Chemical Engineering 412

Introductory Nuclear Engineering

Lecture 14

Industrial Applications

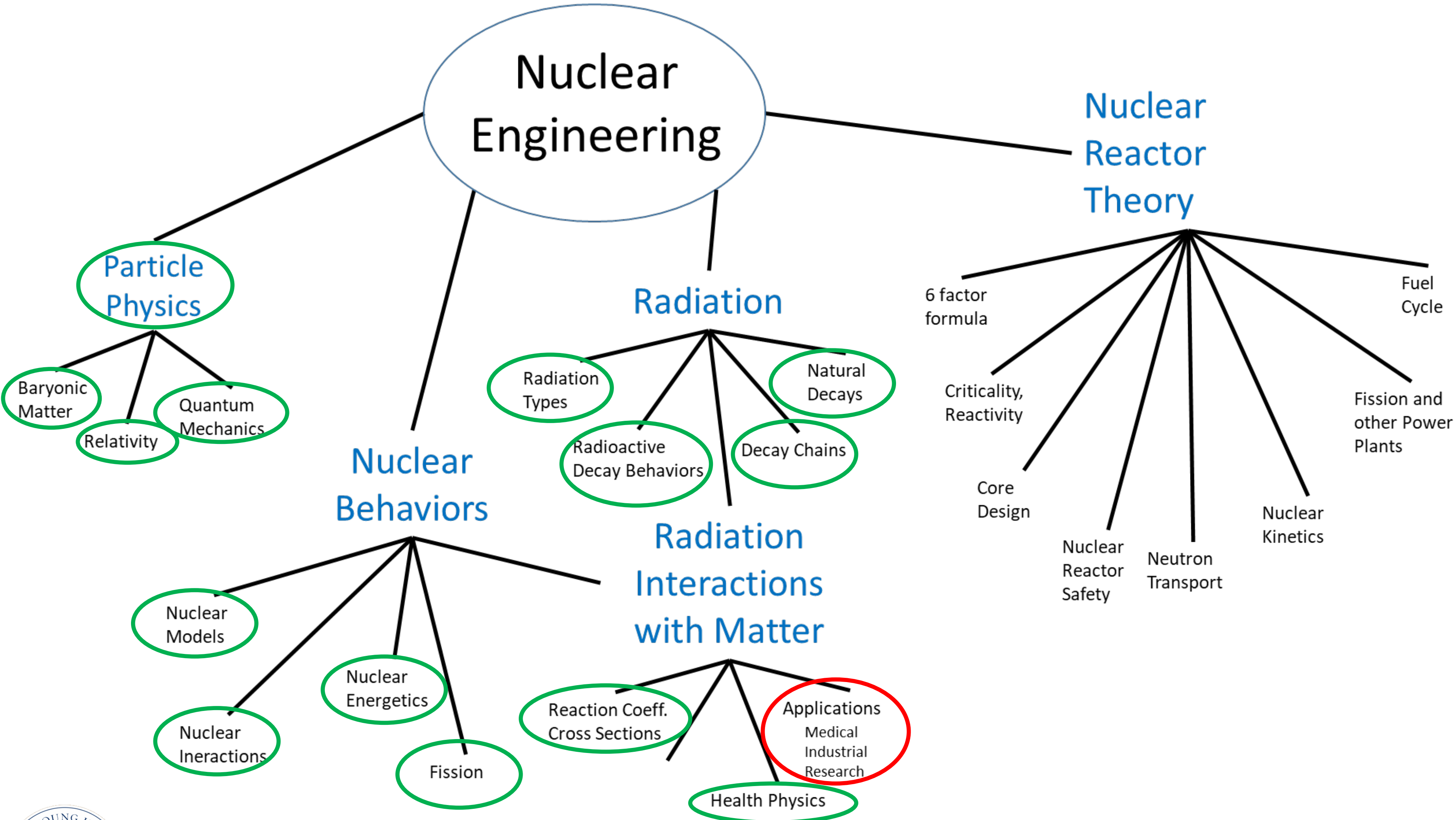
Spiritual Thought

Mosiah 27:24, 29

24. For, said he, I have repented of my sins, and have been redeemed of the Lord; behold I am born of the Spirit…

29. My soul hath been redeemed from the gall of bitterness and bonds of iniquity. I was in the darkest abyss; but now I behold the marvelous light of God. My soul was racked with eternal torment; but I am snatched, and my soul is pained no more.

Roadmap


Nuclear Engineering
Particle Physics
Baryonic Matter
Relativity
Quantum Mechanics
Nuclear Behaviors
Nuclear Models
Nuclear Ineractions
Nuclear Energetics
Fission
Radiation
Radiation Types
Radioactive Decay Behaviors
Natural Decays
Decay Chains
Radiation Interactions with Matter
Reaction Coeff. Cross Sections
Health Physics
Applications
Medical
Industrial
Research
Nuclear Reactor Theory
6 factor formula
Criticality, Reactivity
Core Design
Nuclear Reactor Safety
Neutron Transport
Nuclear Kinetics
Fission and other Power Plants
Fuel Cycle

Key Points

- Know 5 general categories of industrial/research uses of nuclear technology
- Know how to calculate tracer amounts
- Know general uses of radiation in industry
- Be able to categories uses according to 5 general categories
- Be enthusiastic about nuclear industrial applications!

Research Use

- Biological and Genetic research
- Agricultural research
- Space research
- Pharmaceutical research
- Biology Research
- Geological Research
- Energy Research
- Oceanographic
- Etc. etc. etc.

Beneficial Uses of Radiation

- Radioisotope Production
- Tracer Applications
- Materials Affect Radiation
- Radiation Affects Materials
- Particle Accelerators

Radioisotope Production

- Reactor Irradiation
  - ^{60}Co, ^{14}C, ^{3}H
- Fission Products
  - ^{238}Pu, ^{244}Cm, ^{252}Cf
- Accelerators (proton addition)
  - ^{65}Zn, ^{67}Ga, ^{54}Mn, ^{22}Na, ^{57}Co
  - ^{98}Mo -> ^{99m}Tc, ^{137}Cs->^{137m}Ba

Industrial Radiation Applications

Industry: Products/Services	Use	Types of Sources
Manufacturing: • numerous	Measure: • thickness of metal components • thickness of coatings • moisture content in manufactured products	Gamma emitters such as: • barium-133 • cobalt-60 • cesium-134 • cesium-137 • antimony-124 • selenium-75 • strontium-90 • thulium-170
Chemical Processing: • various	Measure process characteristics, such as: • density • thickness of coatings • specific gravity • level Measure equipment parameters such as: • pipe thickness • corrosion • wear	Gamma emitters neutron sources (for level measurement)
Construction: • buildings, geophysical structures	Measure: • moisture content • location of reinforcing bar (rebar)	Gamma emitters; neutron sources such as: • americium/beryllium • plutonium/beryllium • californium-252
Mineral Processing: • measuring mineral levels in process streams	• density gauges • spectroscopy	Gamma emitters, such as: • americium-241 • cobalt-57 • cesium-137
Coastal Engineering: • measuring environmental parameters	Measure: • levels of sediments in rivers and estuaries • sediment mobilization	Gamma emitters, such as: • americium-241 • cobalt-57 • cesium-137

