Overview of Non-Power Applications of Nuclear Technology

Part 3

Alan Waltar

Retired Director of Nuclear Engineering
Pacific Northwest National Laboratory

World Nuclear University Summer Institute
Oxford, England
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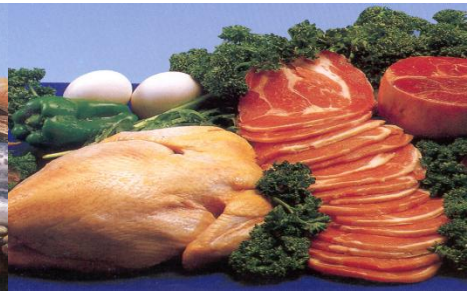


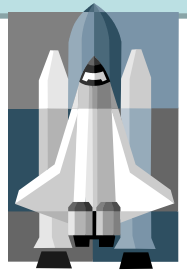
Outline for Part 3
Non-Power Applications

- **Space Exploration**
- **Terrorism, Crime, and Public Safety**
- **Arts & Sciences**
- **Environmental Protection**
- **Modern Economy**

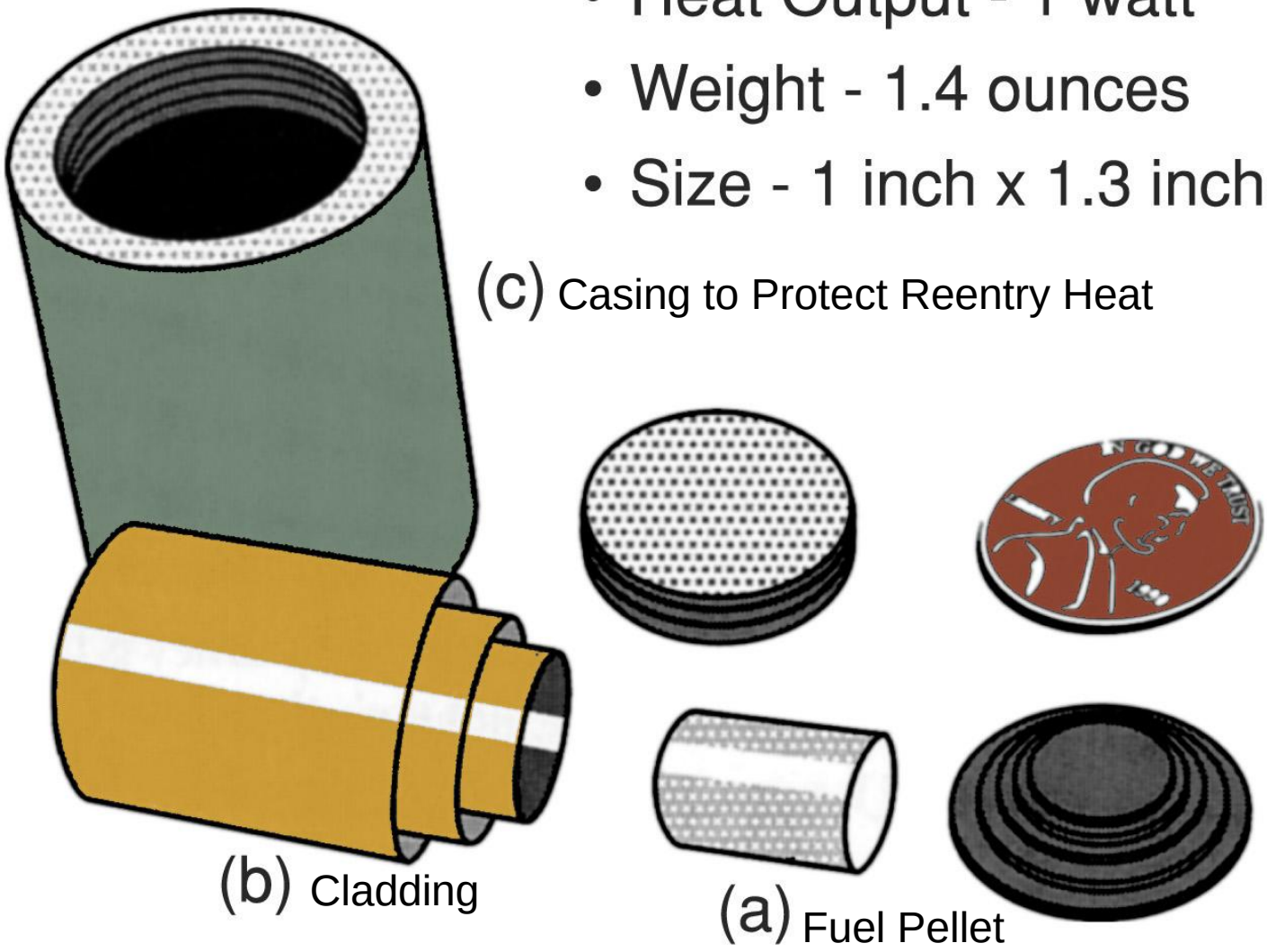
SPACE EXPLORATION

- **Heat Generation**
  - **Radioisotope Heater Unit (RHU)**
    - Pu-238 excellent heat source (87.7 yr half-life)
- **Electricity Generation**
  - Radio-Thermal Generators (RTG)
    - Direct conversion to electricity (~ 7% efficiency)
  - Dynamic Isotope Power System (DIPS)
    - Pu-238 still excellent heat source
    - Rankine cycle active system (~20% efficiency)

- **Nuclear Reactors**
  - For Missions > 100 KW



- Heat Output - 1 watt
- Weight - 1.4 ounces
- Size - 1 inch x 1.3 inches



Radioisotope Heater Unit (RHU)

