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.
Research Use

• Biological and Genetic research
• Agricultural research
• Space research
• Pharmaceutical research
Beneficial Uses of Radiation

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

- Reactor Irradiation
  - $^{60}\text{Co}$, $^{14}\text{C}$, $^{3}\text{H}$
- Fission Products
  - $^{238}\text{Pu}$, $^{244}\text{Cm}$, $^{252}\text{Cf}$
- Accelerators (proton addition)
  - $^{65}\text{Zn}$, $^{67}\text{Ga}$, $^{54}\text{Mn}$, $^{22}\text{Na}$, $^{57}\text{Co}$
  - $^{60}\text{Mo}$ -> $^{99m}\text{Tc}$, $^{137}\text{Cs}$->$^{137m}\text{Ba}$
<table>
<thead>
<tr>
<th>Industry: Products/Services</th>
<th>Use</th>
<th>Types of Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturing: • numerous</td>
<td>Measure: • thickness of metal components • thickness of coatings • moisture content in manufactured products</td>
<td>Gamma emitters such as: • barium-133 • cobalt-60 • cesium-134 • cesium-137 • antimony-124 • selenium-75 • strontium-90 • thulium-170</td>
</tr>
<tr>
<td>Chemical Processing: • various</td>
<td>Measure process characteristics, such as: • density • thickness of coatings • specific gravity • level Measure equipment parameters such as: • pipe thickness • corrosion • wear</td>
<td>Gamma emitters neutron sources (for level measurement)</td>
</tr>
<tr>
<td>Construction: • buildings, geophysical structures</td>
<td>Measure: • moisture content • location of reinforcing bar (rebar)</td>
<td>Gamma emitters; neutron sources such as: • americium/beryllium • plutonium/beryllium • californium-252</td>
</tr>
<tr>
<td>Mineral Processing: • measuring mineral levels in process streams</td>
<td>• density gauges • spectroscopy</td>
<td>Gamma emitters, such as: • americium-241 • cobalt-57 • cesium-137</td>
</tr>
<tr>
<td>Coastal Engineering: • measuring environmental parameters</td>
<td>Measure: • levels of sediments in rivers and estuaries • sediment mobilization</td>
<td>Gamma emitters, such as: • americium-241 • cobalt-57 • cesium-137</td>
</tr>
</tbody>
</table>
# Industrial Radiation Applications

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

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

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

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

\[ ^{14}\text{C} \approx 10^{-11} \text{ g} \]
\[ ^{32}\text{P} \approx 10^{-16} \text{ g} \]
Example Problem

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

\[
M_m = \frac{CR_m T_1 A}{N_a \epsilon \ln 2}
\]

\[
M_m = \frac{(0.5 \text{s}^{-1})(1.18 \times 10^{11} \text{ s}) (14 \text{ g/mol})}{(6.024 \times 10^{23} \frac{\text{atoms}}{\text{mol}})(0.1)(\ln 2)} = 2 \cdot 10^{-11} \text{ g}
\]
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
Iron mostly transparent – plastic and Teflon less transparent
Level Gauge
Gamma Switching Technique

- Source
- NaI detector
- High signal reject
- Can/package content monitor
- Low level alarm
- High level alarm
- Storage hopper level control

Diagram shows the setup of a level gauge using a gamma switching technique with a detector, source, and various alarm mechanisms.
Thickness Gauge
Transmission Thickness Technique
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
Thicknness Gauge
Beta backscattering technique
Radiation Affecting Materials

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

- $60 billion in tax revenues to local, state & federal governments
- $330.7 billion annually in total industrial sales
- 4,000,000 jobs
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
Once they are produced, they are packaged and shipped safely to users throughout the United States; users are:

- Universities
- Laboratories
- Hospitals
- Industries
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.
Archaeologists use $^{14}$C to date artifacts containing plant or animal material.

Museum investigators use radiation to examine evidence for forgery.

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.
Computer disks retain data better when treated with radiation

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
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.
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, which is located near Geneva. Part of CERN is in France. The LHC collides protons with a Center of Mass Energy of 14 TeV, which is approximately 7 times higher than Fermilab. It has a very high luminosity, approximately 100 times higher than Fermilab. The goal of the LHC is to discover the Higgs boson, SUSY, and possibly other particles.
The Large Hadron Collider

ATLAS site

main lab
Overall view of the LHC experiments.
The Large Hadron Collider
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

~7 TeV final beam energy

~450 GeV

~25 GeV

~2 GeV

~1 GeV

0.999999c by here

0.87c by here

0.3c by here

~10^{11} protons/beam

Start the protons out here