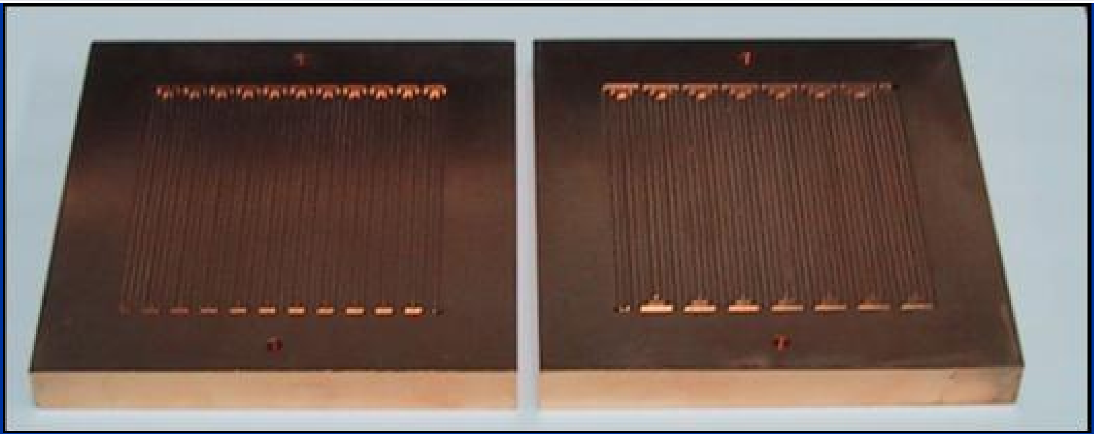
Polyethylene = gray

C O D E

Neutron Radiograph

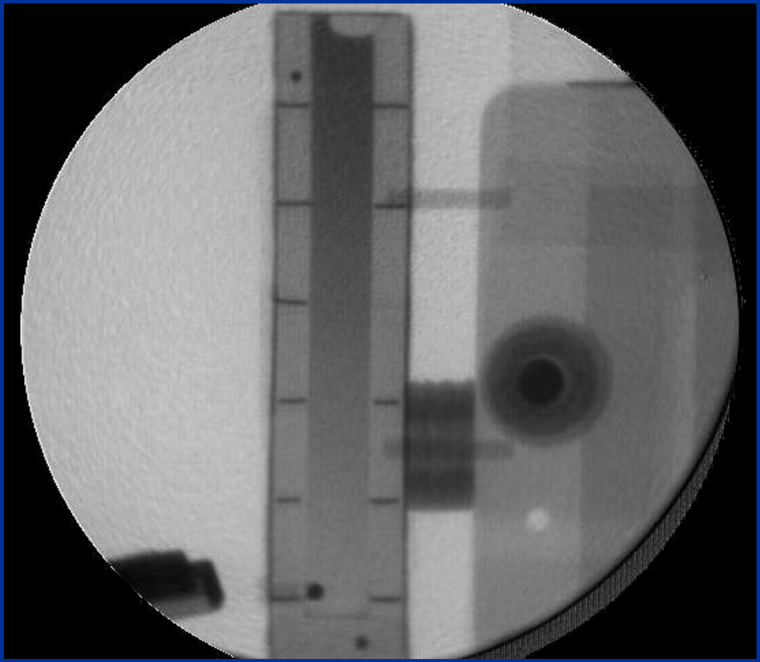
Hydrogen Fuel Cell Imaging



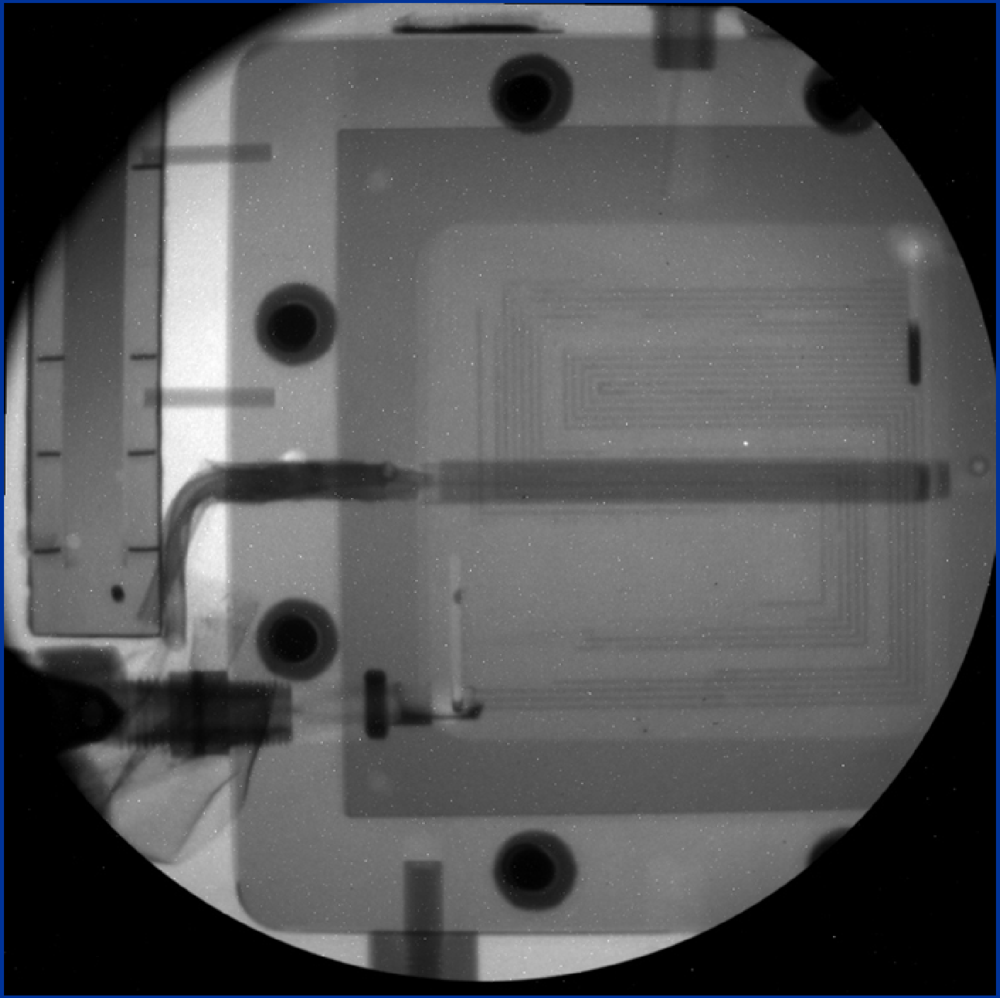


Fuel Cell research conducted at RSEC

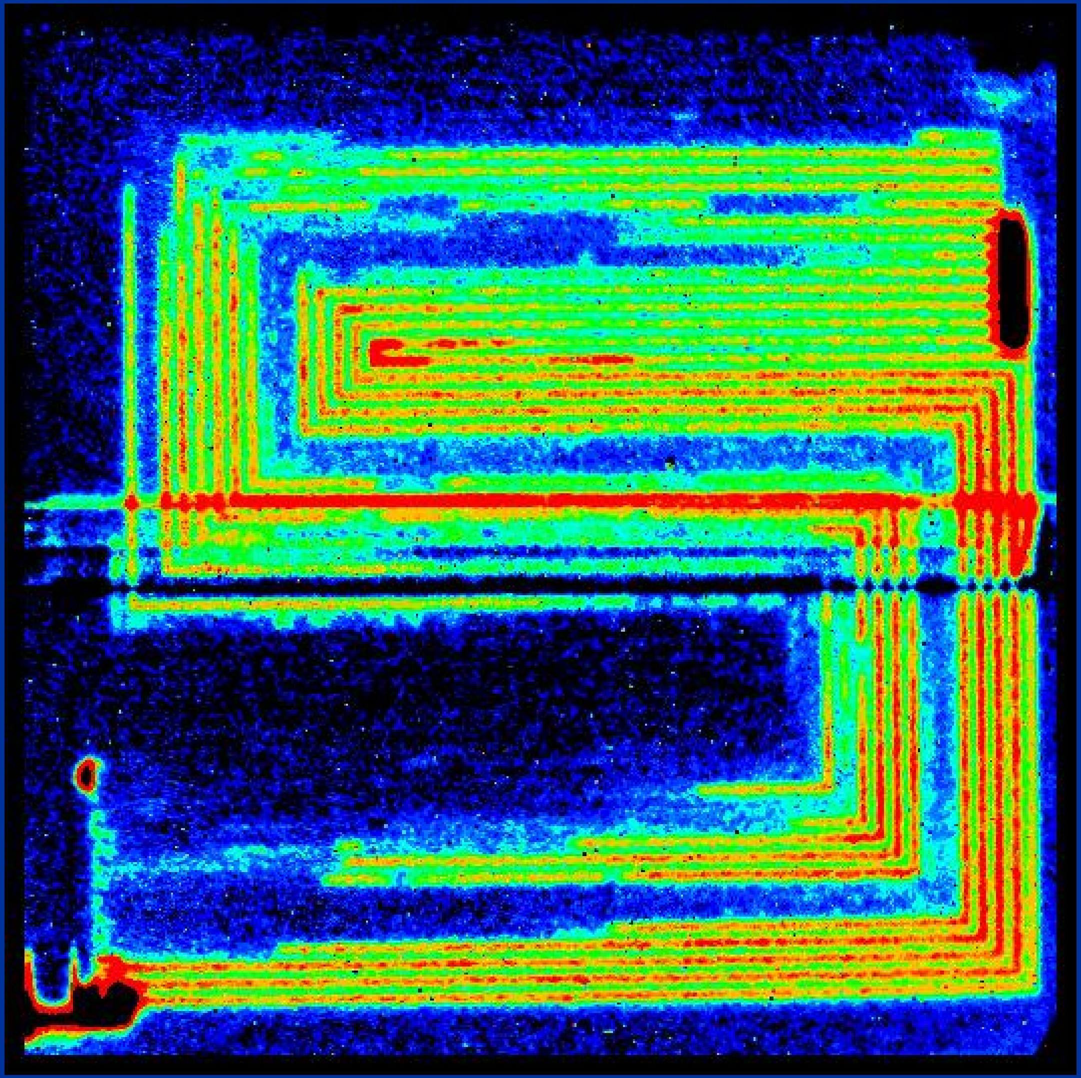
Hydrogen Fuel Cell Imaging



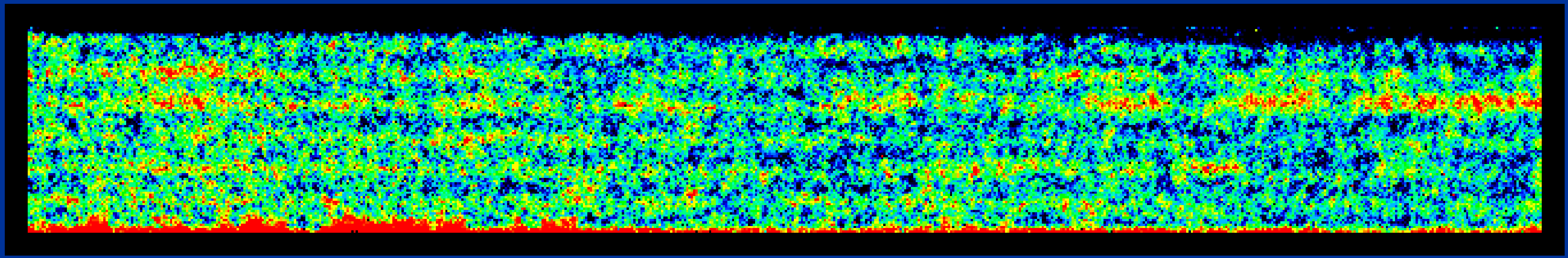
Water Calibration Wedge



