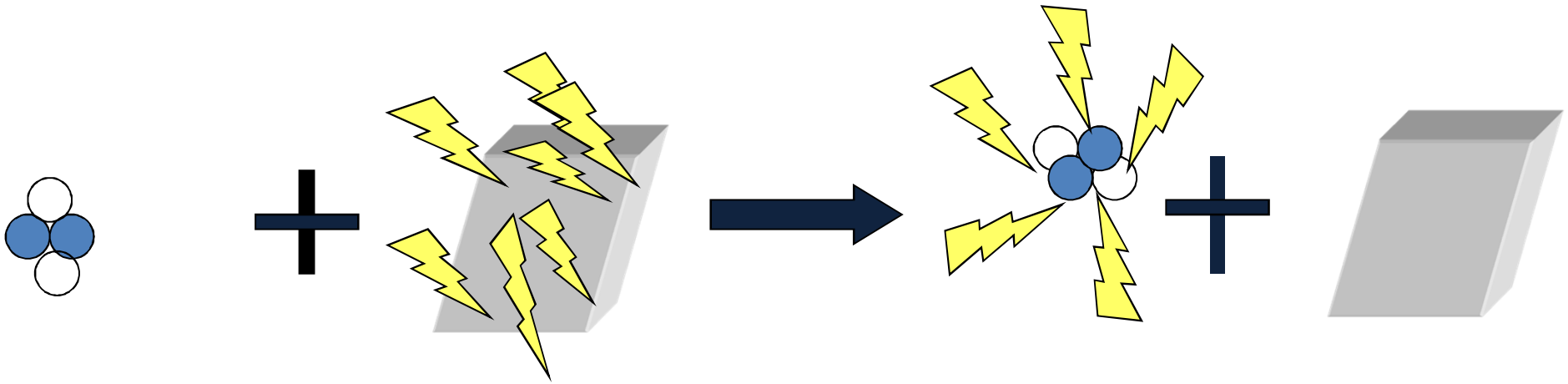
Applications of Radiation

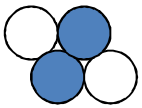
Overview

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

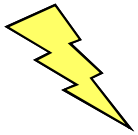
Alpha Radiation

- Highly ionizing
- Removes Static Charge





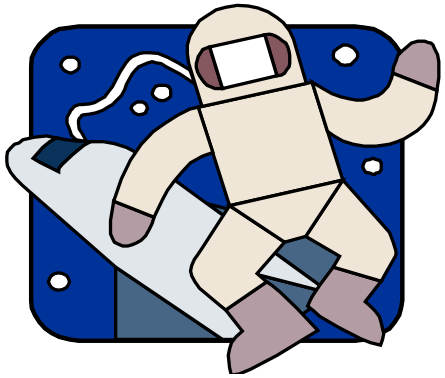
Alpha Particle

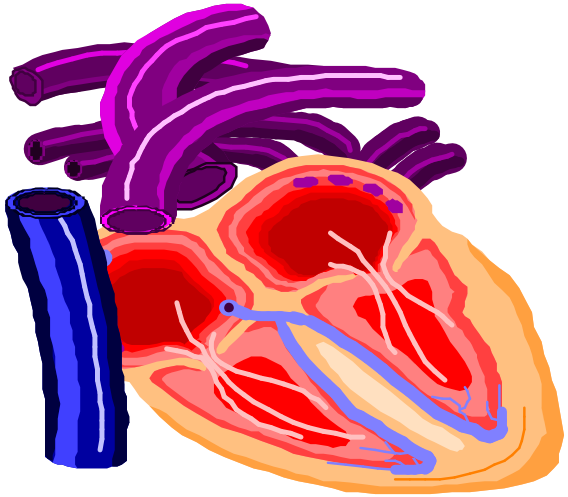


Static Charge

Uses of Alpha Radiation

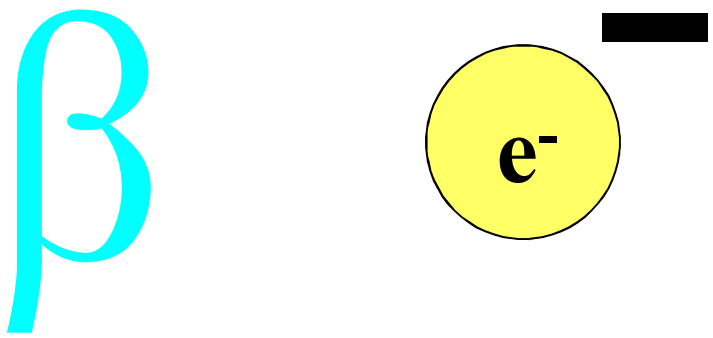
- Pacemakers (Older models)
- Airplanes
- Copy Machines
- Smoke Detectors
- Space exploration



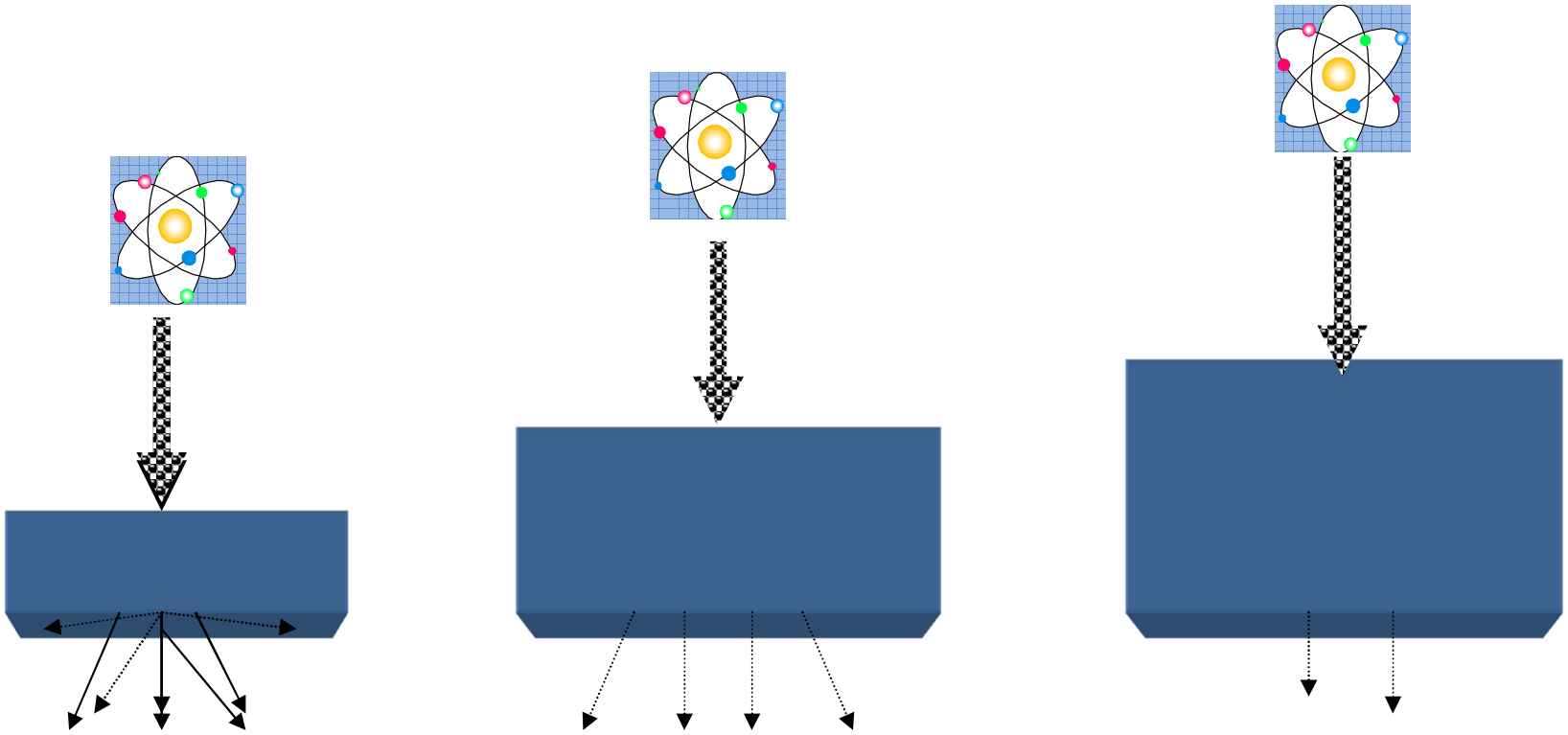


Beta Radiation

- Small electron particle
- More penetrating than alpha



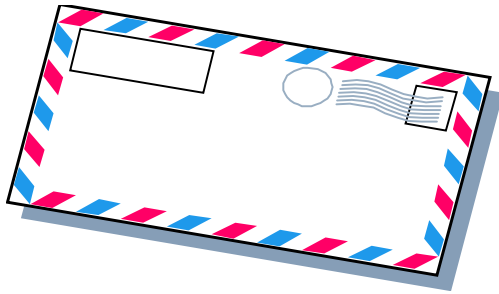
Beta Radiation is used in thickness gauging

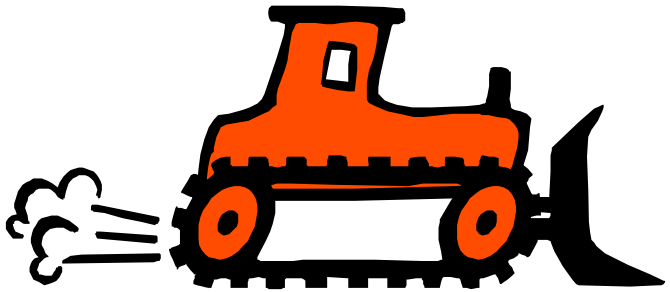


The thicker the material, the less radiation will pass through the material.

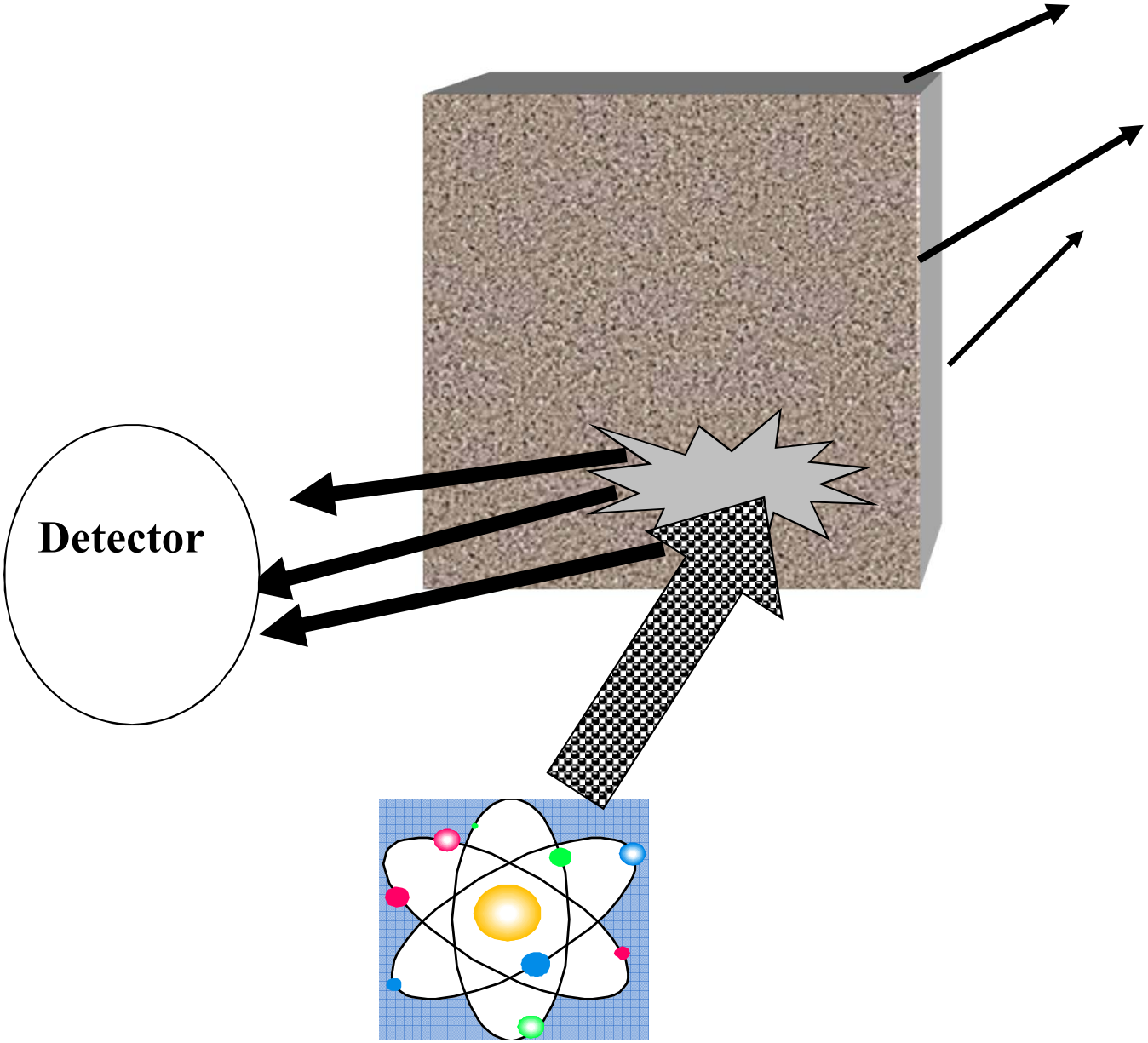
Gauging is used to:

- 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.