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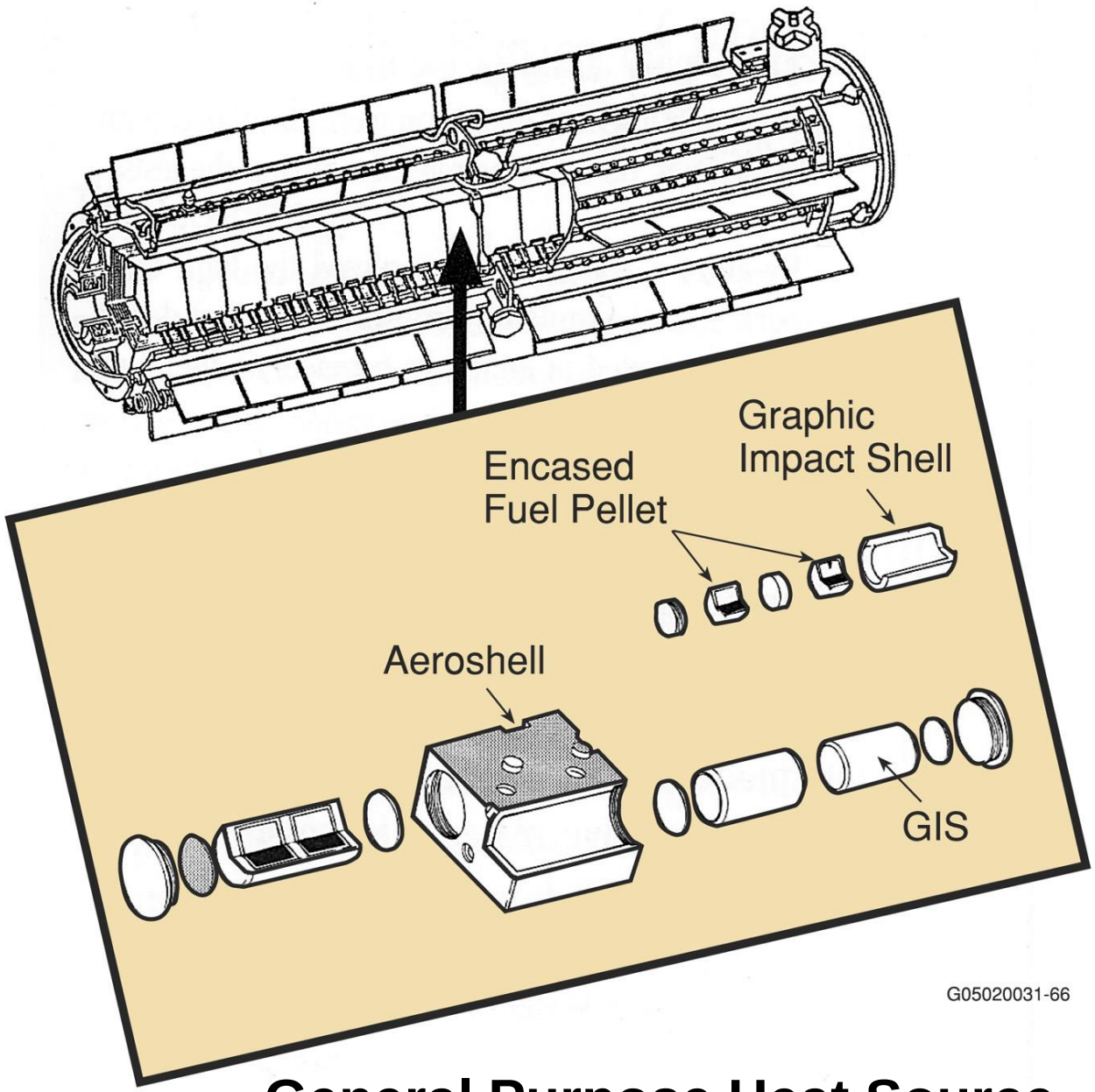
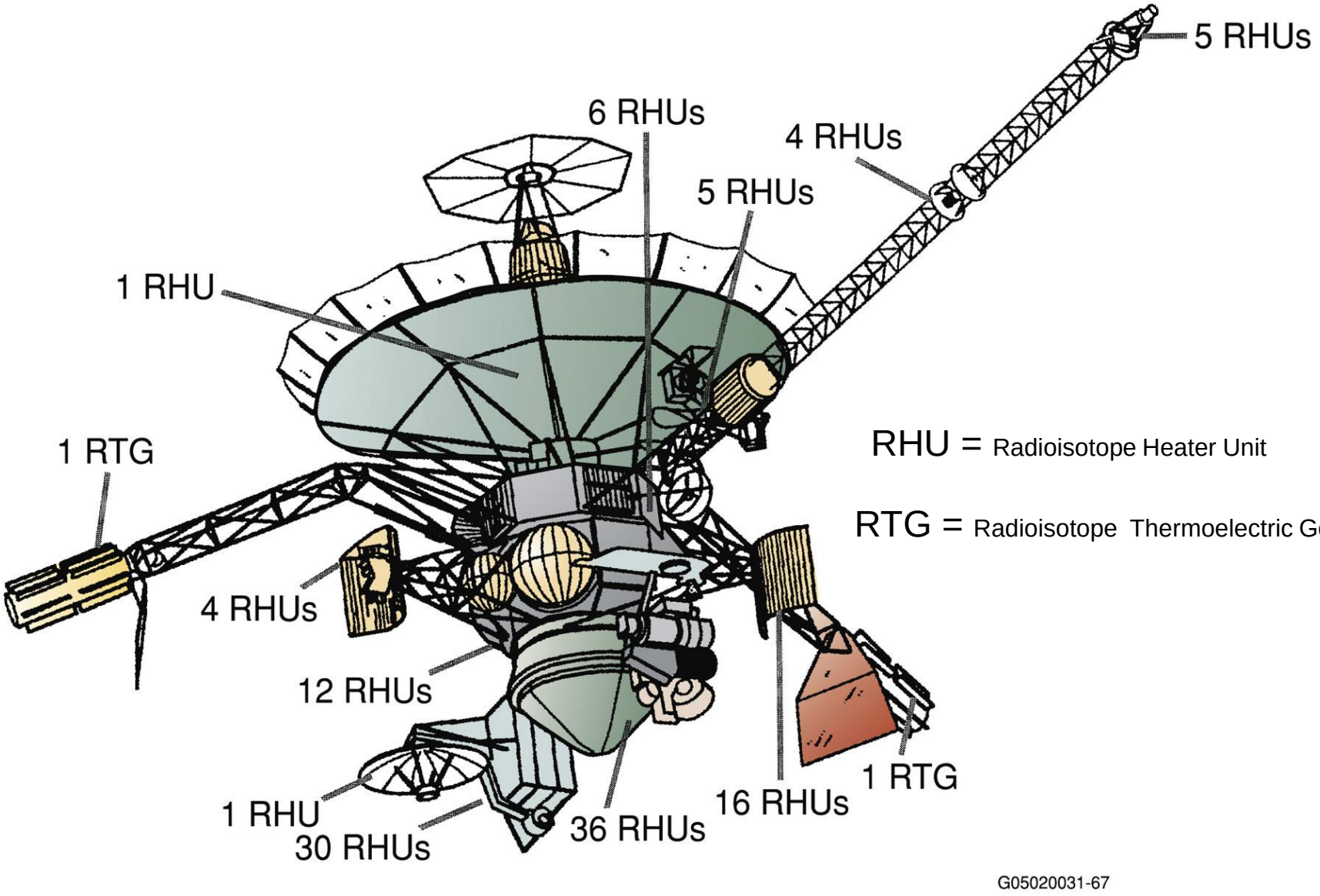
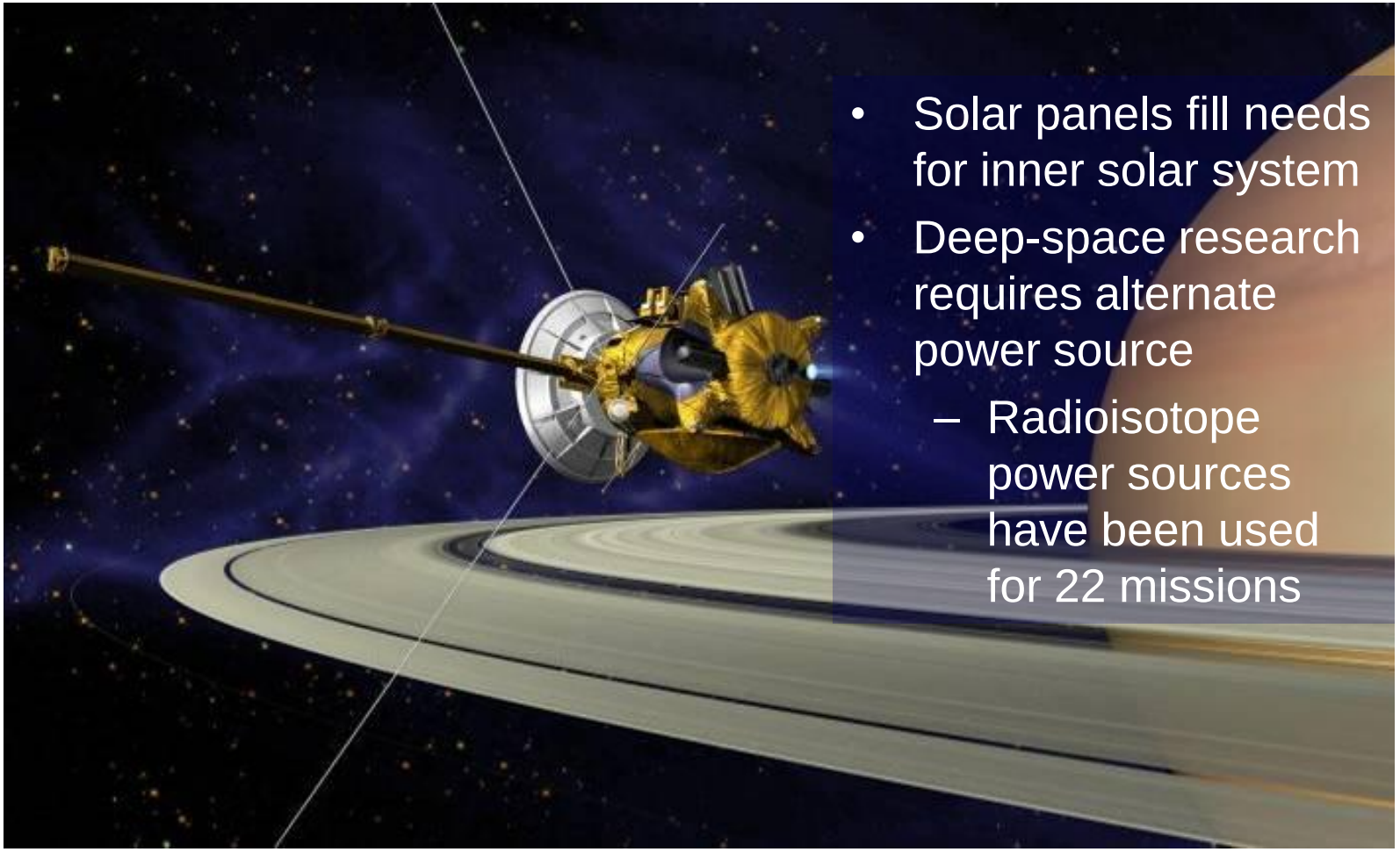


General Purpose Heat Source



Radioisotope Power Sources Used on Galileo Spacecraft

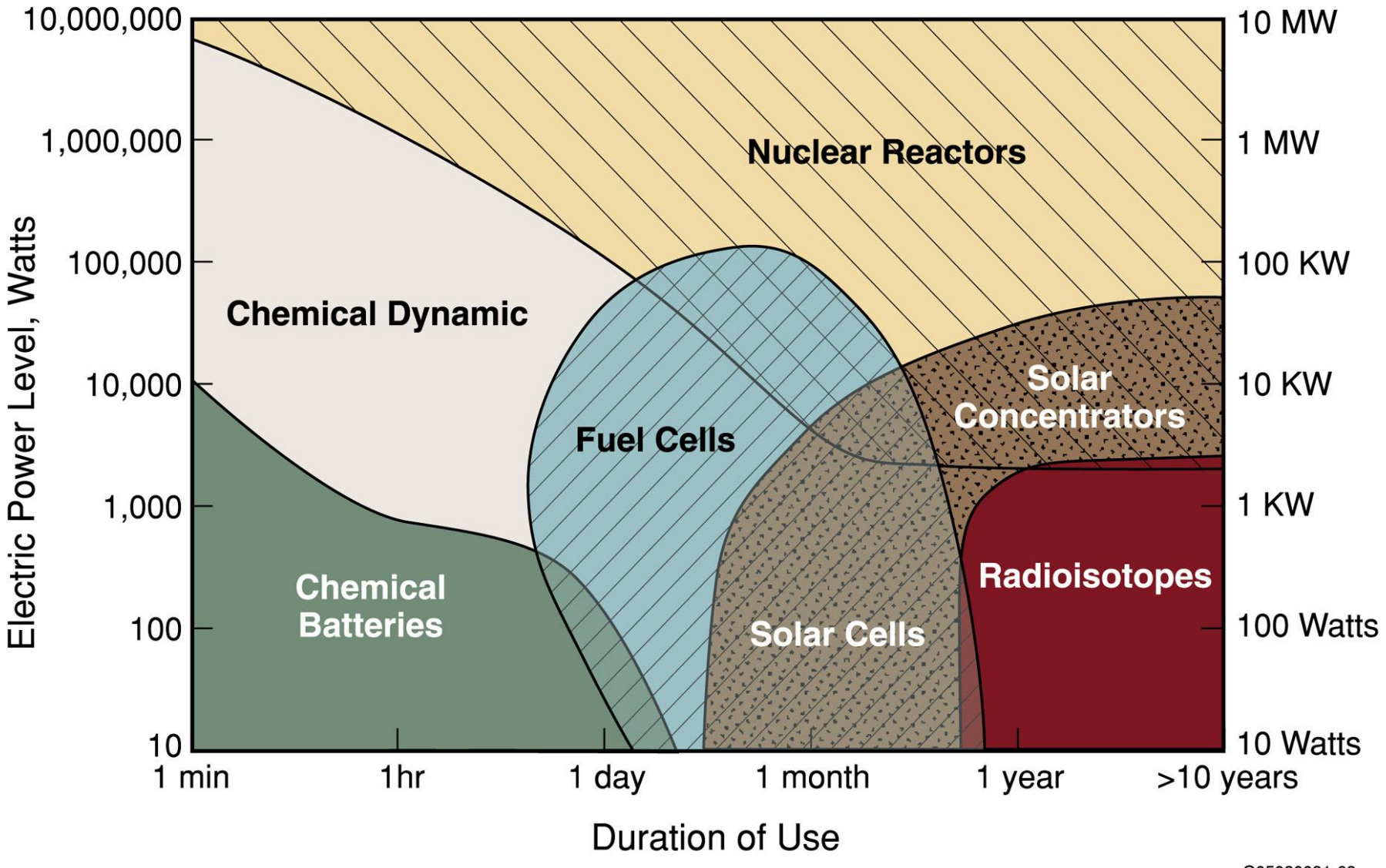
Nuclear batteries power exploration



- Solar panels fill needs for inner solar system
- Deep-space research requires alternate power source
  - Radioisotope power sources have been used for 22 missions