Hydrogen Fuel Cell Imaging

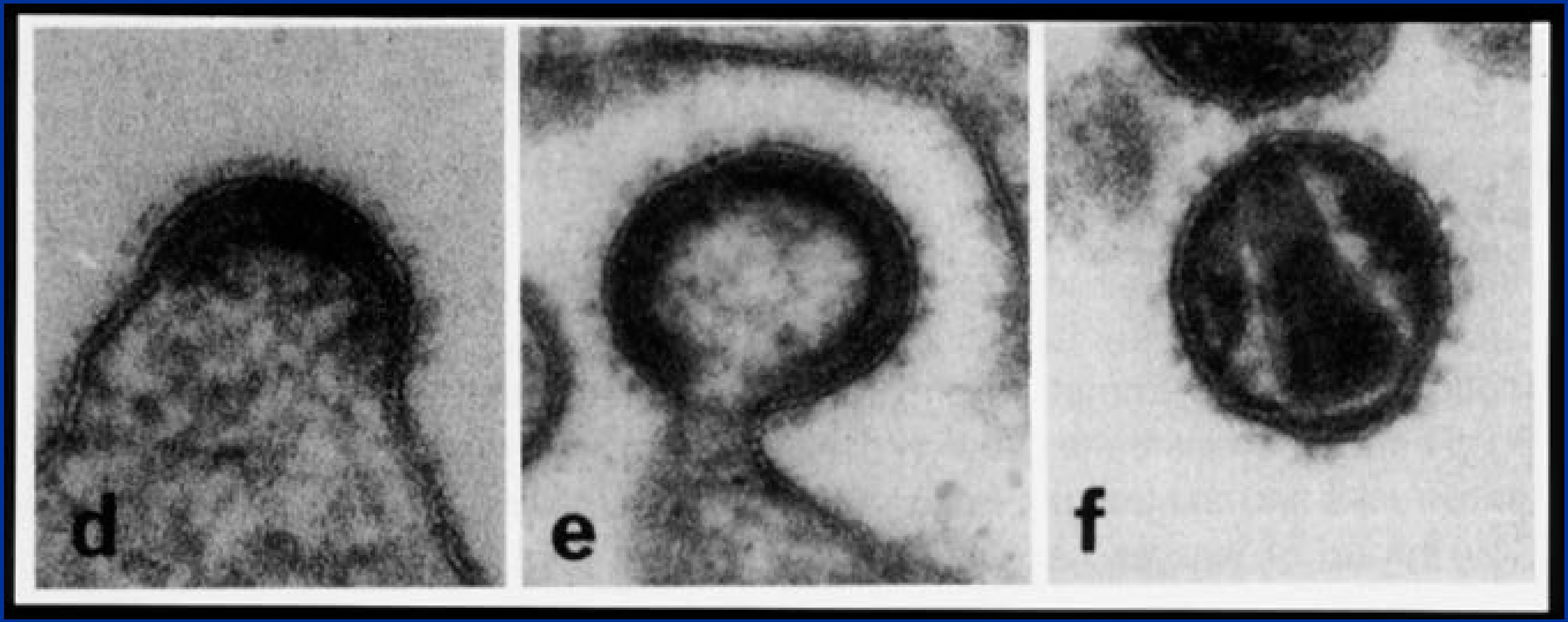


Hydrogen Fuel Cell Imaging



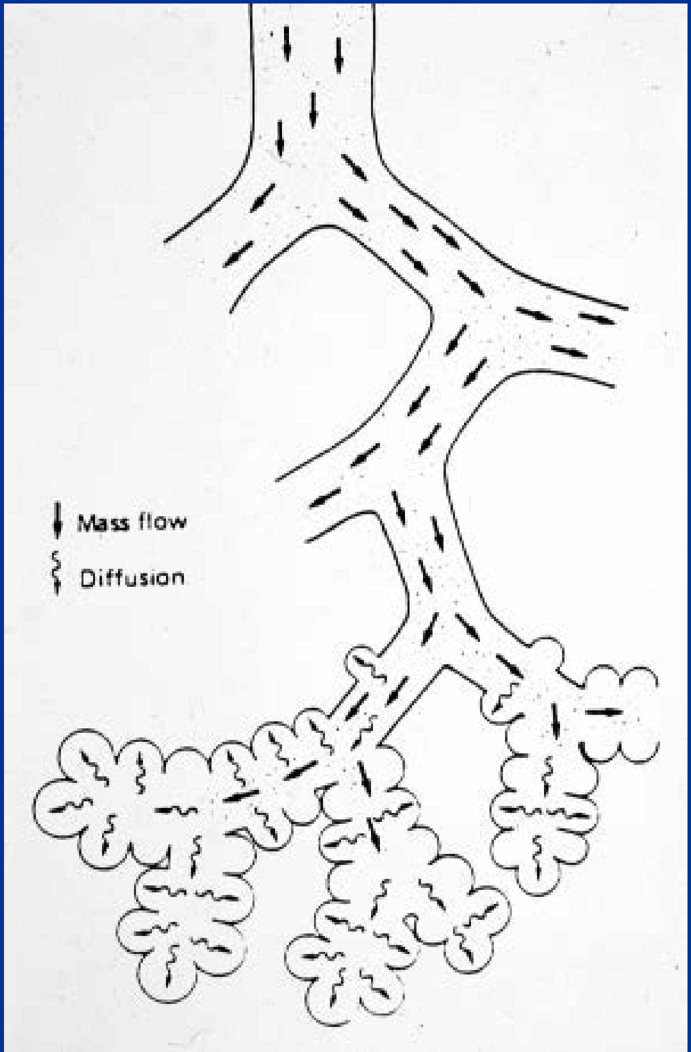
Clinical Uses
of
Radioactive Materials

Understanding the Replication Process of the HIV Retrovirus



- DNA sequencing, using ^{35}S and ^{32}P, is used to investigate the process by which new viruses "bud" or form from host cells

