Chemical Engineering 412

Introductory Nuclear Engineering

Lecture 31

Nuclear Industry and Research

Homework

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

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

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
  - ^{60}Mo -> ^{99m}Tc, ^{137}Cs->^{137m}Ba

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
  - There are a number of disadvantages to the use of radioactive sealed sources that are common to all industries. These include:
  - 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 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	

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 gamm-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?

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

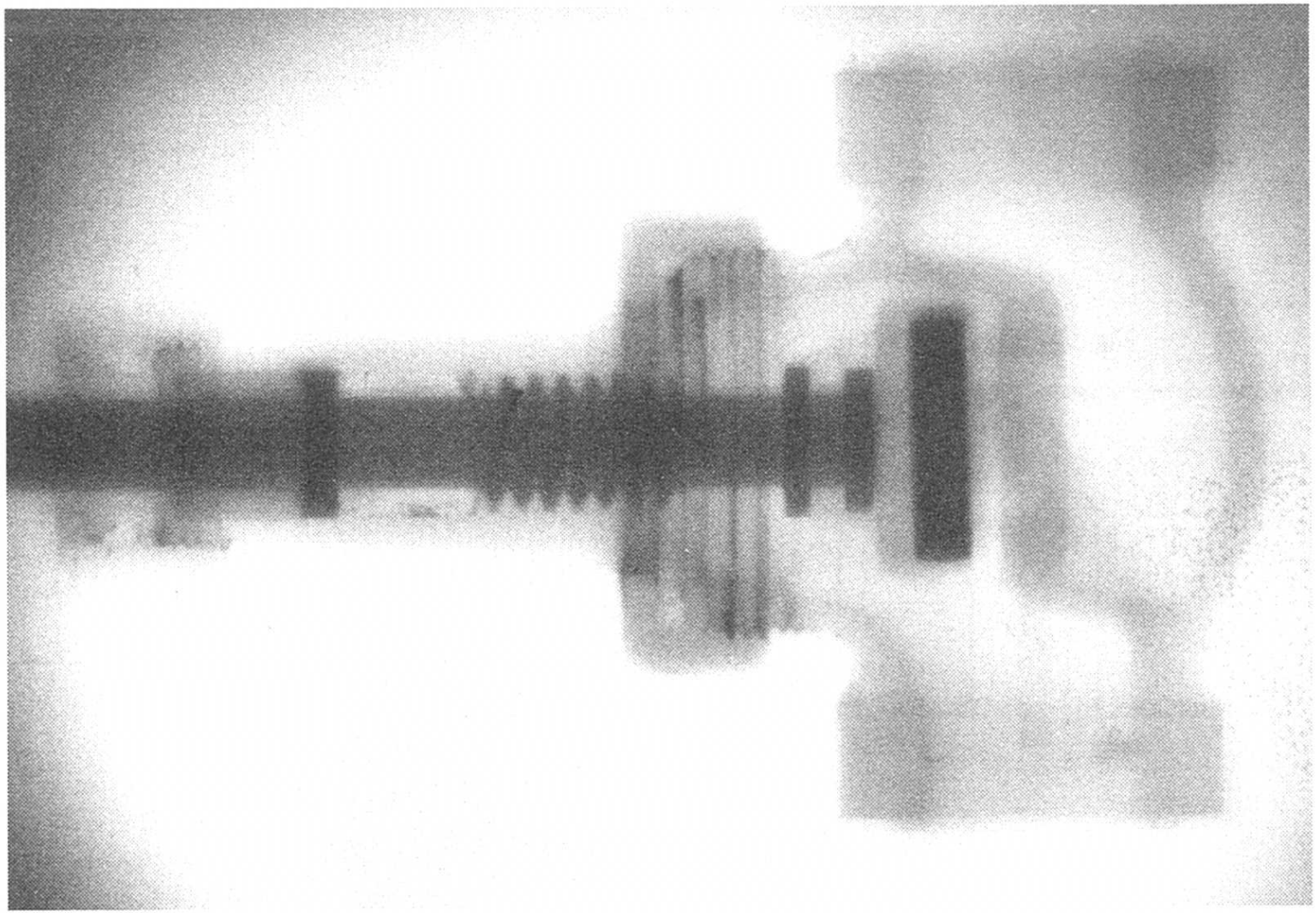
$$M_m = \frac{(0.5 s^{-1})(1.18 \cdot 10^{11}\ s)\left(14\ {}^{g}/_{mol}\right)}{\left(6.024 \cdot 10^{23}\ \frac{atoms}{mol}\right)(0.1)(\ln 2)} =$$