The Mars rovers use radioisotope heat sources to keep warm during the night

Compliments of Dr. Harold McFarland



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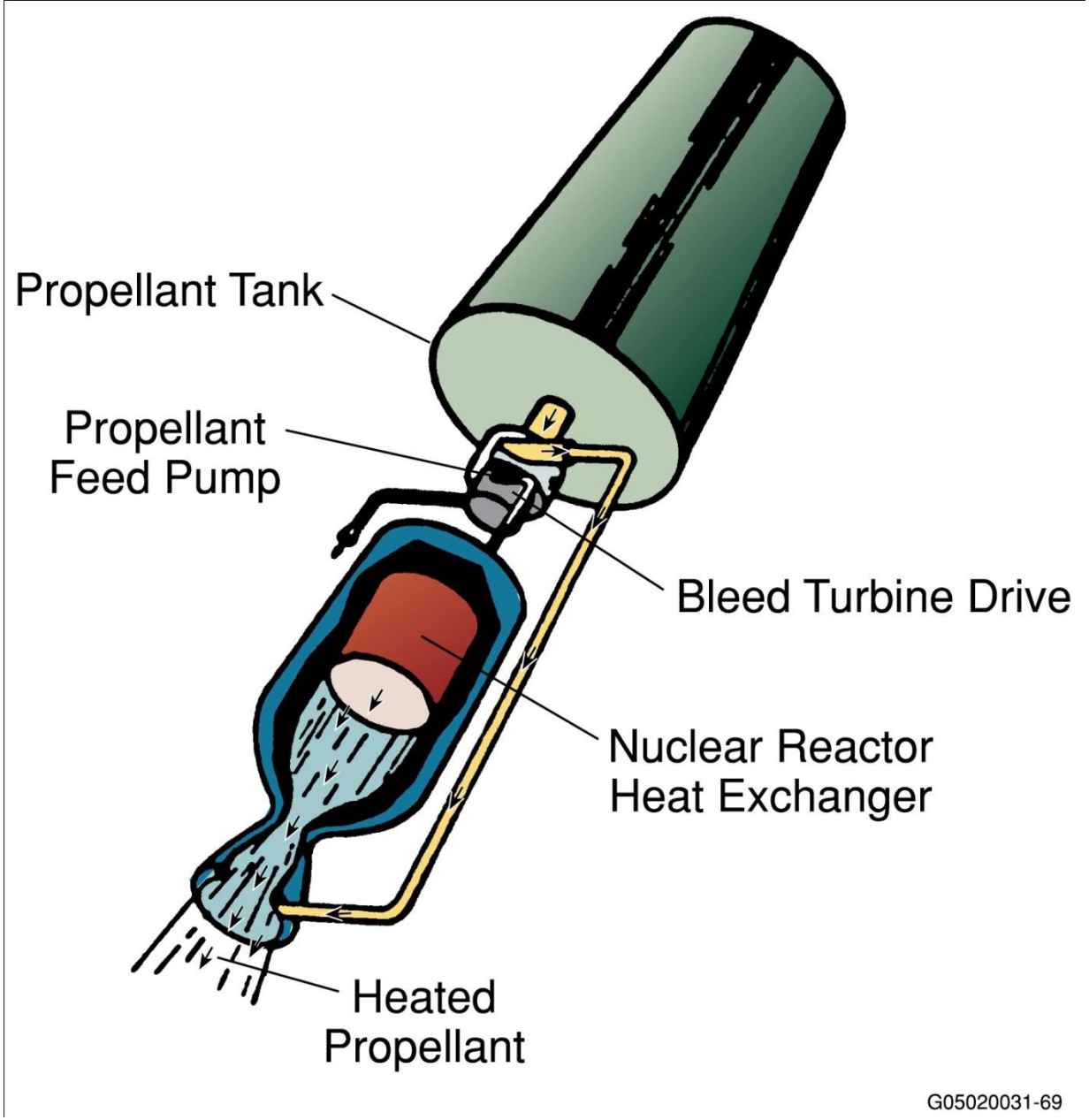
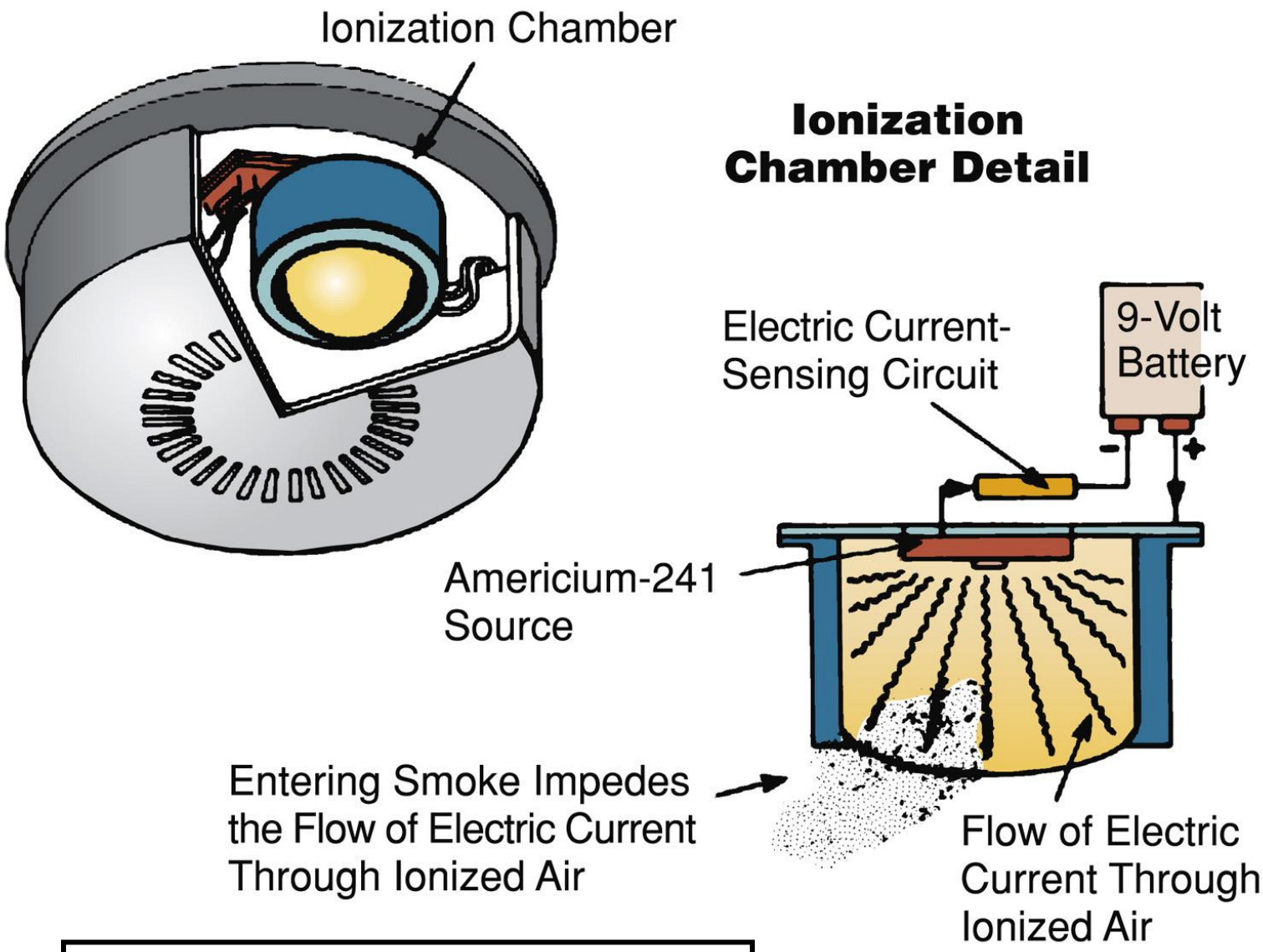
Electric Power Sources for Space Exploration



Nuclear Powered Rocket

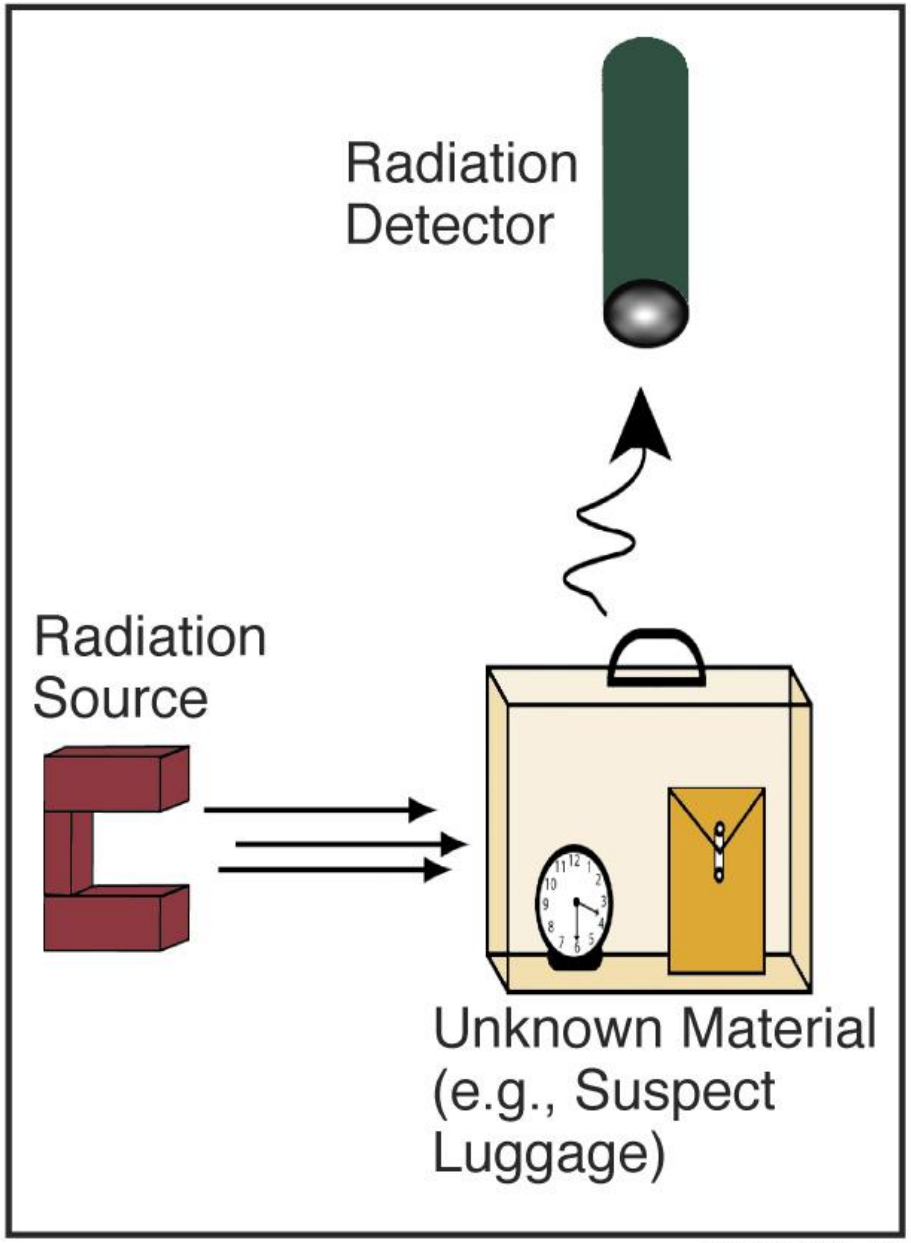
TERRORISM, CRIME, & PUBLIC SAFETY

- **Public Safety**
  - Smoke Detectors
  - Exit Signs
  - Airport Runway Lighting
  - Reduce Static Electricity (printing process, paper making)
- **Fighting Crime**
  - Neutron Activation of Body Samples
  - DNA Analysis
- **Fighting Terrorism**
  - Luggage Inspections (weapons, explosives, etc.)
  - Anthrax in Mail
  - Portal Monitoring
  - Detecting Mine Fields
  - Sensing Clandestine Weapons Testing
  - Sensing Contamination Releases (e.g. “Dirty Bombs”)