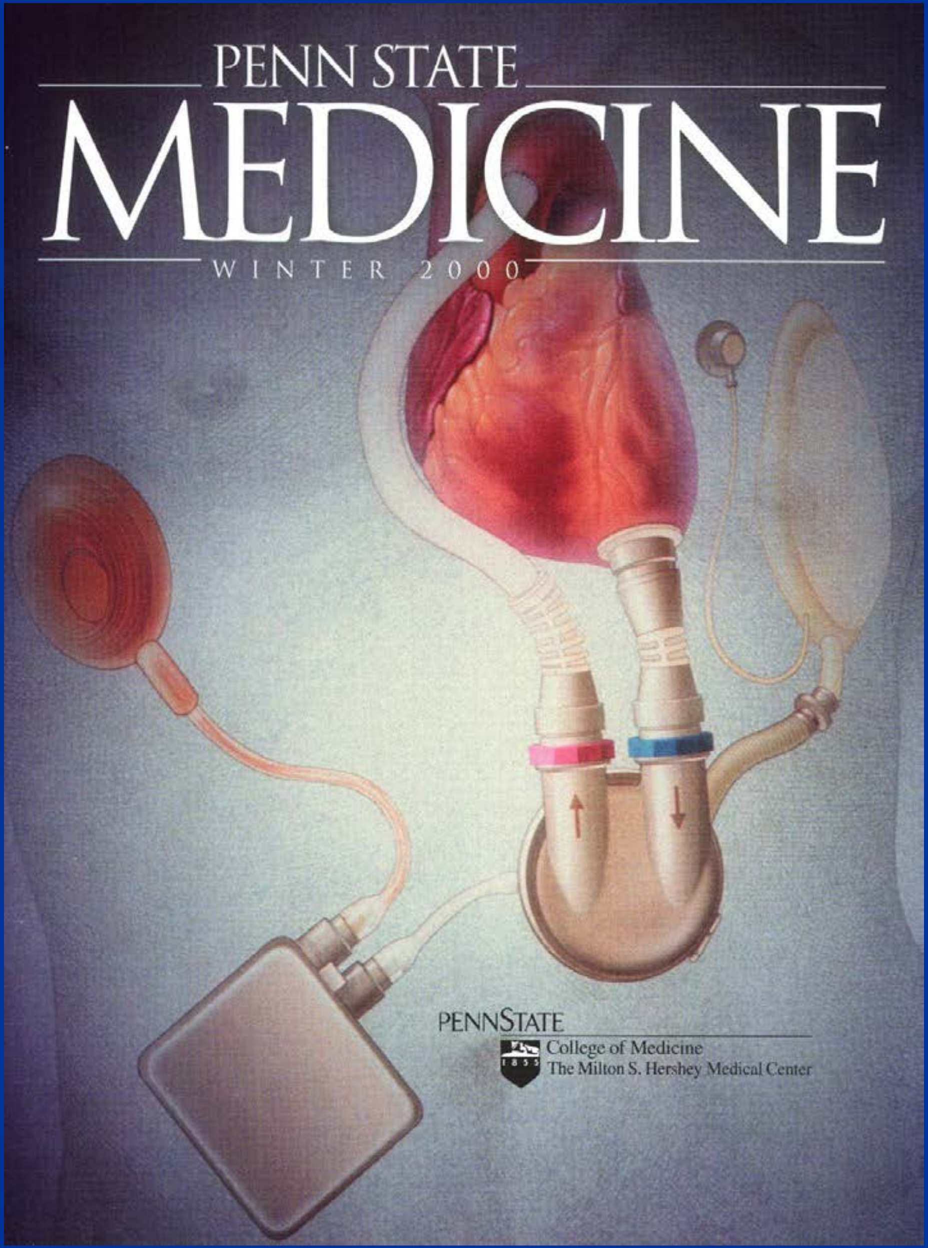
5000 Premature Infants Die Annually from Respiratory Distress/SIDS



- The infant lacks a protein which produces a surfactant in the lung alveoli
- Without the surfactant, there is too much surface tension – the lung is too weak to expand. A respirator is needed.
- ^{32}P-research identified the missing protein
- Gene therapy may one day be available

Benefits from Radioisotope Research

The Penn State Artificial Heart



RIA (Radio Immuno Assay)

- Extremely sensitive test for the presence of radiolabeled antibodies in blood serum samples
- Dr. Rosalyn Yalow developed the technique ca. 1961, won 1977 Nobel Prize

- Many tests exist for
  - Adrenal Function
  - Anemia
  - Diabetes and Related
  - Drugs of Abuse
  - Newborn Screening
  - Reproductive Hormones
  - Therapeutic Drugs
  - Thyroid Function
  - Tumor Markers
  - Veterinary Tests

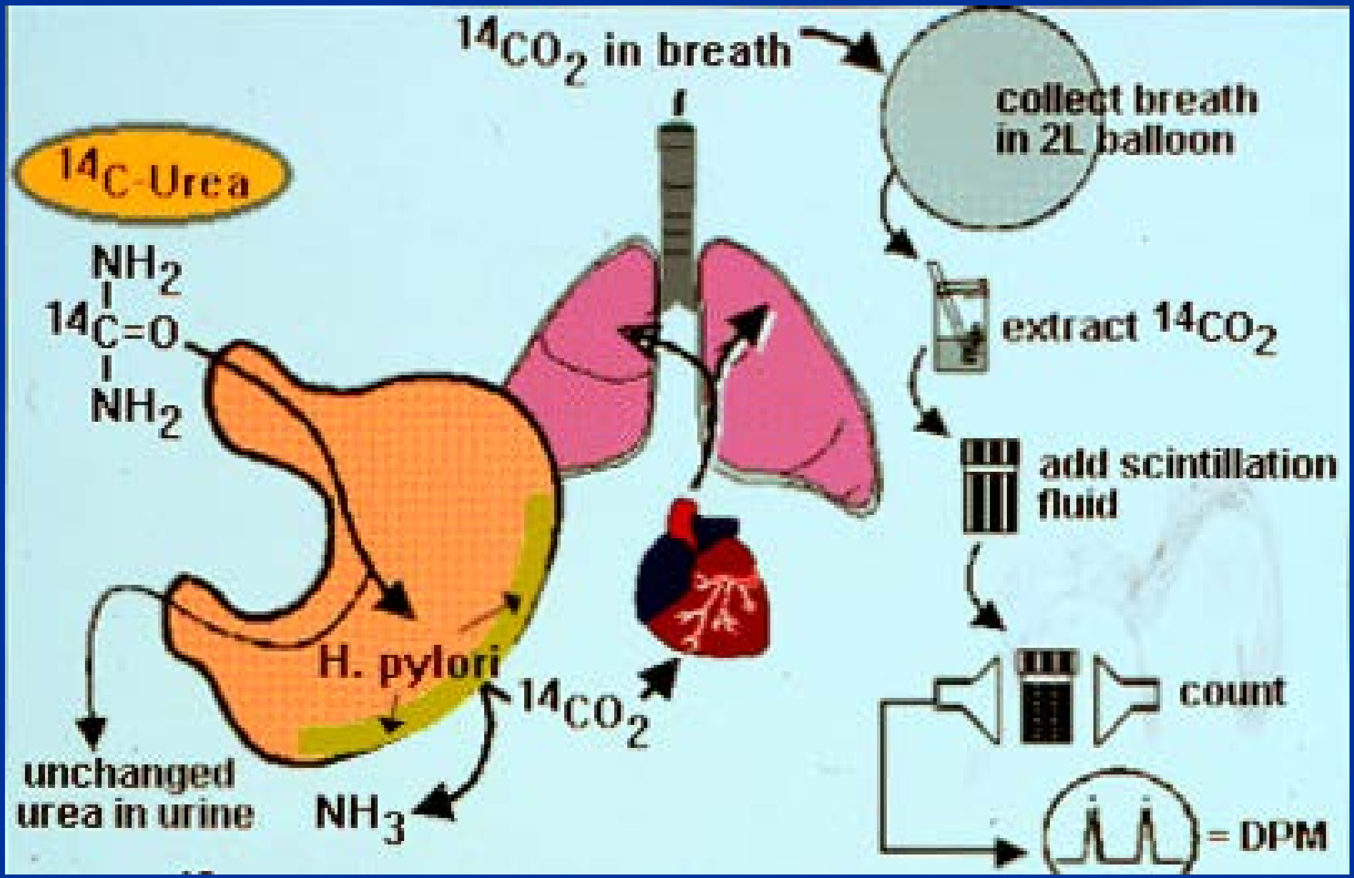
RIA Kit

- A standard test kit includes reagents, antigens, and a minute amount of radioactivity

- One kit can be used to test 100 to 500 patient serum samples

^{14}C Test for Helicobacter pylori

- H. pylori is often implicated in Gastric Reflux Disease
- If present, a specific antibiotic can be prescribed to eliminate it
- The use of radioactive ^{14}C provides a simple and sure test



^{137}Cs Blood Irradiator

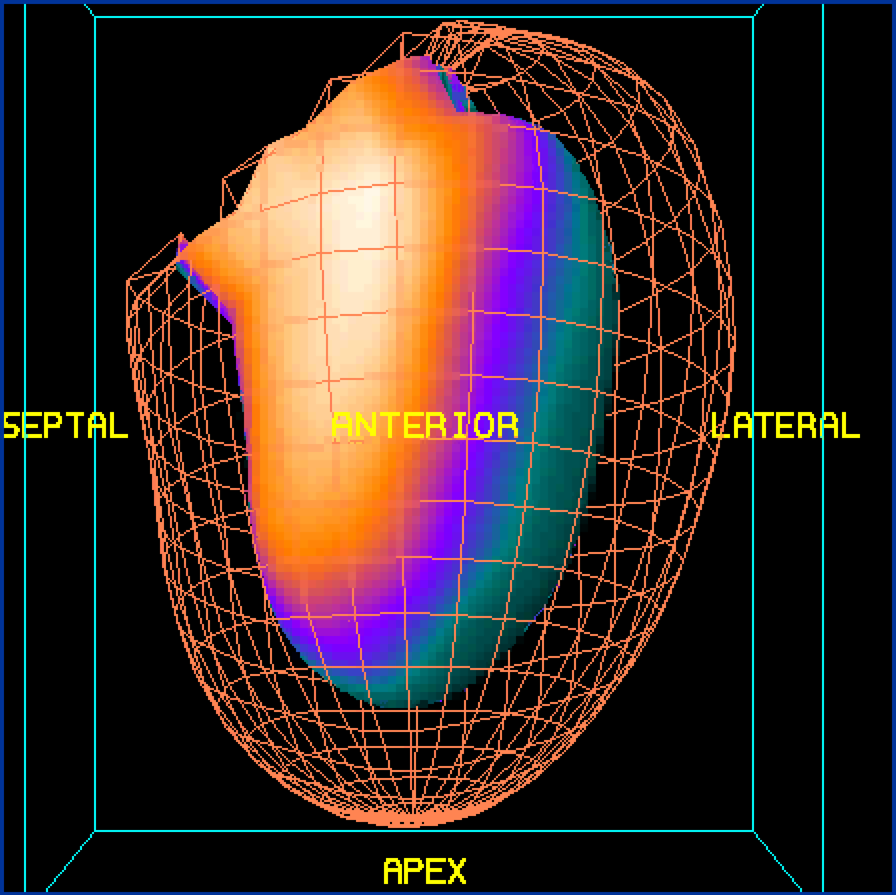
- Delivers 2500 rads to blood products
- Reduces potential for Graft-vs-Host Disease
- Essential for bone marrow transplants

