Chemical Engineering 412

Introductory Nuclear Engineering

Lecture 15

Industrial Applications

Exam II Review

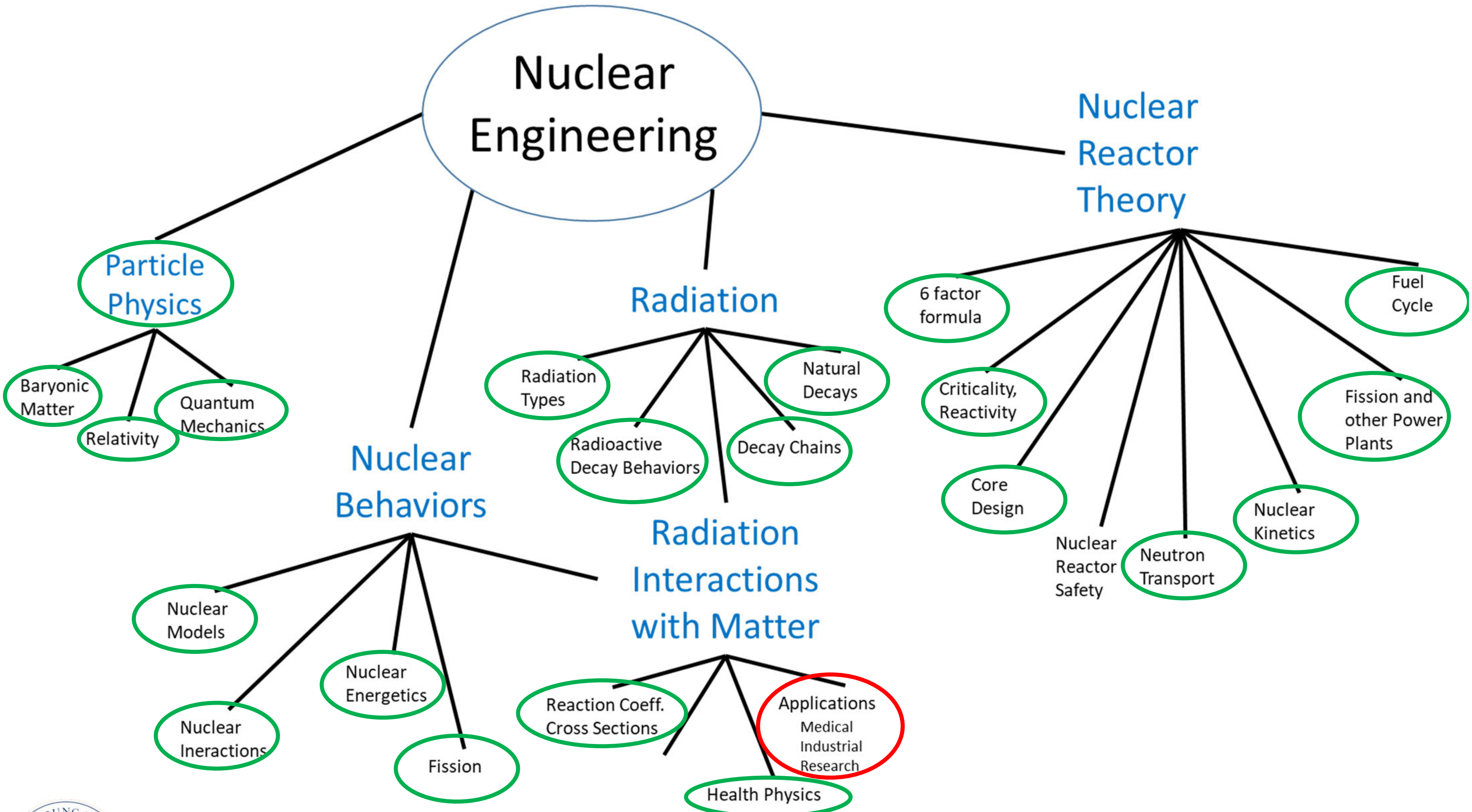
Spiritual Thought

"Repentance is one of the first principles of the gospel. Forgiveness is a mark of divinity. There is hope for you. Your lives are ahead, and they can be filled with happiness, even though the past may have been marred by sin. This is a work of saving and assisting people with their problems. This is the purpose of the gospel.

This is the time, this is the very hour, to repent of any evil in the past, to ask for forgiveness, to stand a little taller and then to go forward with confidence and faith."