Common Smoke Detector


EXIT



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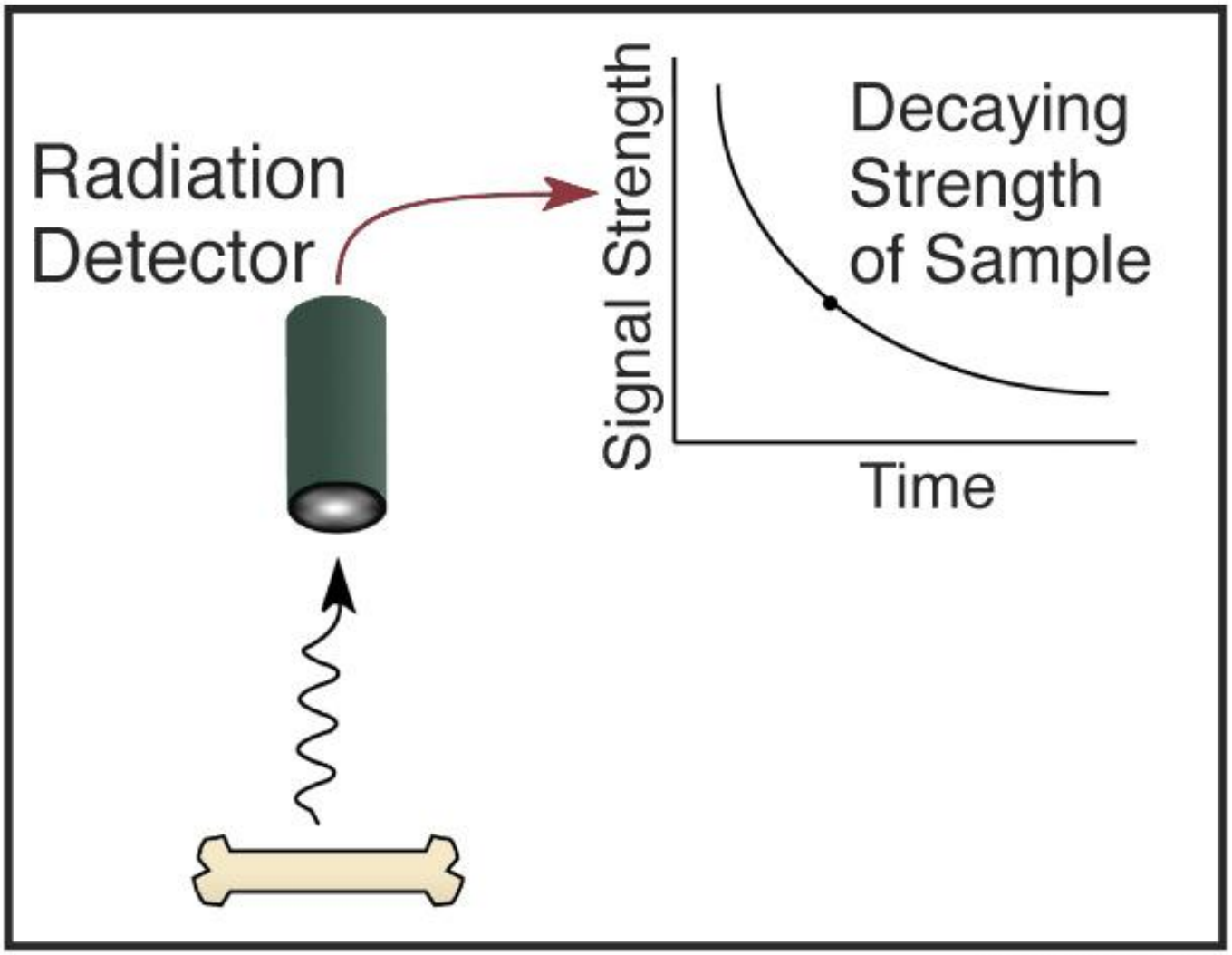
Cargo Ship Entering Port

ARTS AND SCIENCE

- **Understanding our Origins**
  - Carbon-14 dating
- **Precious Gems**
  - “Cobalt Blue” Topaz
- **Radiation and the Arts**
  - Restoring and preserving artifacts
  - Authenticating paintings



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Dating Archeological Events

The physics of radioactive decay

Carbon-14 Dating: 50 to 50,000 years

	Present in Atmosphere
C-12:	98.89 %
C-13:	1.11 %
C-14:	1 atom in one trillion!

Carbon-14 Dating Procedure

- Living species maintain a constant ratio of C-14 to C-12

- But, when death occurs, there is no more intake of carbon:
  C-12 is stable
  C-14 decays with $T_{1/2}$ of 5715 years

- Hence, **ratio of C-14 to C-12 diminishes with time**

- Measuring this ratio dates the time of death

NOTE: Now possible to measure 3 atoms of C-14 out of a total of 10^{16} carbon atoms!

Dating: 50,000 to few million years

Potassium Method

- K-39 is stable
- K-40: $T_{1/2}$ = 1.27 billion years

Potassium crystallizes in material of volcanic origin

- Hence, **measure** **ratio of K-39 to K-40**

(Determine K-39 by irradiating it to form Ar-39, which is radioactive)

Dating: Multiple Millions of Years

Cosmic Bombardment

- Be-10 $T_{1/2}$ = 1.5 million years
- Al-26 $T_{1/2}$ = 0.71 million years

If traumatic condition occurs (e.g. volcano, earthquake, etc.), cosmic bombardment no longer applies

- Hence, **measure ratio Be-10 to Al-26**

Dating: Billions of Years

Primordial Methods

- U-238 $T_{1/2}$ = 4.46 billion years
- Decay chain ends at Pb-208

•Hence, measure number of lead atoms in sample:

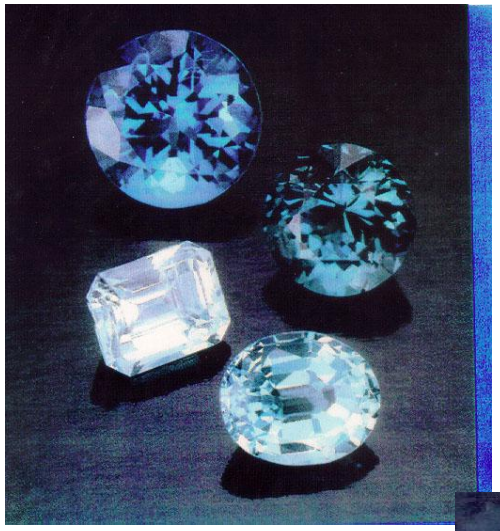
Ratio Pb-208 to U-238

(This method used to date age of earth at 4.55 billion years)

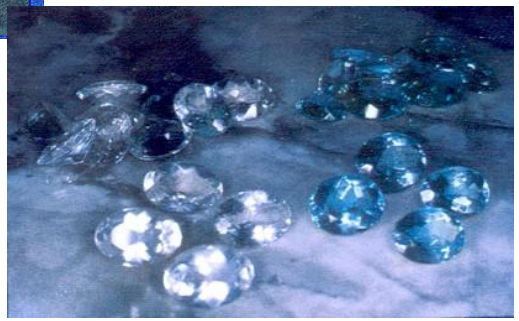
Blue Topaz (color created by irradiation)

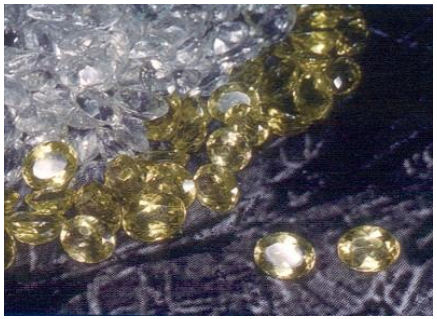
GEMSTONE IRRADIATION

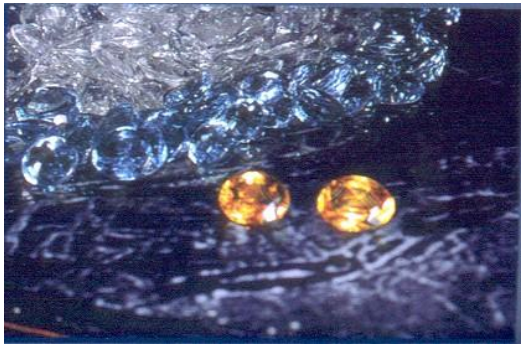
(EB and Gamma Rays)



Topaz, Rubelita, Quartz, Citrine and Ametista







Source: IPEN-CNEN/SP & Wilson Calvo

PRESERVATION OF ART WORKS AND BOOKS

- *Peruvian painting of XVII Century*
- *Leonardo Flores*
- *1,90 x 3,20m; Dose=6kGy*

Gamma Rays

Source: CBE and IPEN/CNEN-SP

Compliments Wilson Calvo

Environmental Protection

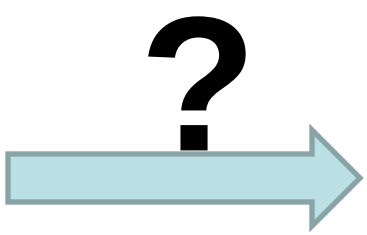
…..ENVIRONMENTAL POLLUTION…..

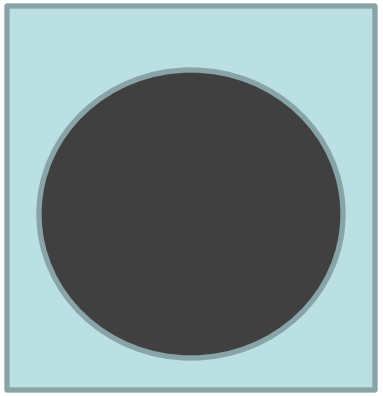
Determine 1) Amounts and Locations of Pollution
2) Causes of Pollution
3) Proper Remedy

- **Managing Fresh Water Resources**
  - Preserving and Obtaining Potable Water Sources
- **Guarding the Oceans**
  - Coastal Zones and the Deep Seas
- **Understanding Soil Erosion**
  - Loss of topsoil and erosion of waterways
- **Radiological Contamination**
  - Weapons production and commercial power
- **Polluting our Atmosphere**
  - Brown Clouds and global climate change
- **Energy & the Environment**

An Environmental Perspective

- Every second of every day:
  - 1000 Tons of topsoil are lost
  - 1000 Tons of unwanted gases are released into the atmosphere
  - 1/4 acre of forestland is lost
  - 1/2 acre of arable land becomes a desert





Managing Fresh Water Resources

- **1/5 of our global population (1.2 billion) lack safe and affordable drinking water**
- **Global demands for fresh potable water is doubling every 21 years!**
- **Renewable water supplies available per person are ½ that of 40 years ago**
- **This will drop in half again in another 20 years**
- **The demand for potable water is increasing *double* the rate of population increase.**

Water Use

- **70% of fresh water is used for agriculture**
  - Neutron probes are used to determine the ***water available*** for root systems
  - Radioactive tracers are used to determine the ***amount of water and fertilizer actually needed***
    - **NOTE: Huge amounts of energy needed to produce fertilizer**

Measuring Water Flow

- **Why is flow important?**
  - A) Direct source of potable water
  - B) Source to recharge underground aquifers
- **How to measure water flow?**
  - Use tritium (β) or Bromine-82 (γ)
  - Inject upstream and detect downstream
  - Known cross-section and time of travel determines volume of flowing water