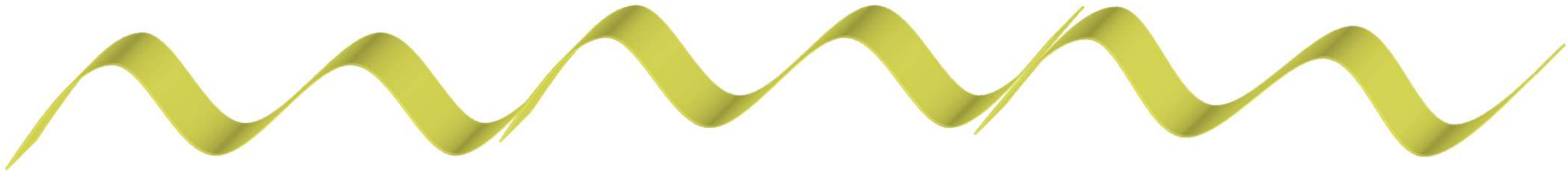




Back Scattering



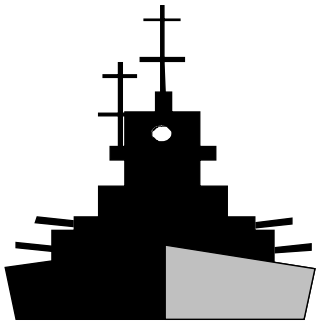
Gamma Radiation γ

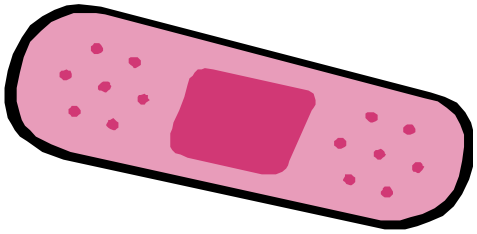


A penetrating wave

Uses for Gamma radiation

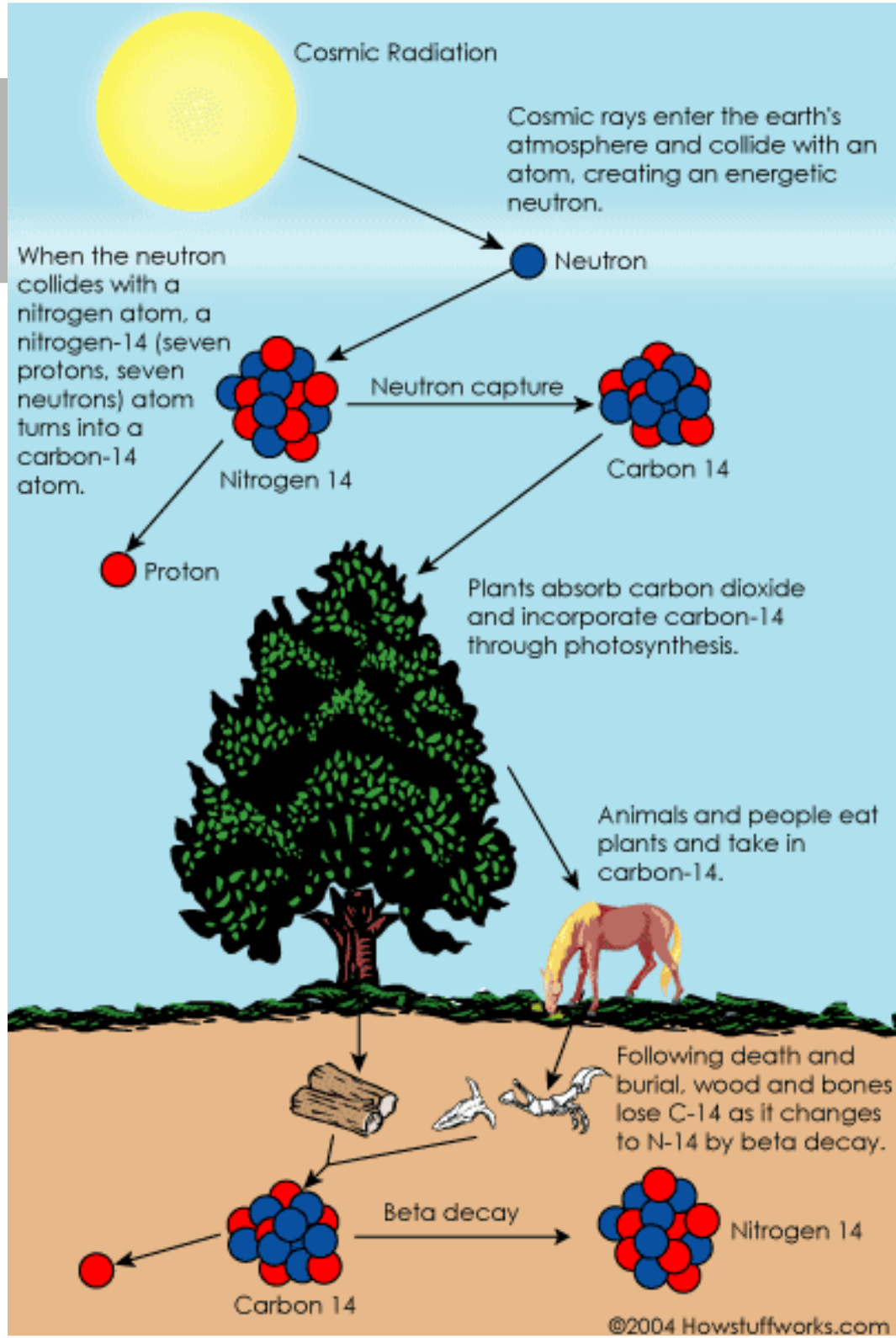
- Food irradiation
- Sterilization of medical equipment
- Creation of different varieties of flowers
- Inspect bridges, vessel welds and Statue Of Liberty.





Nitrogen-14 Carbon-14 Cycle

http://science.howstuffworks.com/environmental/earth/geology/carbon-141.htm



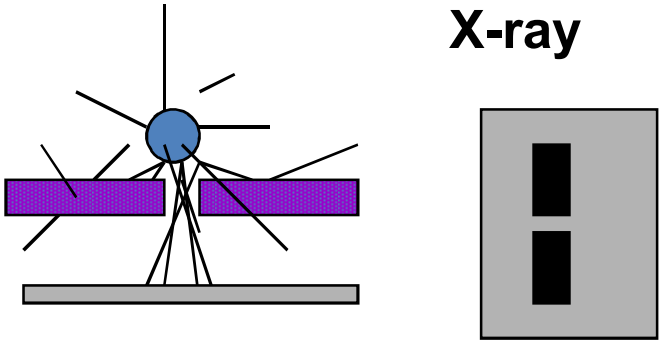
What were original uses of mysterious rays?

- Becquerel's discovery
- Roentgen X-ray of Wife's hand
- Marie Curie – WWI – x-ray unit

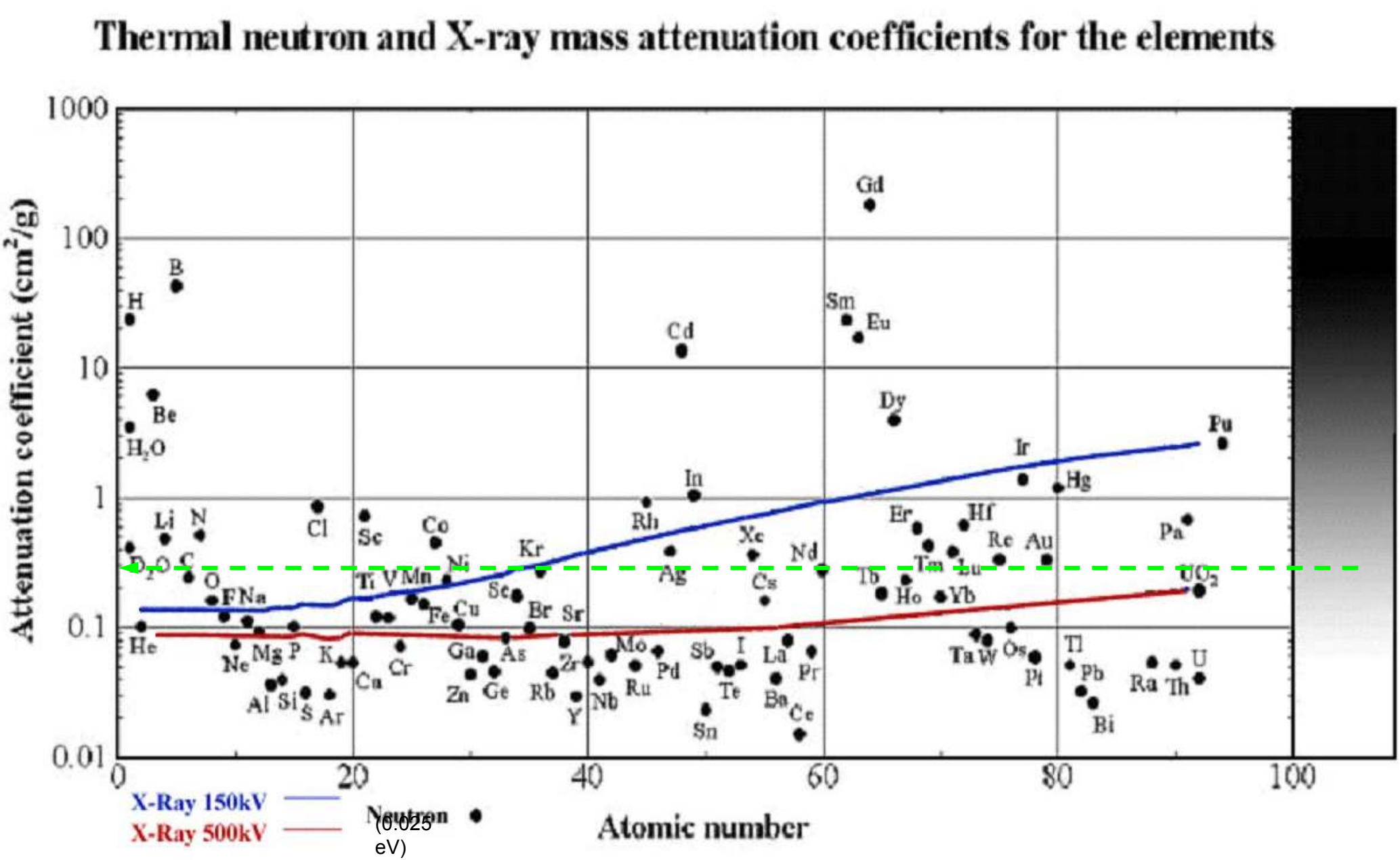
Early X-ray

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

Radiographs



- Radiograph - radiation energy passes through object
- Autoradiograph - use radiation from object itself

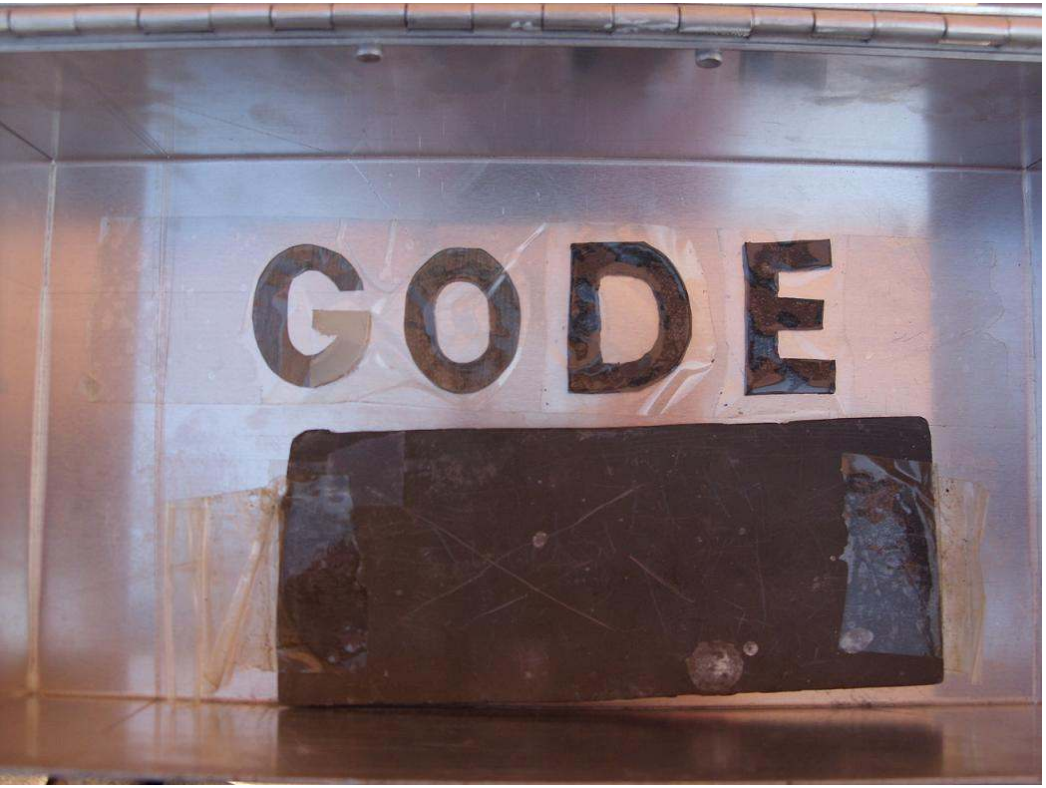

Thermal neutron and X-ray mass attenuation coefficients for the elements
Attenuation coefficient (cm²/g)
1000
100
10
1
0.1
0.01
0
20
40
60
80
100
Atomic number
X-Ray 150kV
X-Ray 500kV
Neutron (0.025 eV)
H
B
Be
H2O
Li
N
O
F
Na
Cl
Sc
Co
Ti
V
Mn
Ni
Kr
Fe
Cu
Br
Sr
He
Ne
Mg
P
K
Cr
Ga
As
Al
Si
S
Ar
Zn
Ge
Rb
Y
Zr
Nb
Mo
Ru
Pd
Rh
In
Ag
Sb
I
Te
Sn
Xe
Cs
La
Ba
Pr
Ce
Nd
Sm
Eu
Gd
Cd
Dy
Er
Tb
Ho
Tm
Yb
Lu
Hf
Ta
W
Re
Os
Ir
Pt
Au
Hg
Tl
Pb
Bi
Pa
Ra
Th
U
Pu
UO2