Industrial Radiation Applications

Industry: Products/Services	Use	Types of Sources
Non Destructive Examination: • radiography	Measure: • weld and weld overlays • castings • forgings • valves and components • machined parts • pressure vessels • structural steel • aircraft structures	Gamma emitters, such as: • cobalt-60 • cesium-137 • iridium-192
Oil Refining: • refinery products	• column scanning • level measurement	Gamma emitters (column scanning); neutron sources (level measurement) especially americium-241/beryllium-
Coal Fired Boilers: • electricity generation	Measure: • ash and moisture content of coal	Gamma sources such as cesium-137 with americium-241 (for ash content)
Drilling / Borehole Logging: • geophysical investigations	Measure: • hydrogen content	Gamma emitters, especially Cobalt-60, and neutron sources americium-241/beryllium
Agriculture: • various crops	Measure: • soil moisture measurements	Neutron sources such as: • americium/beryllium • plutonium/beryllium • californium-252
Hydrology: • environmental assessments	Measure: • soil moisture	Neutron sources such as: • americium/beryllium • plutonium/beryllium • californium-252
Consumer Products: • smoke detectors	Produce an ionization current that is affected by the presence of smoke	Alpha emitter typically americium-241

Industrial Radiation Applications

Industry: Products/Services	Use	Types of Sources
Materials Processing: • blown film • cast film and sheet • rubber • vinyl • coatings & laminations • nonwovens • textiles • composites • paper • plastic pipe • film thickness • electroplating	Measure: • thickness or weight • basis weight • consistency • moisture content	Gamma emitters, such as: • americium-241 Beta emitters such as: • praseodymium-147 • krypton-85 • strontium-90
Various: • remote weather stations • weather balloons • navigation beacons and buoys	Power sources for applications requiring small amounts of portable energy	

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Radiation Source Advantages

- Advantages
  - Robust, sources are amenable to a variety of environments
  - Reliable – while the detection of the emitted radiation can be sophisticated, the energy source is simple and cannot fail
  - Portable energy source not requiring other sources of energy (e.g., electricity) for operation
  - Range of energies
  - Easily transportable
  - Interact with other media in a well defined manner that facilitates various measurements
  - Do not require contact with other materials or media for use
  - Devices are typically easy to use and do not require sophisticated operator training
  - Commercially available from a large number of vendors in a variety of forms and energies
  - Mature technology

Radiation Source Disadvantages

- Disadvantages
  - Need for precautions to prevent exposure of individuals to harmful radiation
  - Energy source is always “on”, thus requiring significant attention to storage
  - Loss of the source can create an environmental and health hazard
  - “Spent” sources require appropriate disposal

Industrial Uses

- Tracers – movement through some process
- Materials properties through radiation property changes
- Materials properties through materials property changes
- Energy from Radioisotopes

Tracers

- leak detection
- flow measurements
- isotope dilution
- tracking of material
- radiometric analysis
- metabolic studies
- wear and friction studies
- labeled reagents
- preparing tagged materials
- chemical reaction mechanisms
- material separation studies

How Much Tracer Needed?

M_m= min mass needed
CR_m= min count rate (> background, typically 0.5 s^{-1})
$T_{\frac{1}{2}}$= half life
A = atomic weight
N_a = Avogadro's number
ϵ = efficiency of detector (about 0.1 for gamma rays)

$$M_m = \frac{CR_m T_{\frac{1}{2}} A}{N_a \epsilon \ln 2}$$

$^{14}C \approx 10^{-11}$ g
$^{32}P \approx 10^{-16}$ g

Example Problem

A typical gamma-ray detector efficiency is ~10%. A minimum count rate for this detector is 30 min^{-1}. Assuming the detector is picking up ^{14}C emissions, what is the minimum detectable mass of ^{14}C?

$$M_m = \frac{C R_m T_{\frac{1}{2}} A}{N_a \epsilon \ln 2}$$

$$M_m = \frac{(0.5 s^{-1})(1.18 \cdot 10^{11}\ s)\left(14\ {}^{g}/_{mol}\right)}{\left(6.024 \cdot 10^{23}\ \frac{atoms}{mol}\right)(0.1)(\ln 2)} =$$

$$2 \cdot 10^{-11}\ g$$

Other problems – isotope balances

- Mercury in Fish
- Activation of other isotopes and measuring decays (quantities)

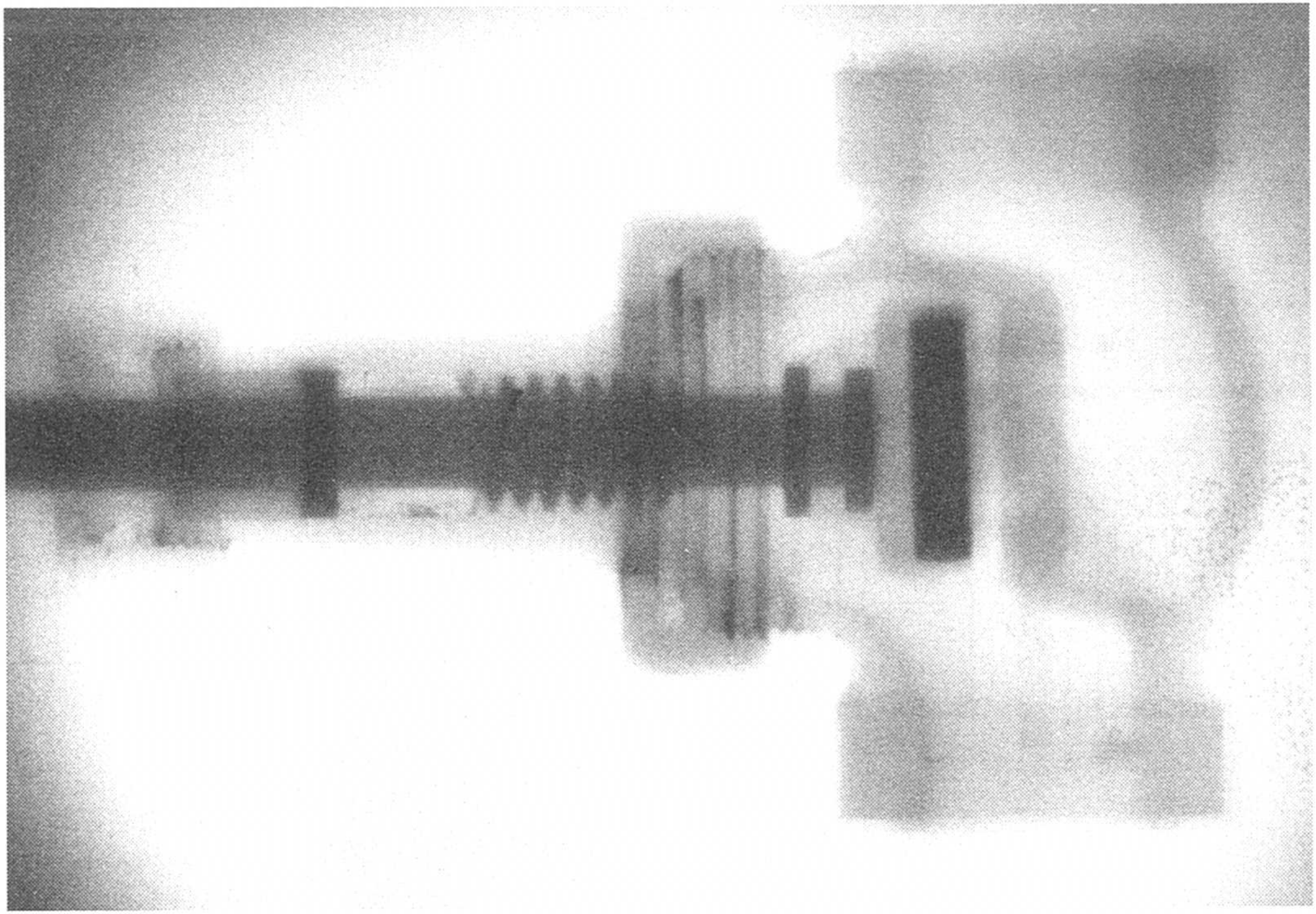
$$\frac{d\,{}^{n}I}{dt} = -\lambda\,{}^{n}I + N_0^{n-1}\sigma^{n-1}\phi$$

- Problems 13.1, 13.2, 13.11, 13.12
  - (Use Table 13.3 for 13.11)