Diagnostic Radiology Modalities

- X-Ray Radiography
  - Angiography
  - Mammography
  - Fluoroscopy
  - Cardiac Catheterization
  - CT (Computed Tomography)

Heart Image

- Gated study of radiolabeled cardiac muscle
- Allows visualization of heart tissue viability

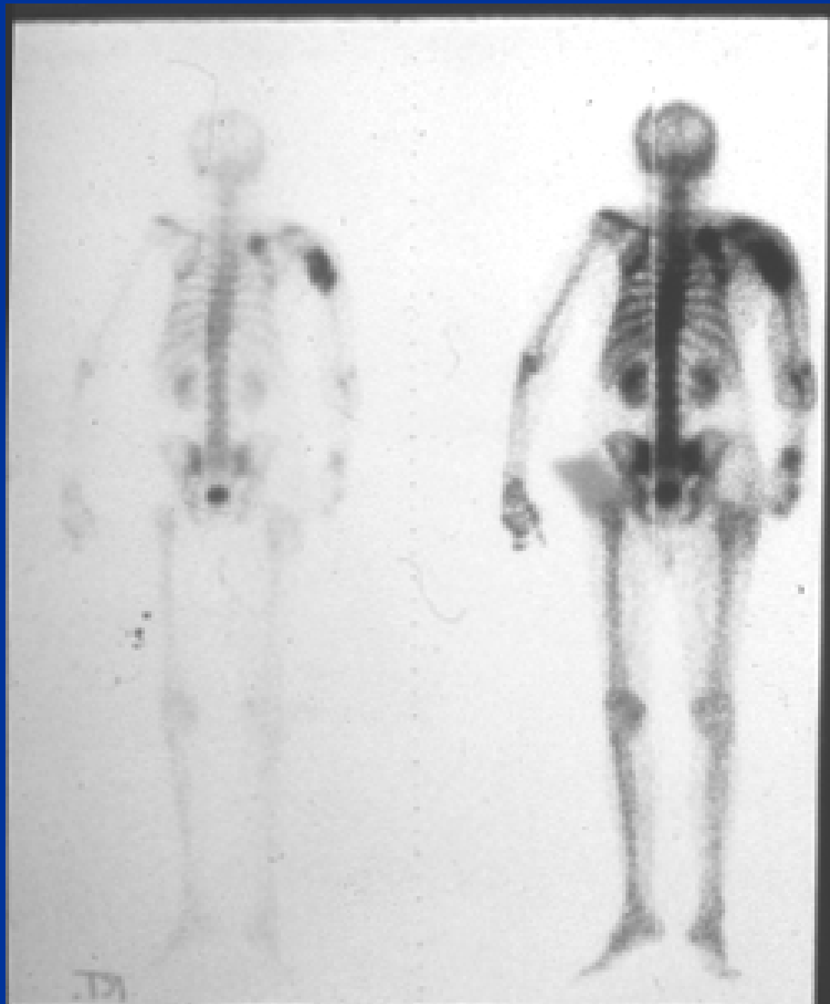


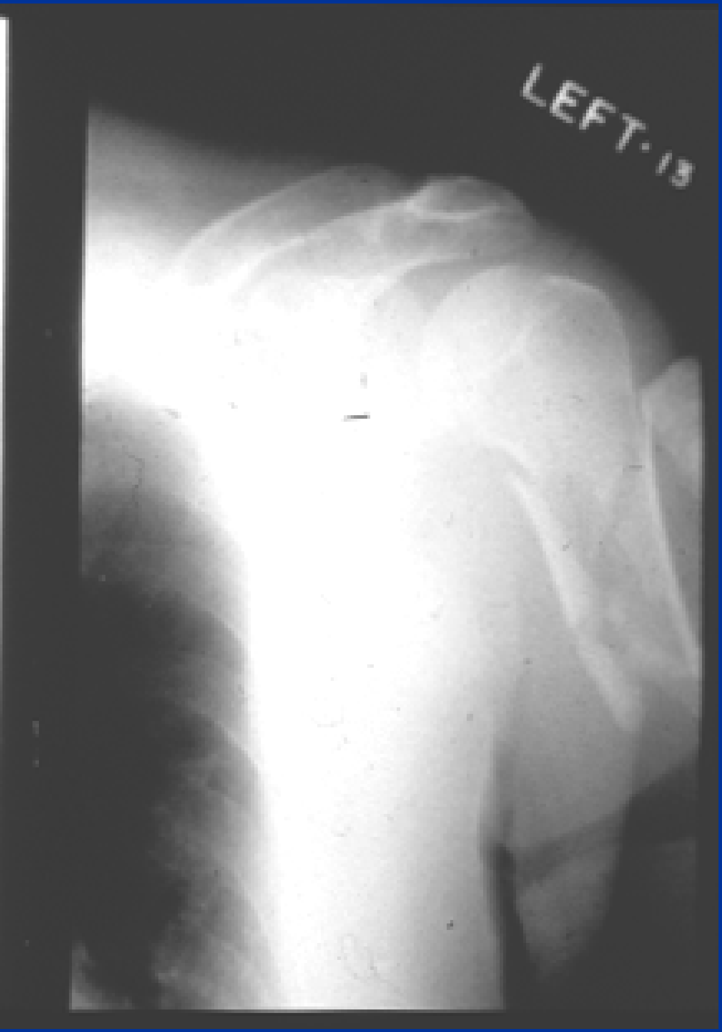
Bone Scan with ^{99m}Tc-HDP

- Active bone surface is labeled
- Note “hot spots” and kidneys

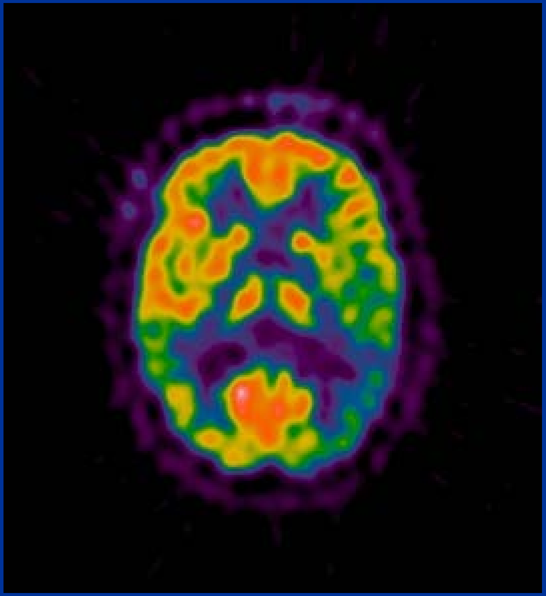
Nuc Med & Radiographic Images Compared

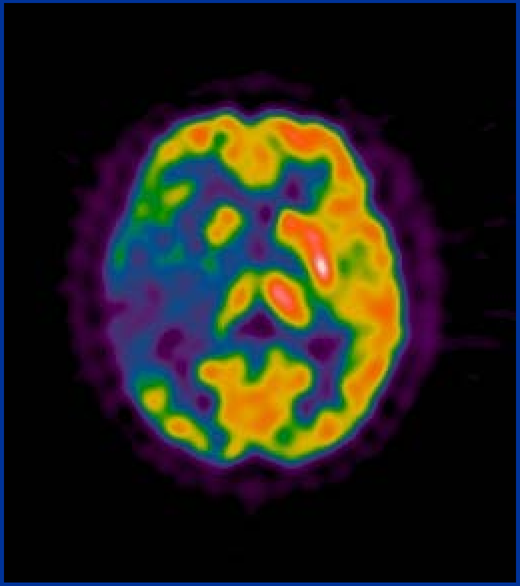
- Metabolic hotspots highlighted – possibly cancerous
- X-ray image shows break, but no metabolic information