President Gordon B. Hinkley

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

Economics

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

$330.7 billion annually in total industrial sales

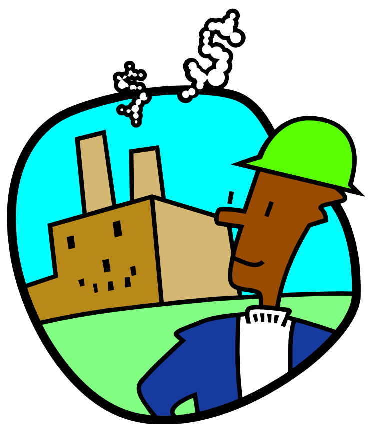
4,000,000 jobs

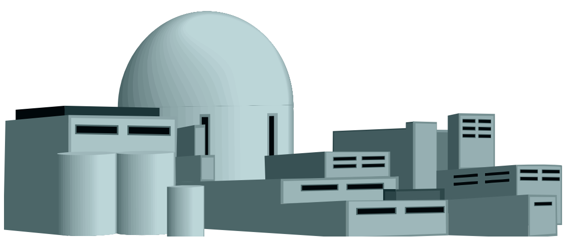
$60 billion in tax revenues to local, state & federal governments

Economics

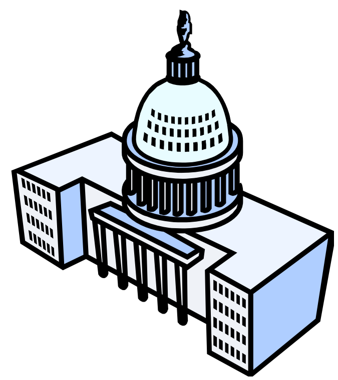
Nuclear energy's direct and indirect economic impacts in the US:

442,000 jobs





$90 billion in total sales of goods & services

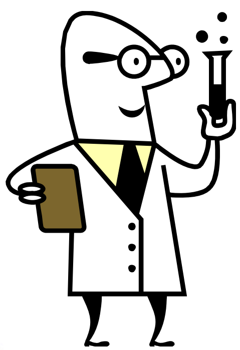


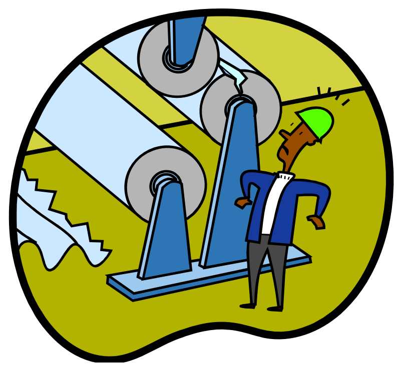
$17.8 billion in local, state & federal tax revenues

Destination

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

Universities





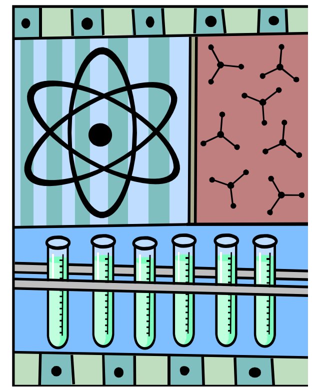
Hospitals

Industries

Laboratories

Scientific Research

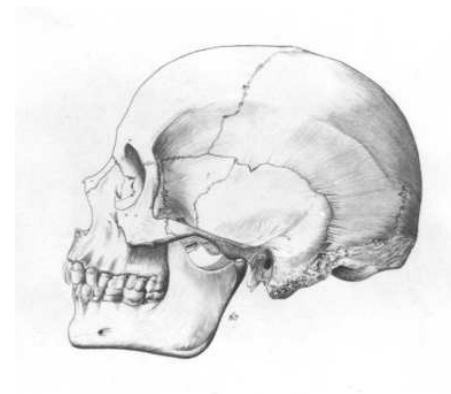
The FDA requires that all new drugs be tested for safety and effectiveness; more than 80% are tested with radioactive materials



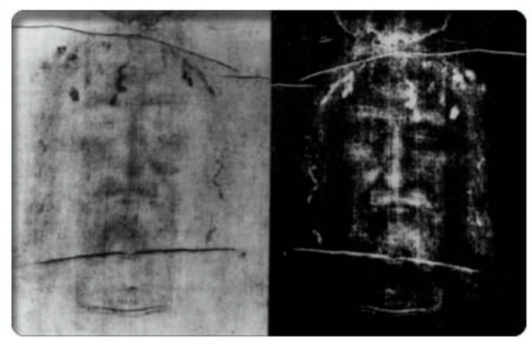
Radioactive materials are also used in biomedical research, metabolic studies, genetic engineering and environmental protection studies

Scientific Research

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



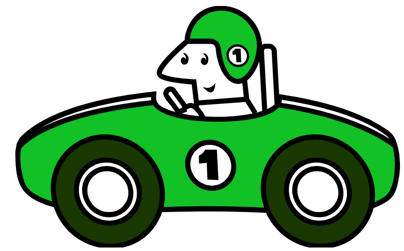
Criminal investigators use radiation to examine evidence

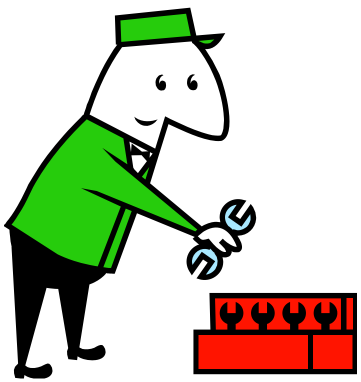


Museums rely on radioactive materials to verify authenticity of art objects and paintings