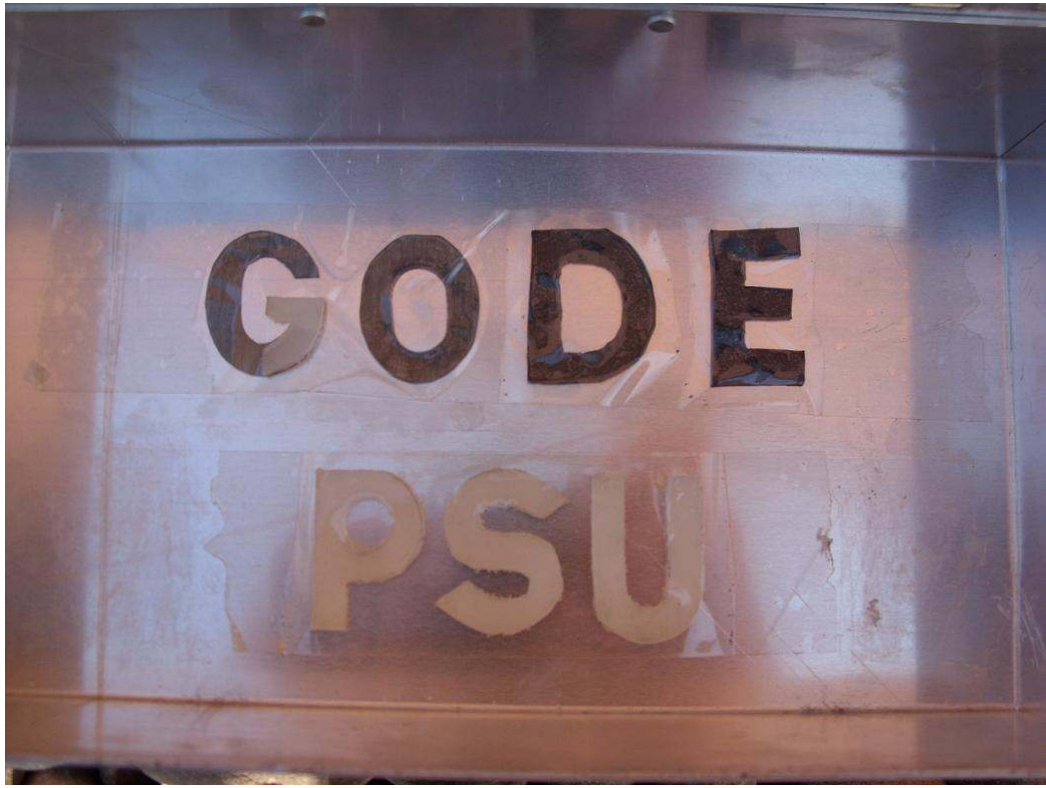
Compare Different Materials

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

CODE Box

Student Project to Demonstrate X-Ray/Neutron Radiography





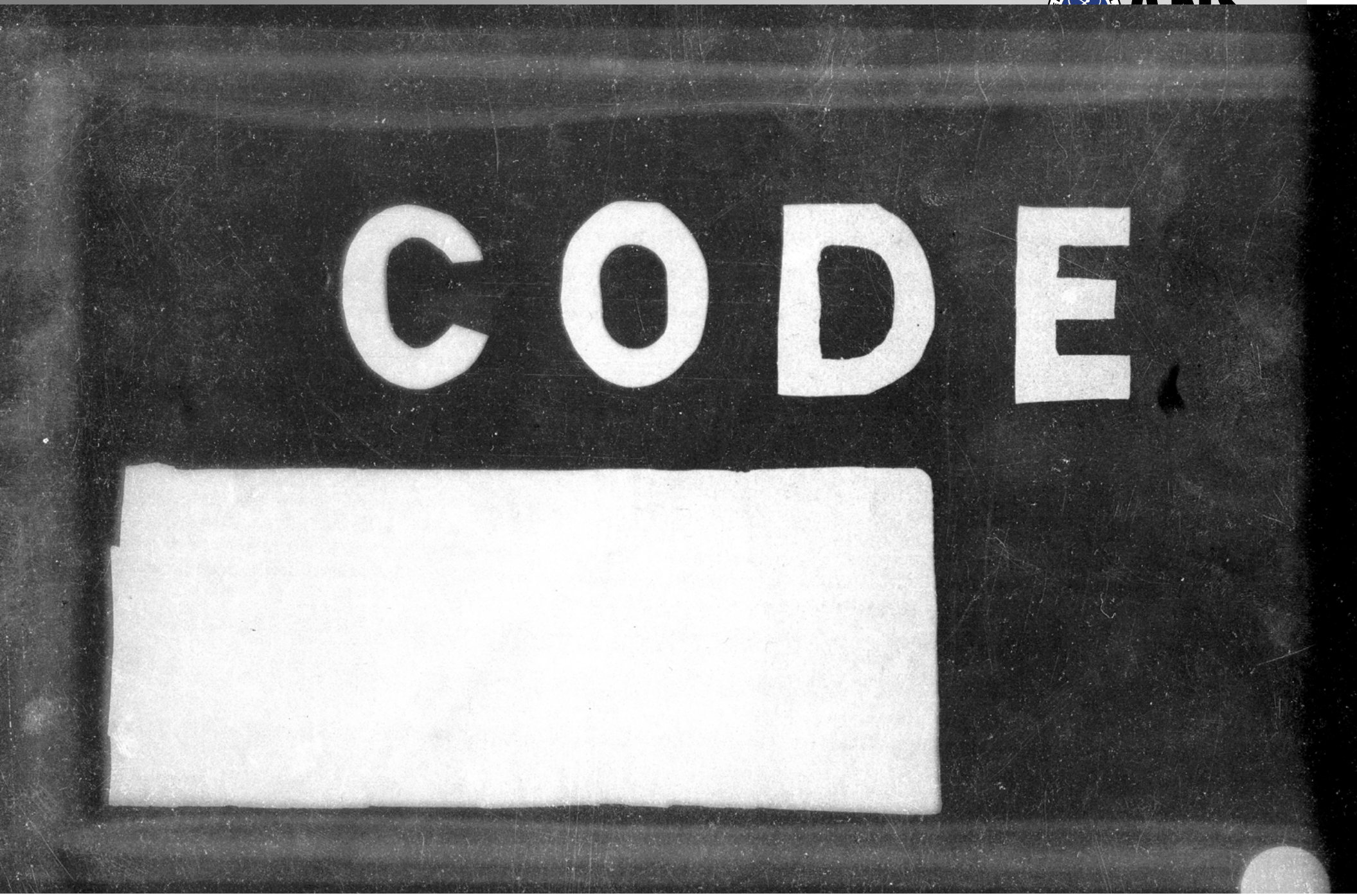
Was originally in cardboard shoe box, but was replaced by more durable aluminum.