The New(er) Kid on the Block: PET Positron Emission Tomography

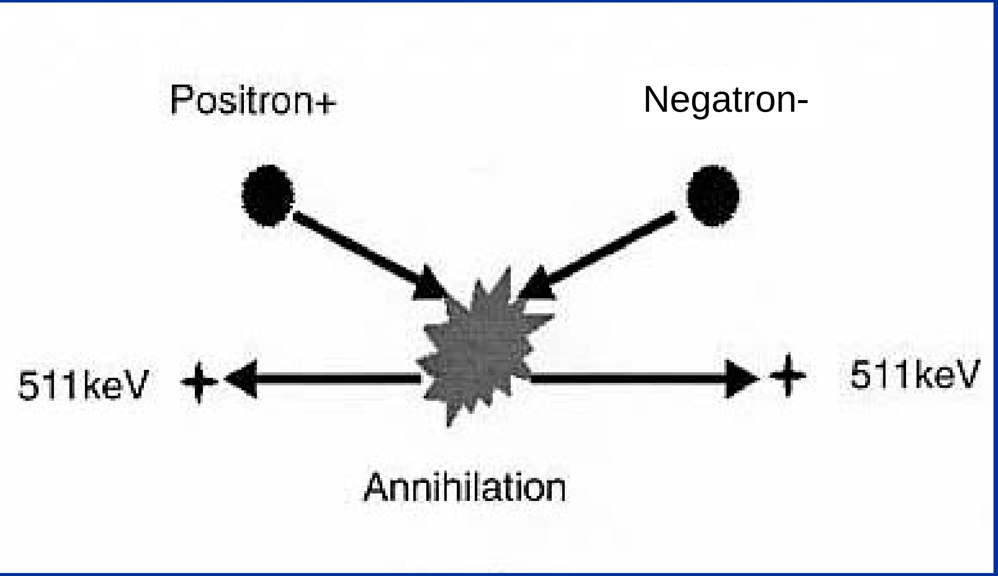


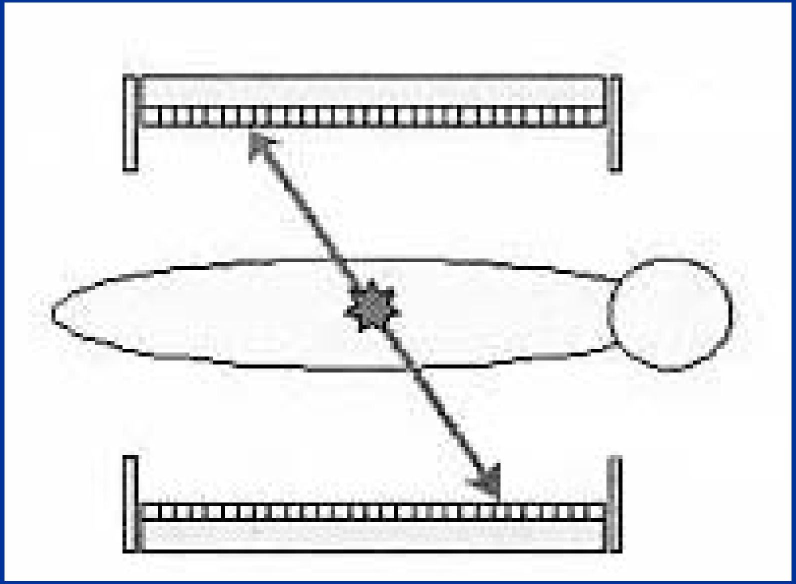


- ^{18}FDG Images of a normal vs. an epileptic brain
- Rapidly growing in popularity for tumor imaging

Positron Decay and Coincidence Photon Detection

- $p^+ \rightarrow n^0 + e^+ + \nu$
- Positron escapes the nucleus
- Two oppositely directed photons result from the annihilation of the positron with an electron



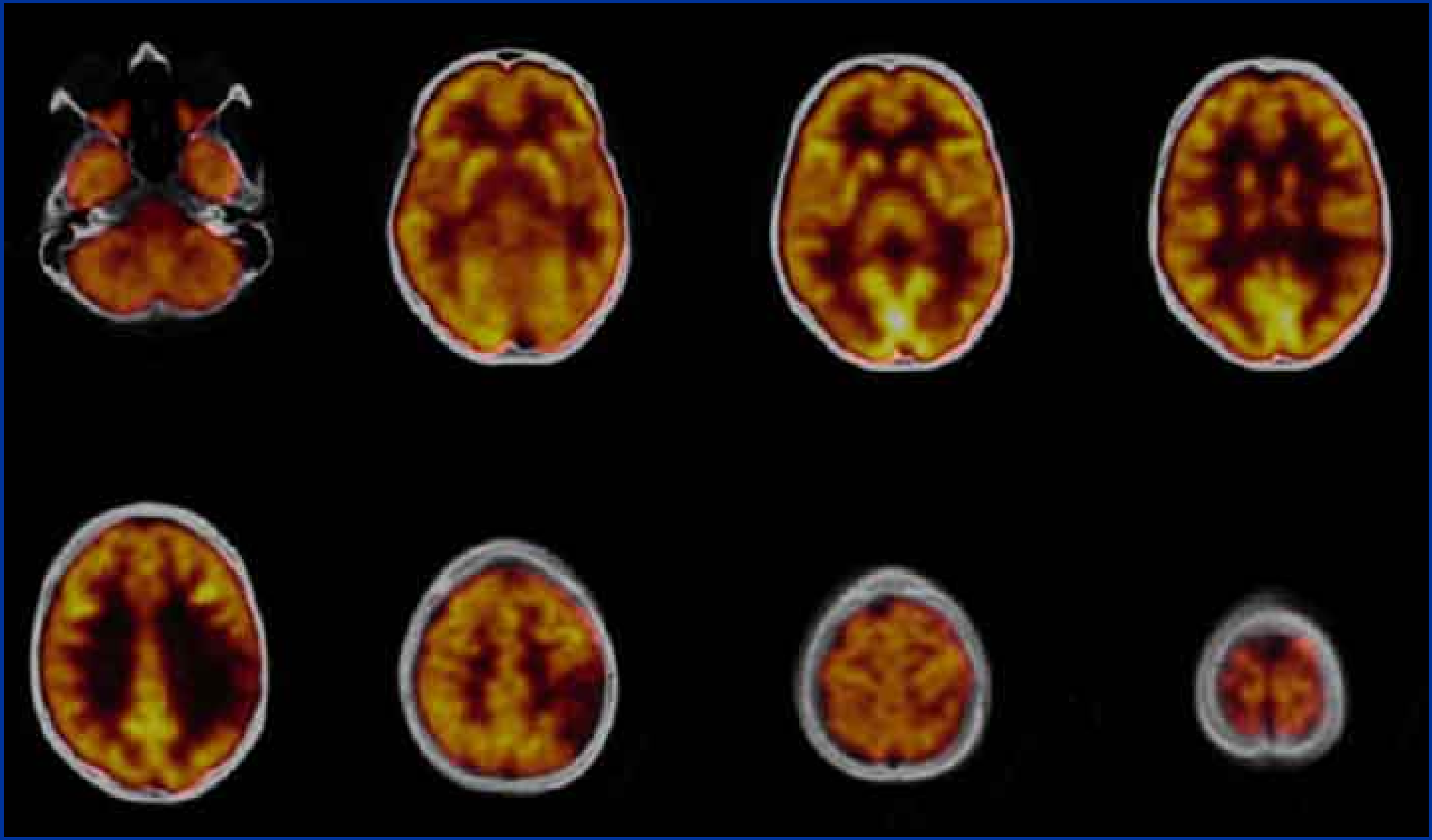


PET Scanner Coincidence Detectors

^{18}FDG

- Fluorodeoxyglucose
- Most commonly used PET radiocompound
- A glucose analog, useful for
  – Differentiating malignant from benign tumors
  – Differentiating scar from viable myocardial tissue
  – Brain function studies

Cerebral Glucose Metabolism



- Brain tumor diagnosed
- MRI scan suspicious for low-grade astrocytoma
- PET/CT scan shows large hypo-metabolic area in left posterior temporal lobe

Siemens Clinical Solutions, www.medical.siemens.com

Other PET Applications

- Neurological studies
  - Epilepsy
  - Alzheimers
  - Parkinson's Disease
  - Addictions

- Cancer imaging and localization
  - In demand by Oncologists

- Cardiology studies

The ‘Historical’ Problem in Modern Radiology

- Images obtained from Nuclear Medicine were obtained on a computer platform different from those obtained from CT, and also from MRI, Ultrasound, etc.