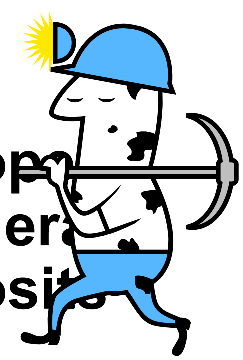
Industrial Uses

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





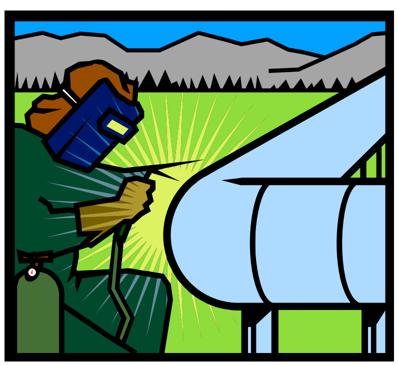
Aircraft manufacturers use radiation to check for flaws in jet engines



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

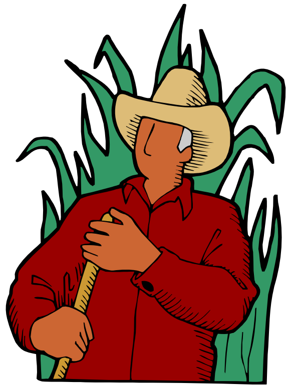
Hardier and more disease resistant crops (peanuts, tomatoes, onions, rice, soybeans, barley) have been developed using radioactive materials in agricultural research

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

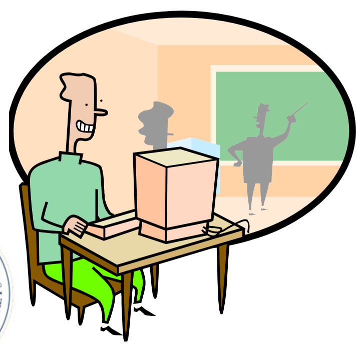


Isotopes help farmers and scientists control pests; e.g., California has used radiation sterilization since the mid-70s to control Mediterranean fruit fly infestations

Consumer Products & Services

96 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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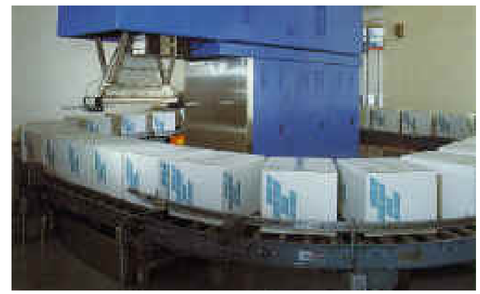
Consumer Products & Services