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

Materials Affecting Radiation

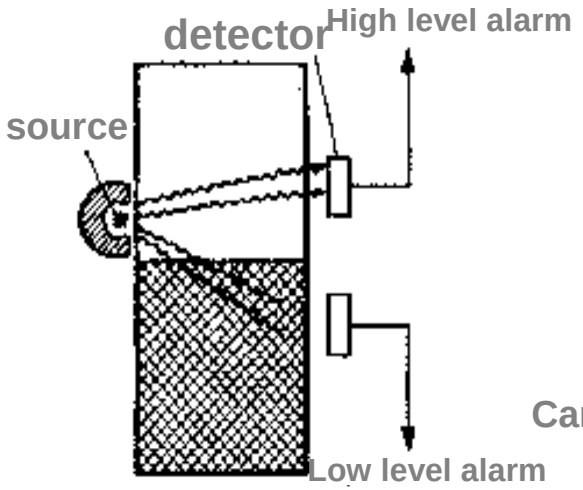
- density gauges
- thickness gauges
- radiation absorptiometry
- x-ray and neutron scattering
- liquid level gauges
- neutron moisture gauges
- x-ray / neutron radiography
- bremsstrahlung production

Neutron Absorption/Radiograph

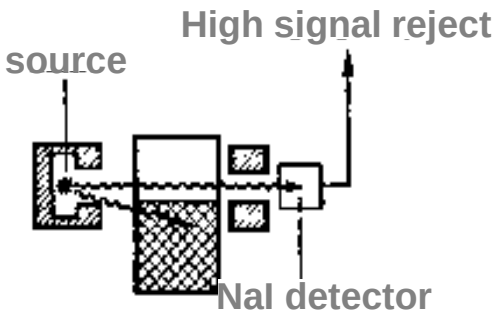


Iron mostly transparent – plastic and Teflon less transparent

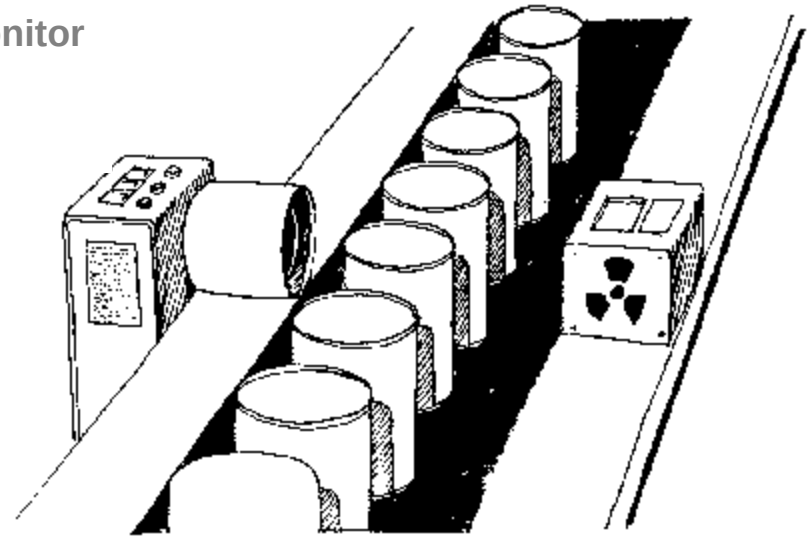
Level Gauge
Gamma Switching Technique



Storage hopper level control

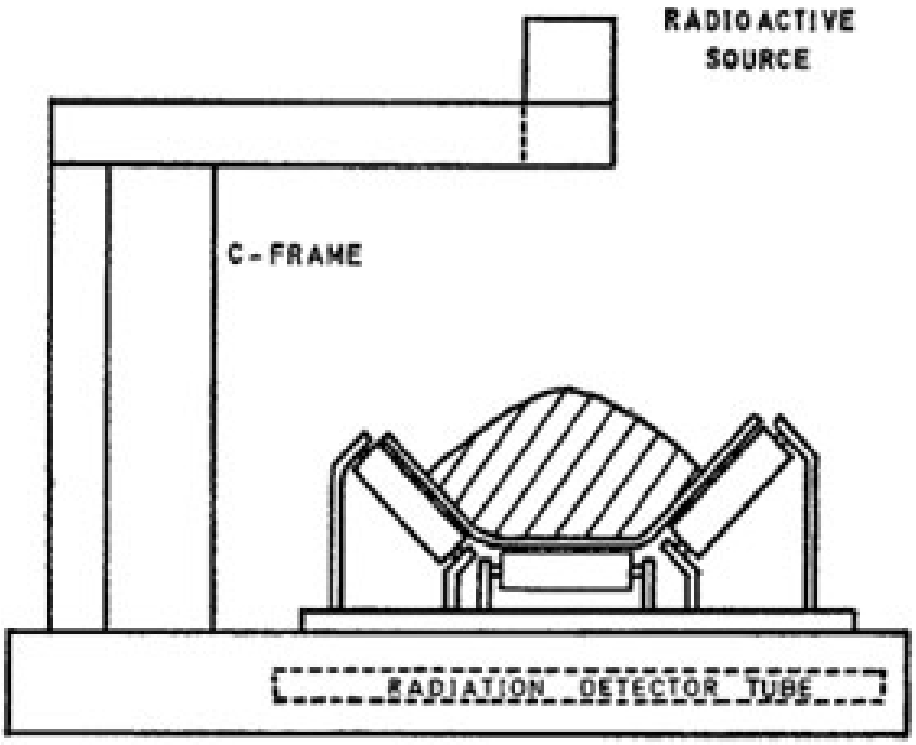


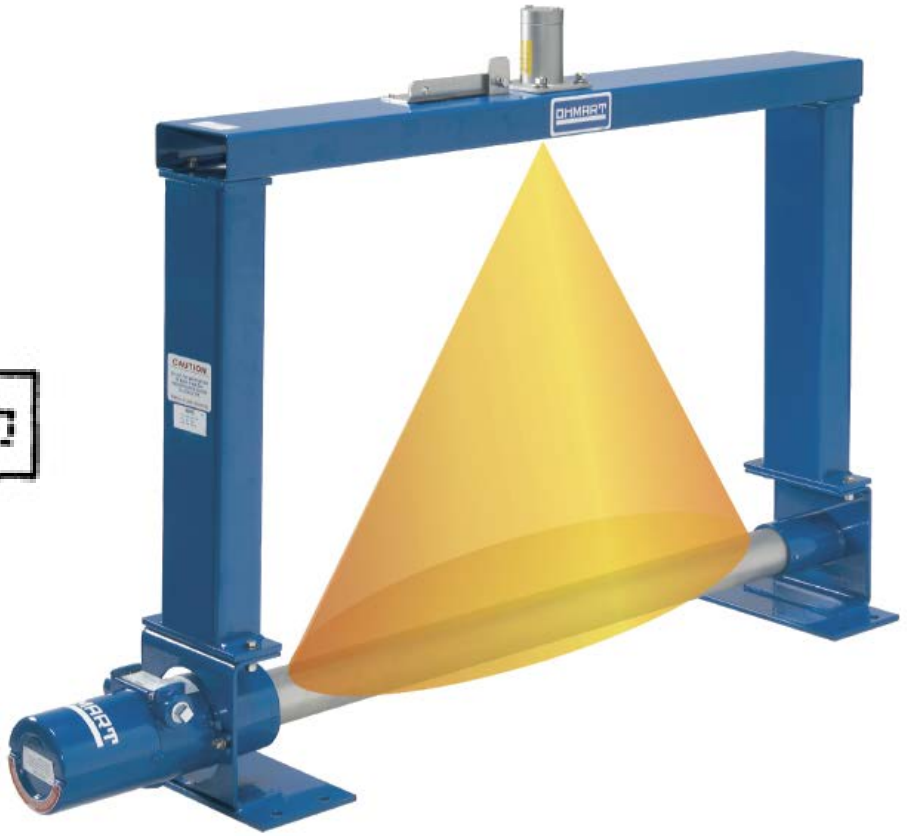