- Thus, images could not be easily overlaid

- A common software was needed to make best use of the information from each modality

Radiation Doses from Medical X-rays

- Medical Radiation (Effective Whole Body Dose Equivalent)
  - Chest X-ray: 8 mrem (0.08 mSv)
  - Head CT scan: 111 mrem (1.11 mSv)
  - Barium Enema: 406 mrem (4.06 mSv)
  - Extremity X-ray: 1 mrem (0.01 mSv)

Source: NCRP Report 100

Radiation Doses and Dose Limits

Flight from Los Angeles to London	5 mrem
Annual public dose limit	100 mrem
Annual natural background	300 mrem
Fetal dose limit	500 mrem
Barium enema	870 mrem
Annual radiation worker dose limit	5,000 mrem
Heart catheterization	45,000 mrem
Life saving exposure (NCRP-116)	50,000 mrem
Mild acute radiation syndrome	200,000 mrem
$LD_{50/60}$ for humans (bone marrow dose)	350,000 mrem
Radiation therapy (localized & fractionated)	6,000,000 mrem

Electricity in Space - RTG

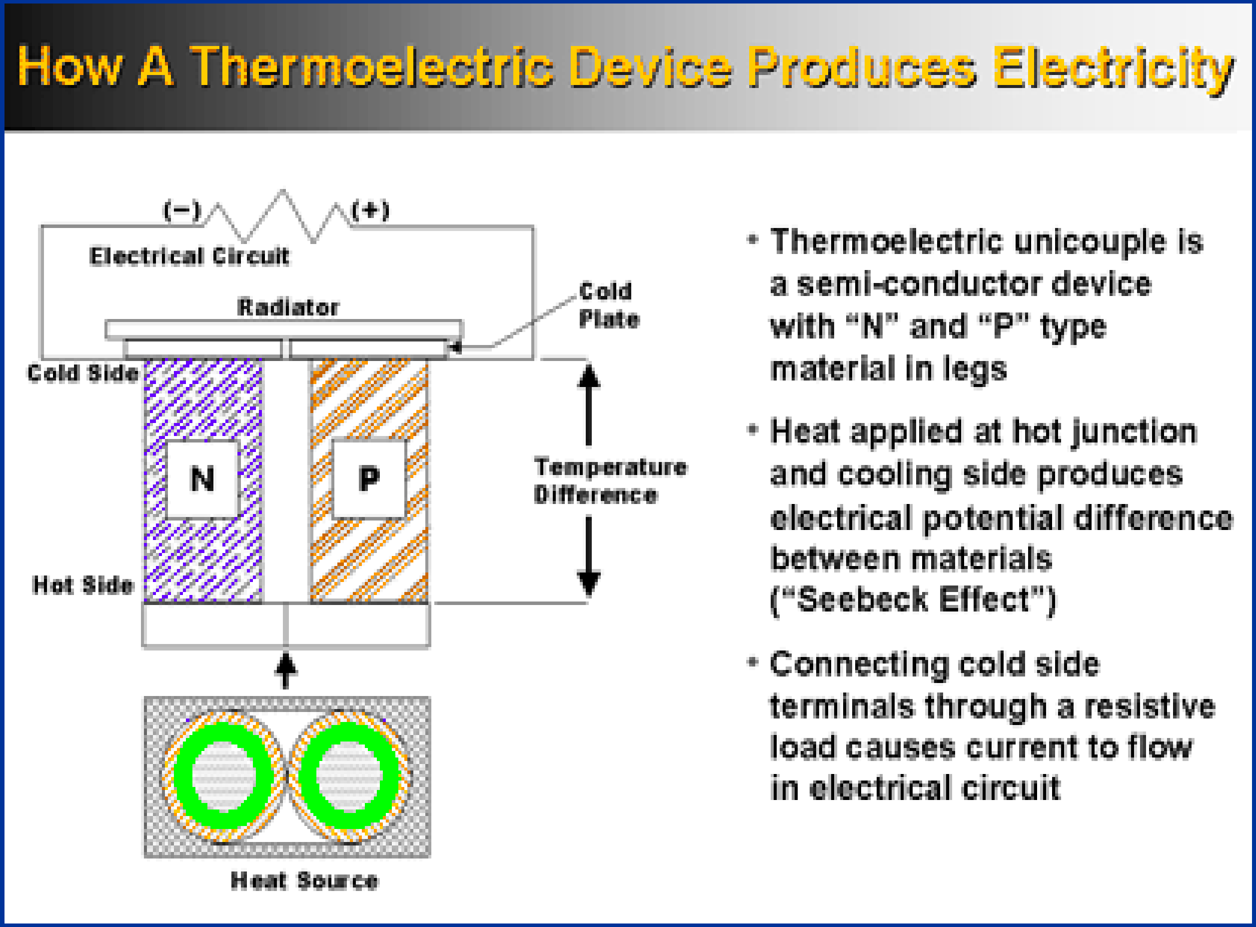
Nuclear Options

- Radioisotope Thermoelectric Generators (RTG)
  - Work on principle of radioactive decay
  - Energy proportional to activity
  - Activity proportional to half-life and amount of material
  - More material and shorter half-life means more power
  - Shorter half-life runs out sooner
  - Must balance energy supply and mission length

$$A(t) = A_0 * e^{\left(\ln 2 * time / Half-Life \right)}$$

RTGs in Space - Theory

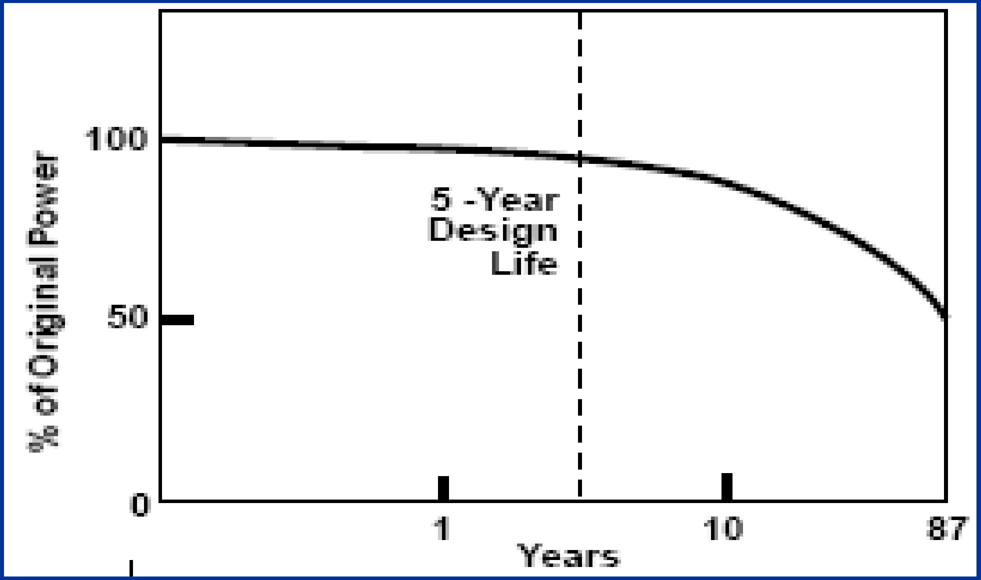
Work on the thermoelectric principle also known as the 'Seebeck Effect'



~10% efficiency

RTGs in Space – Half-Life

- US RTGs use Pu^{238} as the radioactive material
  - –Half-Life of 87.7 years
  - –96% of energy (activity) after 5 years
  - –50% of energy after 87.7 years
- Old US and Russian RTGs used Po^{210}
  - –Half-Life of 138 days

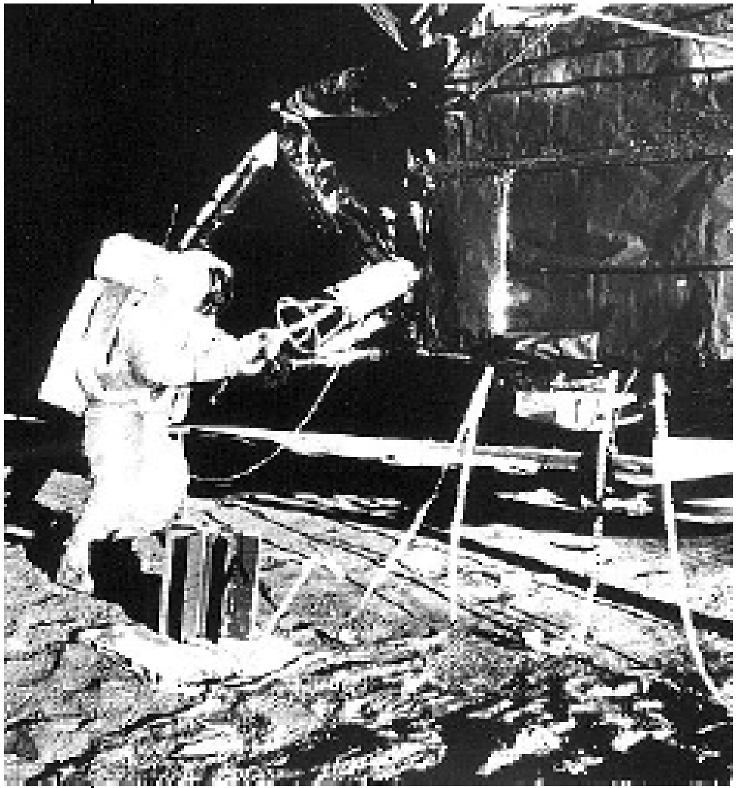


RTGs in Space - Radiation

- ^{238}Pu and ^{210}Po are alpha (α) emitters
- Alpha radiation cannot penetrate very far
  - Stopped by a sheet of paper or 10cm of air
  - Turns into heat in the RTG material
  - Very little radiation gets out of the shielding
  - Not ‘weapons grade’ material
  - Ceramic form that is very heat and impact resistant

RTGs in Space - History

1959: Atomic Energy Commission members show President Eisenhower the new ‘nuclear battery’ for use in US satellites