Materials Affecting Radiation

- density gauges
- thickness gauges
- radiation absorptiometry
- x-ray and neutron scattering
- liquid level gauges
- neutron moisture gauges
- x-ray / neutron radiography
- bremsstrahlung production

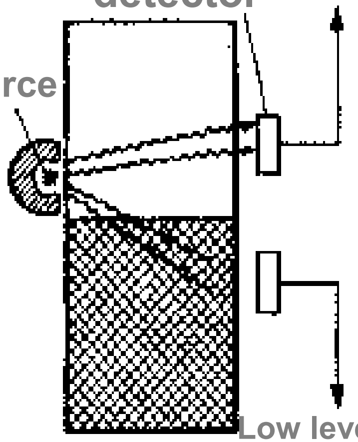
Neutron Absorption/Radiograph



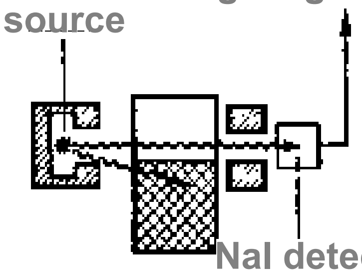
Iron mostly transparent – plastic and Teflon less transparent

Level Gauge

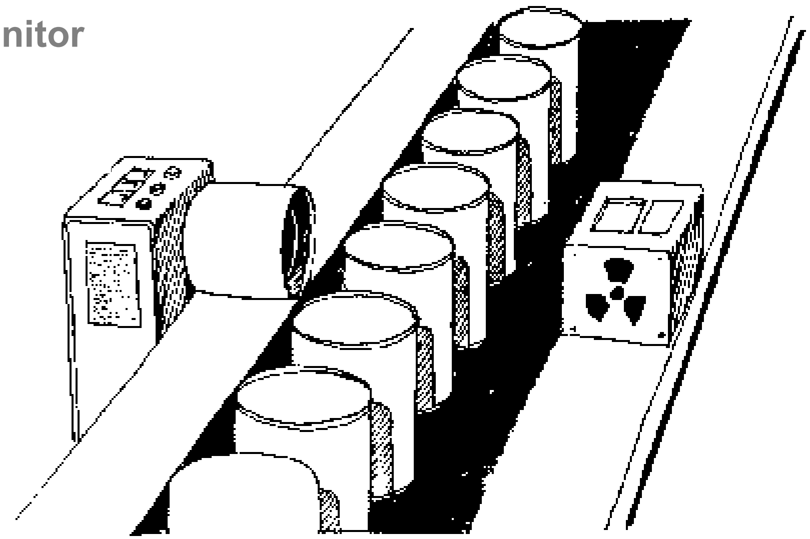
Gamma Switching Technique



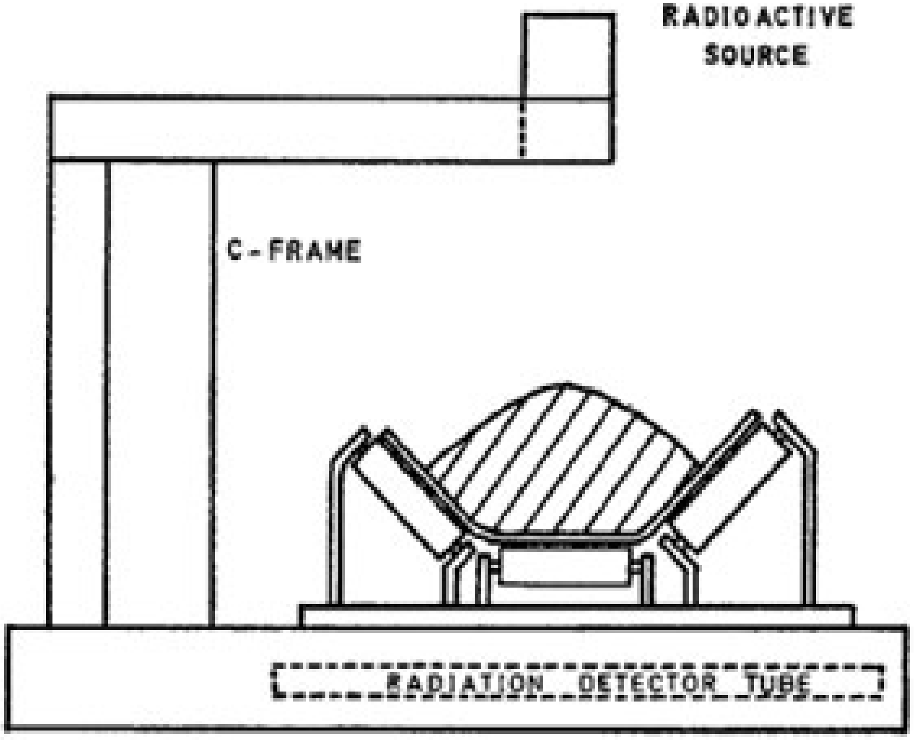
Storage hopper level control

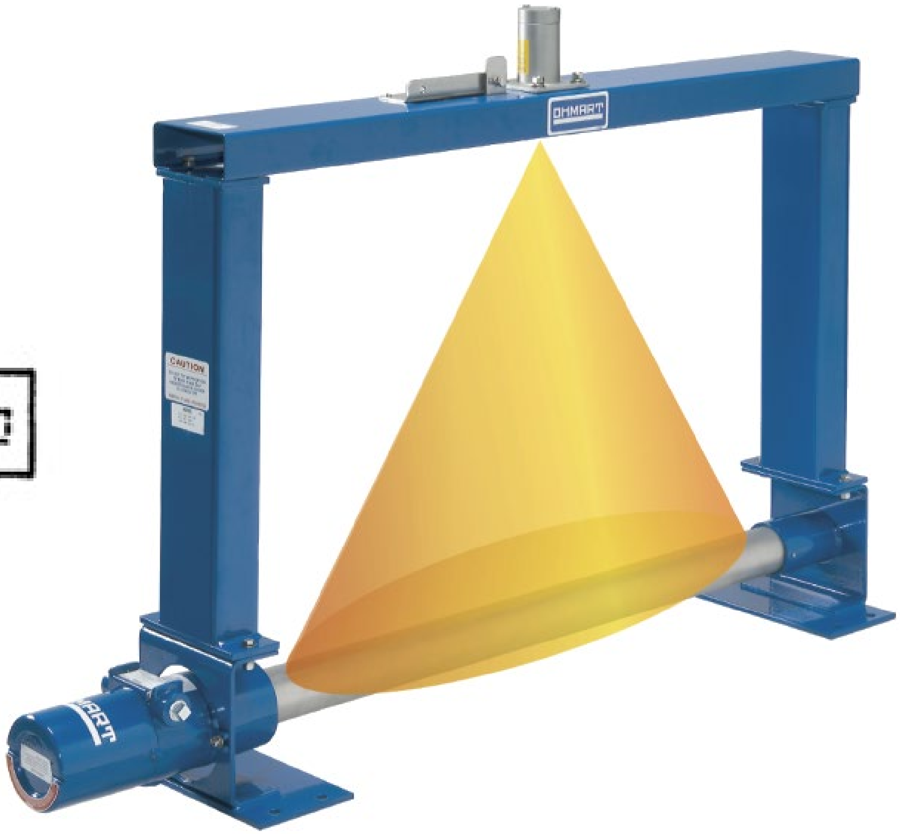


Can/package content monitor



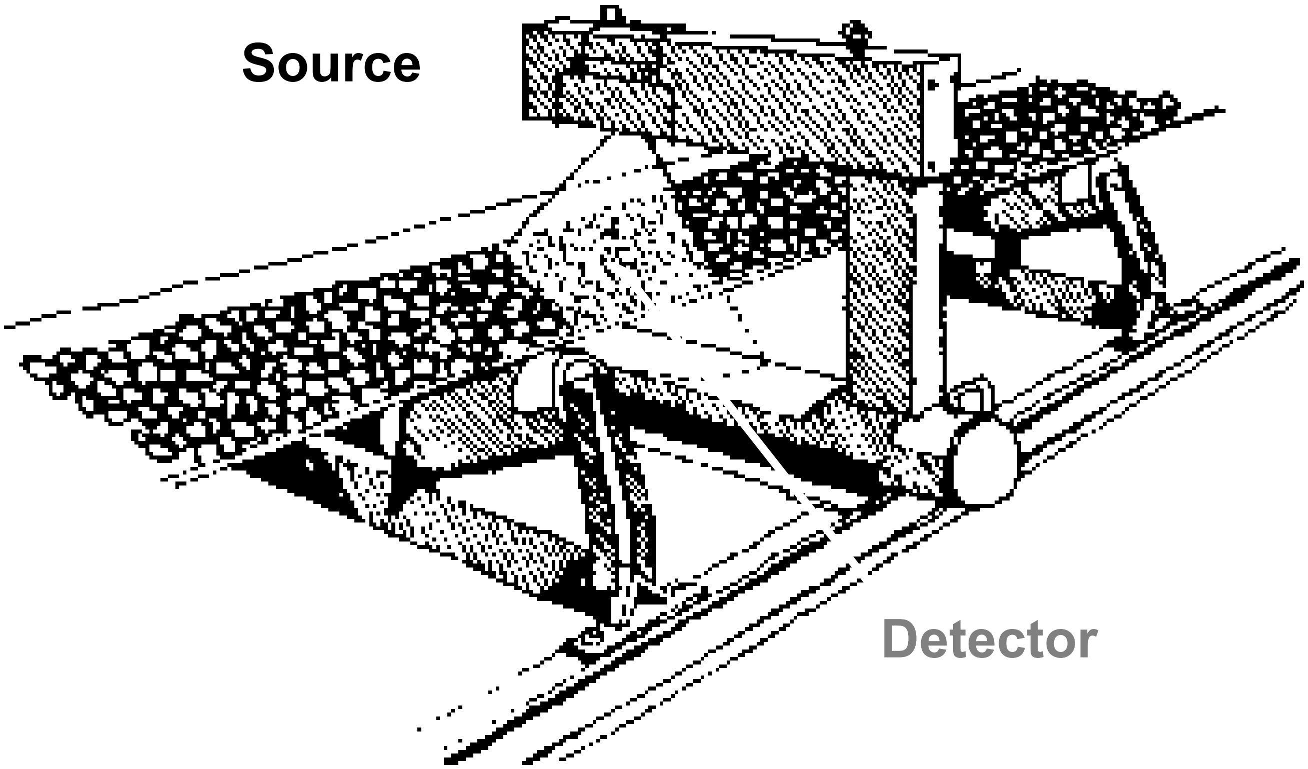
Thickness Gauge
Transmission Thickness Technique



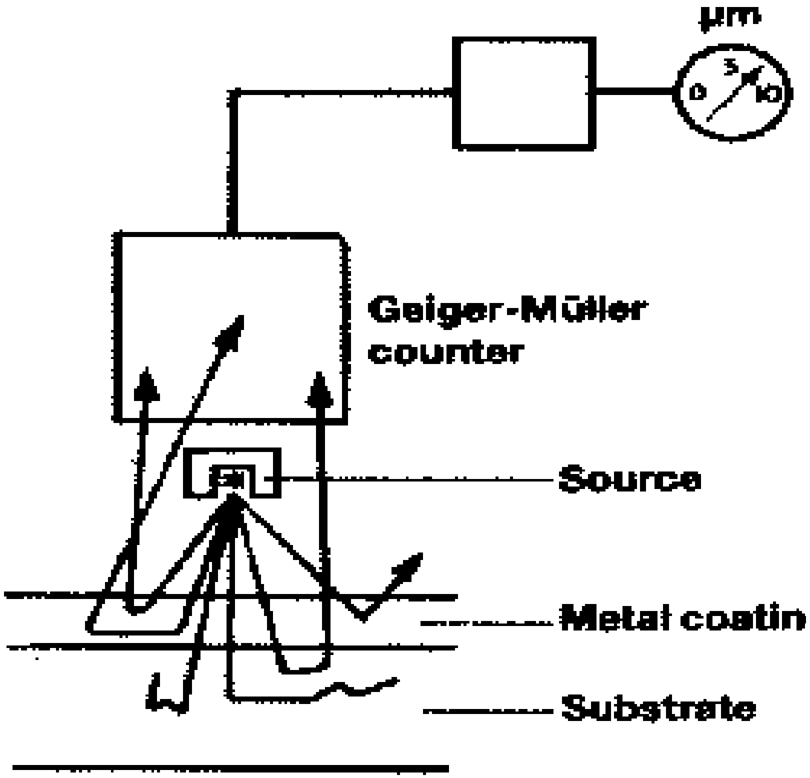