Can/package content monitor



Thickness Gauge

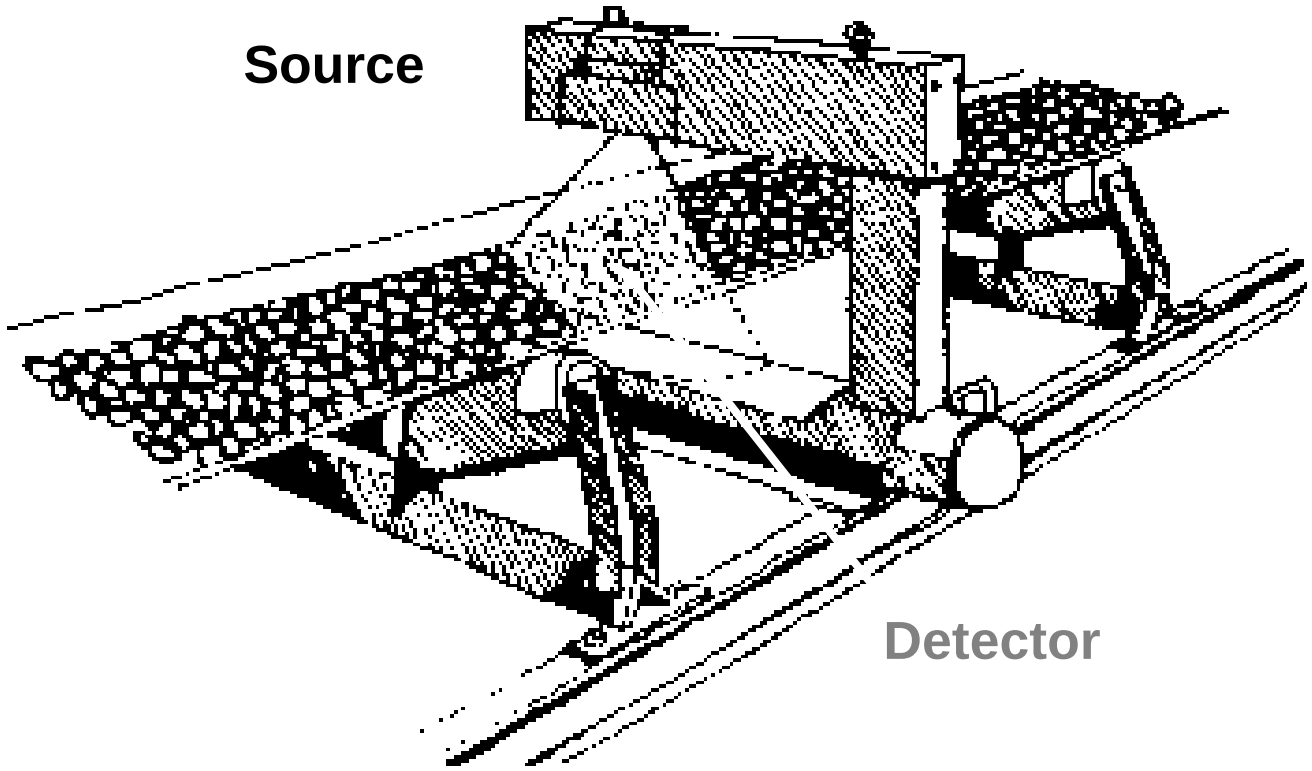
Transmission Thickness Technique



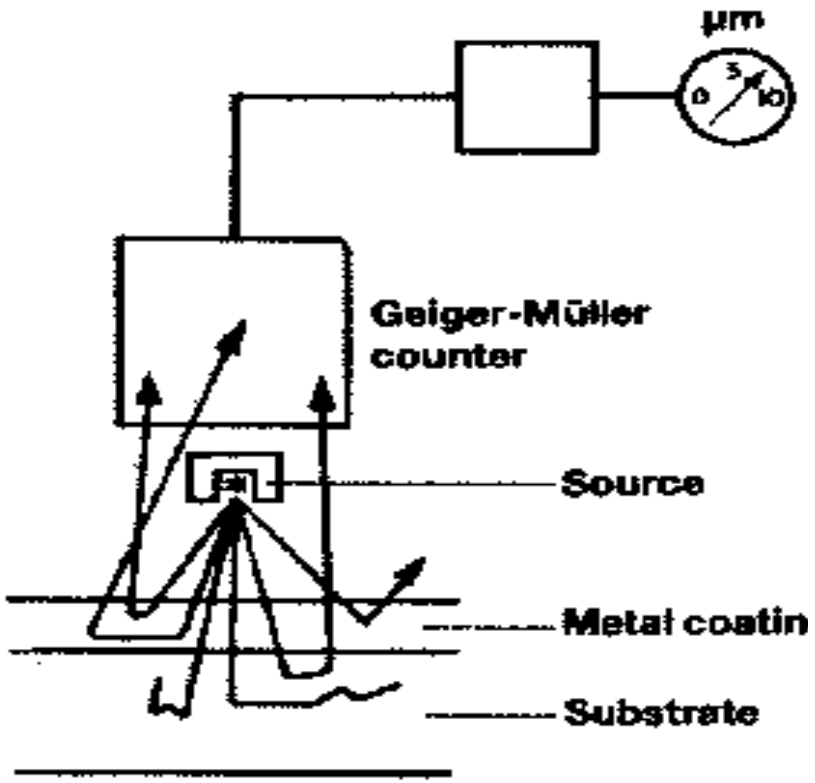


Thickness Gauge

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



Thickness Gauge
Beta backscattering technique



Beta backscatter thickness gauging