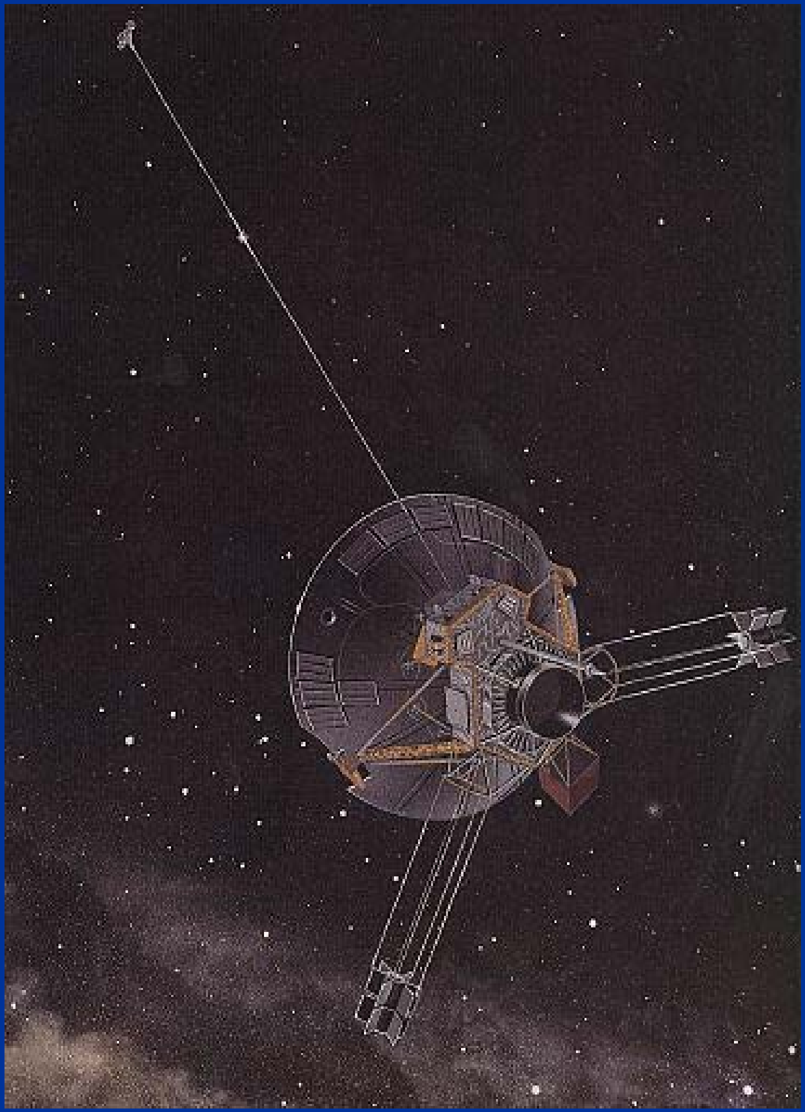
On the moon, Apollo-12 astronaut Gordon Bean prepares to load the plutonium-238 heat source into the SNAP-2 thermo-electric generator (arrow). The generator produced 73 watts of power for the Apollo lunar surface experiment package for nearly eight years.

RTGs in Space - History

- Original RTG in space was for a US Navy navigation satellite
  - 1961 SNAP-3 unit (Space Nuclear Auxiliary Power)
  - 2.7 watts of electrical power
  - Lasted for 15 years
- RTGs were used in 25 other missions from 1961 to 2005 from military satellites to the Apollo missions

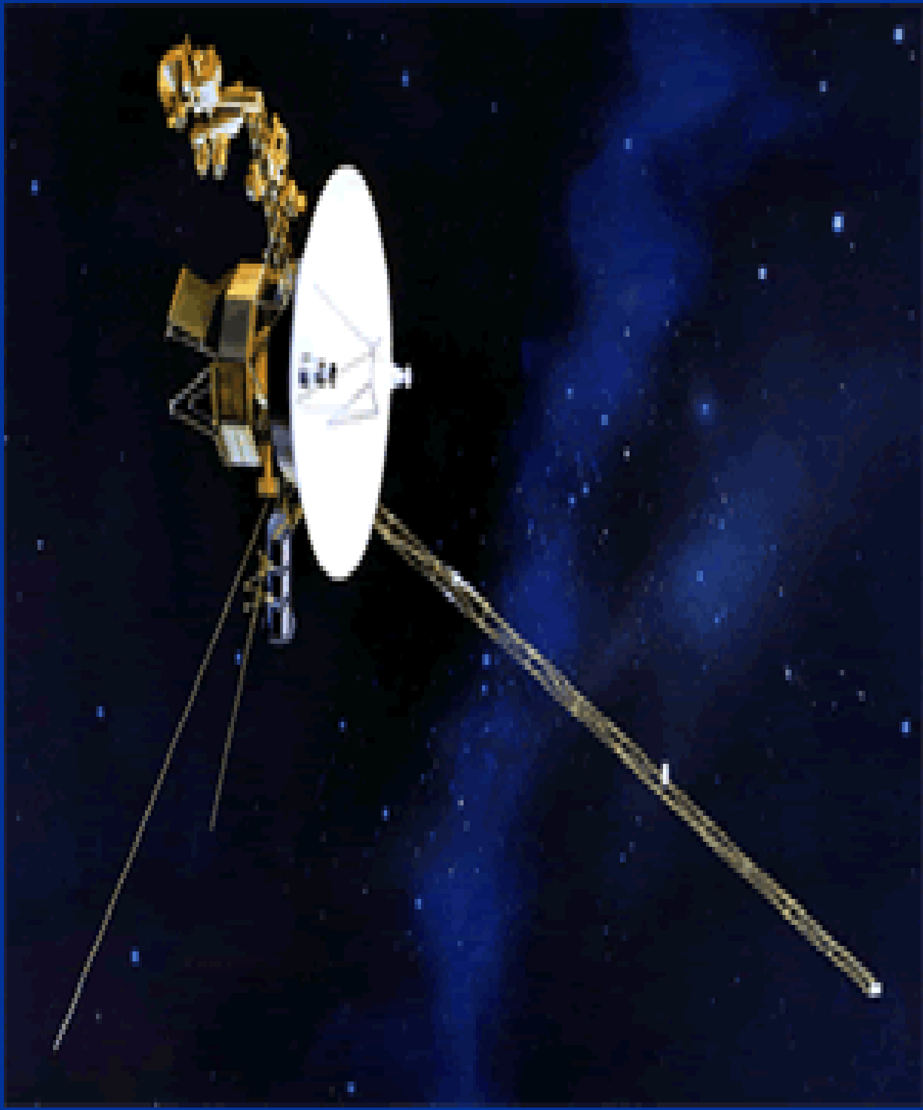
RTGs in Space - History

- 1972: Pioneer 10 & 11 launched to explore the outer planets
  - – Both survived high radiation around Jupiter
  - – Both crafts left solar system after mission performed and continued to send data for 17 years
  - – Still in contact with crafts



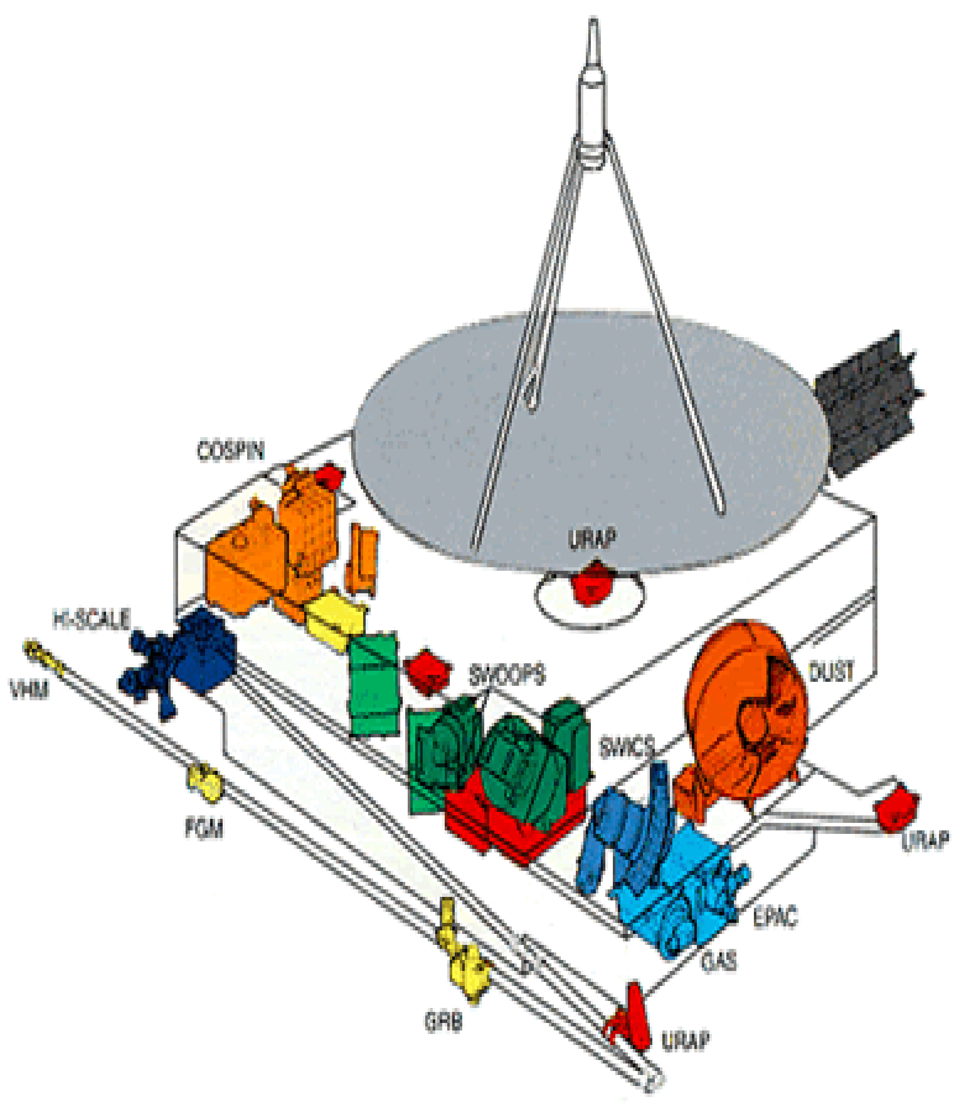
RTGs in Space - History

- 1977: Voyager 1&2 launched to explore the outer planets
  - – Transmitted high speed data and first high-quality pictures
  - – Both crafts left solar system after mission was performed and continue to send data



RTGs in Space - History

- 1990: Ulysses launched to explore top and bottom of sun
  - – Mission extended after initial successes
  - – First mission to explore solar system outside the ‘disk’ of the planets
  - – Can you see the RTG?