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

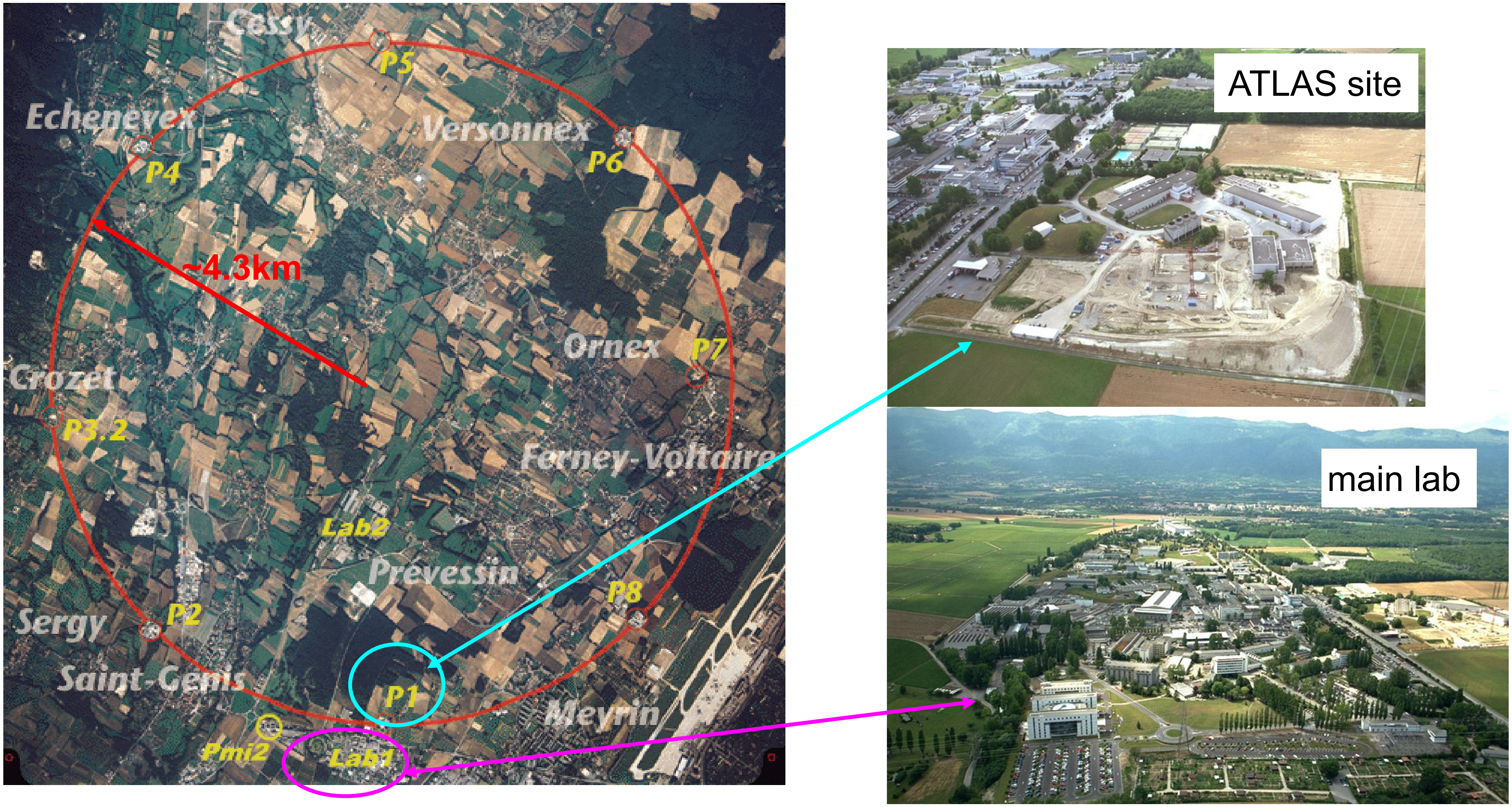
The Large Hadron Collider

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

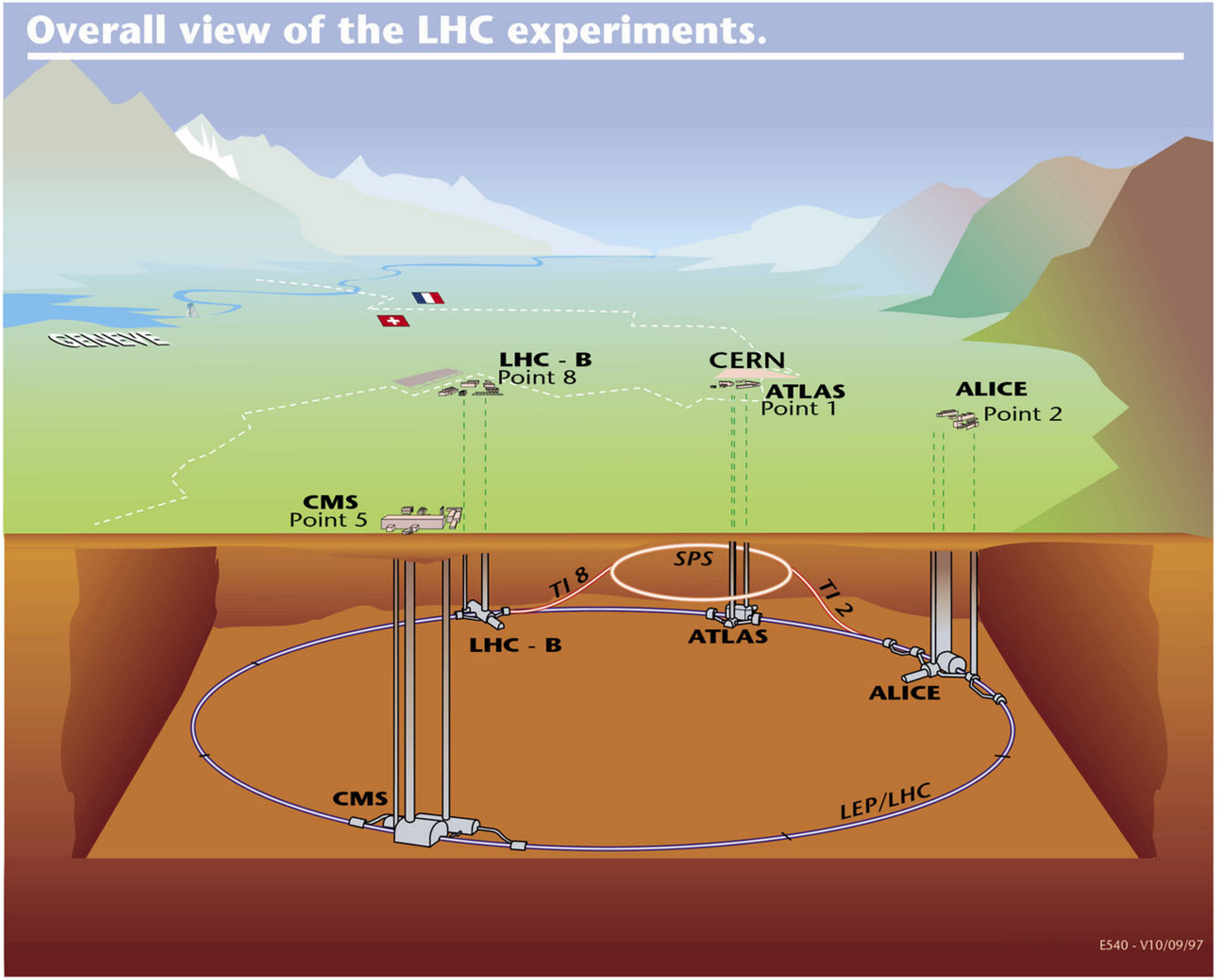
The LHC collides protons
Center of Mass E=14 TeV ~7X Fermilab
Very high luminosity ~100X Fermilab