Cadmium

Lead

C O D E

X-Ray Image



Cadmium

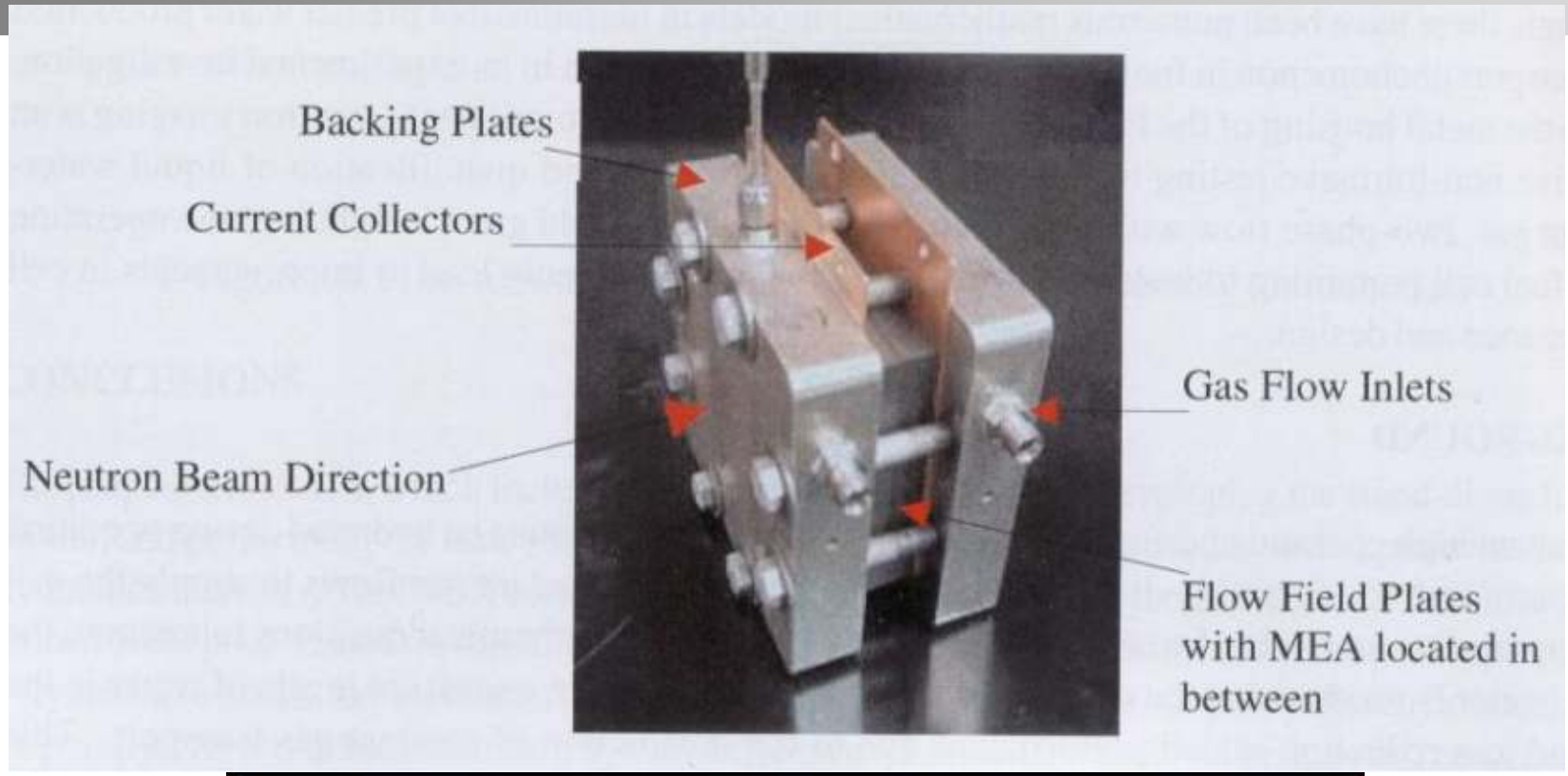
Lead

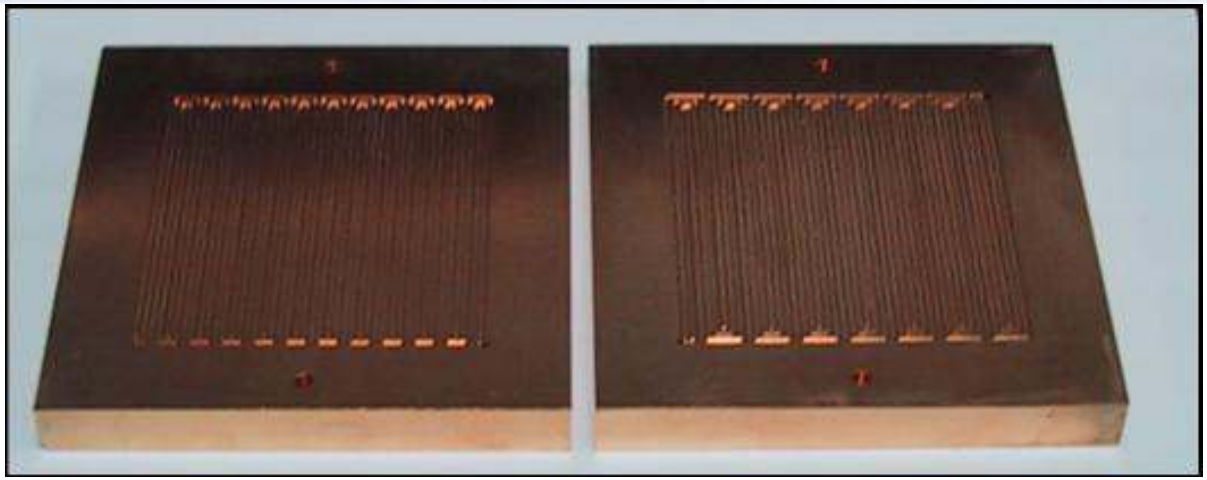
Polyethylene

C–O D E

Neutron Radiograph

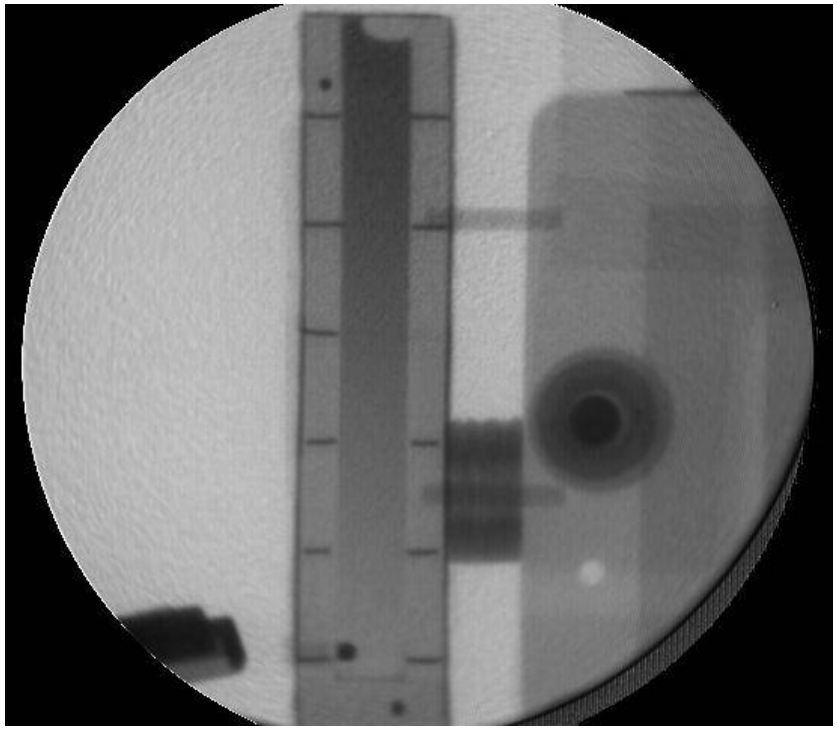
Hydrogen Fuel Cell Imaging



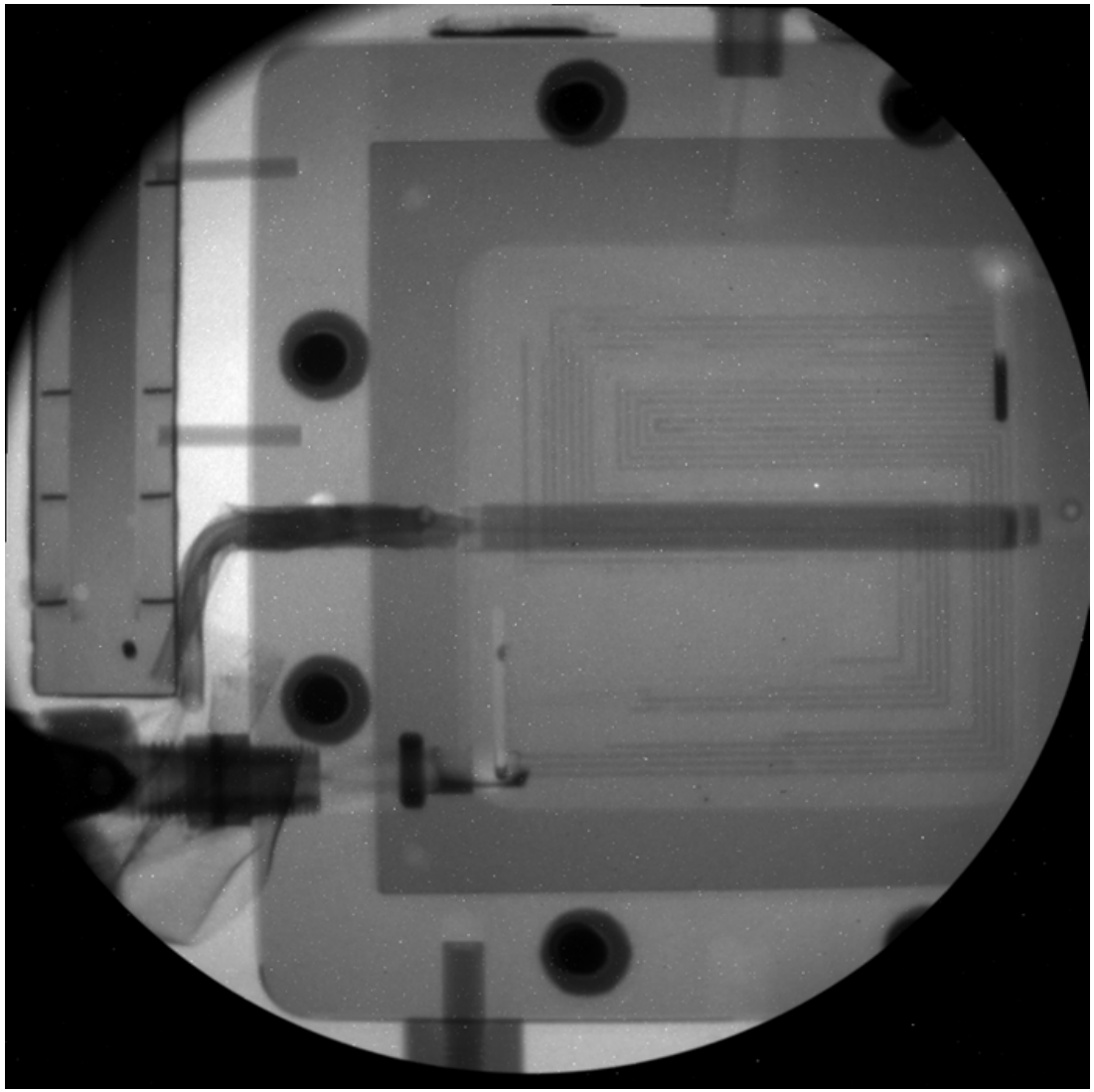


Fuel Cell research conducted at RSEC

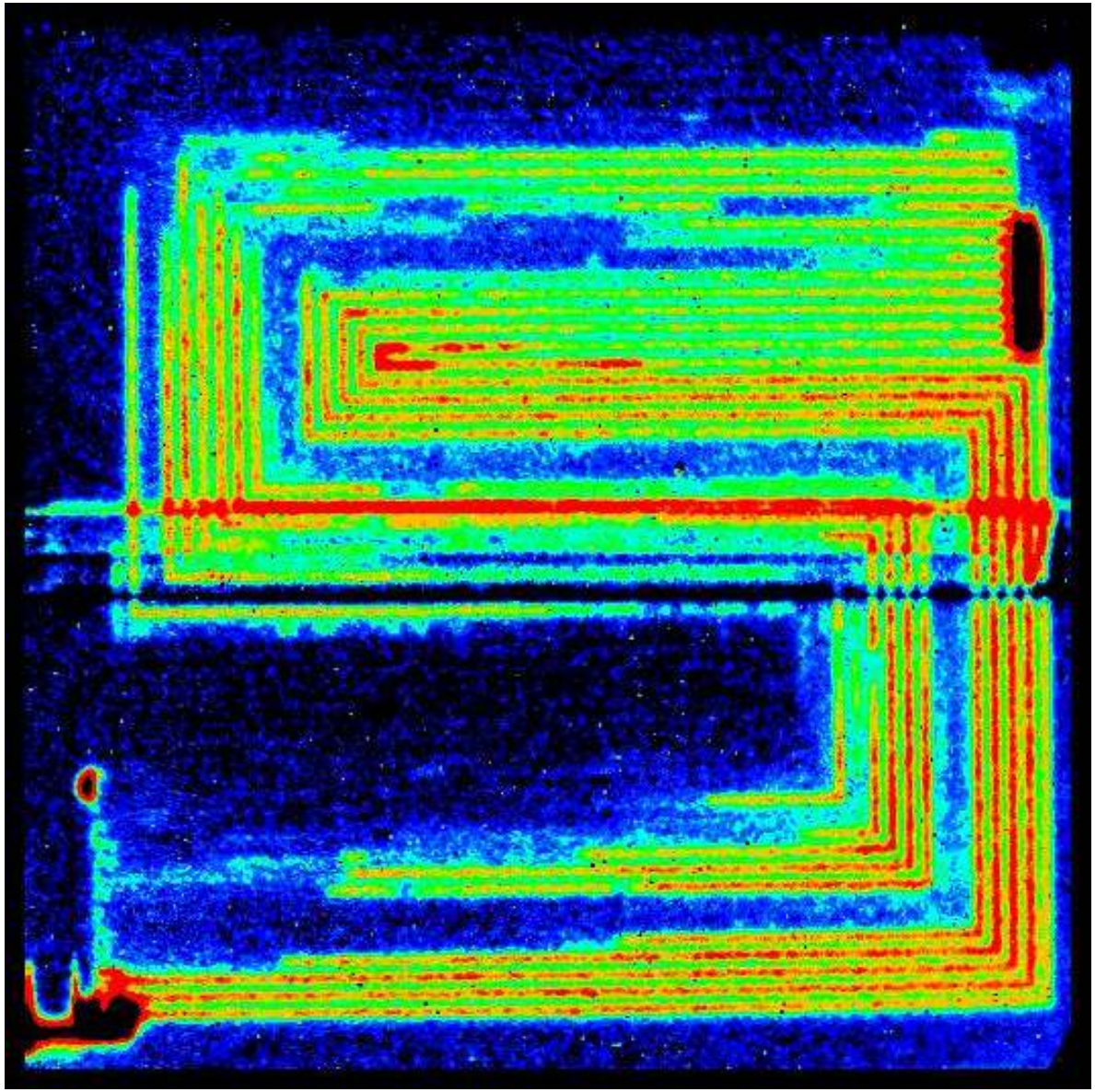
Hydrogen Fuel Cell Imaging



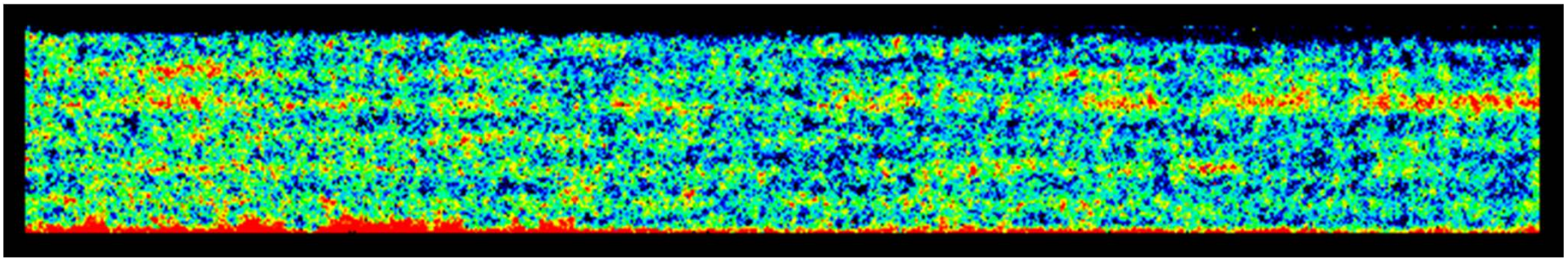
Water Calibration Wedge



Hydrogen Fuel Cell Imaging

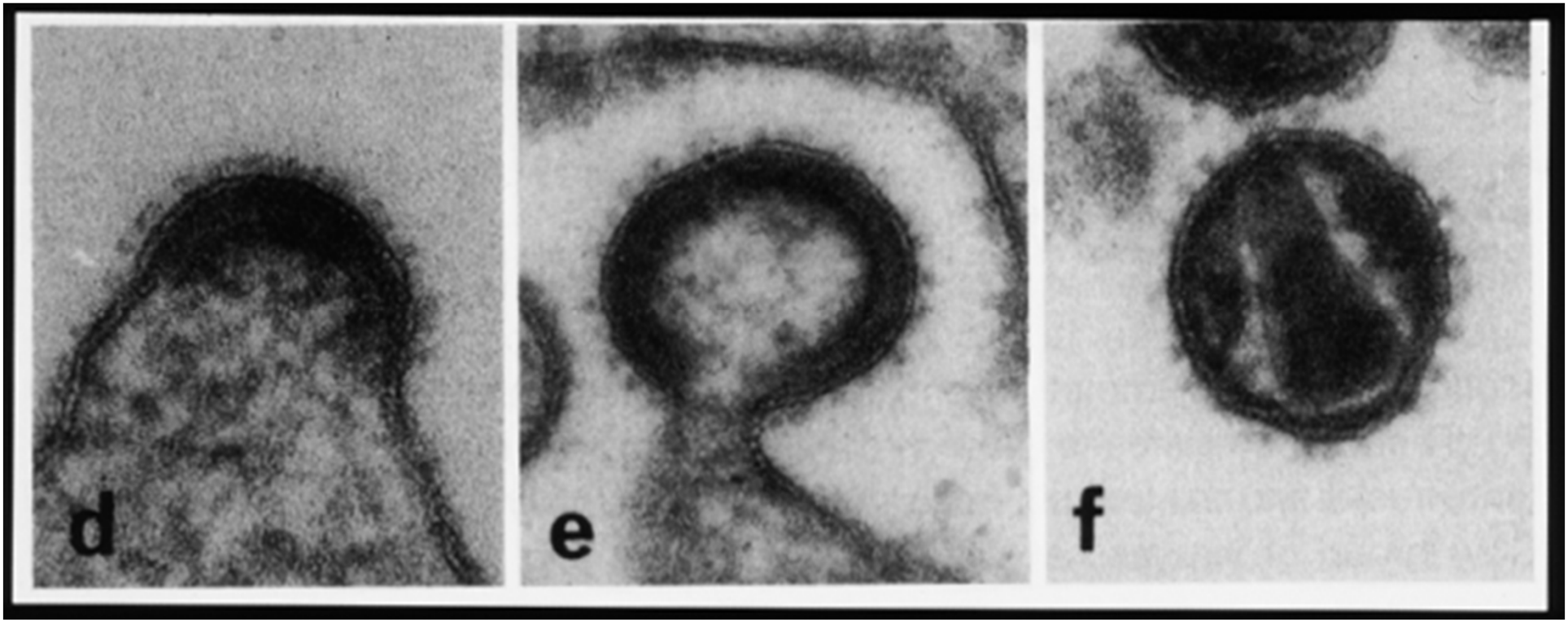


Hydrogen Fuel Cell Imaging



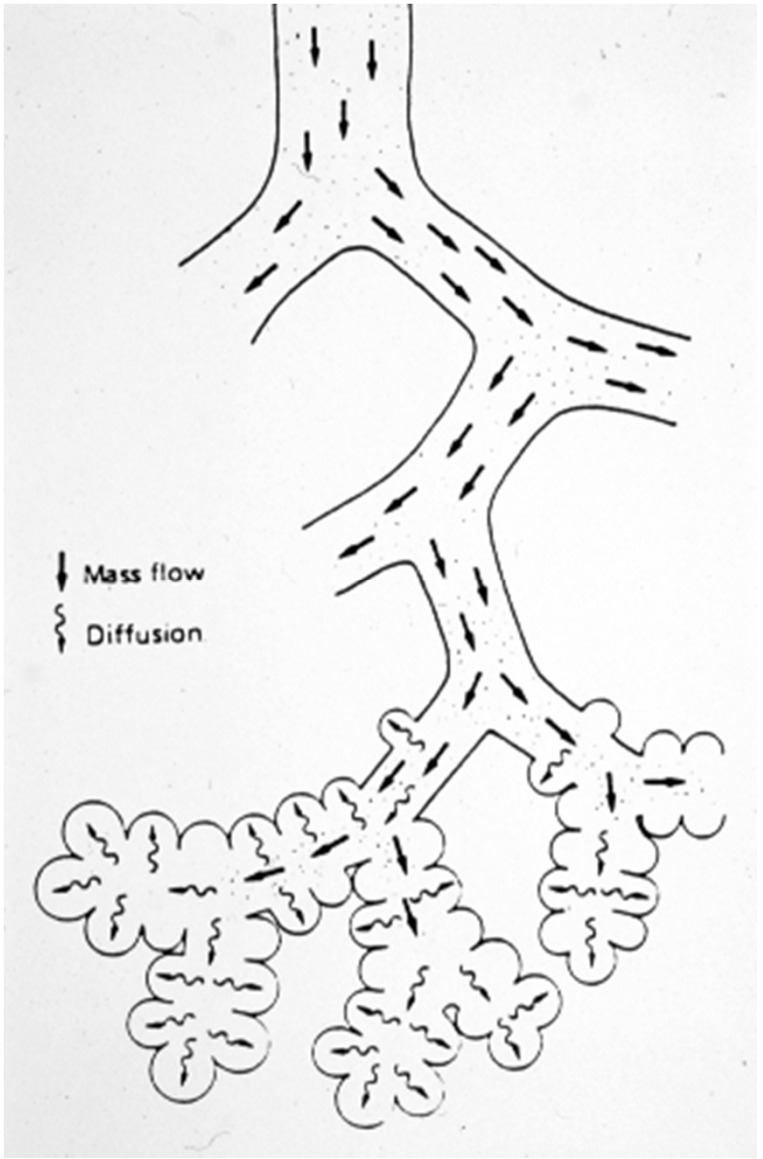
Clinical Uses of Radioactive Materials

Understanding the Replication Process of the HIV Retrovirus



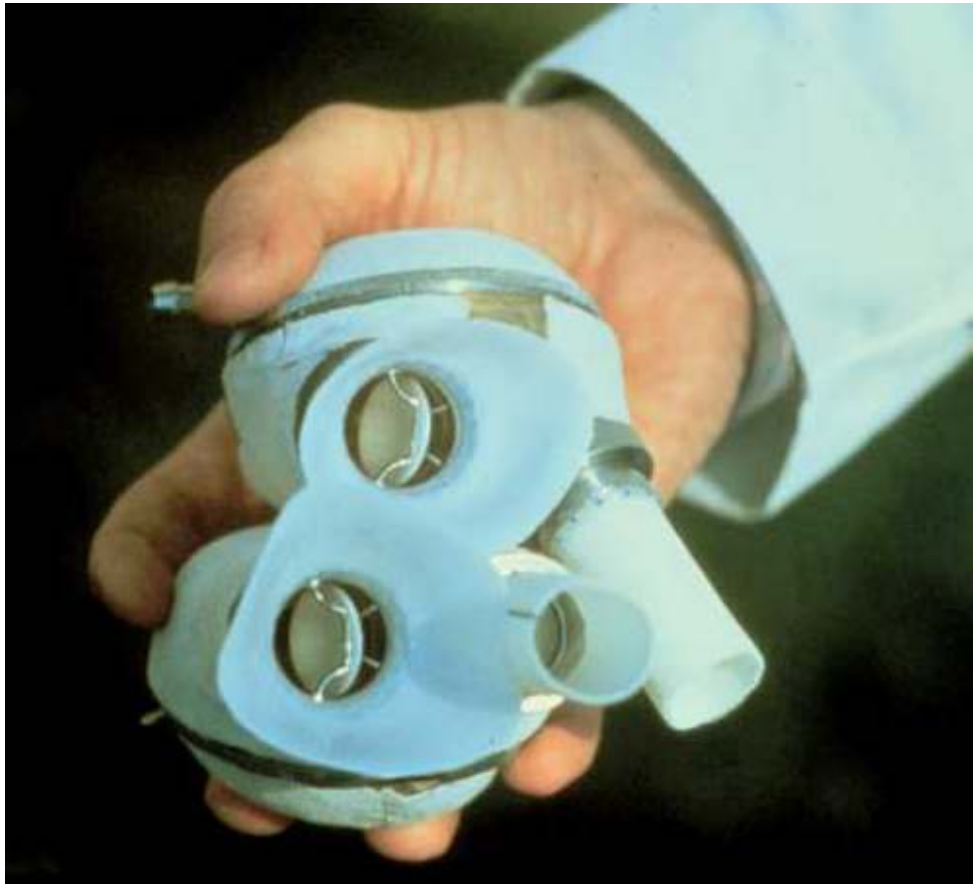
- DNA sequencing, using ^{35}S and ^{32}P, is used to investigate the process by which new viruses "bud" or form from host cells