RTGs in Space - History

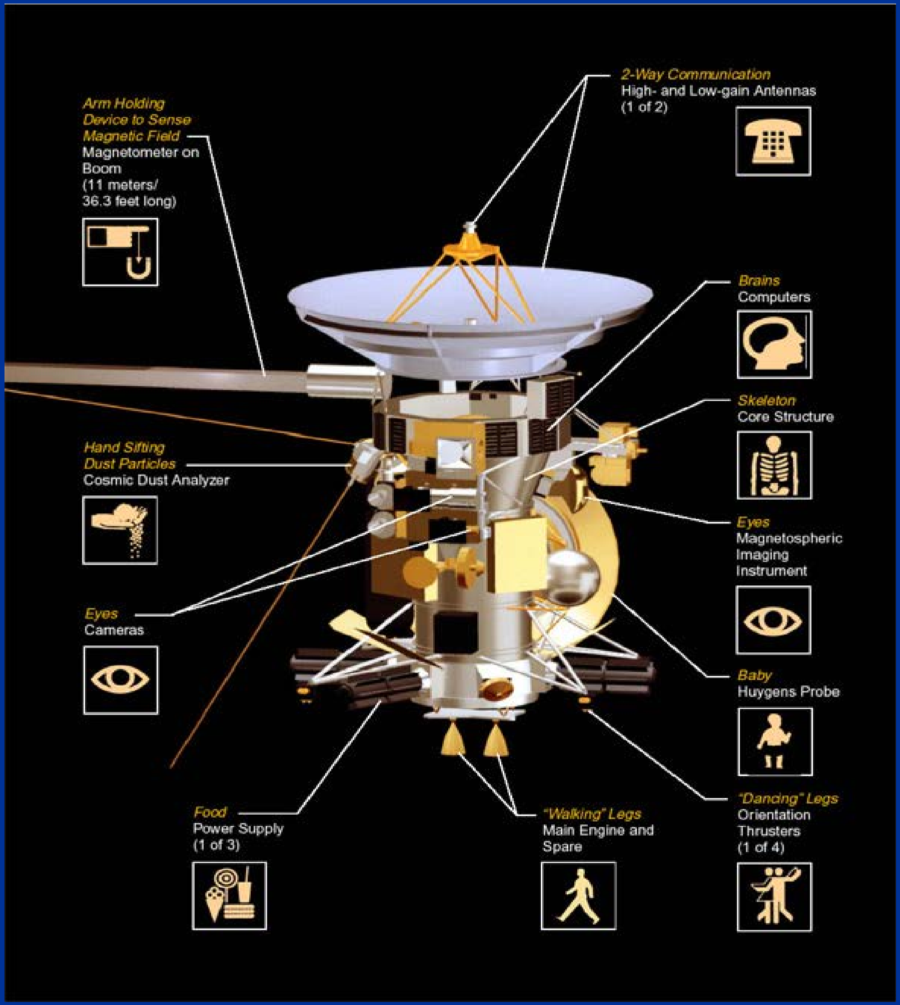
- 1989: Galileo launched to explore Jupiter and her moons
  - –Took the long-way to Jupiter; by Venus and Earth twice
  - –Required long-lived power supply to make the 4-year flight
  - –Operated for 14 years
  - –Can you see the RTG?

RTGs in Space - History

- Galileo also needed heat for its long mission
- 120 - 1watt Radioactive Heater Units (RHU) placed all over the spacecraft
- Safety design similar to RTGs

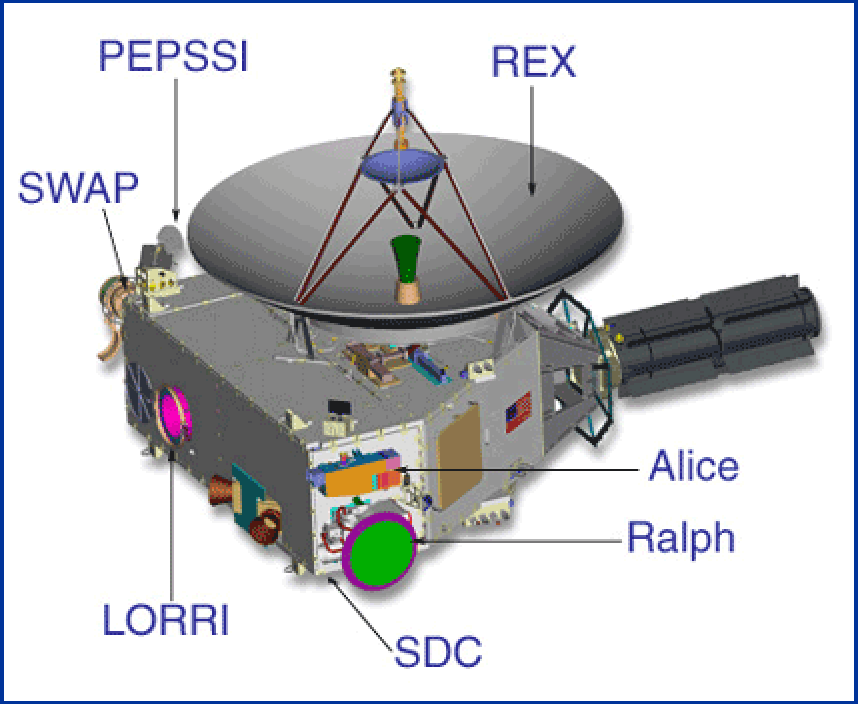
RTGs in Space - History

- 1997 -Cassini Mission to Saturn and moons
  - – 3 General Purpose Heat Source RTGs (current generation)
  - – 4-year mission once the craft gets to Saturn.
  - – Great results coming back from craft
  - – Recently discovered new moon of Saturn



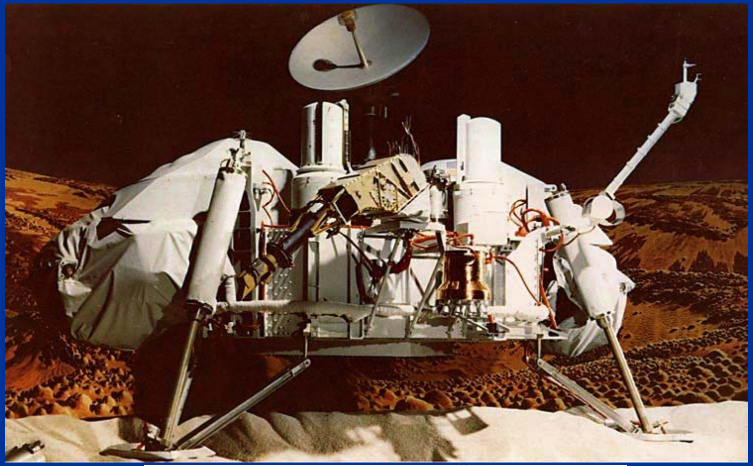
RTGs in Space - History

- January 2006
- New Horizons Mission
  - –Pluto & Charon
  - –Kuiper Belt Objects

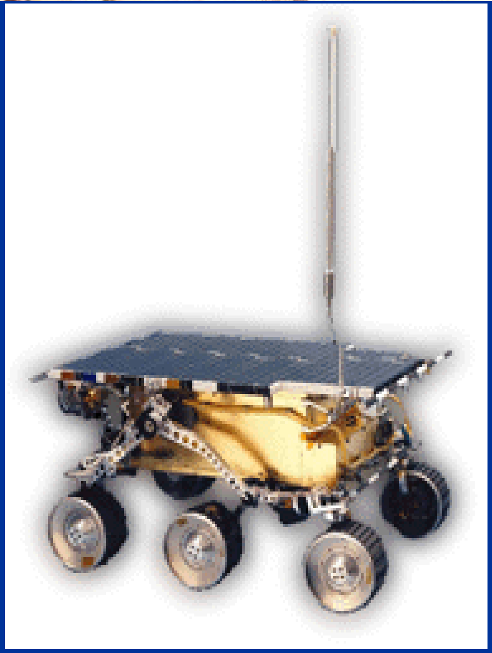


RTGs in Space - History

- Viking Landers- 1975
  - Used RTGs for power
  - 6 Years on Nuclear Power



- Mars Pathfinder-1997
  - Rover used RHUs for heat
  - 3 months on solar power



THANK YOU

MRI:
Radio Waves &
Magnetic Fields

MRI – Magnetic Resonance Imaging

- Utilizes magnetic fields and RF (radio-frequency) energy to gain information via Nuclear Magnetic Resonance
- No ionizing radiation is used in this process