Thickness Gauge

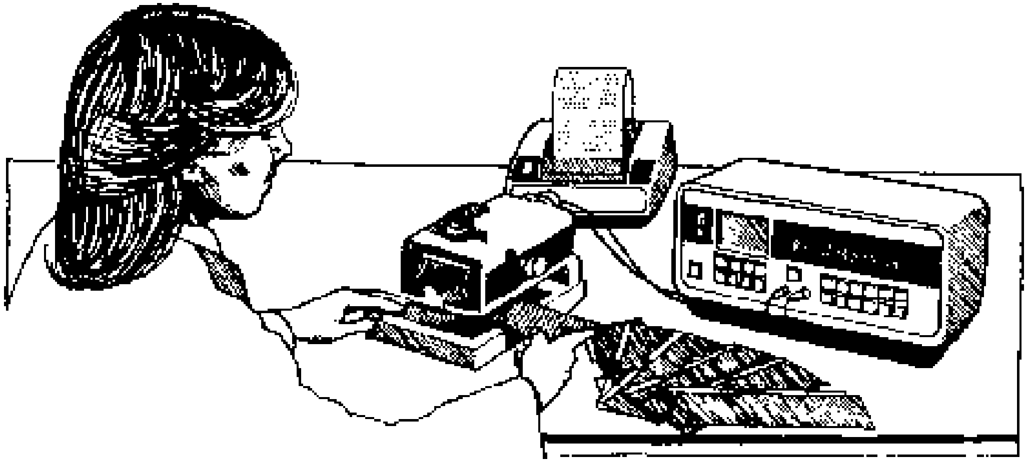
Non-contact measurement and control of liquids, solids or slurries in pipelines. Specific source size is selected for each application. This is also referred to as gamma gauging or belt weighing



Thickness Gauge
Beta backscattering technique



Beta backscatter thickness gauging

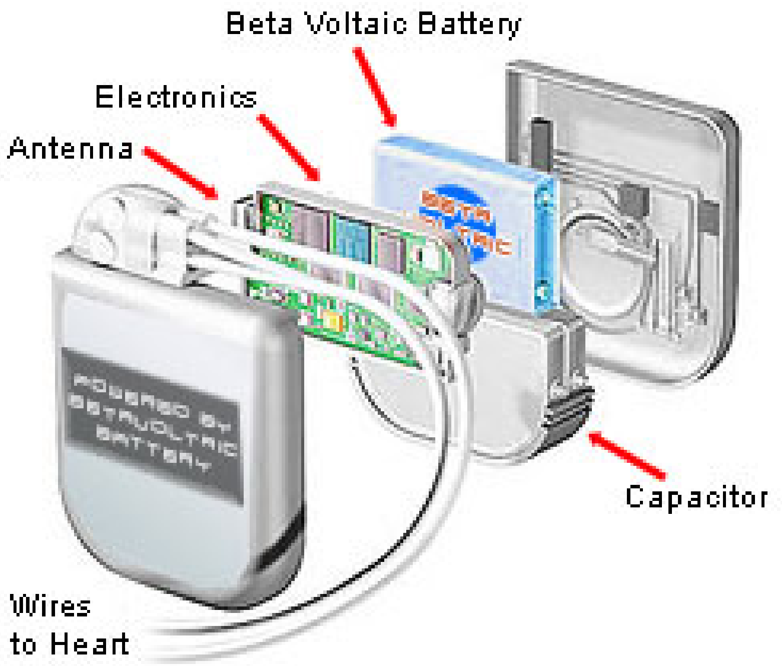


Radiation Affecting Materials

- energy
- radioactive catalysis
- food preservation
- biological growth inhibition
- insect disinfestation
- Mossbauer effect
- radiolysis
- static elimination
- synthesis
- modification of fibers
- increasing biological growth
- sterile-male insect control
- luminescence
- polymer modification
- biological mutations
- bacterial sterilization
- x-ray fluorescence