Goal: discover Higgs+SUSY+???

The Large Hadron Collider

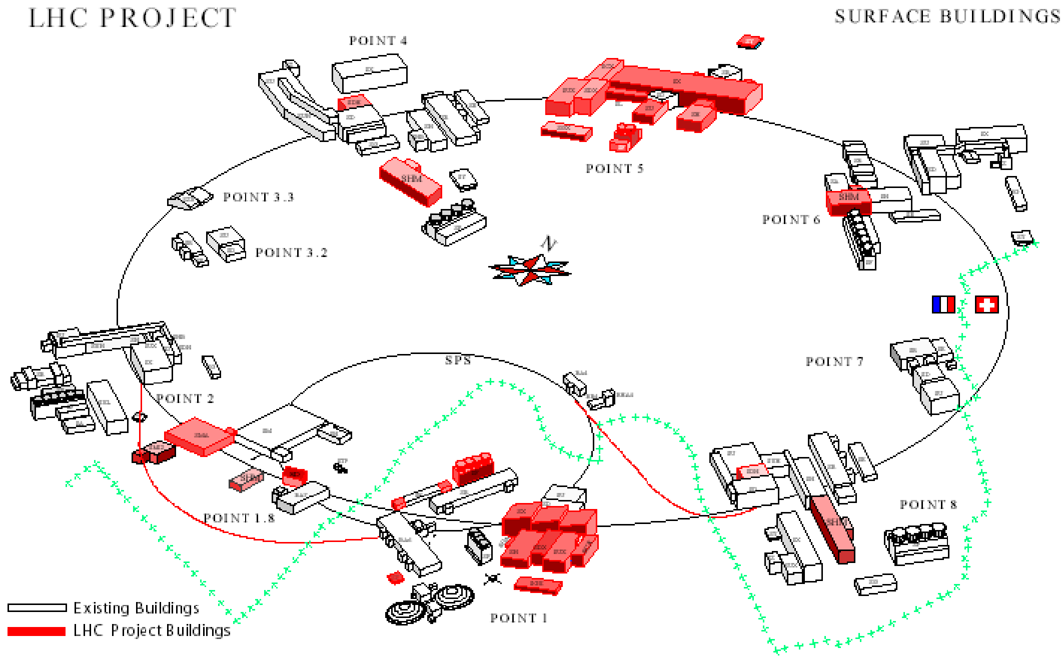


The Large Hadron Collider

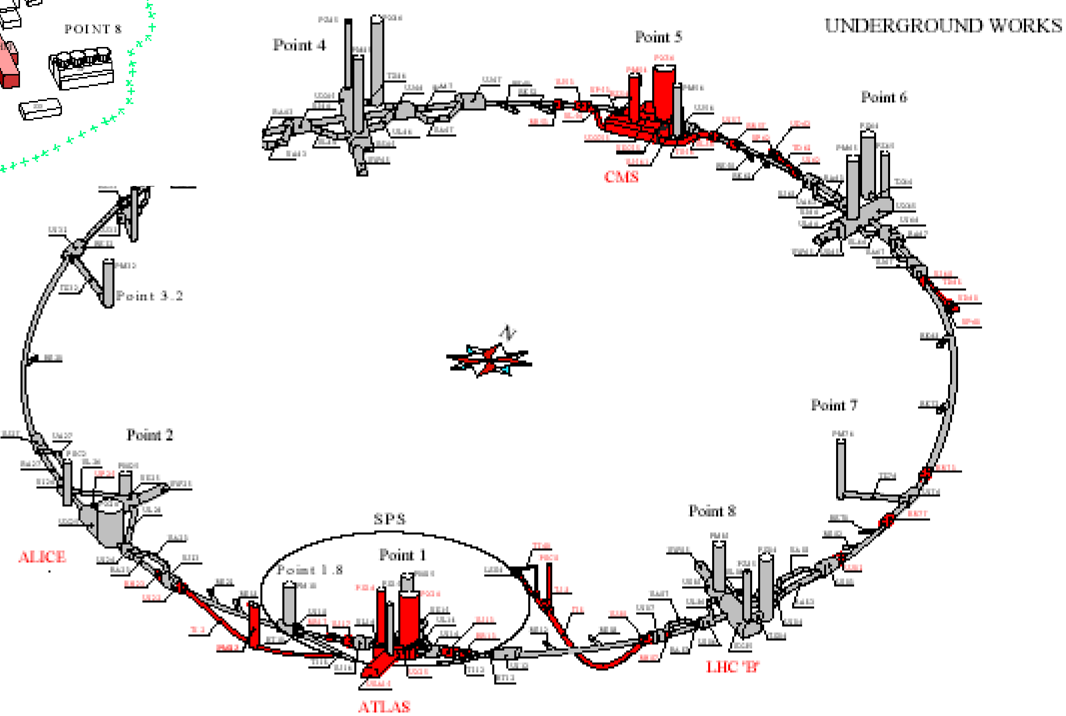


50-175m

The Large Hadron Collider



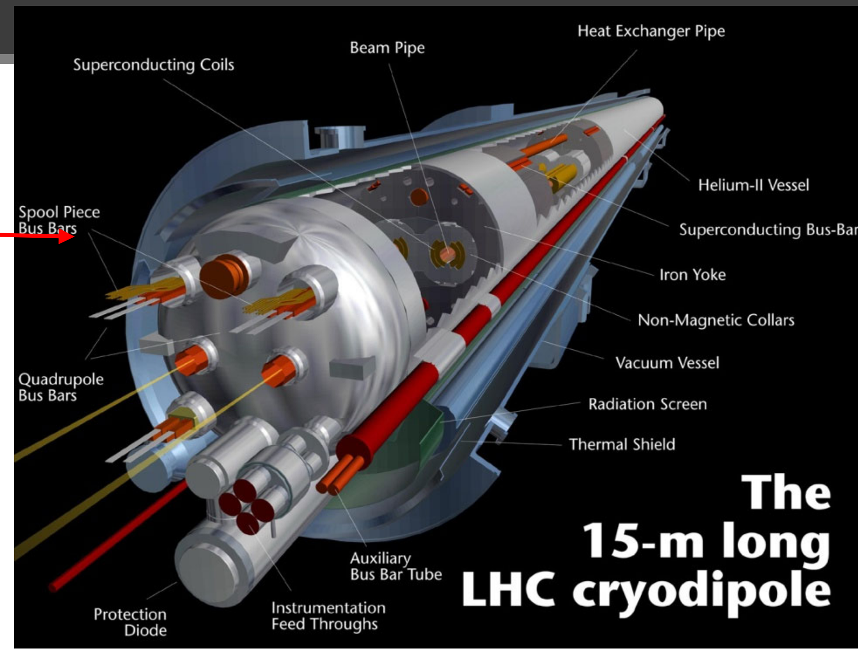