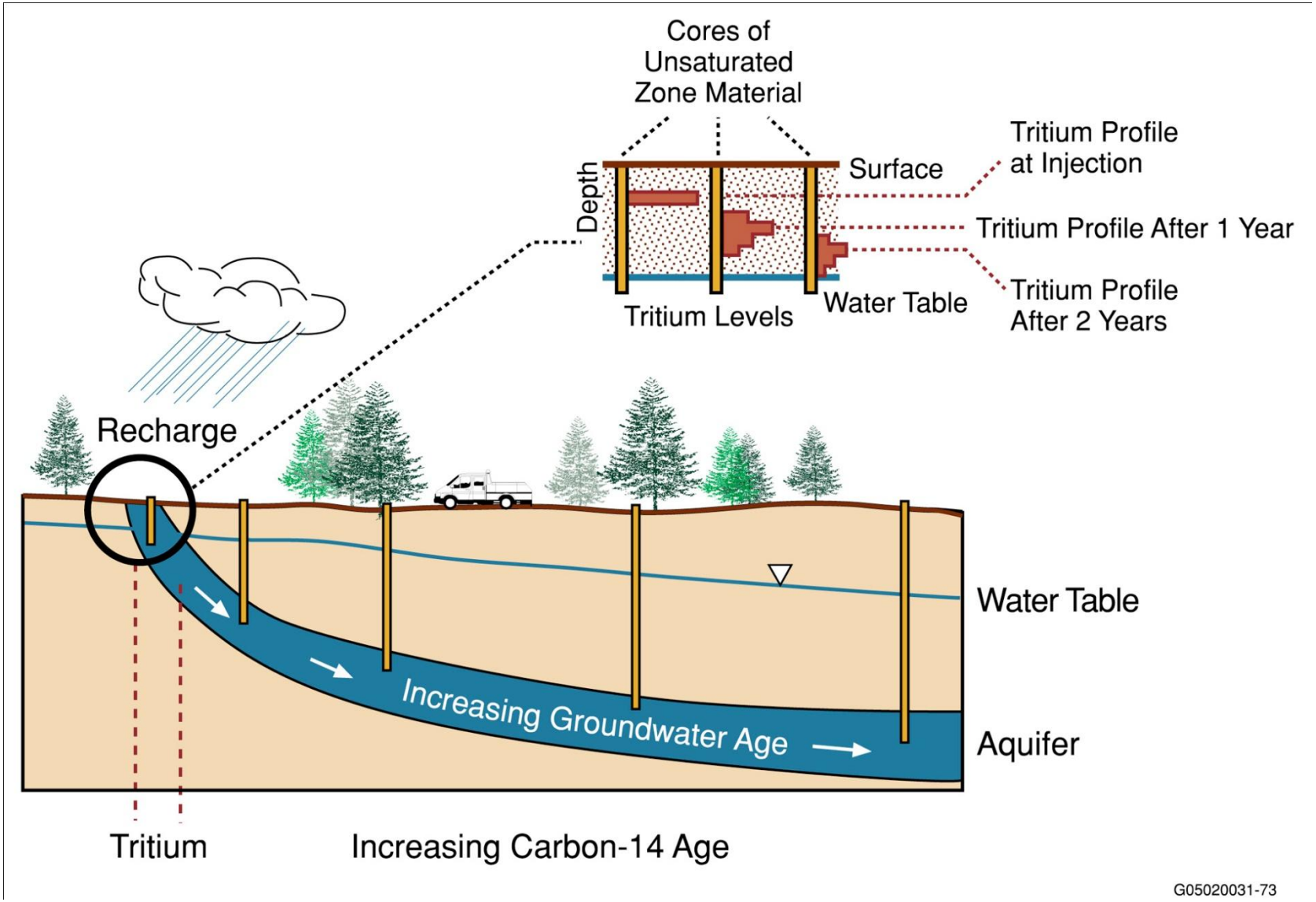
Underground Aquifers

- **Many regions of the world depend upon wells for agricultural, industrial, and domestic use**
- **When withdrawal rates exceed recharge rates, the water table drops**
  - More pumping power required
  - More chance for pollution from surface water
  - Seawater encroachment (if near the ocean)

Determining Status of Underground Aquifers

- A) **Cosmogenic Radioisotopes**
  - Generated in the atmosphere by cosmic radiation
    - tritium, beryllium-10, carbon-14, chlorine-36
- B) **Fallout Radioisotopes**
  - Generated by atmospheric nuclear weapons testing
    - cesium-137, tritium, carbon-14, chlorine-36
- C) **Primordial Radioisotopes**
  - Natural elements in the earth's crust
    - uranium-238, thorium-232 (very long half-lives)

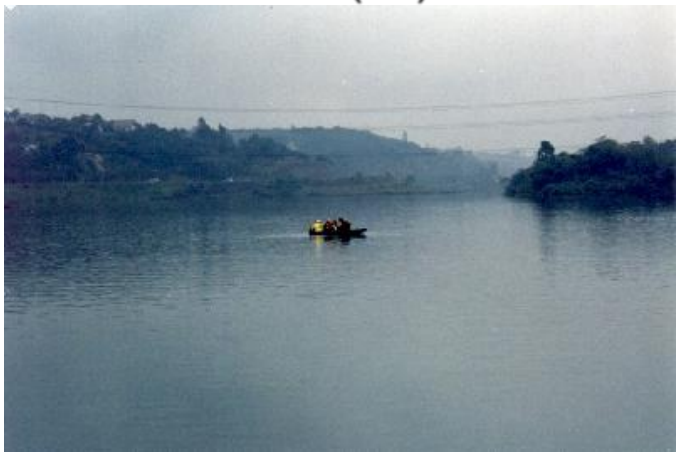
All used to determine volume, age, and movement of underground water



Radiation Used for Environmental Groundwater Tracing

HYDROLOGICAL EVALUATIONS FOR ENVIRONMENTAL PROTECTION and INDUSTRIAL PROCESS CONTROL

Residence Time Distribution in Water Reservoir (^{3}H)



Residence Time Distribution in Wastewater Treatment Plant (^{82}Br, ^{131}I

Liquid Flow Transit Time Determination (^{82}Br, ^{131}I)

Mercury Mass Determination in Electrolytic Cells (^{203}Hg

Source: IPEN-CNEN/SP Compliments Wilson Calvo

Example:
The Great Artesian Basin in Australia

- Covers 1/3 of the entire continent
- Recharges in Eastern Australia
- Flows westward
- Age of water is up to 2 million years!

All determined by radioactive tracers

- Very few rivers in Australia, so the Great Basin is the primary source of water

Preventing/Determining Contamination

- **Prevention**: Best to prevent, but this may not always be possible
  - Areas where high-tech effluent treatment plants are not affordable
  - Water is already polluted
- **Detection**:
  - Identify pollutants via neutron activation analysis
  - Inject small amounts of radioisotope tracers at suspected pollution site and see if the radioisotopes can be detected in the polluted region
  - heavy metals (arsenic, cadmium, copper, lead, mercury) are easy to detect

Example along the Amazon River

- Poor people mysteriously getting sick
- IAEA measured human hair, fish, river sediment
  - Found mercury traces
- Poor people had been using mercury to obtain small quantities of gold from tailings, and they let the mercury vaporize or be dumped into the Amazon River

Dilution sometimes acceptable

- Inject gold-198 (gamma emitter) into polluted materials
- Measure expanding plume by oscillating detector up and down and criss-crossing downstream

Obtaining New Sources of Fresh Water

- 97 % of the water on the planet is seawater
- Major population areas exist in coastal regions
- Hence, desalinate:
  - Requires considerable energy for extraction of salt
  - Nuclear heating may be an answer
    - BN-350 in Kazakhstan produced 150 MWe and 1 million gallons of potable water/day
    - Kalpakkam system in India now produces 1 million gallons of potable water /day via nuclear power

NUCLEAR DESALINATION DEMONSTRATION PROJECT, KALPAKKAM, TAMIL NADU.

Nuclear Desalination

- Reverse osmosis –
  use electric pumps off-peak
- Distillation - scope for cogeneration

Reverse Osmosis Desalination Plant, Jersey, UK

GUARDING THE OCEANS

- 70% of Earth's surface is covered with salt water
- Over half the world's population lies along coastal zones
- One billion people depend on fish as sole source of protein

Oceans worthy of environmental protection

80% of all marine pollution comes from the following:

- sewage & industrial effluents
- fertilizer runoff
- heavy metals discharge
- persistent organic pollutants

All detectable by radioisotopes

The Black Sea Blight

- Major natural & economic resource for over 160 million people
- Impacts 17 nations, 13 capital cities, 6 surrounding countries
- Three of the four largest rivers in Europe discharge into this sea

- Was declared dead near the end of the last century
- Called the “toilet bowl for half of Europe”
- Over 60 plant & animal species essential to the Black Sea ecosystem endangered or extinct
- 13 types of commercial fish seriously endangered
- Outbreaks of cholera closed many beaches

The Black Sea Recovery

- IAEA supplied over 50 research cruises throughout the Black Sea
- Radiation technology provided the major tools to diagnose the underlying causes for the pollution
- Many now believe the sea can be saved

“Red Tides” in the Philippines

- Toxic algae bloom caused massive paralytic shellfish poisoning
- February 2002: hundreds of tons of dead milkfish suddenly floated to the surface in Bolines
- Several other such events (though less severe) in17 other coastal sites

Caused enormous slaughters of fish

(huge economic loss and potential poisoning of locals)

- **New I-125 technique** devised to detect abnormalities in growth hormones of suspected shellfish

DEEP SEAS

- **Ocean currents significantly affect the climate of the world**
- **The Gulf Stream (via thermohaline circulation) keeps Rome considerably warmer than Boston—even though they are at the same latitude**
- **Tritium and C-14 serve as vital radioisotopes to determine the mixing process in the ocean up to a depth of ½ mile**
- **Cosmogenic radioisotopes trace the current directions at greater depths**

SOIL EROSION

- **Topsoil erosion can be devastating to farmers**
  - **(we noted earlier that 1000 tons of topsoil are lost every second over a global basis)**
- **How can we determine when it is lost and where it accumulates?**
  - **A) Satellite images**
  - **B) Mathematical formulas**
  - **C) Radioisotopes—mainly Cs-137 from the fallout of nuclear weapons testing**
    - **Spread relatively uniformly over the globe**
    - **Measure where activity is higher and where it is lower**

Erosion Along Waterways

- Collect sand or sediment, mix with radioisotope (e.g. gold-198) that adsorbs to the surface of the sediment particles

  ⇒ Measure the spread of the mixture by detecting radioactivity

- For sandy beaches: Synthesize glass beads having the same size and density of local sand. Impregnate with target material such as lanthanum, iridium, or silver), irradiate in a reactor to get
  - La-140 (short half-life for weeks)
  - Ir-142 (med. half-life for 2 seasons)
  - Ag-110m (longer half-life for annual investigations).