Use of Energy

- thermal power sources
- electric power sources



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Food Irradiation

- Food treatment comparable to pasteurization
  - Kills pests/microorganisms without food degradation
  - Controls sprouting
- Does not make the food radioactive
- FDA Approved
- Must be labeled
- https://www.omahasteaks.com/info/Product-Recall
- https://www.chicagotribune.com/news/ct-xpm-2001-05-09-0105090264-story.html

Consumer Products

- Smoke Detection Equipment
- Self-powered Lighting in Exit Signs
- Lighted Aircraft Instrumentation
- Pharmaceutical Detection
- Bomb/Weapons Detection
- Scanning and Surveillance Equipment
- Theft Deterrent Systems

Economics

America derives substantial economic and employment benefits from the use of radiation and radioactive materials:

$330.7 billion annually in total industrial sales

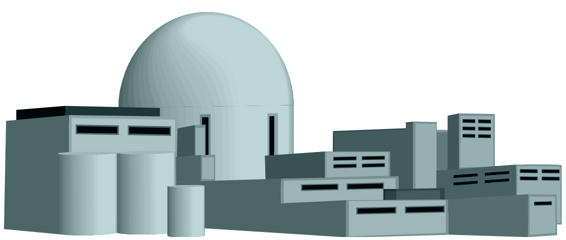
4,000,000 jobs

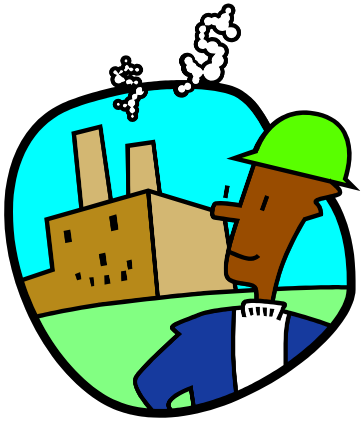
$60 billion in tax revenues to local, state & federal governments

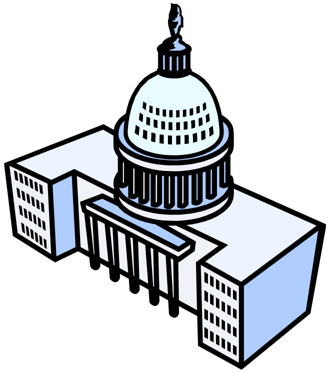
Economics

Nuclear energy's direct and indirect economic impacts in the US:

442,000 jobs







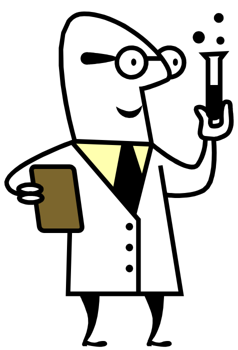
$90 billion in total sales of goods & services

$17.8 billion in local, state & federal tax revenues

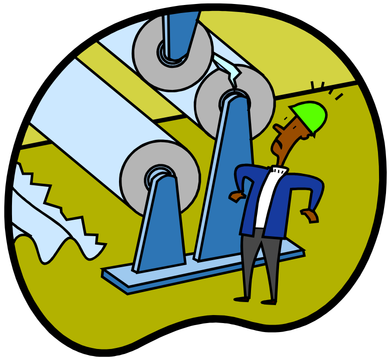
Destination

Once they are produced, they are packaged and shipped safely to users throughout the United States; users are:

Universities



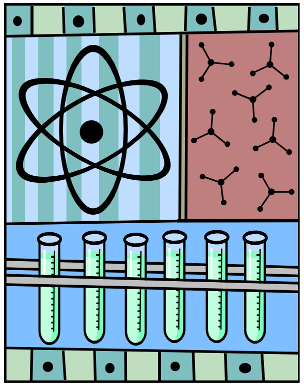
Laboratories



Industries

Hospitals

Scientific Research



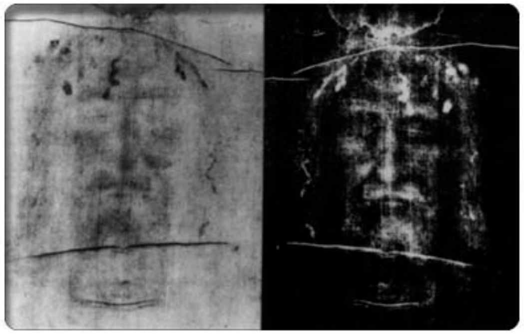
The FDA requires that all new drugs be tested for safety and effectiveness; more than 80% are tested with radioactive materials

Radioactive materials are also used in biomedical research, metabolic studies, genetic engineering and environmental protection studies

Scientific Research

Archaeologists use ^{14}C to date artifacts containing plant or animal material

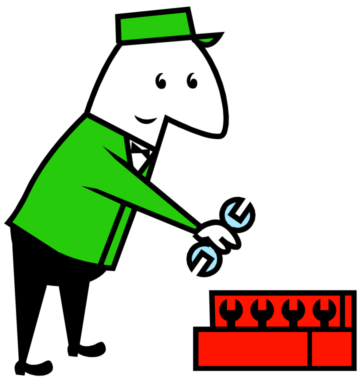
Criminal investigators use radiation to examine evidence



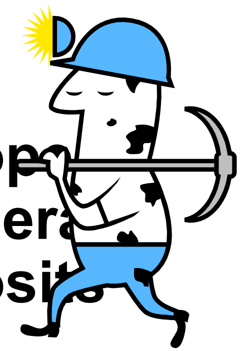
Museums rely on radioactive materials to verify authenticity of art objects and paintings

Industrial Uses

Automobile industry makes use of isotopes to test the quality of steel in cars



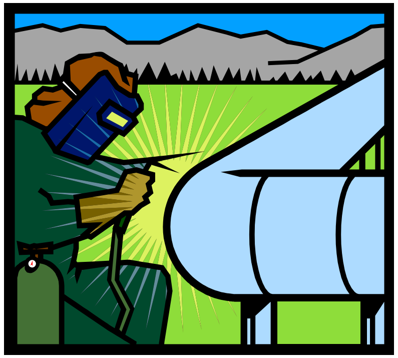
Aircraft manufacturers use radiation to check for flaws in jet engines



Mining & petroleum companies use isotopes to locate and quantify geological mineral deposits

Industrial Uses

Oil gas & mining companies use isotopes to map geological contours (using test wells) and mine bores and to determine presence of hydrocarbons



Pipeline companies utilize radioactive isotopes to look for defects in welds

Construction crews use radioactive materials to gauge soil moisture content and asphalt density