5000 Premature Infants Die Annually from Respiratory Distress/SIDS

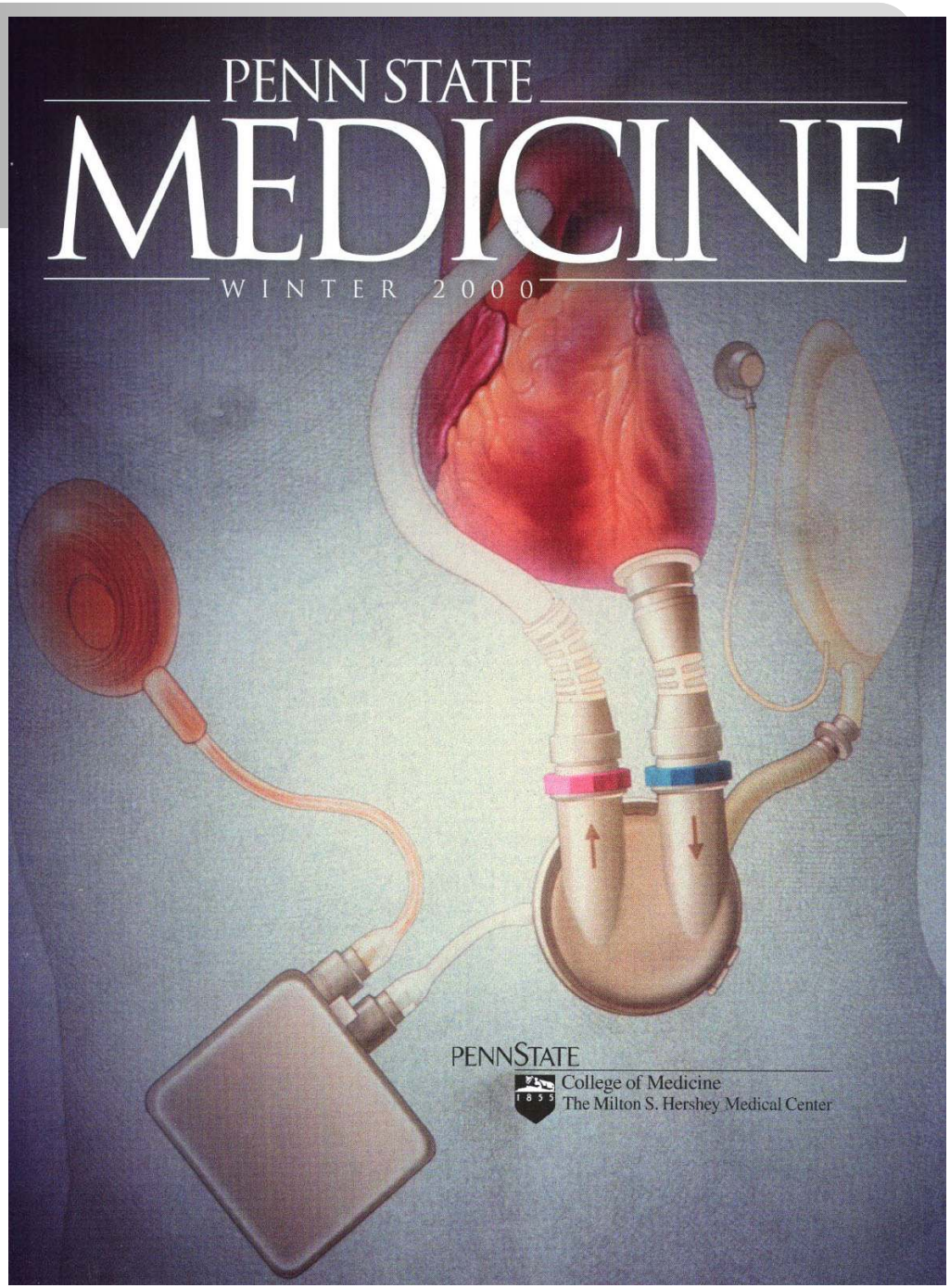


- The infant lacks a protein which produces a surfactant in the lung alveoli
- Without the surfactant, there is too much surface tension – the lung is too weak to expand. A respirator is needed.
- ^{32}P-research identified the missing protein
- Gene therapy may one day be available

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 - Related
  - Drugs of Abuse
  - Newborn Screening
  - Reproductive Hormones
  - Therapeutic Drugs
  - Thyroid Function
  - Tumor Markers
  - Veterinary Tests

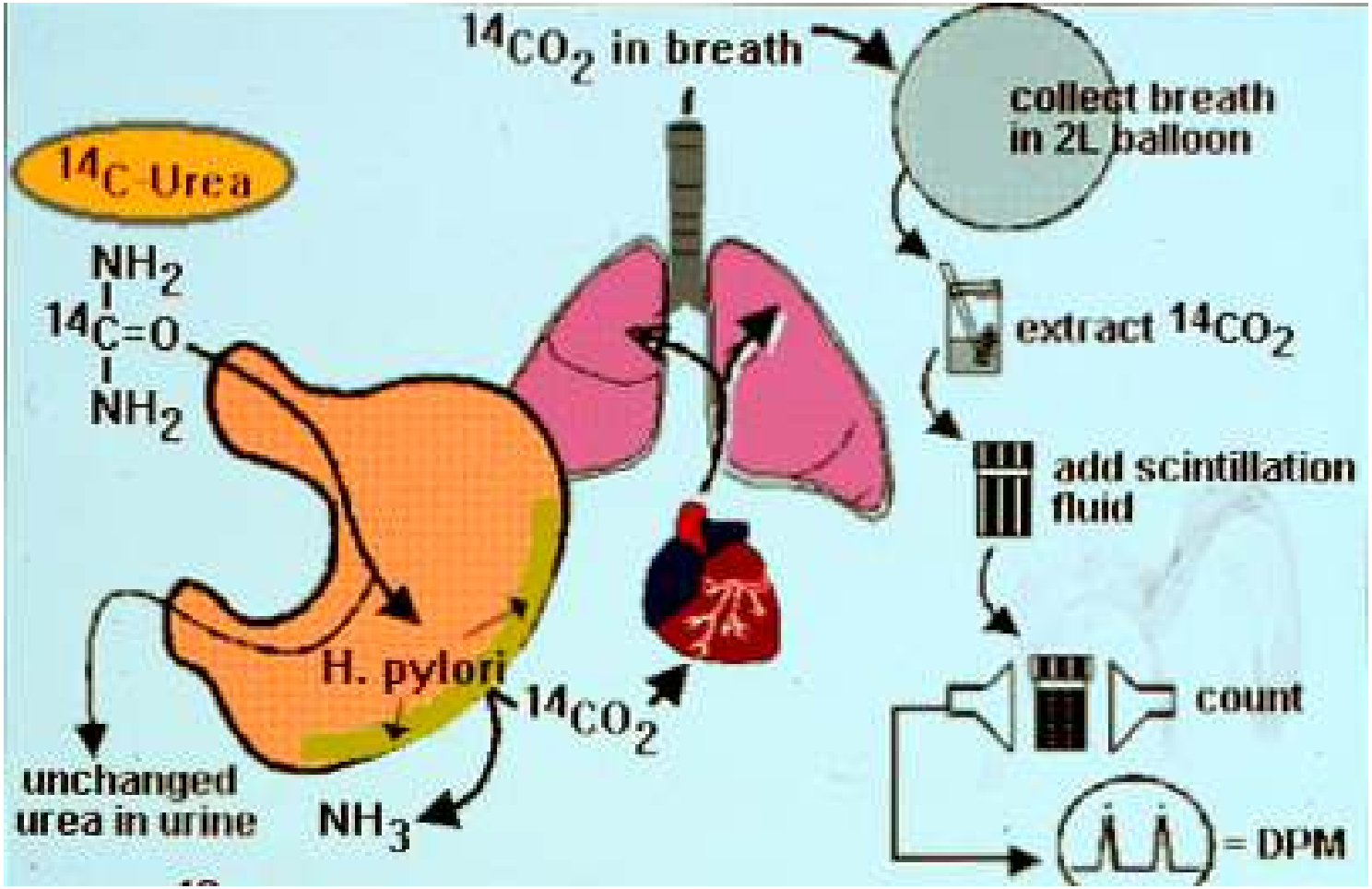
RIA Kit

- 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

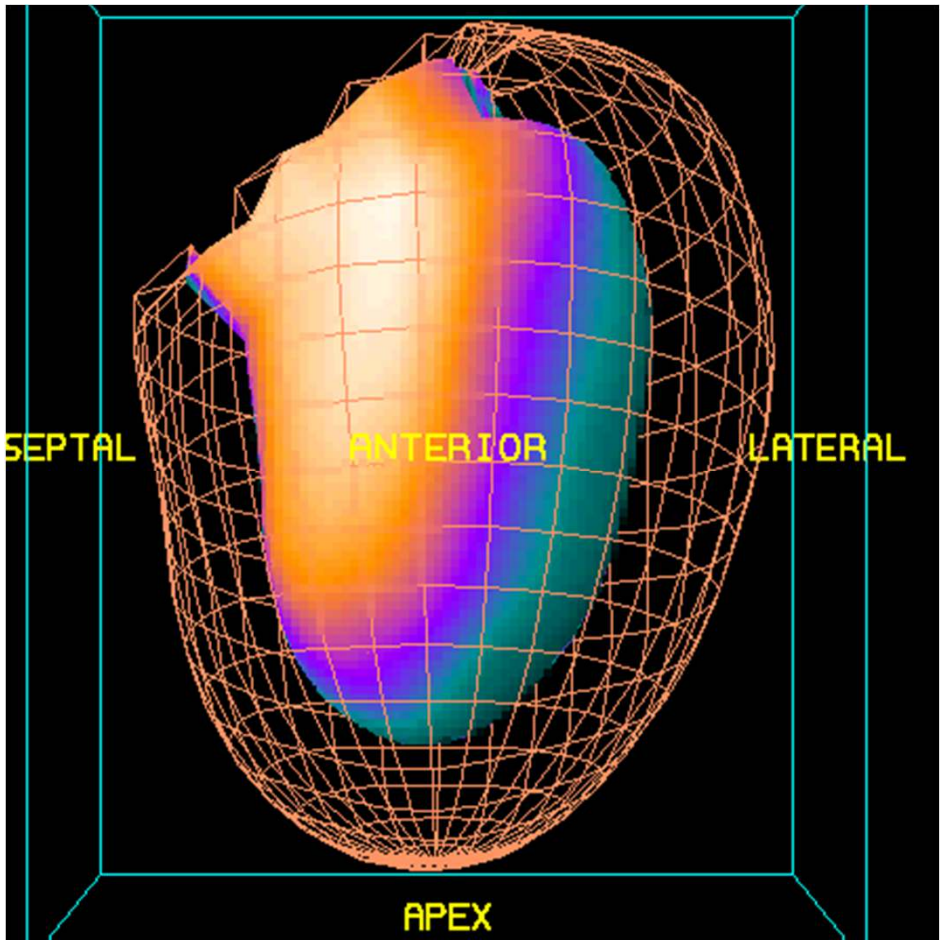
- Delivers 2500 rads to blood products
- Reduces potential for Graft-vs-Host Disease
- Essential for bone marrow transplants

Diagnostic Radiology Modalities

- X-Ray (Roentgenology)
  - Radiography
  - Fluoroscopy
  - CT (Computed Tomography)
  - Interventional Radiology
    - Angiography
    - Cardiac Catheterization
    - Neuro-Interventional