Erosion Within Waterways

- **Determine the accumulation of sand or sediment behind dams, shipping channels, harbors, and discharges into the ocean**
- **Same method as used for sand erosion, but all detection is done under water**

Radioisotope	Half-life	Investigation Time
Au-198	2.7 days	1 – 2 weeks
Cr-51	27.7 days	2-4 months
Ir-192	73.8 days	8 months
Sc-44	83.8 days	9 months
Ag-110m	250 days	> 1 year

RADIOLOGICAL CONTAMINATION

U.S. Nuclear Weapons Production

Hanford (Washington) and Savannah River (South Carolina) major weapons production sites

- **Hanford: reprocessing waste in huge underground tanks**
  - **Single shell (some have leaked and trace amounts of radiation have been detected in the Columbia River)**
  - **Double shell tanks**
  - **Huge vitrification plant now well under construction**

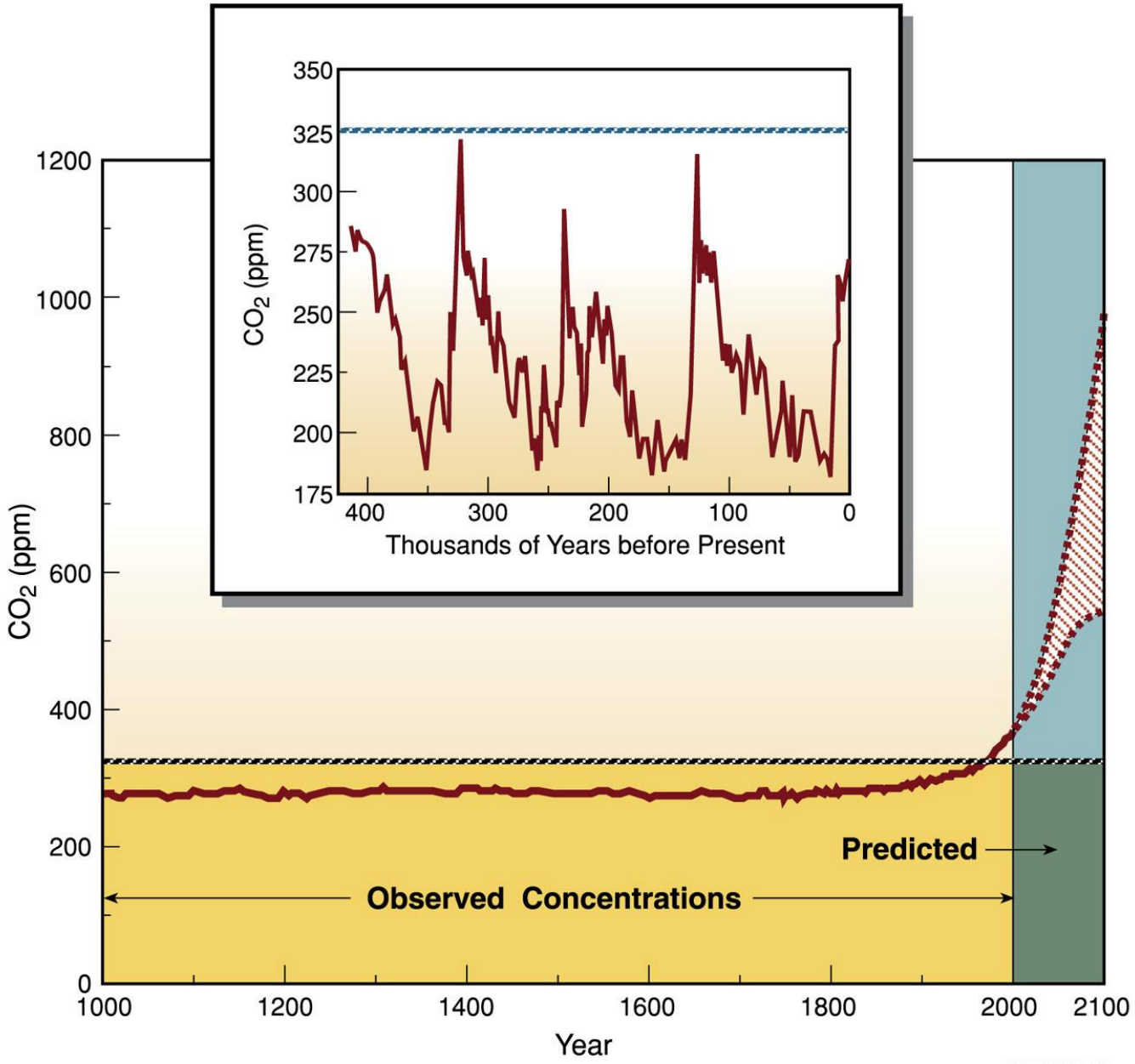
Hanford

Savanna River

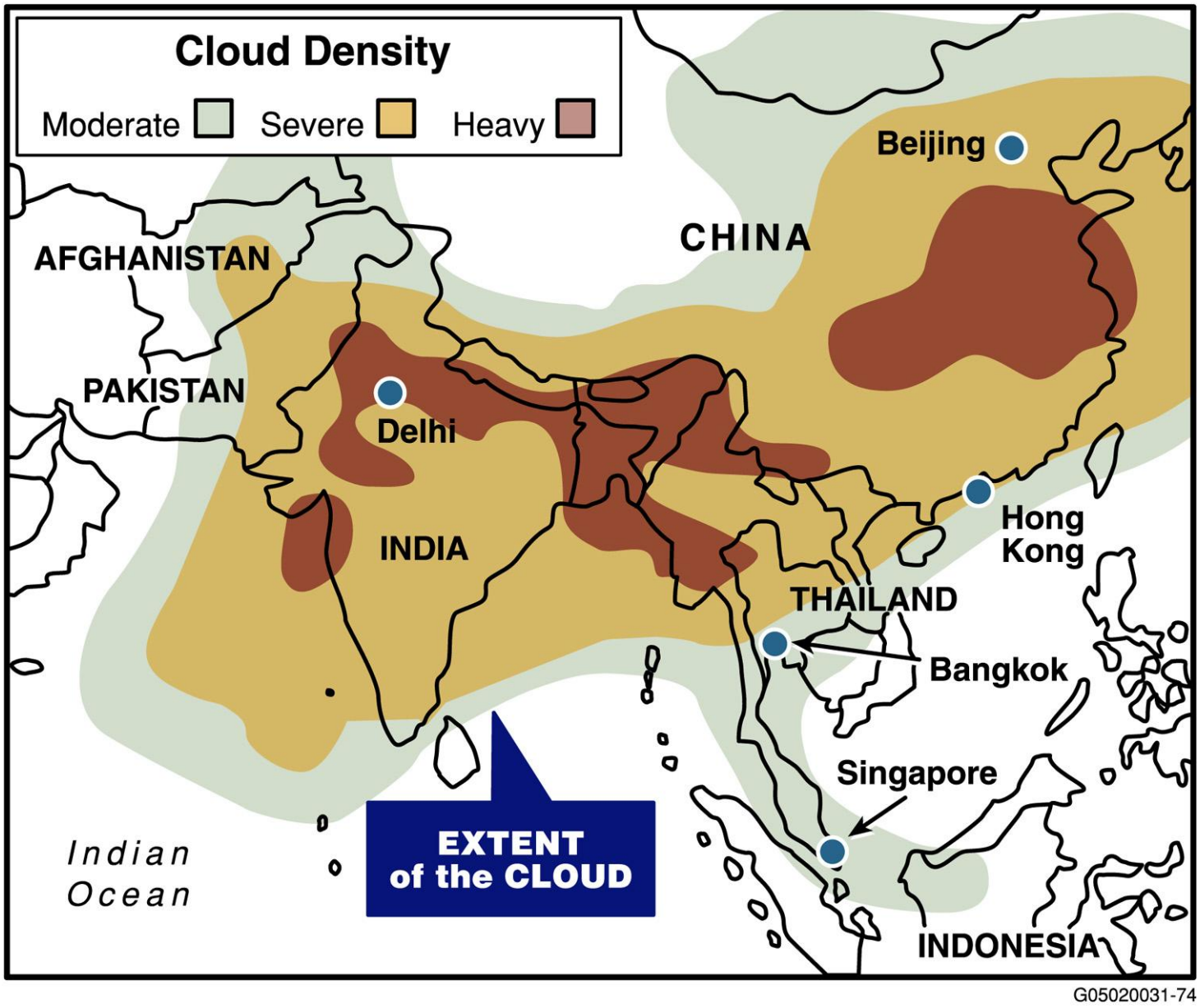
RADIOLOGICAL CONTAMINATION

Russian Nuclear Weapons Production

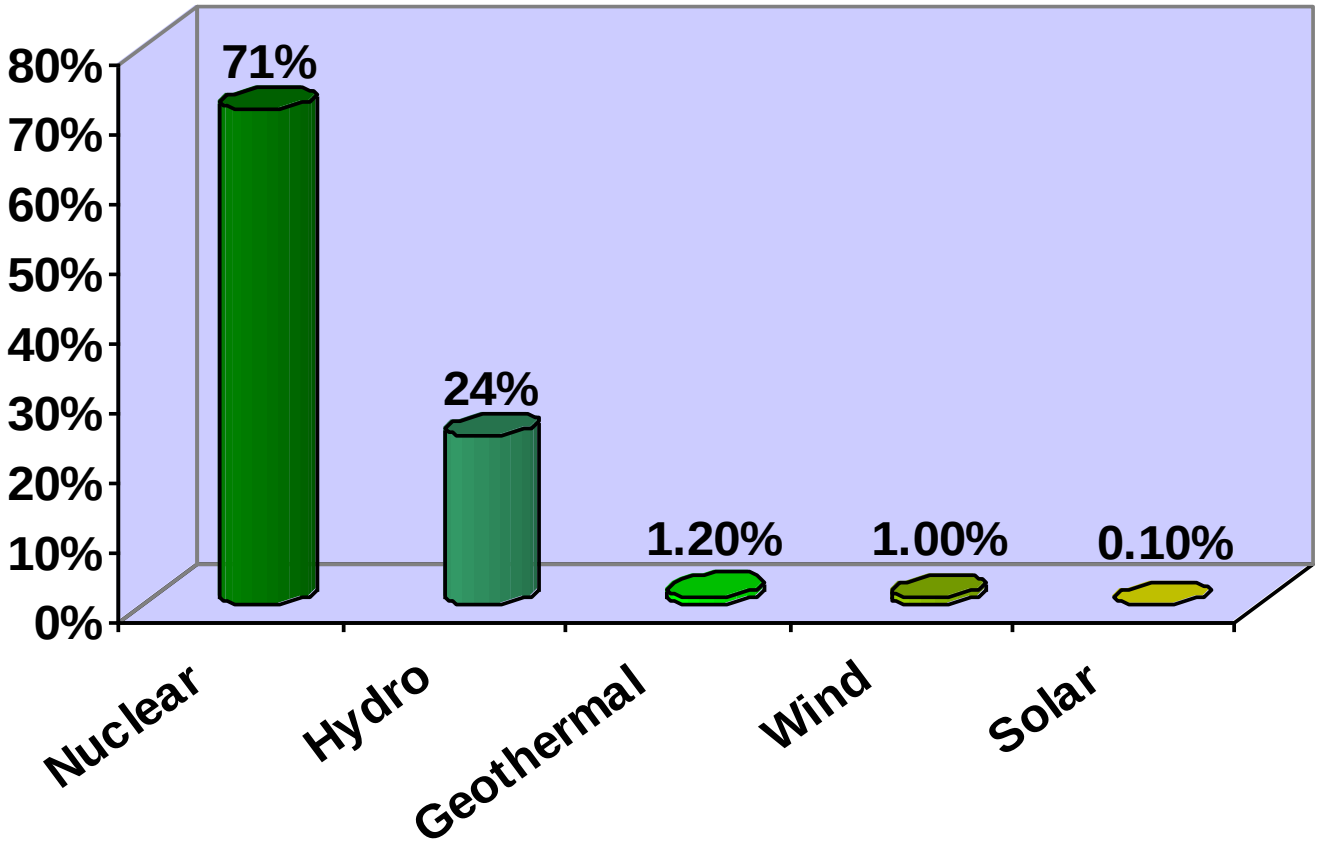
- Raw nuclear wastes dumped directly into the Techa River and Karachai Lake
- 1057 Myak Site: Dehydrated radioactive waste tank exploded
- 1987 Chernobyl Accident
  - but actual hazards considerably less than at nuclear weapons sites
- Sunken Nuclear Submarines in Kara and Barent Sea
  - But sudies indicate very little radiation contamination