Agricultural Uses

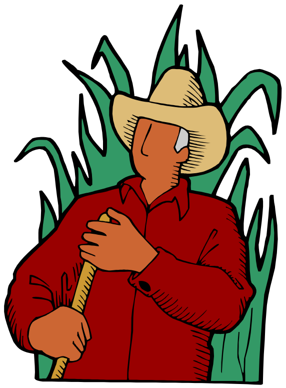
Hardier and more disease resistant crops (peanuts, tomatoes, onions, rice, soybeans, barley) have been developed using radioactive materials in agricultural research

Nutritional value, baking and melting qualities of some crops and cooking times have been improved using isotopes

Radioactive materials pinpoint where illnesses strike animals to breed disease-resistant livestock

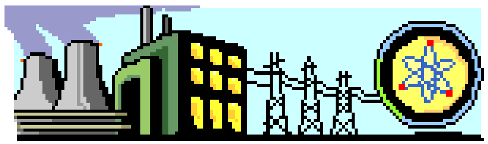
Agricultural Uses

Radioactive materials show how plants absorb fertilizer; this helps researchers figure where and how much to apply to crops for maximum yield



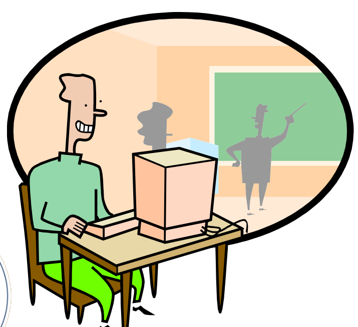
Isotopes help farmers and scientists control pests; e.g., California has used radiation sterilization since the mid-70s to control Mediterranean fruit fly infestations

Consumer Products & Services



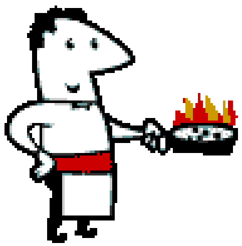
103 US nuclear power plants provide ~20% of electricity

Smoke detectors installed in ~90% of America's homes rely on 1-2 μCi of ^{241}Am to monitor for smoke to signal a fire



Computer disks retain data better when treated with radiation

Consumer Products & Services



Non-stick pans are treated with radiation to retain the coating

Photocopiers and plastic manufacturers use small amounts of radiation to eliminate static and prevent jamming

Cosmetics, hair products and contact lens solutions are sterilized with radiation to remove irritants and allergens

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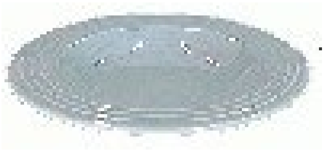
Consumer Products & Services

Radioactive materials are used to sterilize medical bandages and implements as well as foodstuffs to kill pathogens



1930s Fiestaware contains uranium in the ceramic glazes

To maximize light output, some lantern mantles contain radioactive thorium nitrate

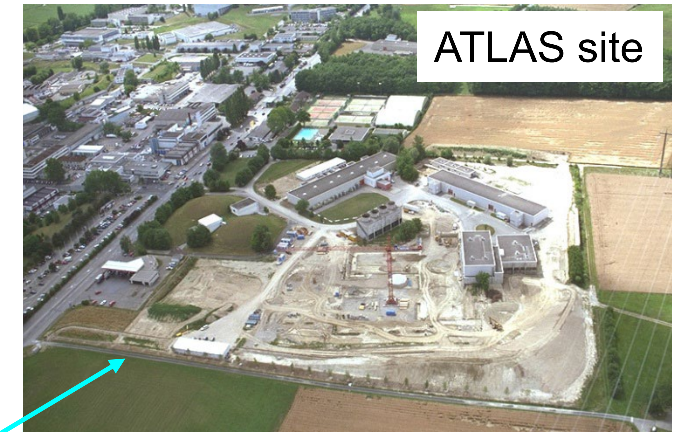
The Large Hadron Collider

LHC is located at CERN
CERN is located near Geneva
Part of CERN is in France

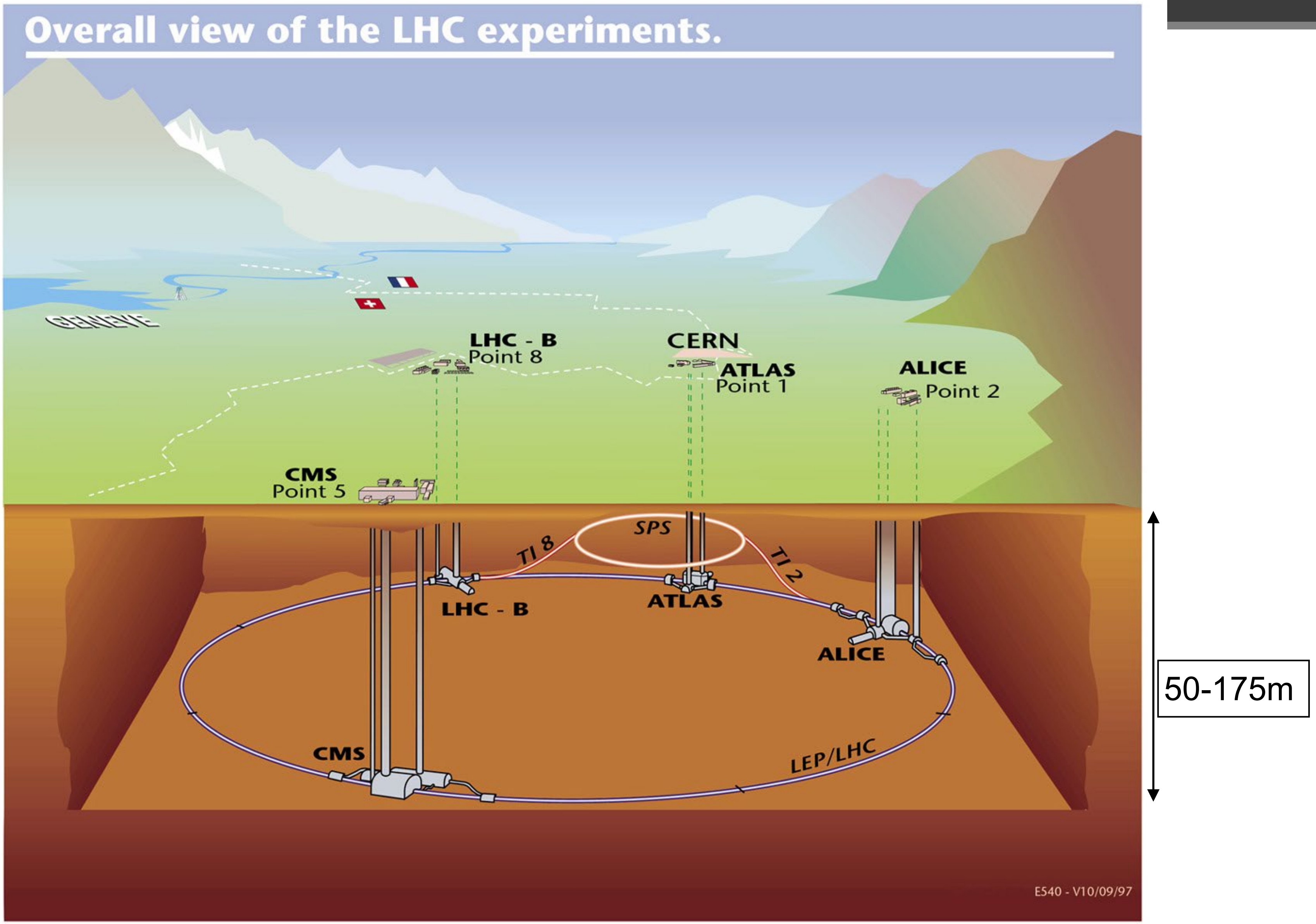
The LHC collides protons
Center of Mass E=14 TeV ~7X Fermilab
Very high luminosity ~100X Fermilab

Goal: discover Higgs+SUSY+???