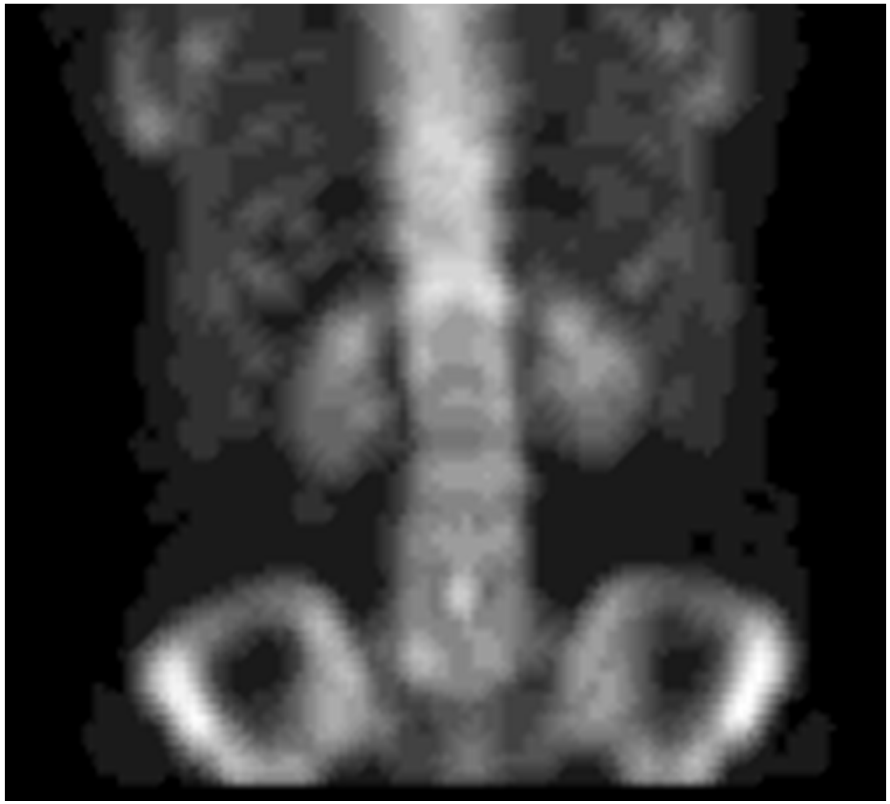
Heart Image

- 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

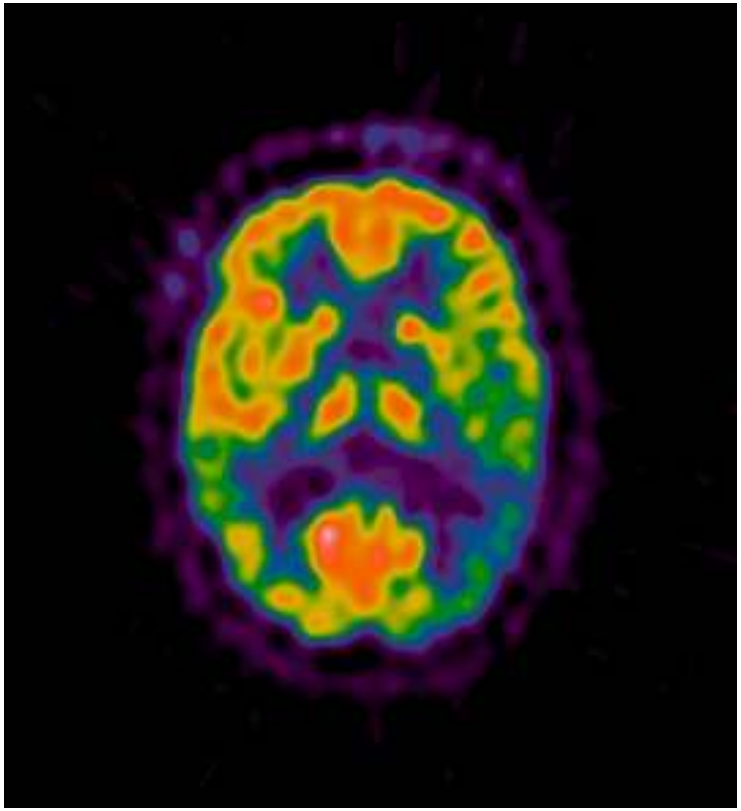


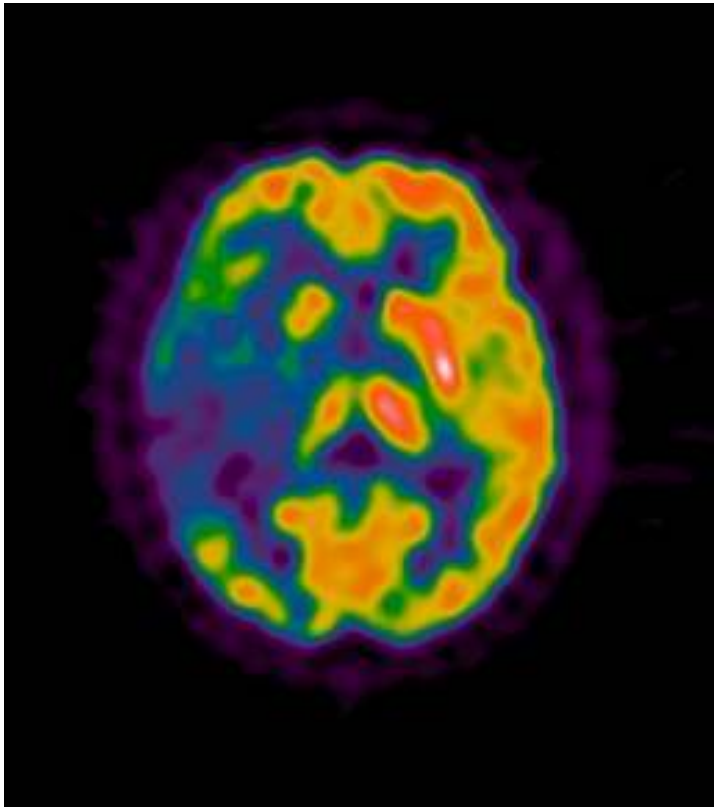
Nuc Med & Radiographic Images Compared

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

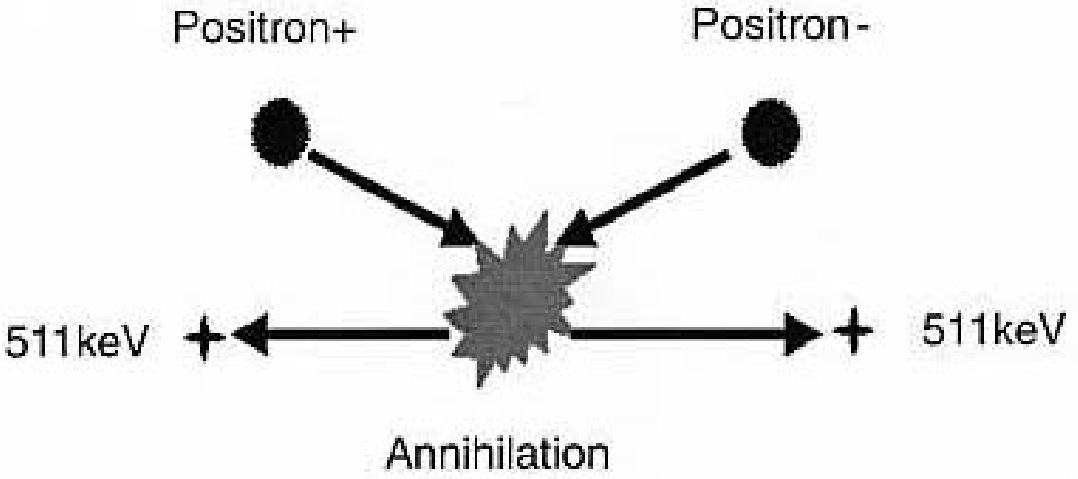


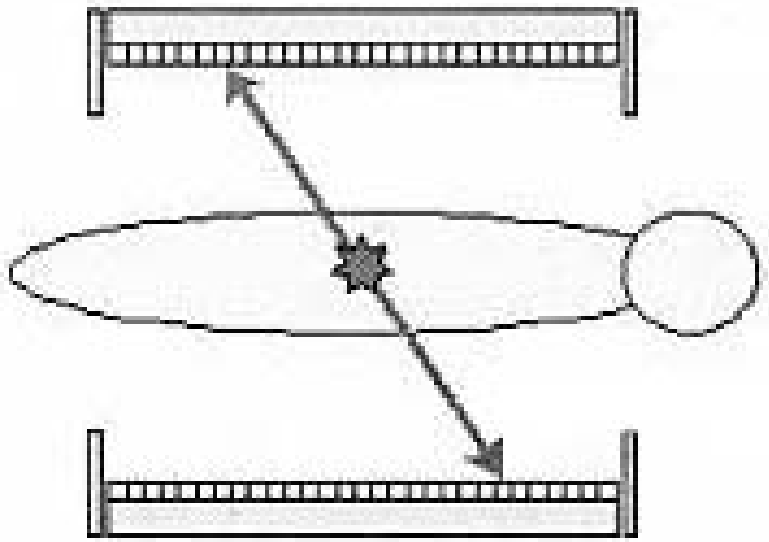


- ^{18}FDG Images of a normal vs an epileptic brain
- Rapidly growing in popularity for tumor imaging

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



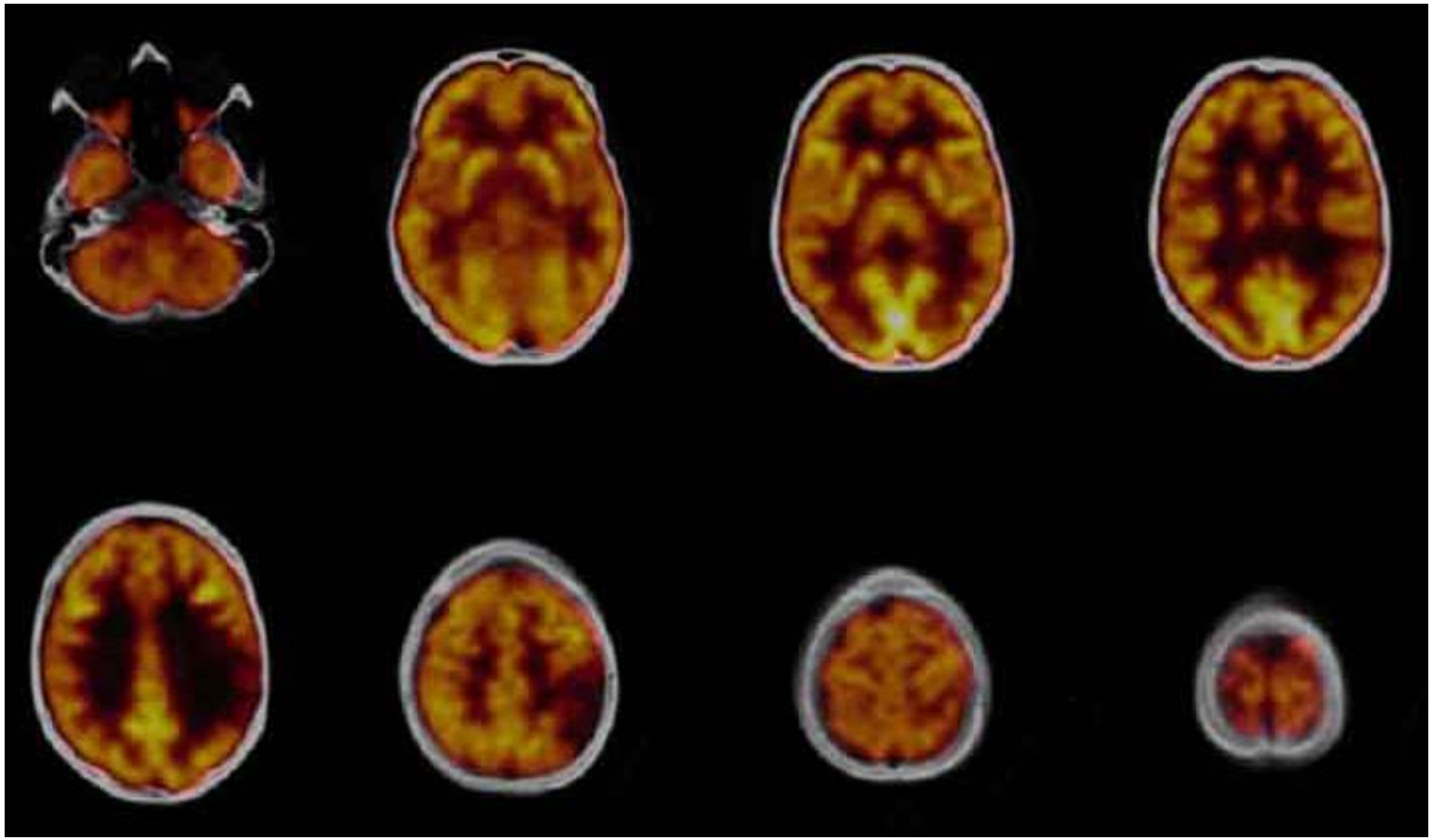


PET Scanner Coincidence Detectors

^{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 are in left posterior temporal lobe

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 Some Medical X-ray Exams

- 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

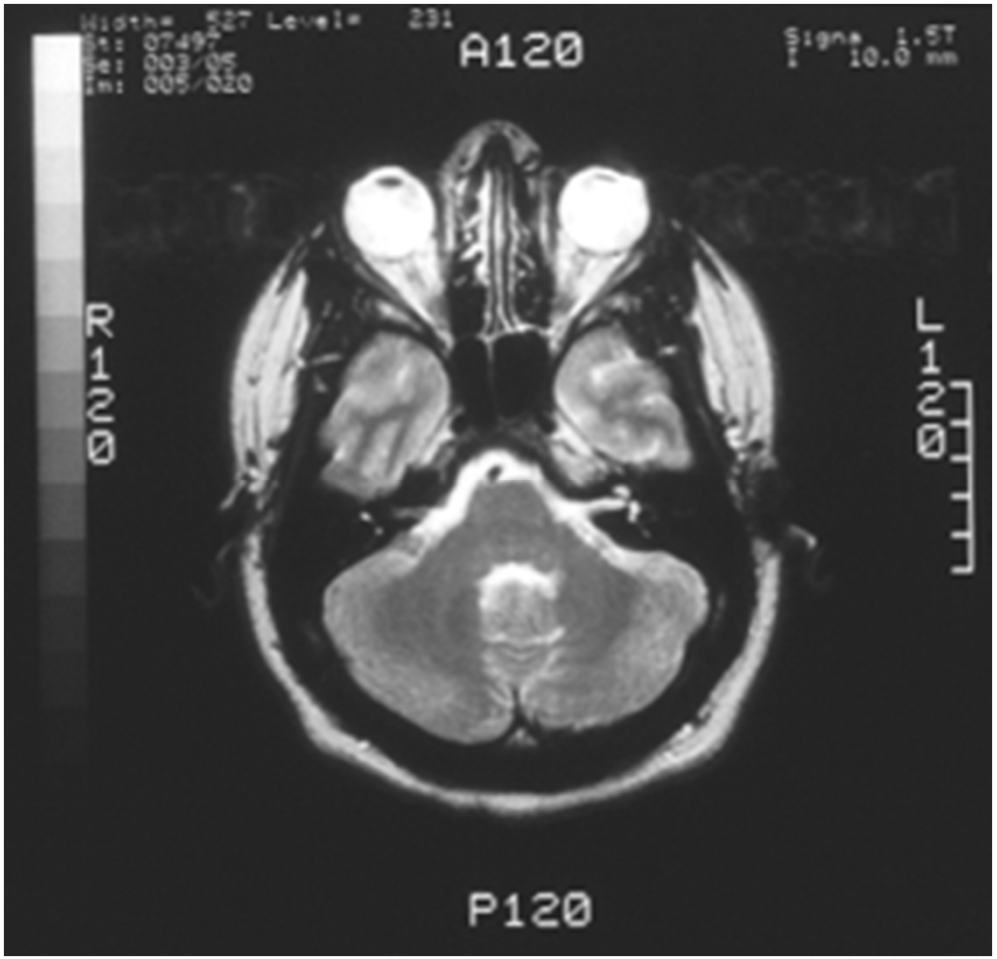
Radiation Doses and Dose Limits

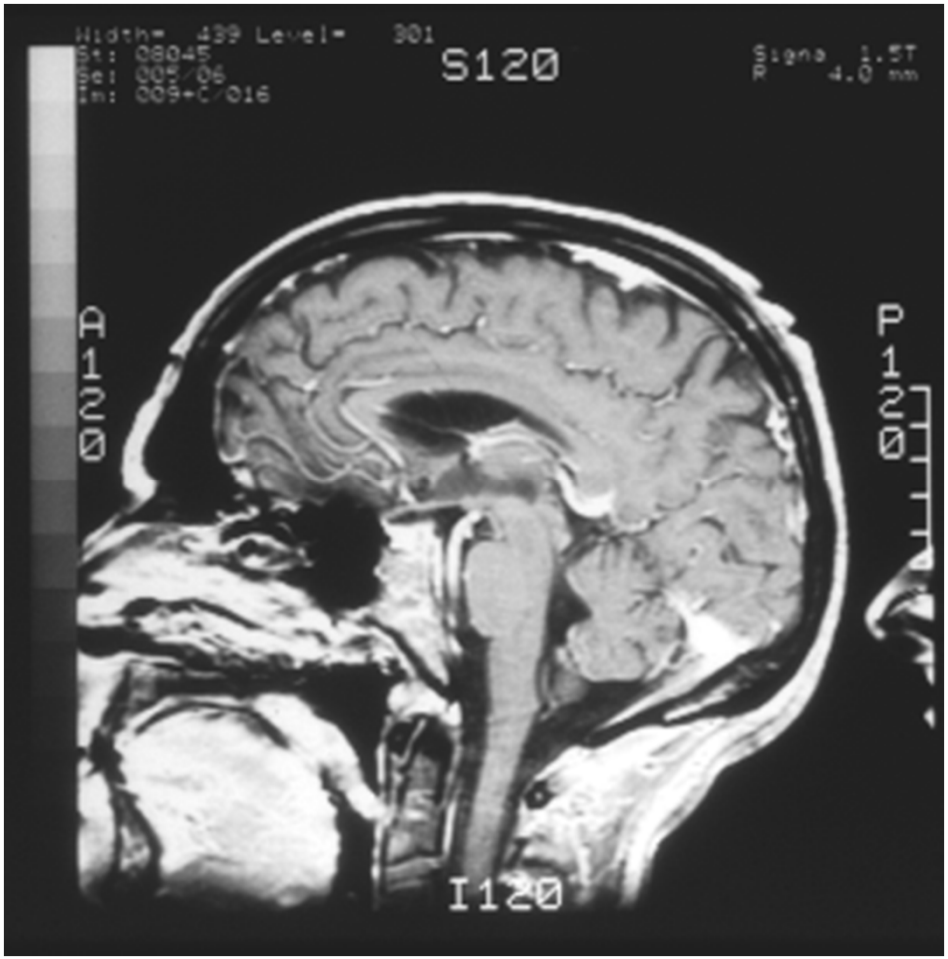
Flight from Los Angeles to London	5 mrem
Annual public dose limit	**100 mrem**
Annual natural background	300 mrem
Fetal dose limit	**500 mrem**
Barium enema	870mrem
Annual radiation worker dose limit	**5,000 mrem**
Heart catheterization	45,000 mrem
Life saving actions guidance (NCRP-116)	50,000 mrem
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