Carbon Dioxide Concentration in Global Atmosphere



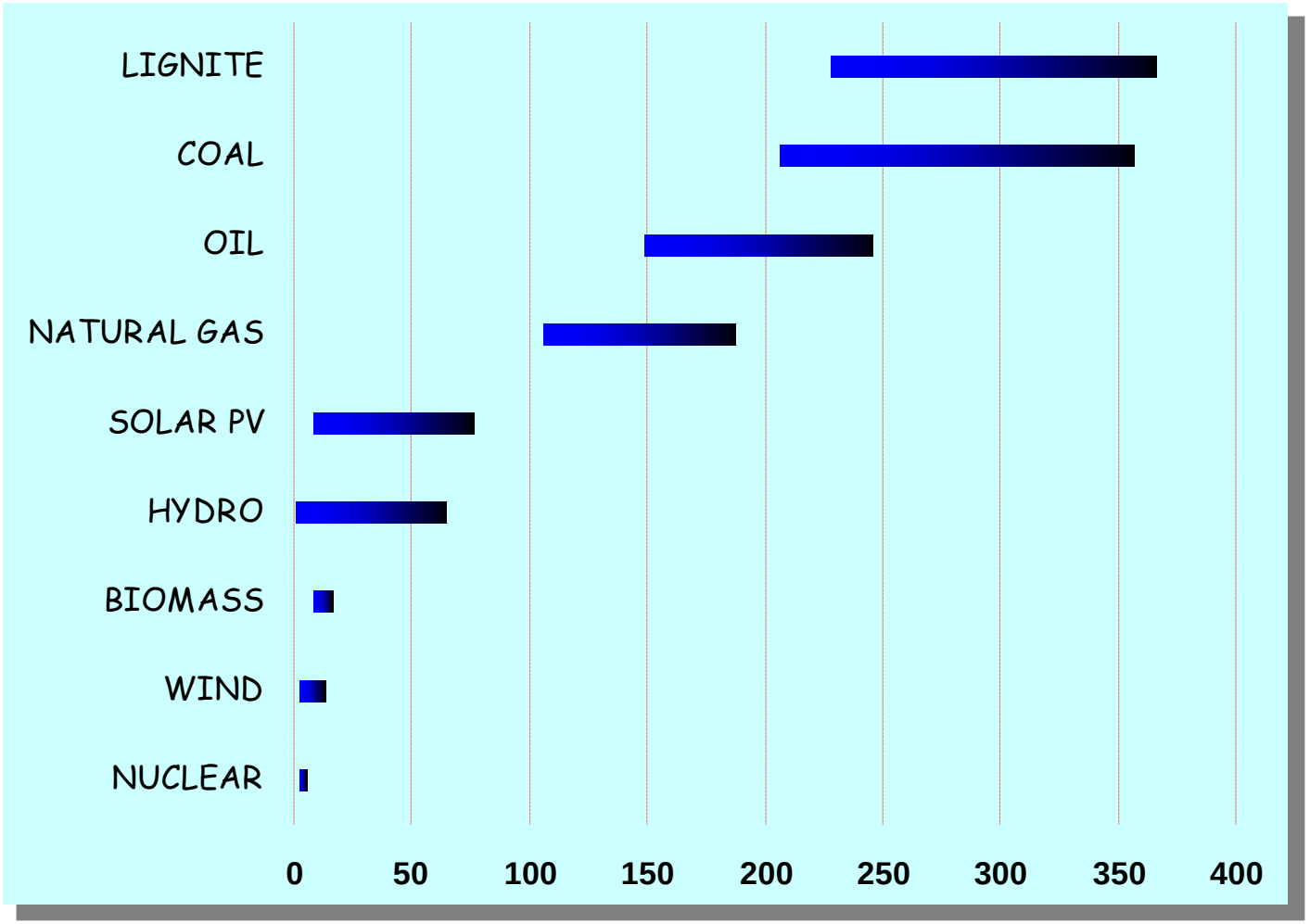
Asian Brown Cloud



Emission-Free Energy in the United States

Nuclear power has a low-carbon life cycle

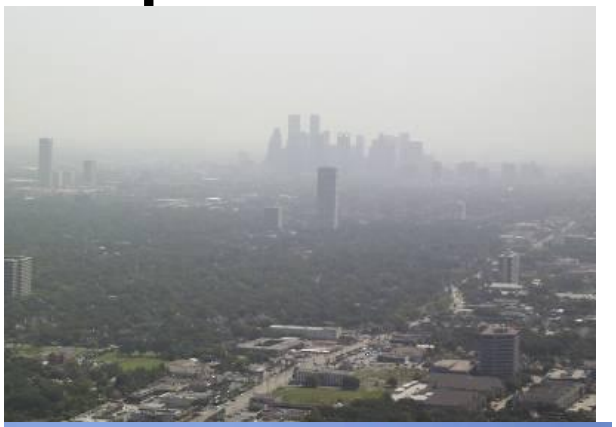
GHG gC_{eq}/kWh



Source: Sokolov, IAEA, 2005

Pollution emissions are avoided by currently installed nuclear plants

- **Pollution avoided in 2004**
  - **3.43 million tons of SO_2**
  - **1.11 million tons of NO_x**
  - **700 million tons of CO_2**



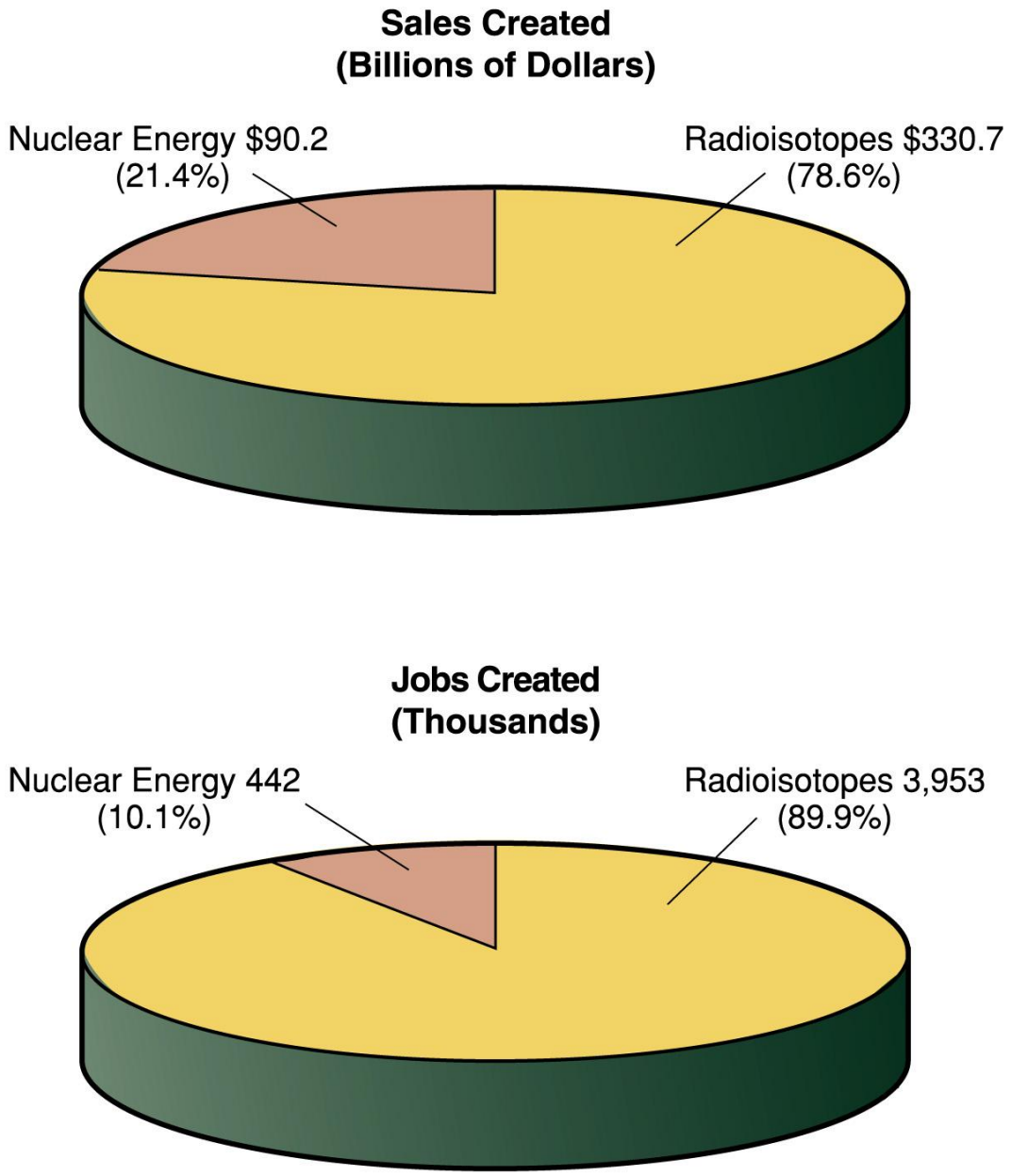
440 worldwide nuclear plants save <u>more than twice</u> the Kyoto Accord CO_2 targets annually

