Chemical Engineering 412

Introductory Nuclear Engineering

Lecture 14

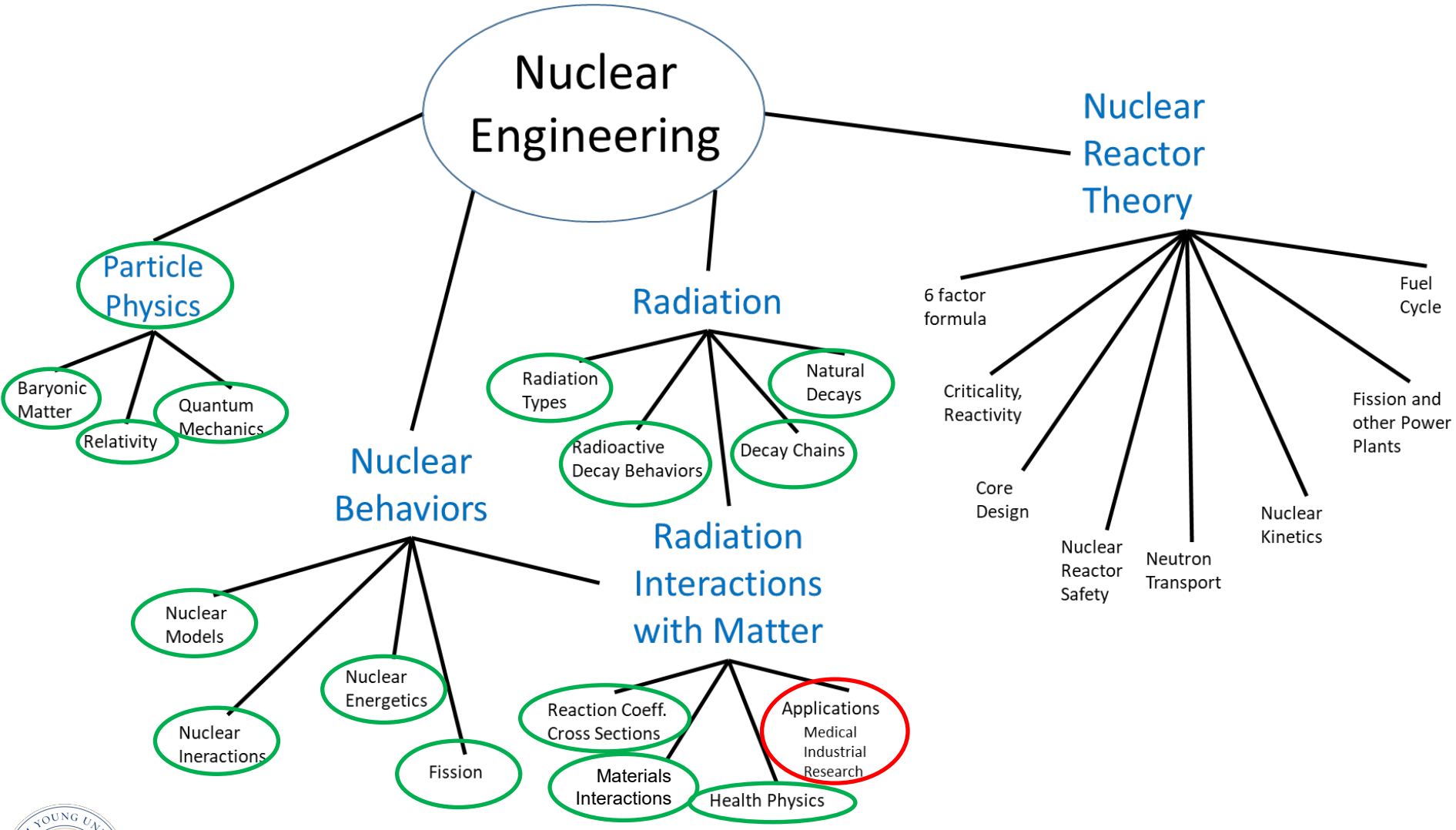
Industrial Applications

Spiritual Thought

"Nothing is going to startle us more when we pass through the veil to the other side than to realize how well we know our Father and how familiar His face is to us."