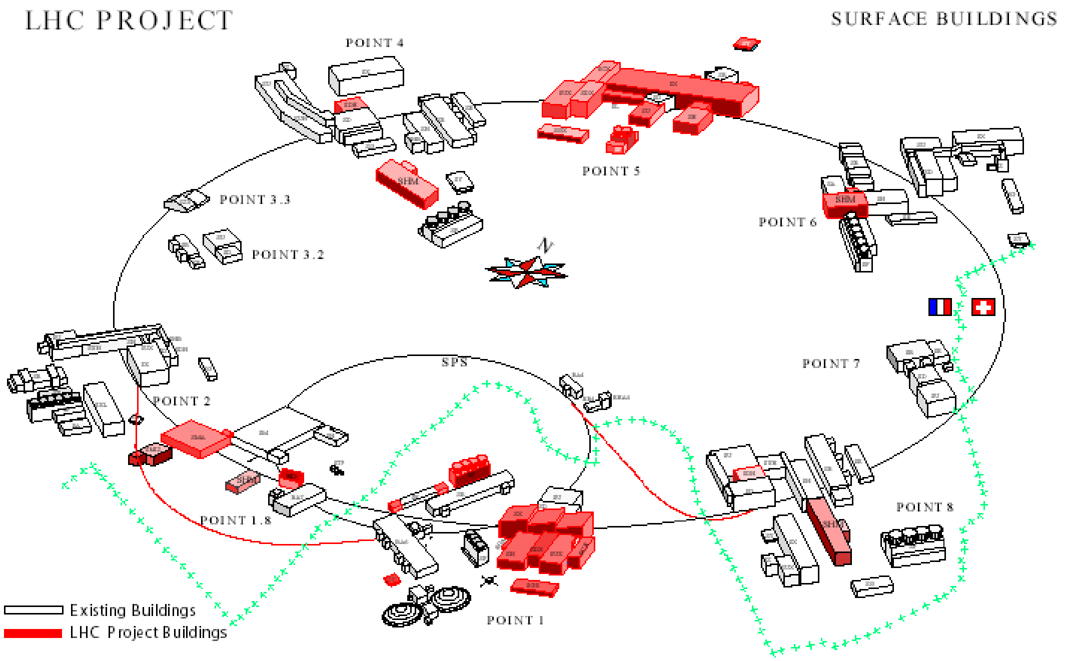
The Large Hadron Collider



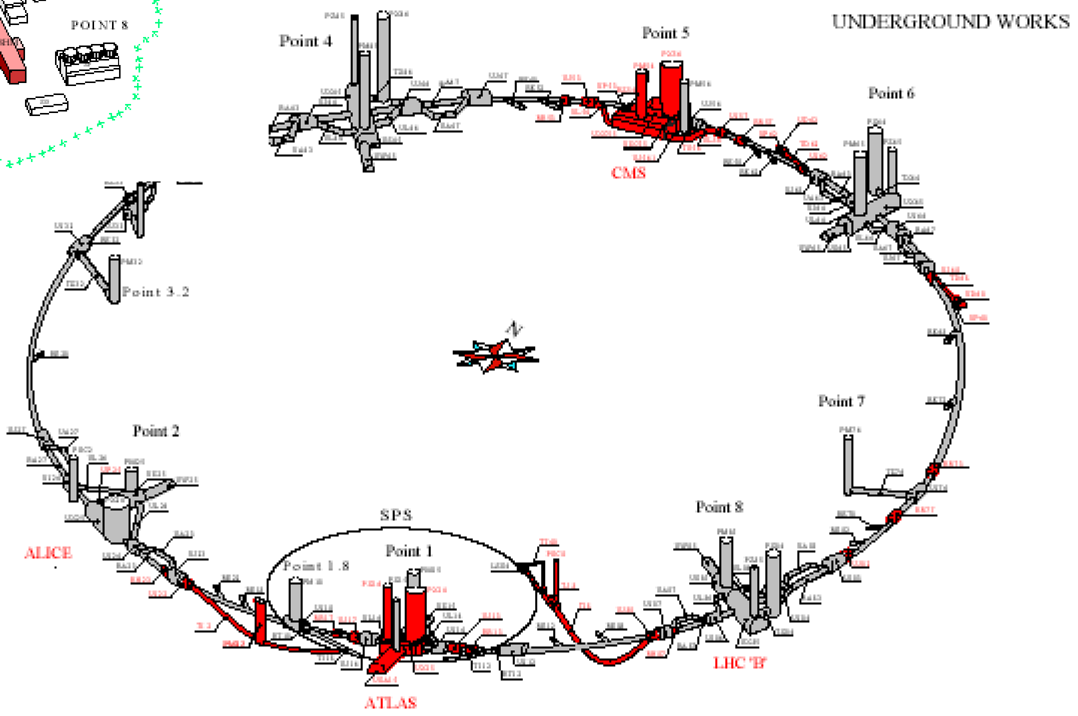
The Large Hadron Collider



The Large Hadron Collider



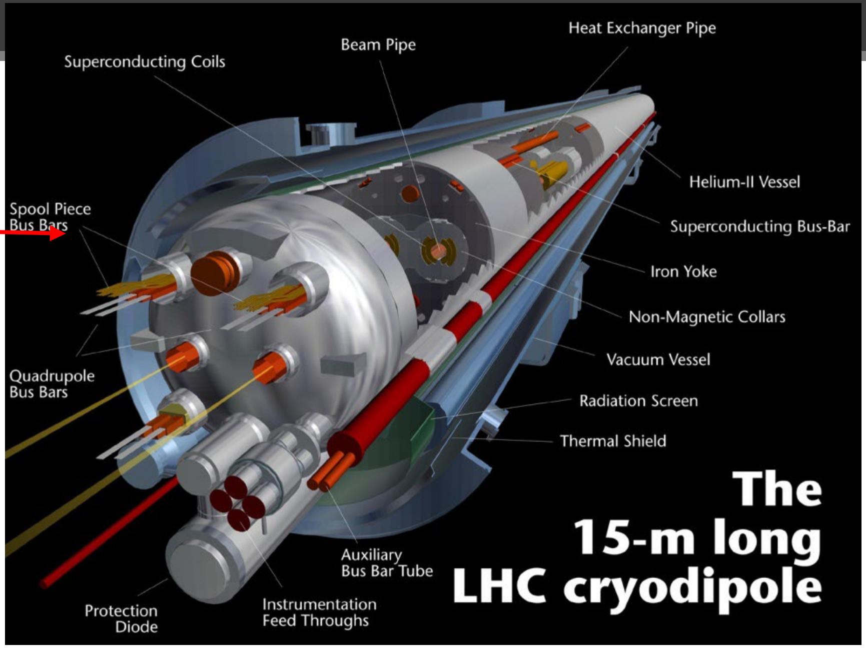
Above Ground

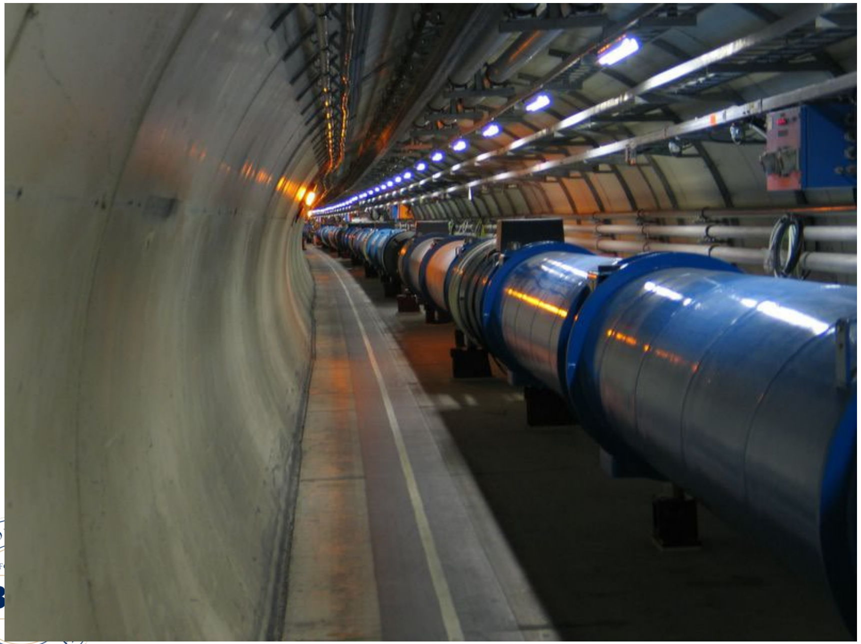


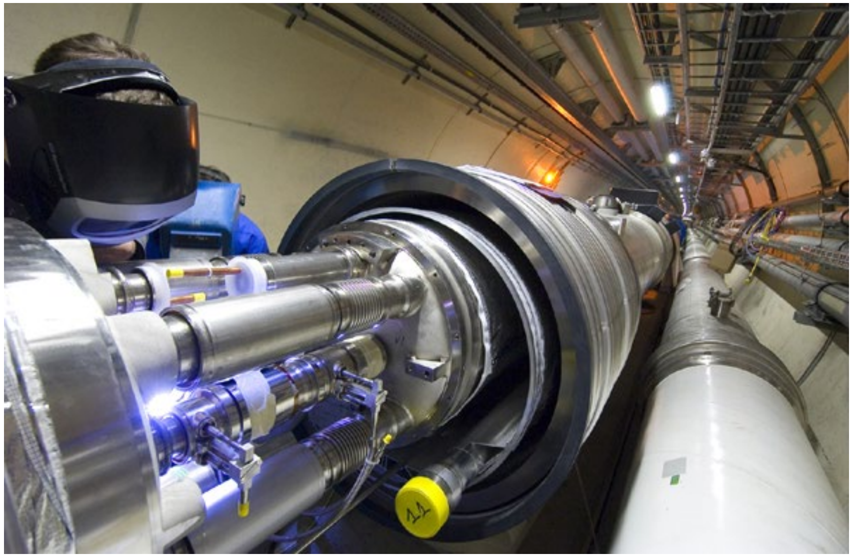
Below Ground

The Large Hadron Collider

Magnetic field at 7 TeV: 8.33 Tesla
Operating temperature: 1.9 K
Number of magnets: ~9300