Above Ground

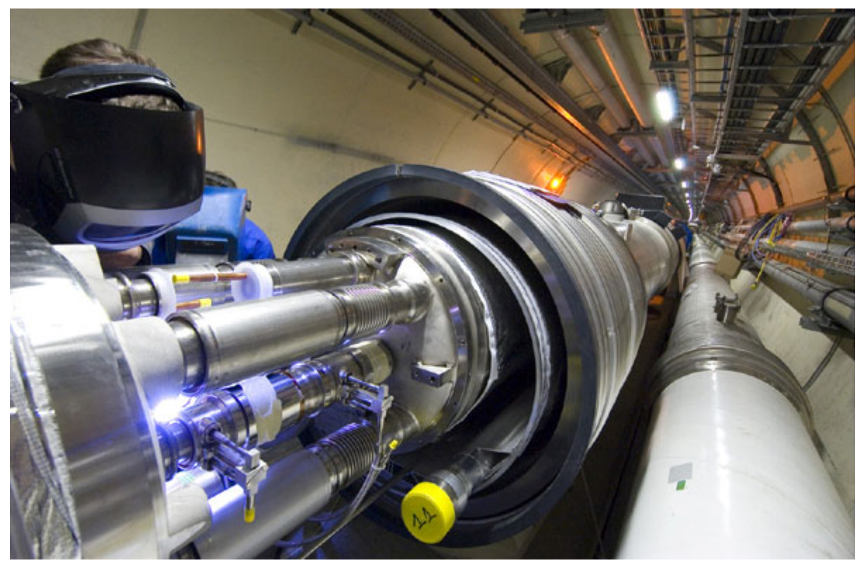


Below Ground

The Large Hadron Collider

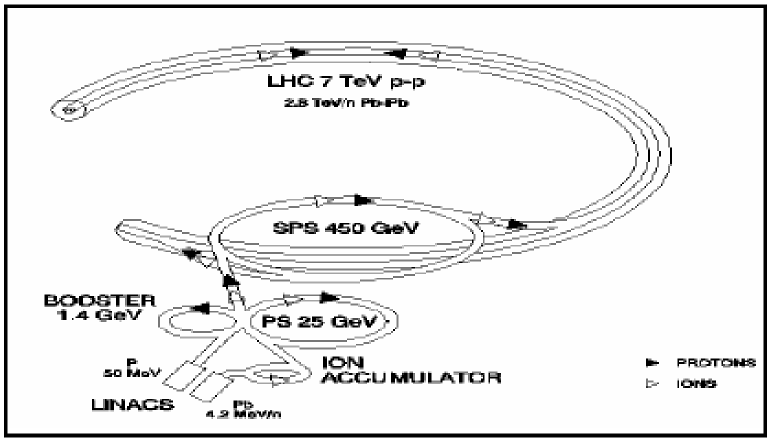
Magnetic field at 7 TeV: 8.33 Tesla
Operating temperature: 1.9 K
Number of magnets: ~9300
Number of main dipoles: 1232