MODERN ECONOMY

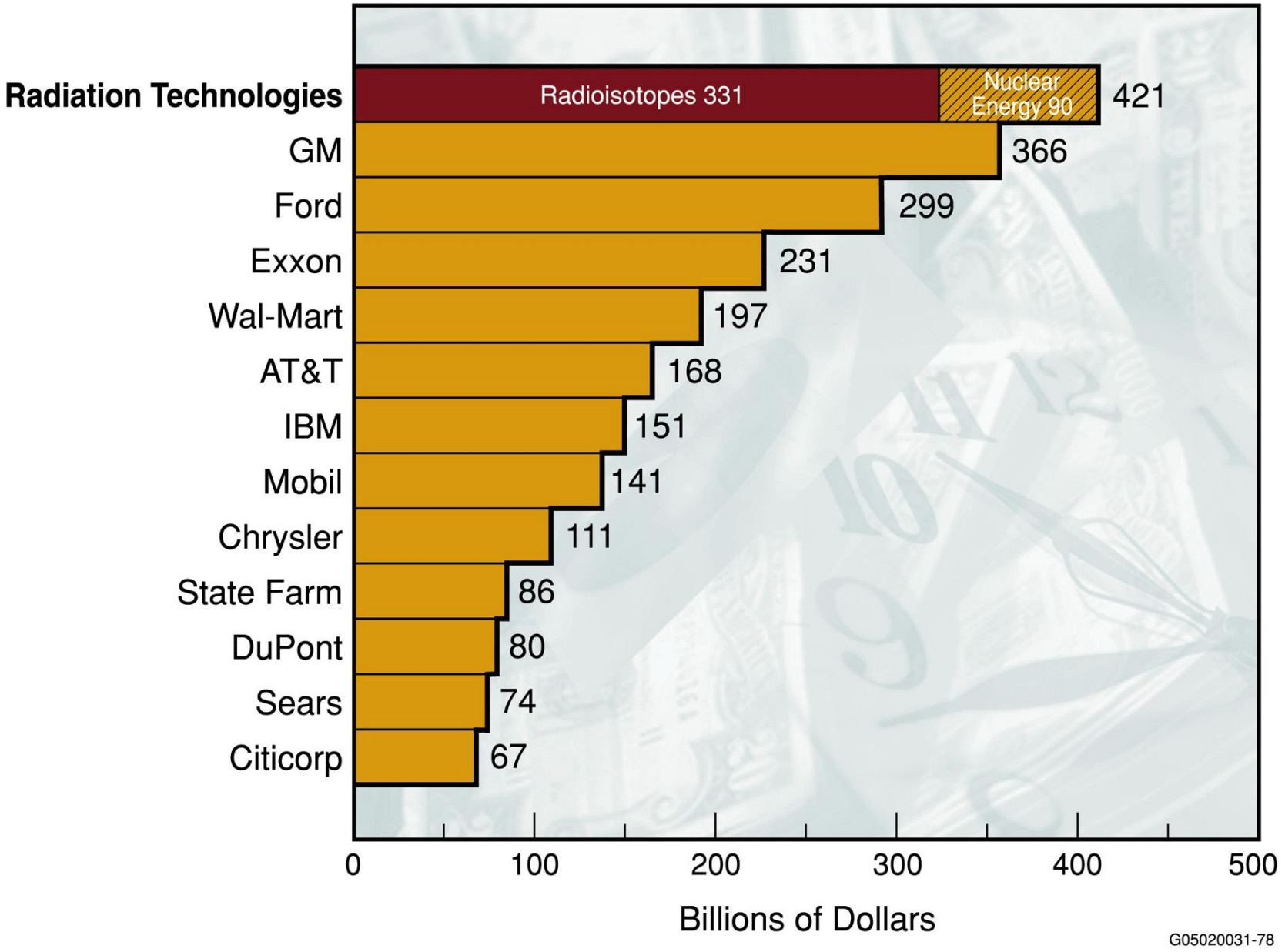
Overall Impact in the U.S

(using multiplicative economic model)

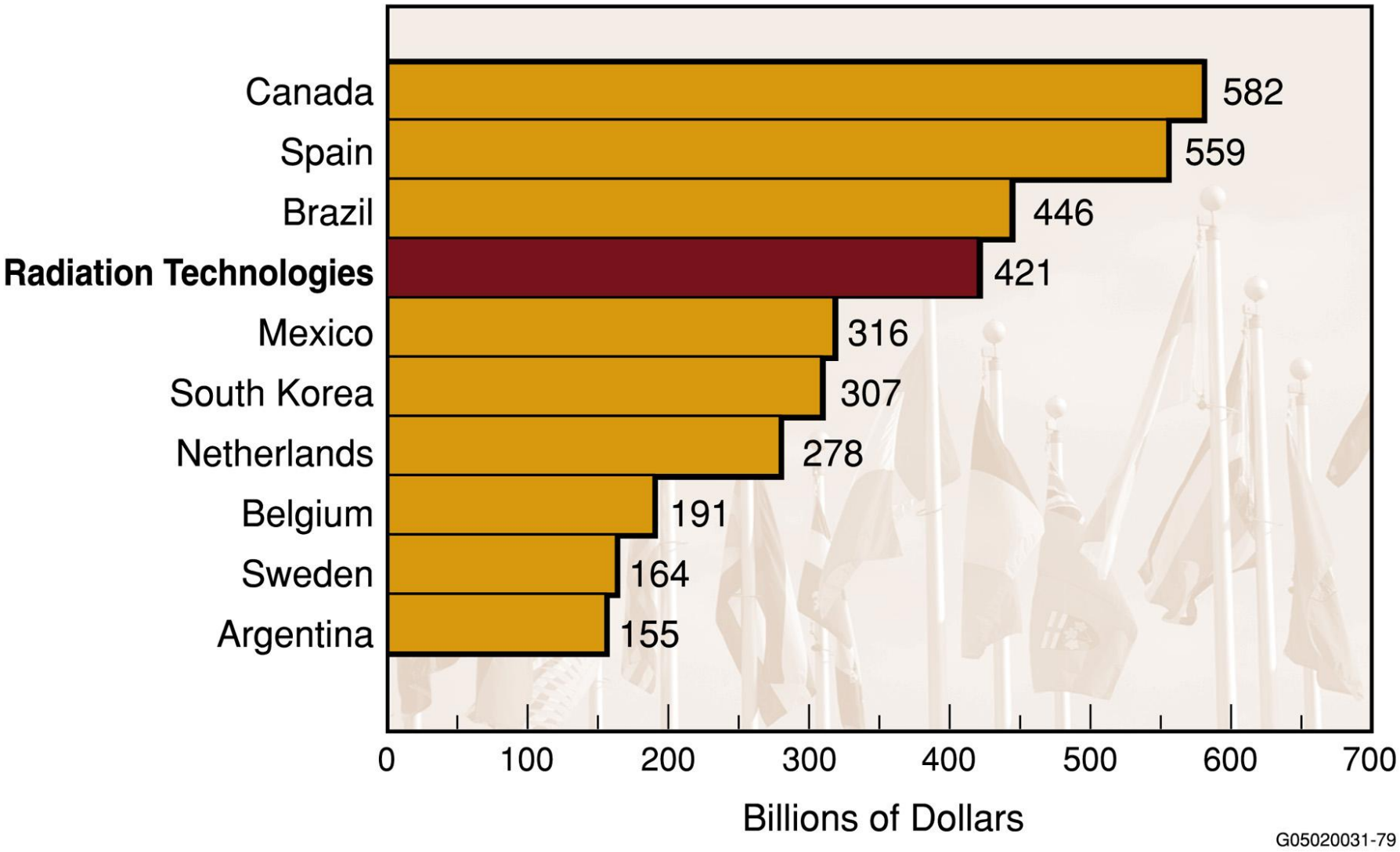
	1991		1995	
	SALES $ Billions	**JOBS** Millions	**SALES** $ Billions	**JOBS** Millions
Radiation	257	3.7	**331**	**4.0**
Nuclear Power	73	0.4	**90**	**0.4**
TOTAL =	**330**	**4.1**	**421**	**4.4**



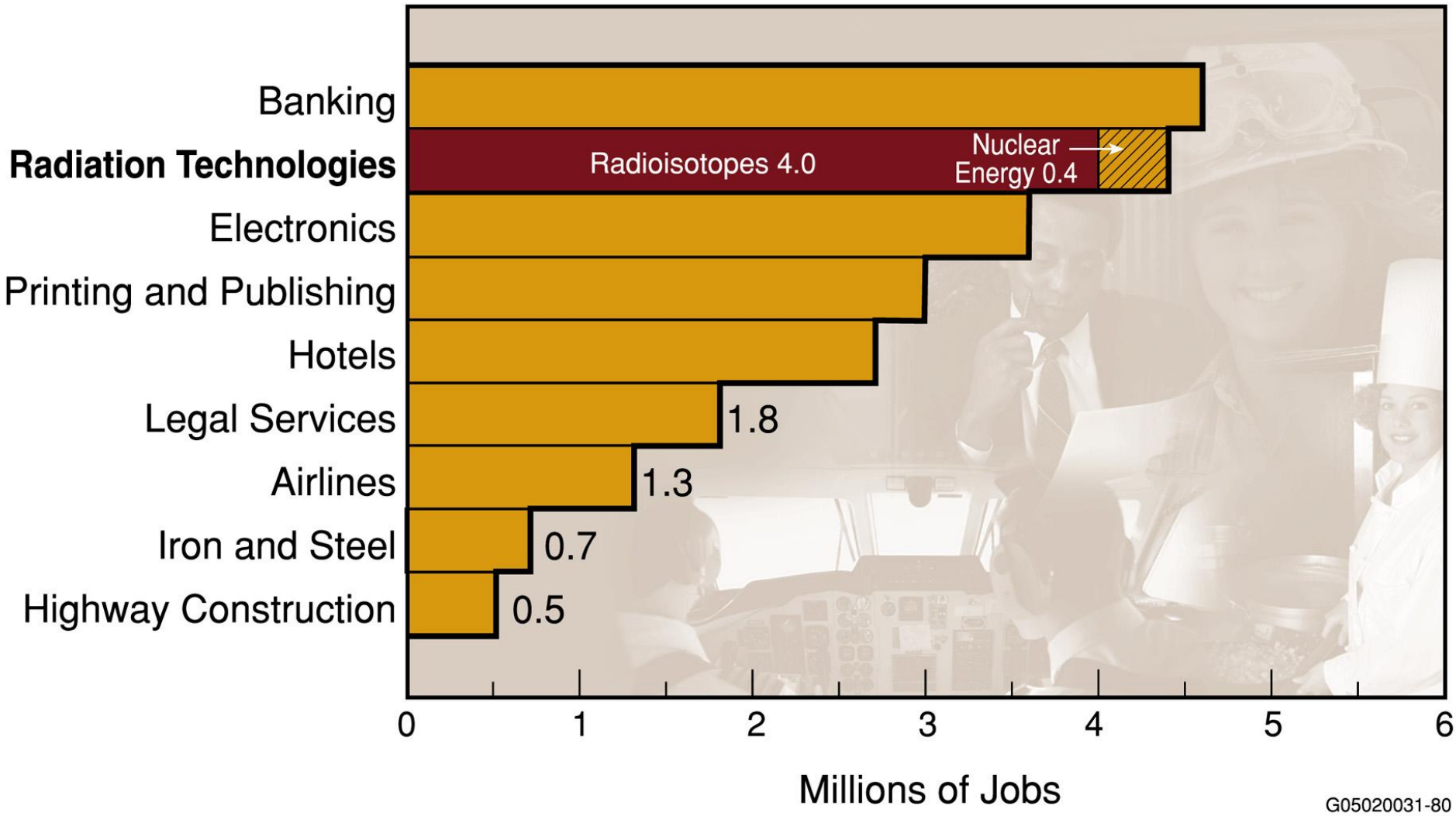
Distribution of Economic and Job Benefits to the US Economy by Radiation Technologies, 1996



Comparison of Radiation Technologies to Fortune 500 Companies



Comparison of Radiation Technologies in US to GDP of Major Countries



Comparison of Radiation Technologies to Major Industries in the US

Japanese Study for 1997
(Direct Financial Contributions, $ Billions)

		Japan	USA
Population (M)		120	270
GDP ($B)		4231	8318
RADIOISOTOPES	Medicine	12	49
	Agriculture	1	14
	Industry	39	56
		52	**119**
NUCLEAR ENERGY*		**47**	**39**
TOTAL =		**99**	**158**
%GDP =		(2.3)	(1.9)

* kW-hr price assumed: Japan = 15.0 cents; USA = 6.8 cents

A DAY WITH THE ATOM

...Living with Zest!

This four page piece is uploaded for your use

Key Take Away Points

1. **Deep space probes impossible without radioisotopes**
2. **Radiation techniques used frequently in solving crimes and fighting terrorism**
3. **The economic benefits of harnessed radiation much higher than nuclear power (at least in the U.S.)**

Thank You!