Number of main dipoles: 1232
Number of quadrupoles: ~858
Number of correcting magnets: ~6208
Number of RF cavities: 8 per beam;
Field strength at top energy ≈ 5.5 MV/m
Power consumption: ~120 MW

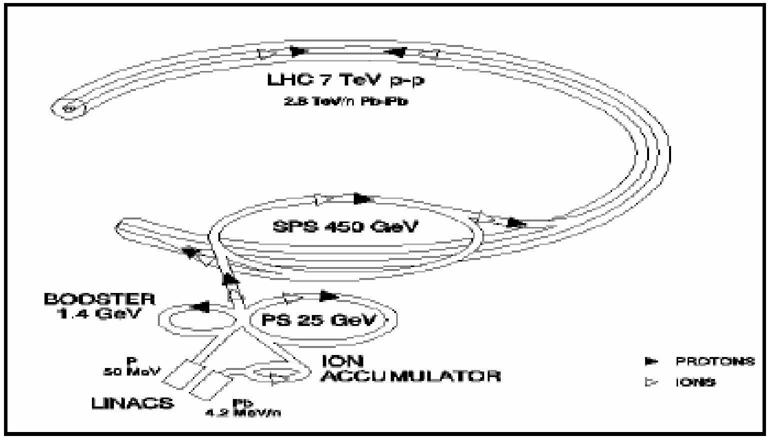




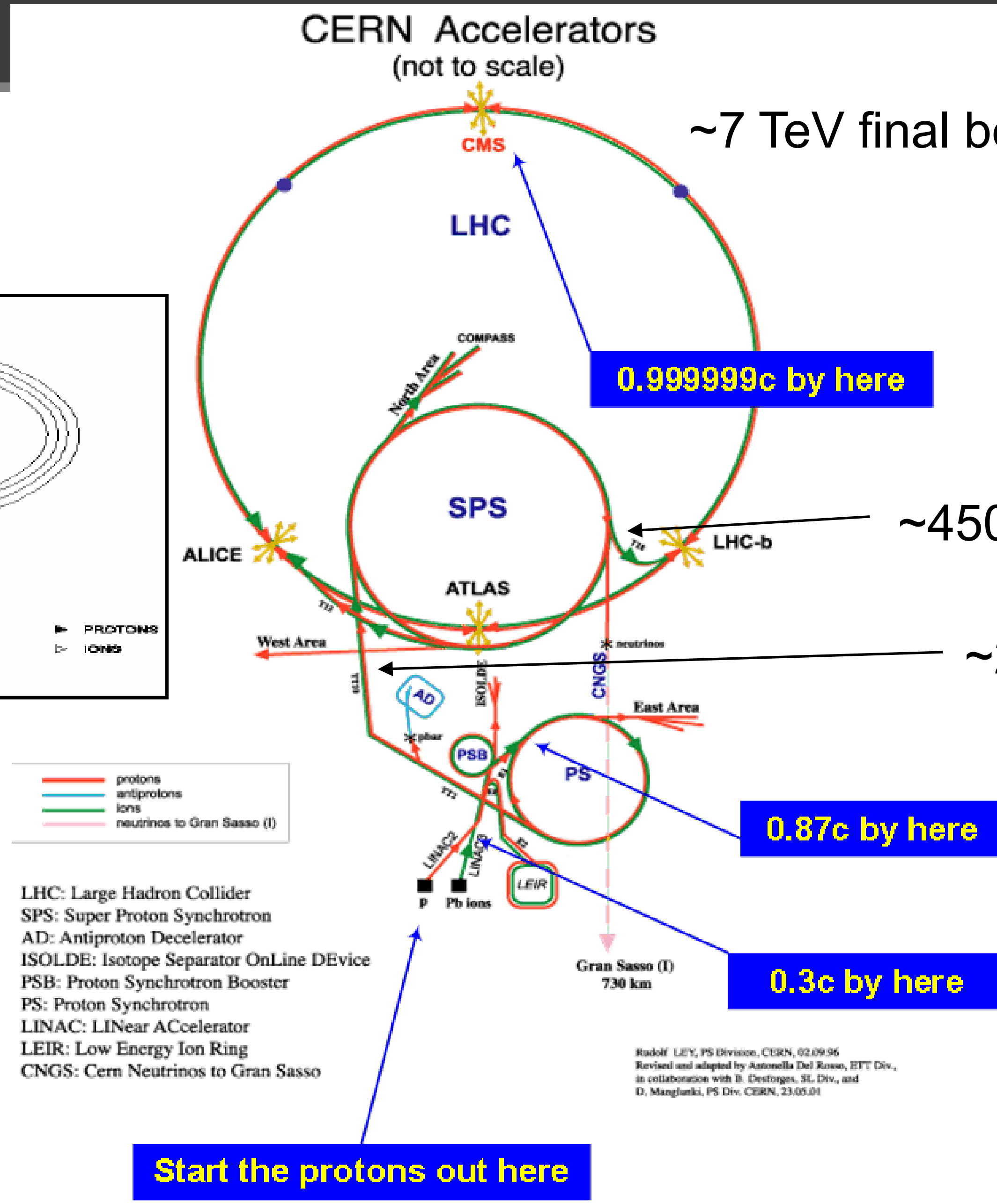


How Do We Get 7 TeV Protons?

LINAC→PSB→PS→SPS→LHC



~10[11] protons/beam



~7 TeV final beam energy

~450 GeV

~25 GeV

~2 GeV

~1 GeV