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





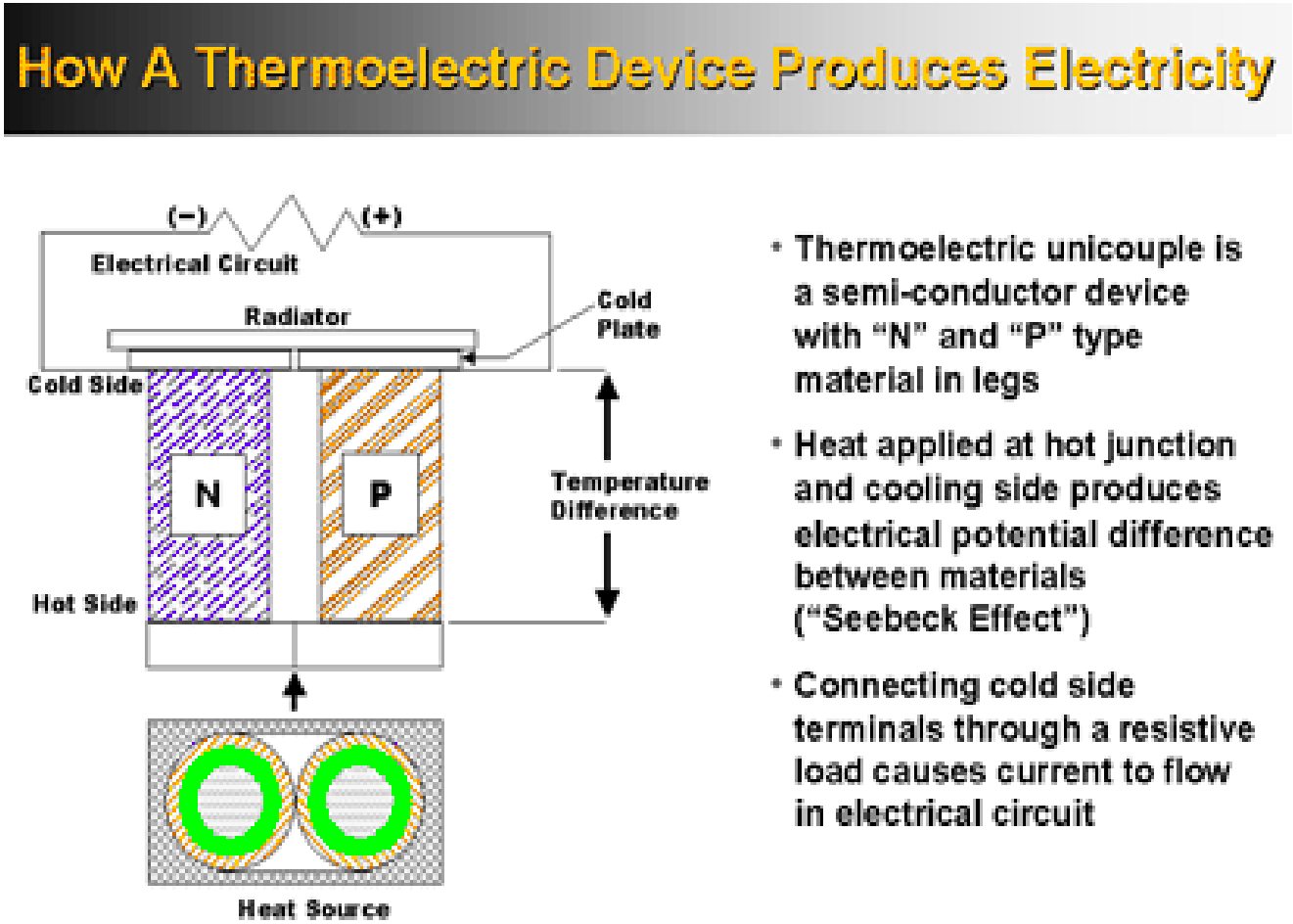
Electricity in Space - RTG

- Nuclear Options:
  - Radioisotope Thermoelectric Generators (RTG)
    - Work on the principle of radioactive decay.
    - Energy is proportional to activity.
    - Activity is 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

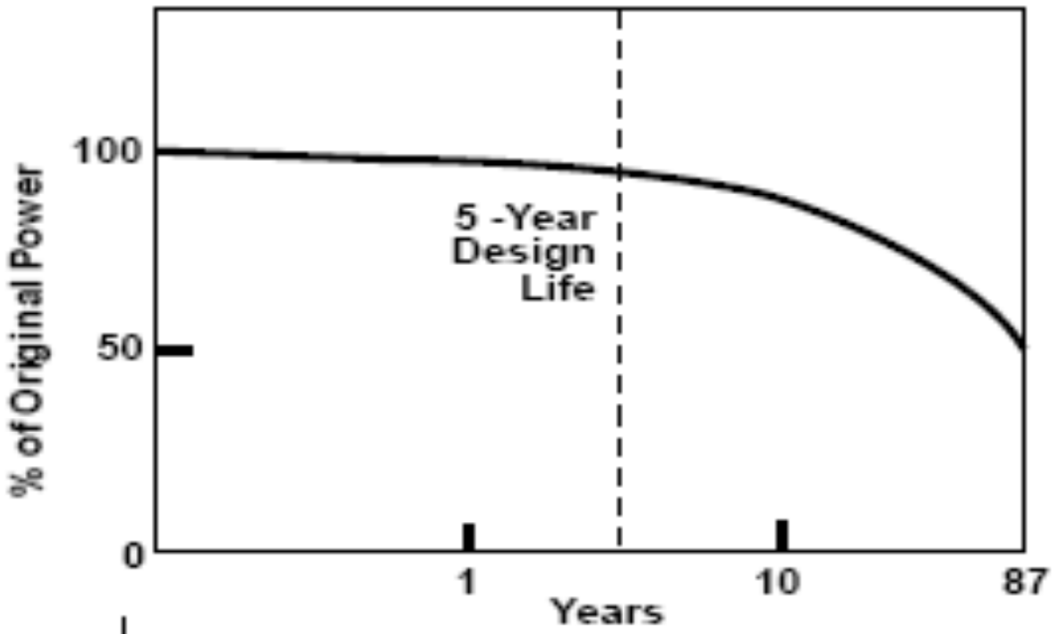
•Works on the thermoelectric principle also known as the 'Seebeck Effect'.



This is about 10% efficient.

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.

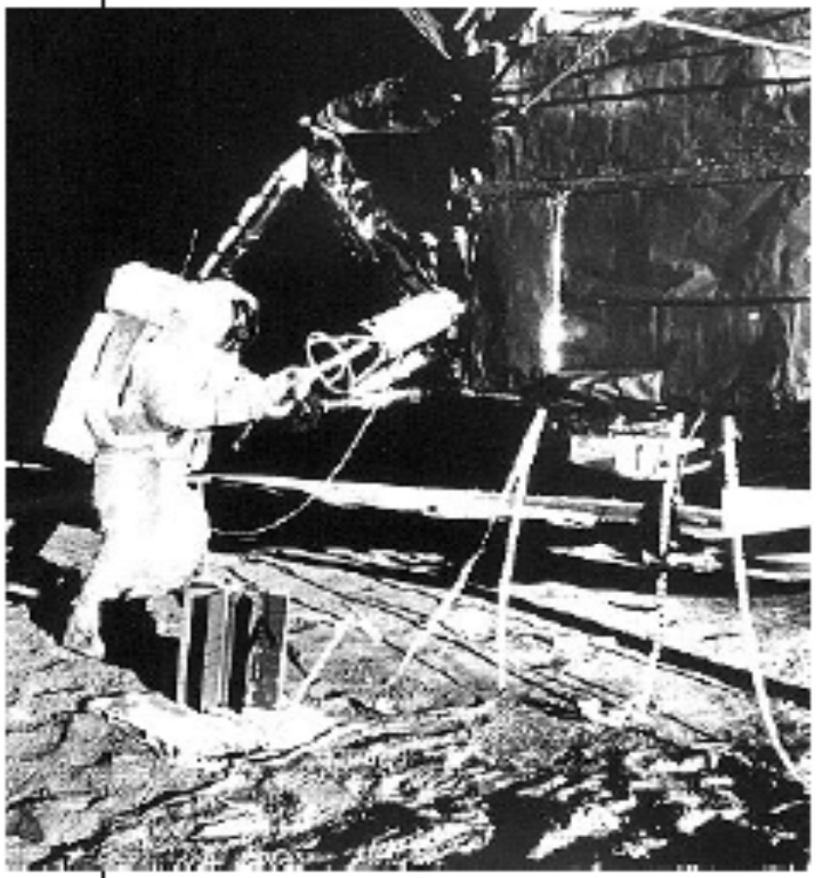


RTGs in Space - Radiation

- Pu-238 and Po^{210} 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.



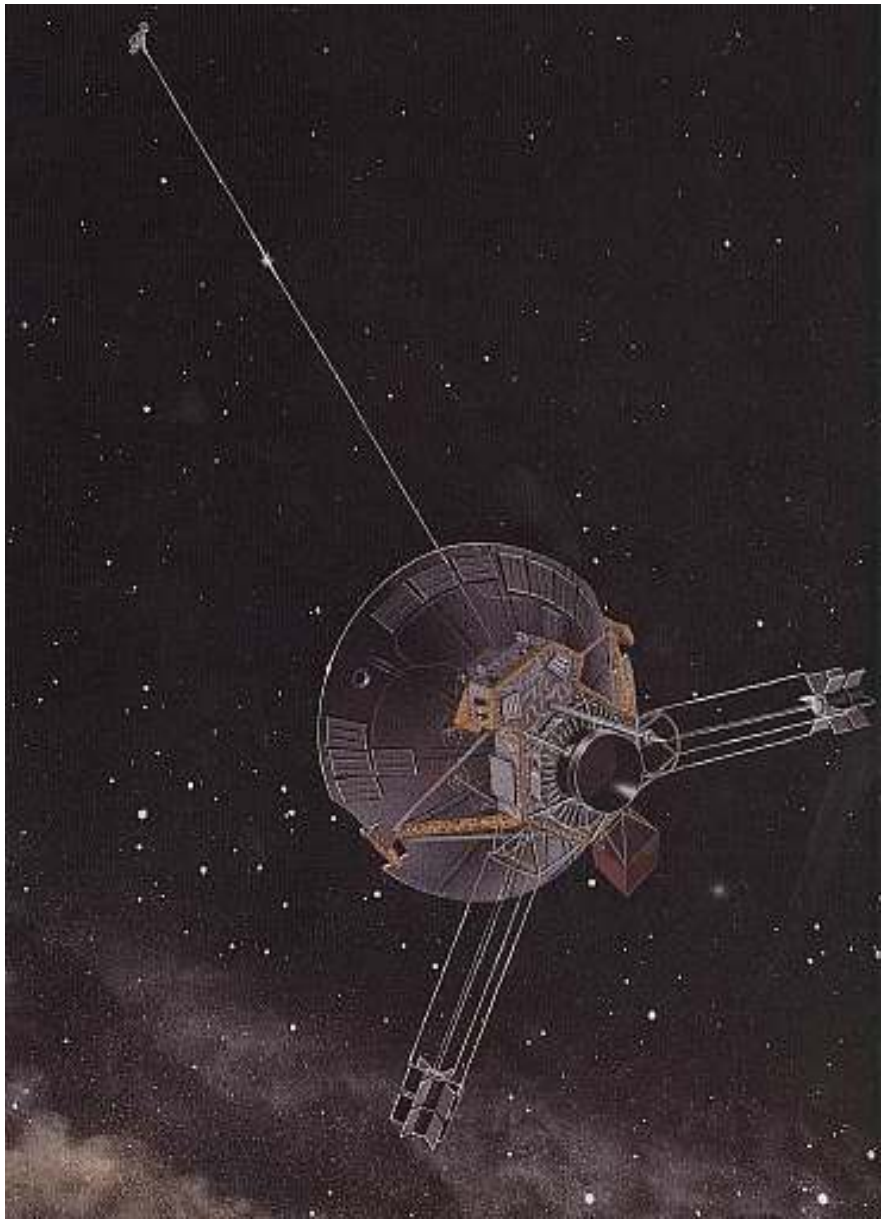
On the moon, Apollo-12 astronaut Gordon Bean prepares to load the plutonium-238 heat source into the SNAP-2 thermo-electric generator (arrow). The generator produced 73 watts of power for the Apollo lunar surface experiment package for nearly eight years.

RTGs in Space - History

- Original RTG is 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.