-President Ezra Taft Benson

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
Decay Chains
Natural Decays
Radiation Interactions with Matter
Reaction Coeff. Cross Sections
Materials Interactions
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 the 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	

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 changes through radiation behavior changes
- Radiation behavior changes 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?

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

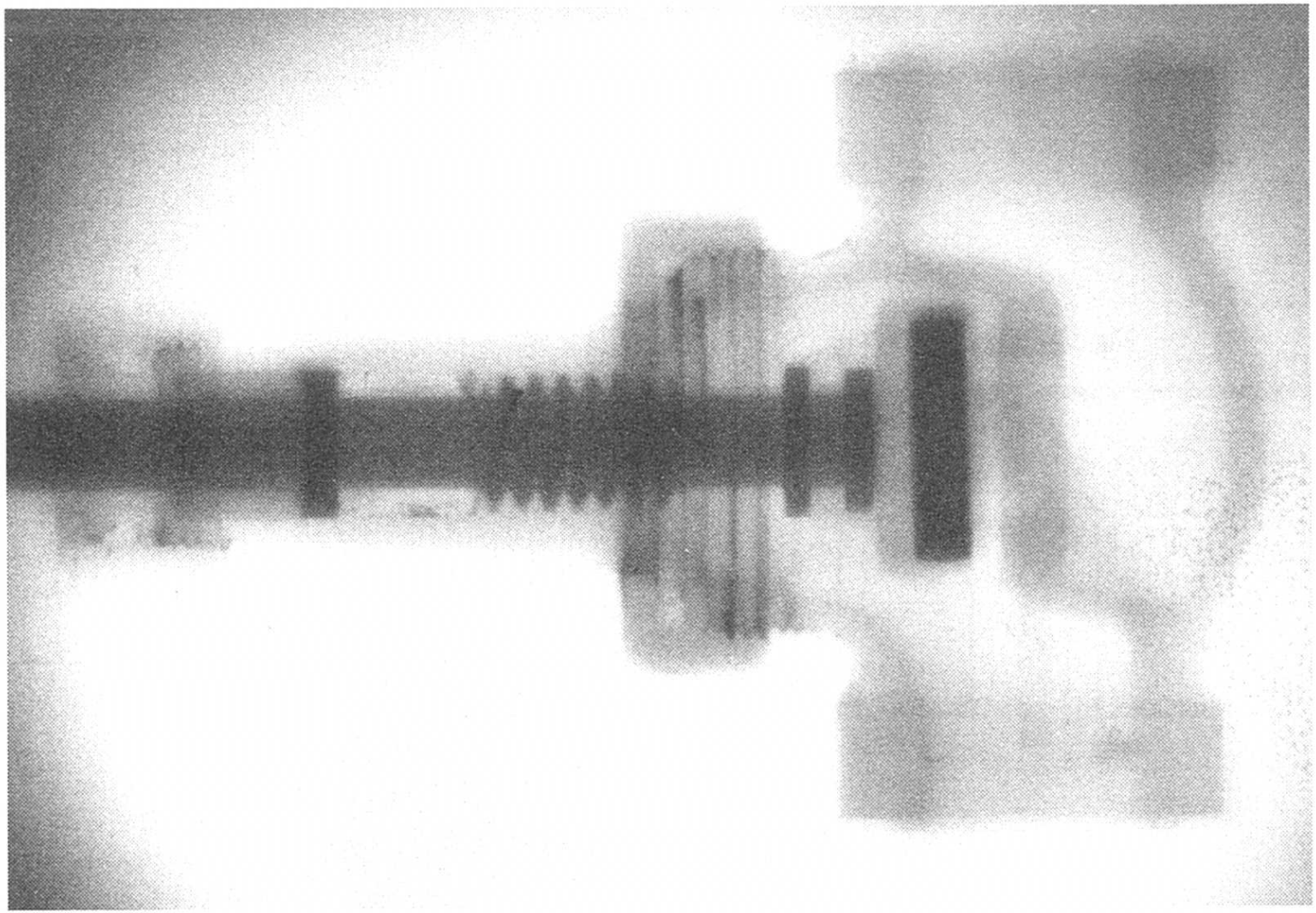
$$M_m = \frac{(0.5 s^{-1})(1.18 \cdot 10^{11}\ s)\left(14\ {}^{g}/_{mol}\right)}{\left(6.024 \cdot 10^{23}\ \frac{atoms}{mol}\right)(0.1)(\ln 2)} =$$