Number of quadrupoles: ~858
Number of correcting magnets: ~6208
Number of RF cavities: 8 per beam;
Field strength at top energy ≈ 5.5 MV/m
Power consumption: ~120 MW



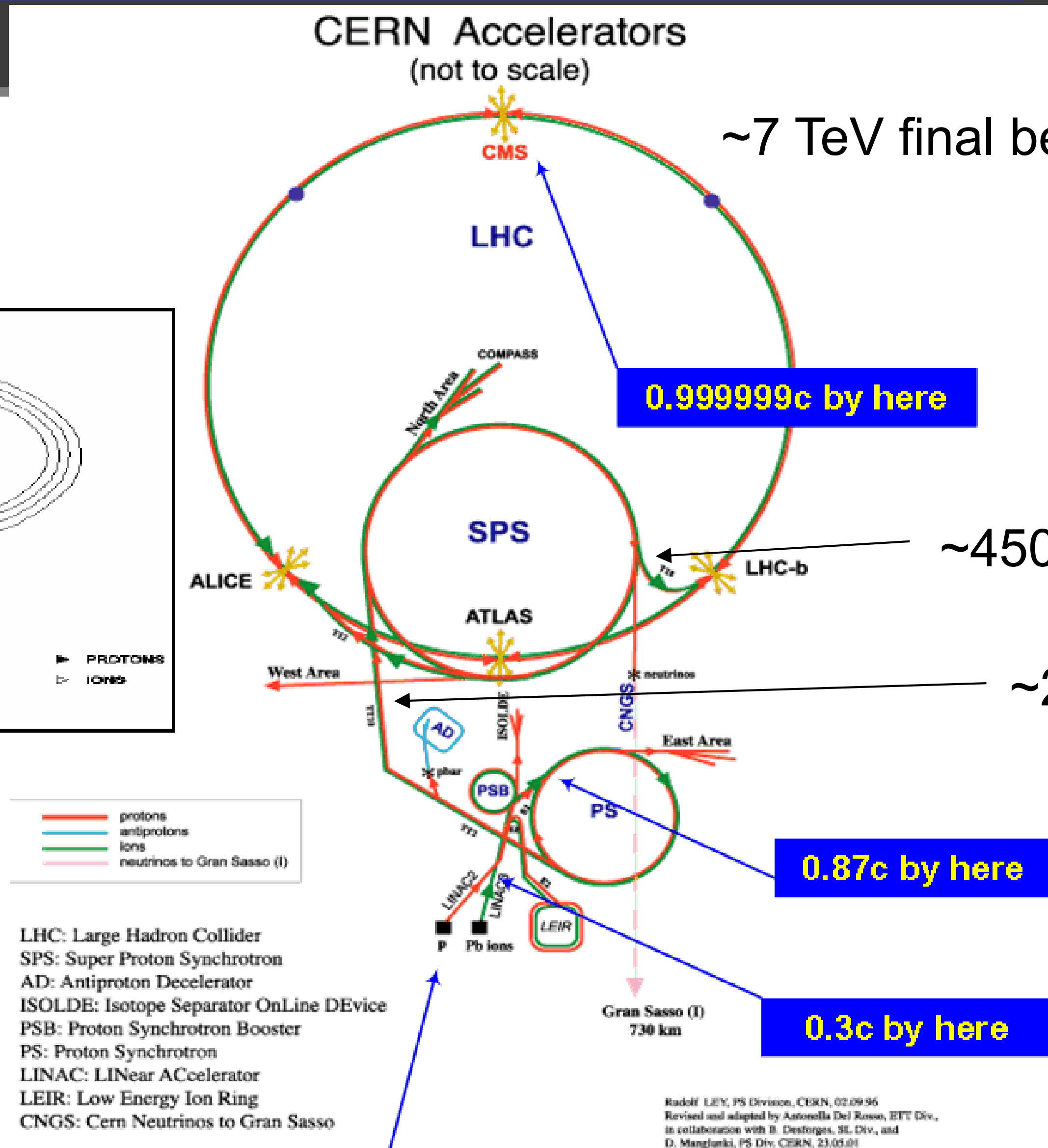


How Do We Get 7 TeV Protons?