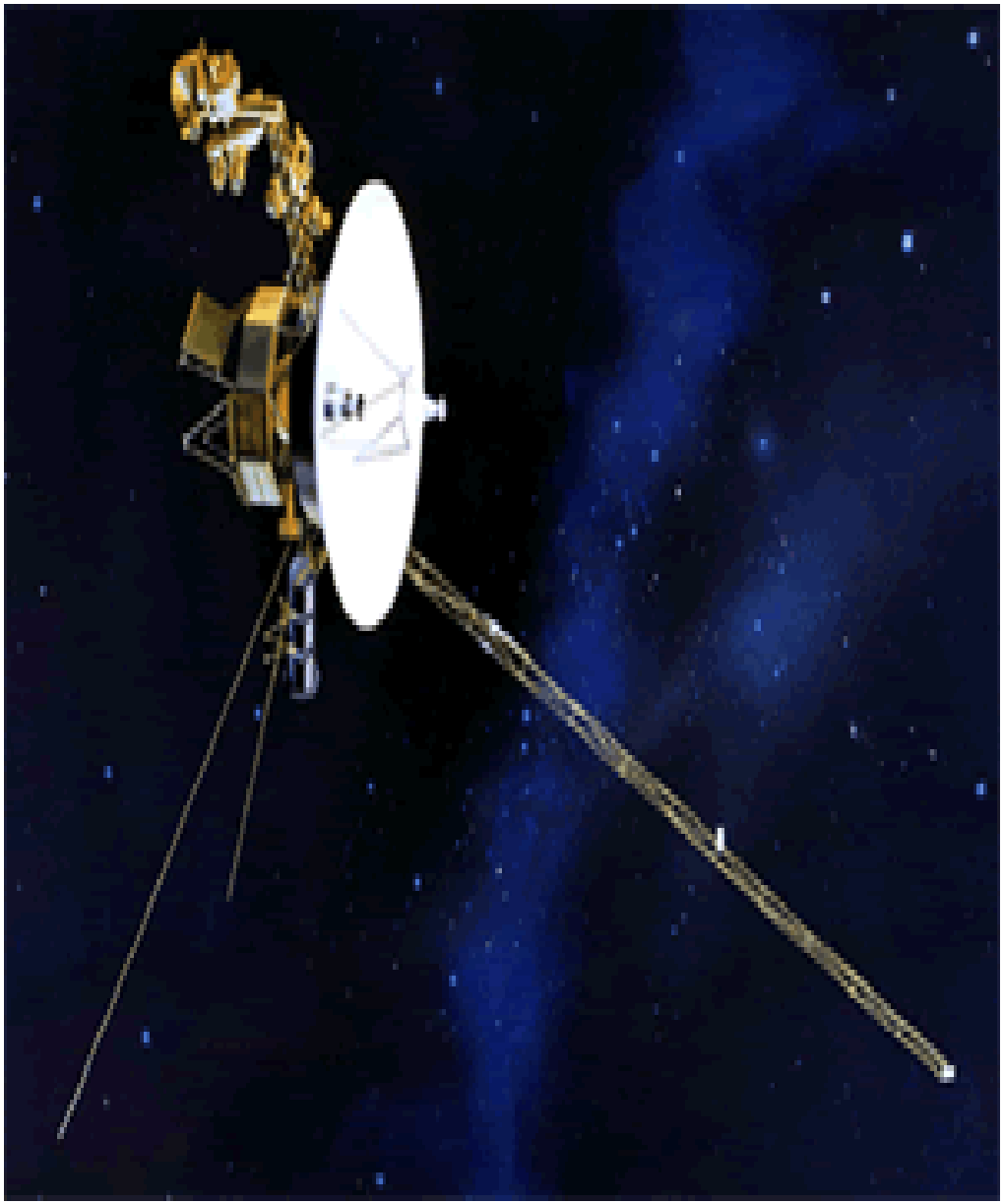
RTGs in Space - History

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



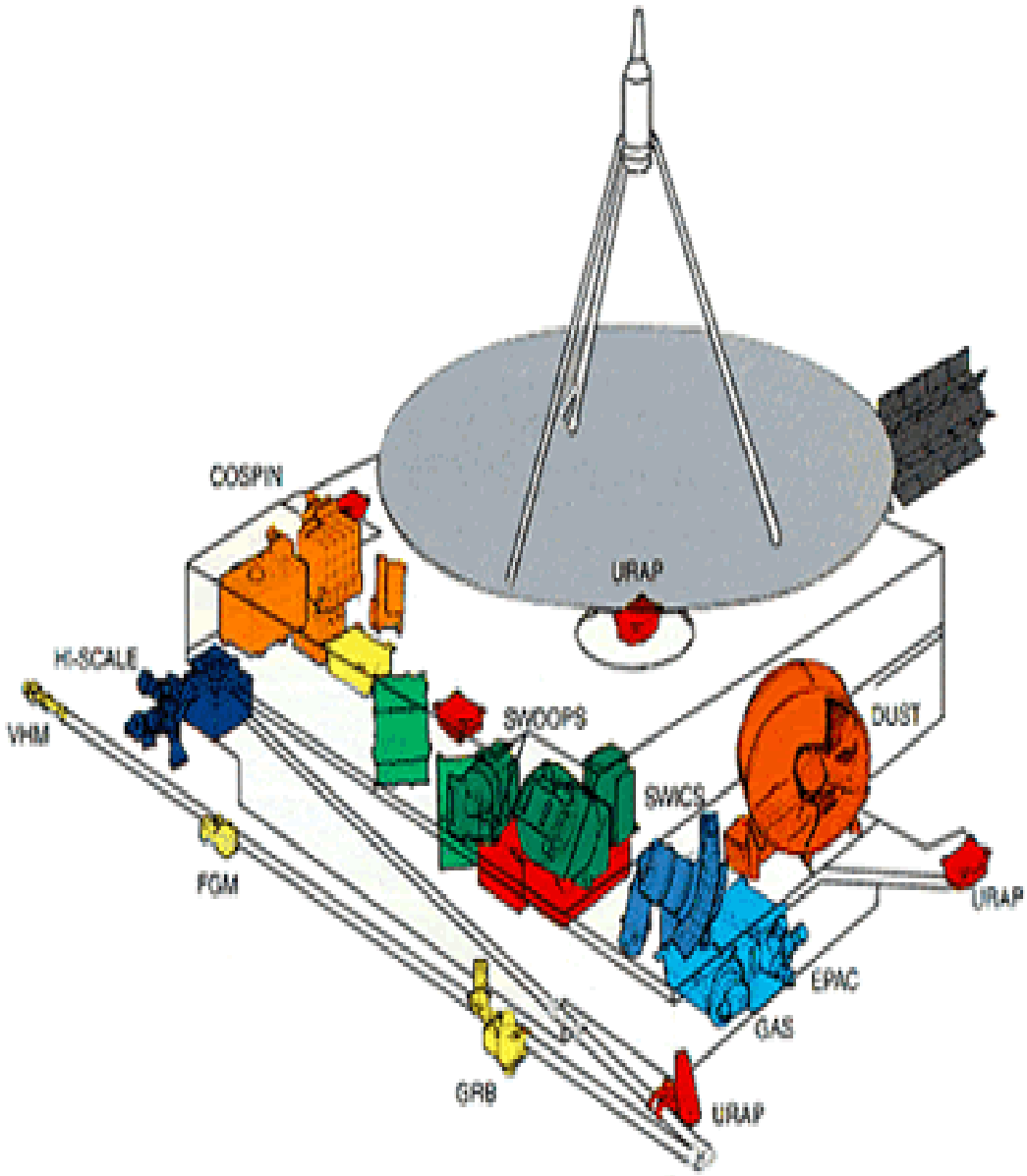
RTGs in Space - History

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



RTGs in Space - History

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



RTGs in Space - History

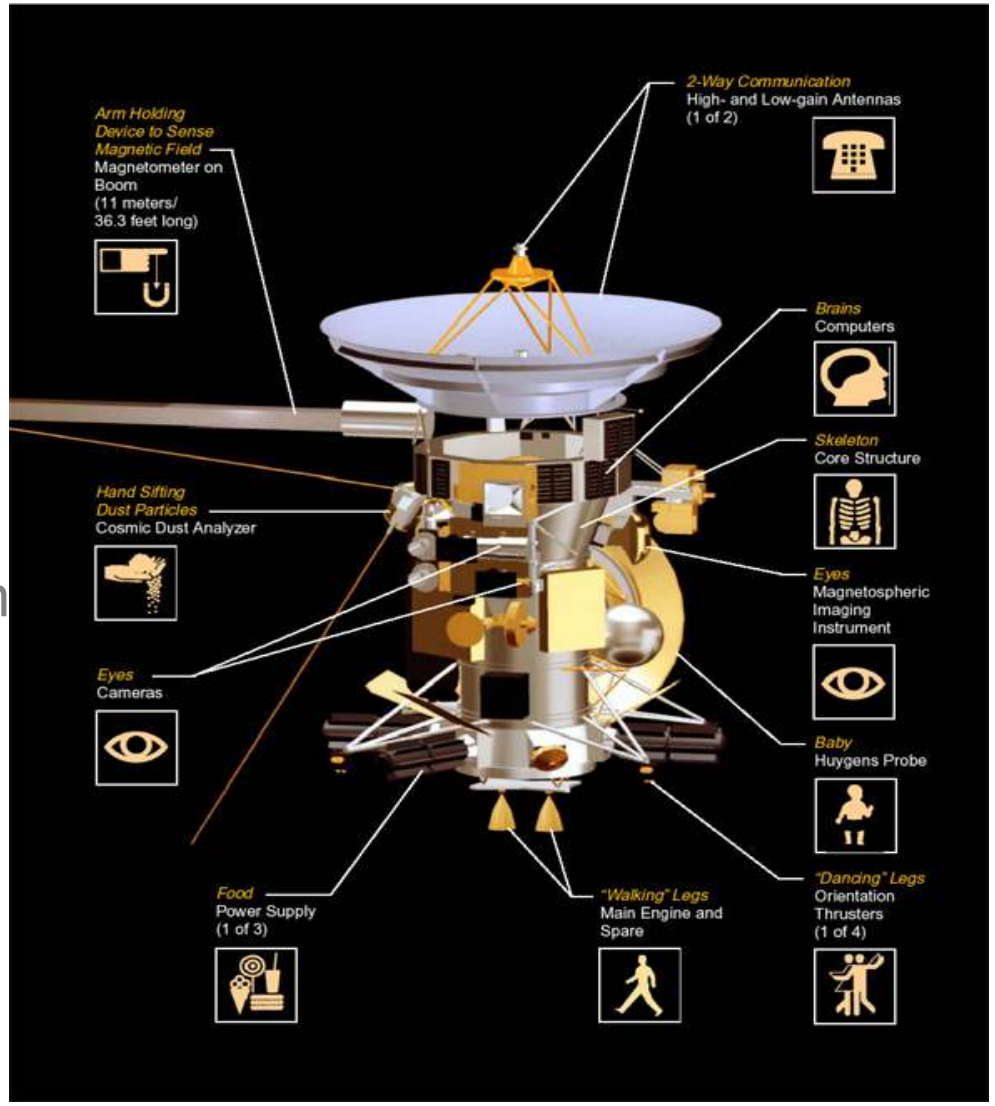
- 1989: Galileo launched to explore Jupiter and her moons.
  - –Took the long-way to Jupiter; by Venus and Earth twice.
  - –Required a long-lived power supply to make the 4-year flight.
  - –Operated for 14 years.
  - –Find the RTG.

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 is similar to RTGs.

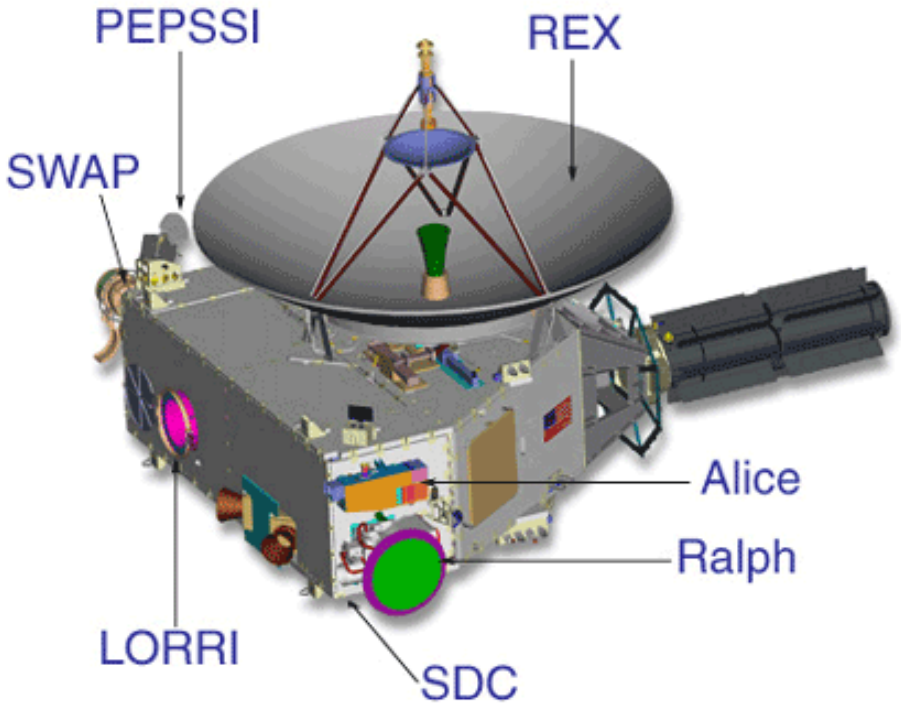
RTGs in Space - History

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



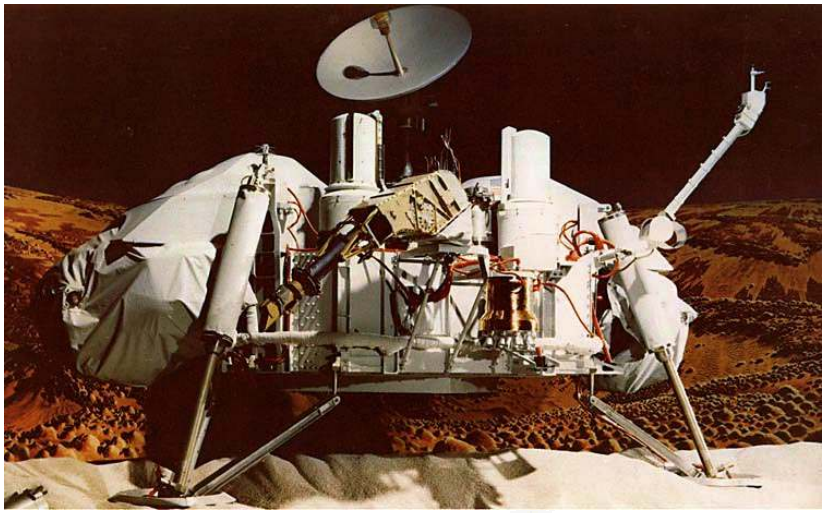
RTGs in Space - History

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

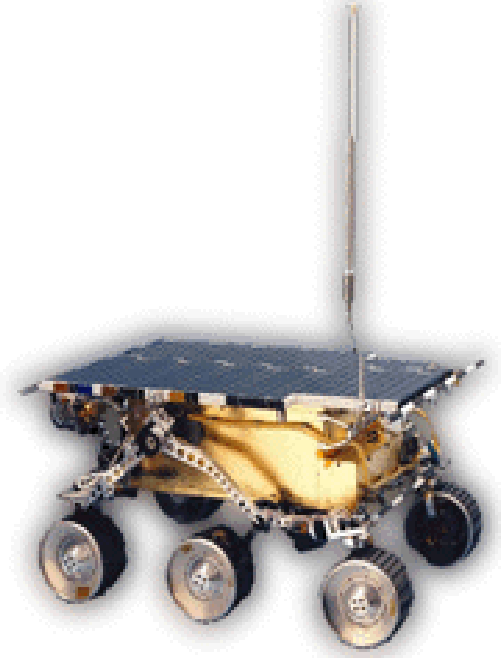


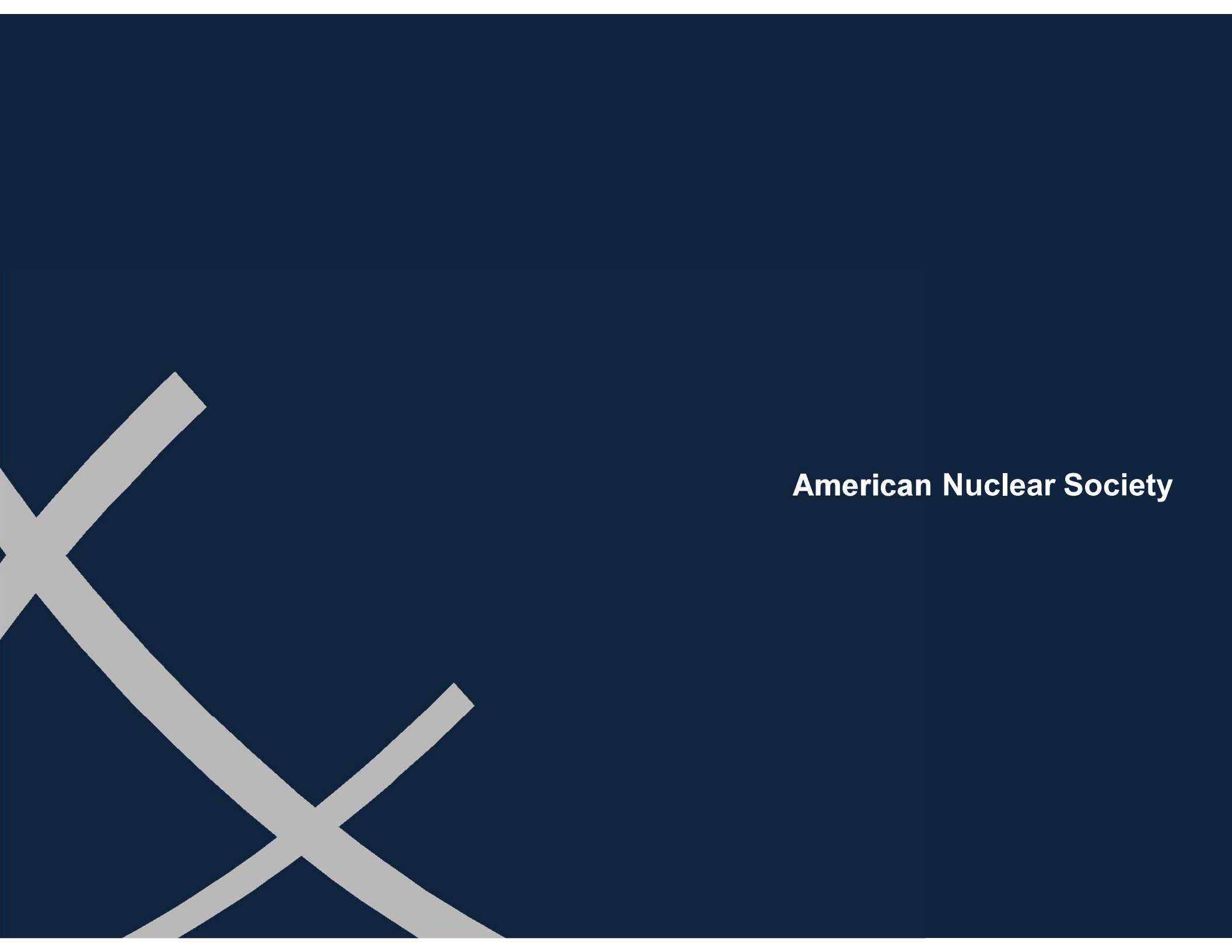
RTGs in Space - History

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



- Mars Pathfinder-1997
  - –Rover used RHUs for heat.
  - –Three months on solar power




American Nuclear Society