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

Materials Affecting Radiation

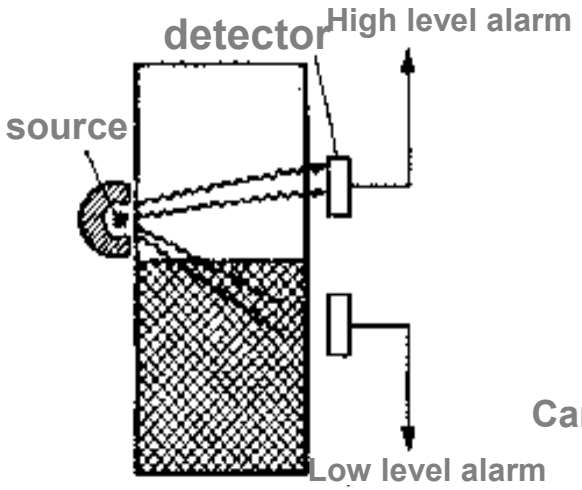
- density gauges
- thickness gauges
- radiation absorptiometry
- x-ray and neutron scattering
- liquid level gauges
- neutron moisture gauges
- x-ray / neutron radiography
- bremsstrahlung production

Neutron Absorption/Radiograph

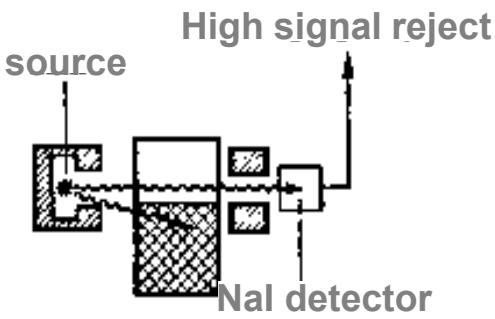


Iron mostly transparent – plastic and Teflon less transparent

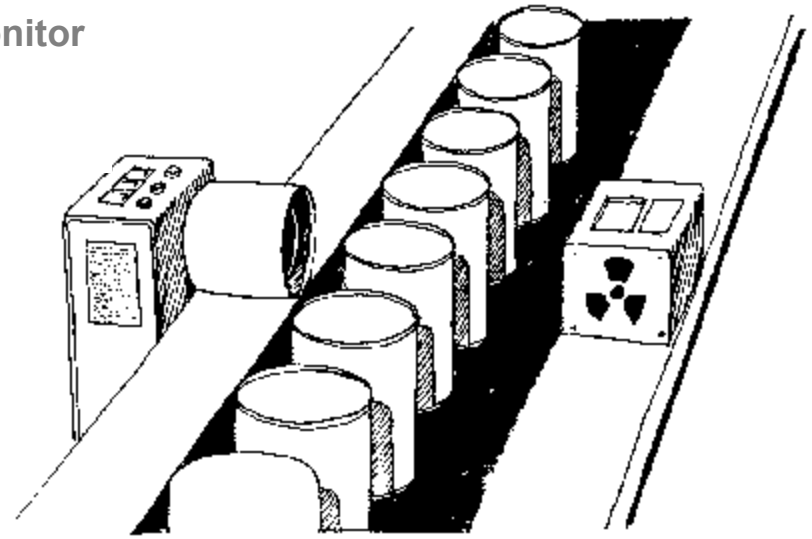
Level Gauge
Gamma Switching Technique



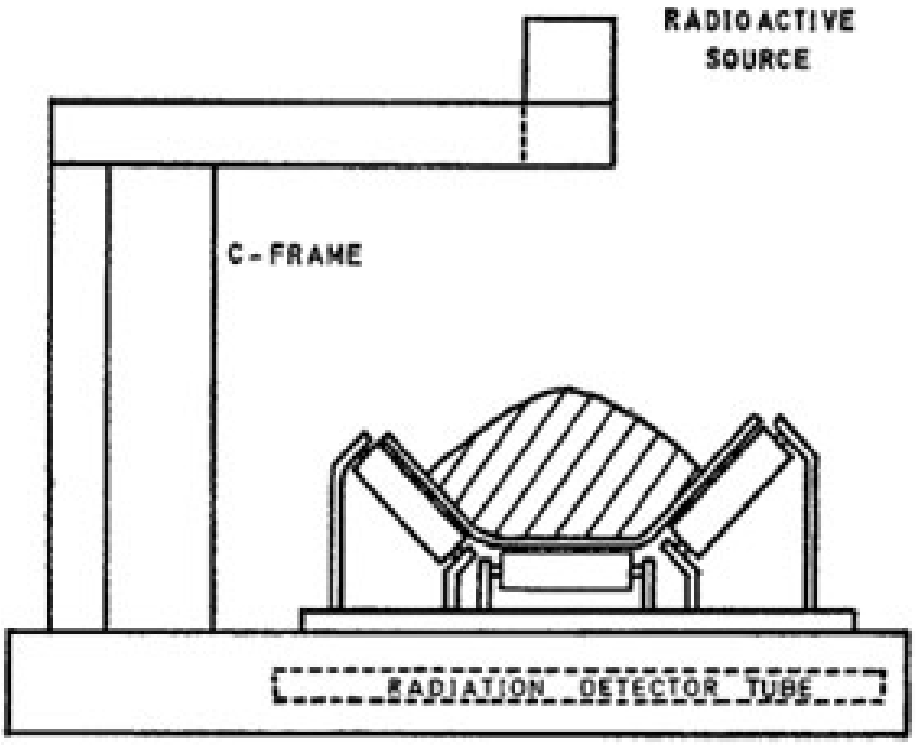
Storage hopper level control

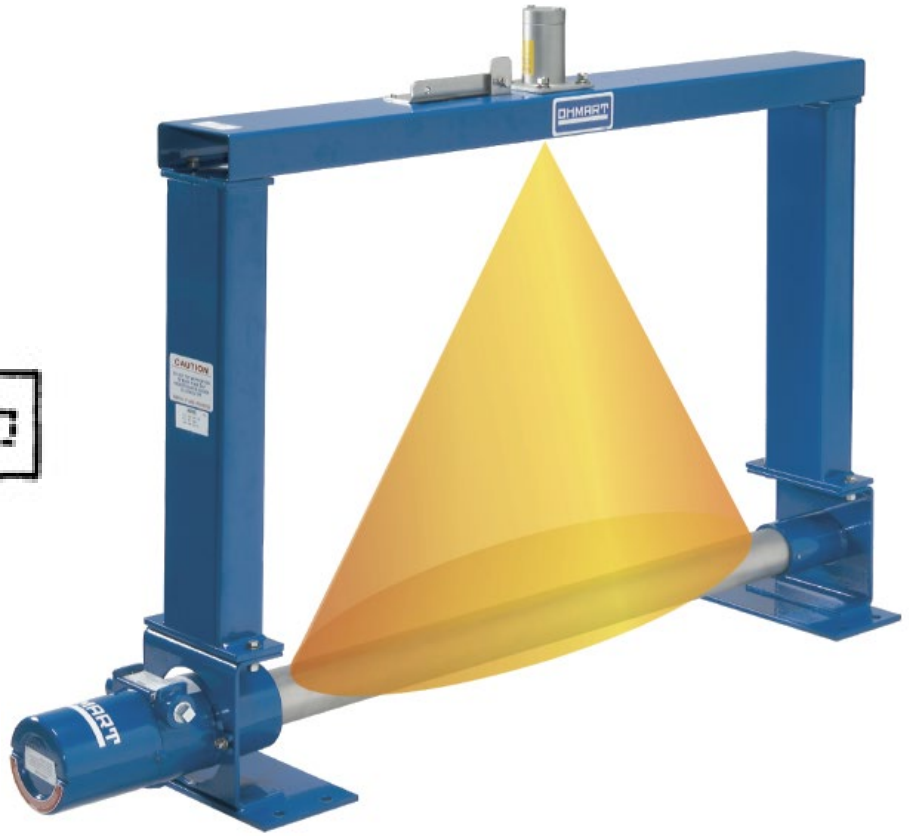


Can/package content monitor



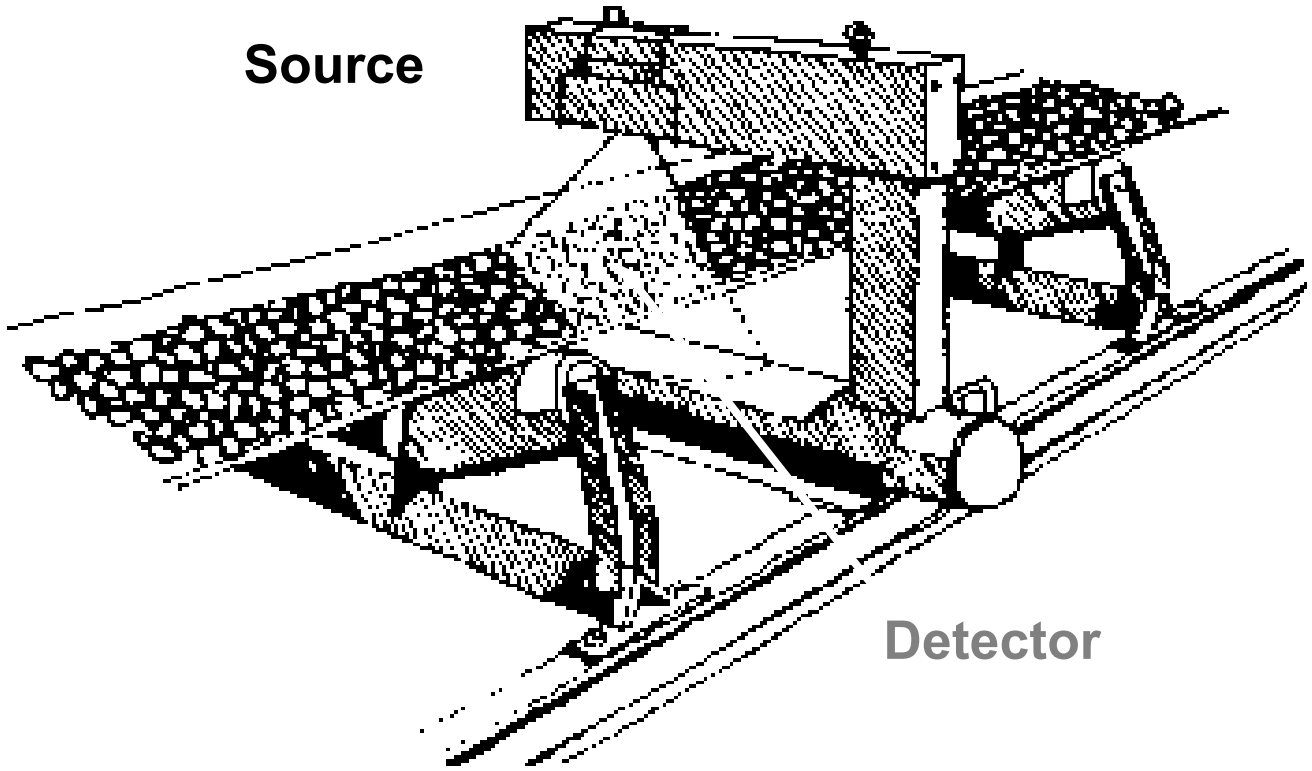
Thickness Gauge
Transmission Thickness Technique





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



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

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

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)

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

Use of Energy

- thermal power sources
- electric power sources