LINAC→PSB→PS→SPS→LHC



~10^{11} protons/beam



~7 TeV final beam energy

0.999999c by here

~450 GeV

~25 GeV

0.87c by here

~2 GeV

0.3c by here

~1 GeV

Start the protons out here

Chapter 8

- Detector Types
  - Dead times, interaction rates, performance, paralyzable, etc.
  - Examples & Diagrams, etc.
  - Fundamental operation principles
- Detection and Operation Modes
- Spectroscopy
- Efficiency
- Related equipment (PMTs, SCPHA, MCA)

Chapter 9

- Know Big picture of Radiation Doses
- Know various measurements, units conversion from one to another
  - KERMA, exposure, Absorbed Dose, etc.
  - Know how to correlate to biological impacts
- Calculation of dose
- Hazards of Radiation (Table usage)
- Exposure limits – amounts, history, etc.
- Perspective on radiation effects
- Acute and latent effects/symptoms
- Does model – Linear, threshold, hormesis

Chapter 13

- Beneficial Uses of Radiation +Applications
  - Specific isotopes and production
- Advantages/Disadvantages of radioactive
- Uses of Tracers (calculate amount needed)
- Uses of "Materials affecting Radiation"
- Uses of "Radiation affecting Materials"
- Particle Accelerators
- Economics and Widespread applciations

Chapter 14

- Medical Uses of Radiation
  - Diagnostic vs. theraputic
- X-Rays
- Mammography & Densitometry
- CT Scan
- SPECT
- PET
- MRI

Example I

Mercury pollution in water is of concern since fish often concentrate this element in their tissues. To measure such mercury contamination by neutron activation analysis, a fish sample is irradiated in a reactor in a thermal neutron flux $\varphi = 1.5 \times 10^{12}\ \text{cm}^{-2}\text{s}^{-1}$. The stable mercury isotope ^{196}Hg has a neutron absorption cross section for thermal neutrons of 3.2 kb. The resulting ^{197}Hg has a half life of 2.67 d and can be detected in a fish sample at a minimum activity of 15 Bq. What irradiation time is needed to detect mercury contamination at a level of 30 ng/g (30 ppm) in a 10-g fish sample?

$A \sim \hat{R}_a^{197}$

Accum = in − out + gen − cons

$$\frac{dN^{197}}{dt} = \hat{R}_a^{196} - A \Rightarrow N^{197}\lambda^{197}$$

$$\frac{dN^{197}}{dt} = \hat{R}_a^{196} - N^{197}\lambda^{197}$$

$$\hat{R}_a = \phi \cdot \sigma_a^{196} \cdot N^{196}$$

$$N = \frac{\rho N_a \gamma}{A} = \frac{\text{atoms}}{\text{cm}^3}$$

$$M_m = \frac{30\ \text{ng Hg}}{\text{g fish}}$$

300 ng Hg $\Rightarrow N = \frac{m N_A}{A} \cdot \gamma = 1.383\times10^{12}$ atoms Hg

$$\frac{dN_a^{197}}{dt} = \sigma_a^{196} N^{196} \phi - N^{197}\lambda^{197}$$

$$\frac{dN^{197}}{dt} + N^{197}\lambda^{197} = C$$

$$N_H'^{197} + N_p^{197} = N^{197}$$

$$N' + N = C$$

$$N_p = C$$

$$N_H' = \frac{\partial N_H}{dt}$$

$$N_H' + \lambda N_H = 0$$

$$N_p' + \lambda N_p = C$$

$$N_H^{197} = C_1 e^{-\lambda t}$$

$$N_p = C = \hat{R}_a$$

$$N^{197}(t) = \frac{\hat{R}_a}{\lambda_{197}}\left(1 - e^{-\lambda^{197} t}\right) \Rightarrow A^{197}(t) = \hat{R}_a\left(1 - e^{-\lambda t}\right)$$

Example II

- If potatoes receive gamma-ray doses between 60 Gy and 150 Gy, premature sprouting is inhibited. Such irradiation can be done in an irradiator with a large ^{60}Co source. Assume all the gamma rays are absorbed in the potatoes. What is the minimum activity of 60Co needed in an irradiator to deliver such a dose of 250kGy to 100,000 kg of potatoes in 8 hours?

- From appendix D, E_γ = 2.5 MeV

$$E_{abs} = \frac{2.5 \times 10^5 \text{ J/kg} \times 10^5 \text{ kg}}{8 \times 3600 \text{ s} \times 1.602 \times 10^{-13} \text{ J/MeV}} = 5.42 \times 10^{18} \text{ MeV/s.}$$

Dose·mass = E / 2.5 MeV = decays / s

- A = 2.17E18 Bq

$N = \frac{m \cdot N_a}{A}$ $m = \frac{N \cdot A}{N_a}$

Example III

- A Lithium-6/Hydrogen-3 sample is bombarded with neutrons (in a flux of 4.5E11 neutrons/cm^2/s) for 15 hours to determine how much is present in a given sample. The cross section of Lithium 6 is 943 b. If the final number of Lithium 7 atoms is N = 4.3E18 atoms, what was the original number of ^{6}Li atoms?