SAND2011-8999P

Industrial Sources

RPM Cargo Report

Department of Homeland Security
Domestic Nuclear Detection Office
Joint Analysis Center
Secondary Reachback Data Mining Group

December 2011
SAND 2011-xxxxP
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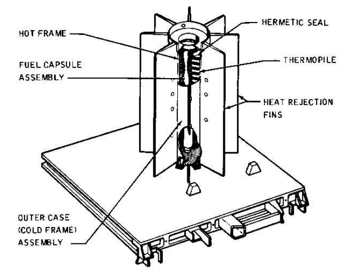
What Is an Industrial Source?

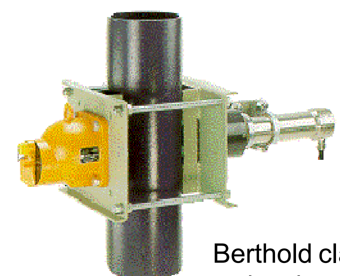
- The term **industrial sources** refers to devices which contain a radioactive source for use in an industrial setting; uses typically include imaging and measurement.
- Device categories include:
  - Deep well loggers.
  - Irradiators.
  - Radiography sources.
  - Gauges.
  - Calibration sources.
  - Signage and luminescent applications.
  - Radioisotopic Thermoelectric (or Thermionic) Generators (RTGs)

Ir-100 radiography source projector

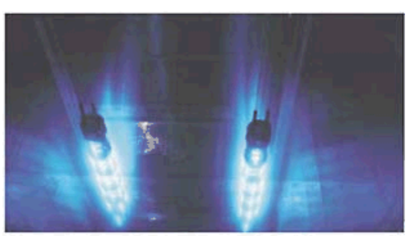


Schematic of Apollo Lunar Surface Experiment Package (ALSEP) RTG

Tritium exit sign

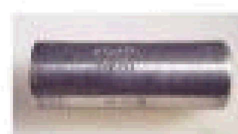


Berthold clamp-on density gauge



Source racks for MDS Nordion Pallet Irradiator

Gamma calibration sources



Oil well logging source – ^{241}AmBe

Well logging unit

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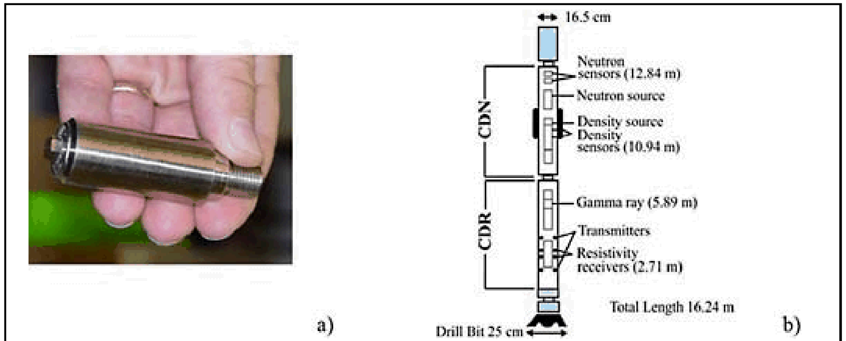
… and What Isn't?

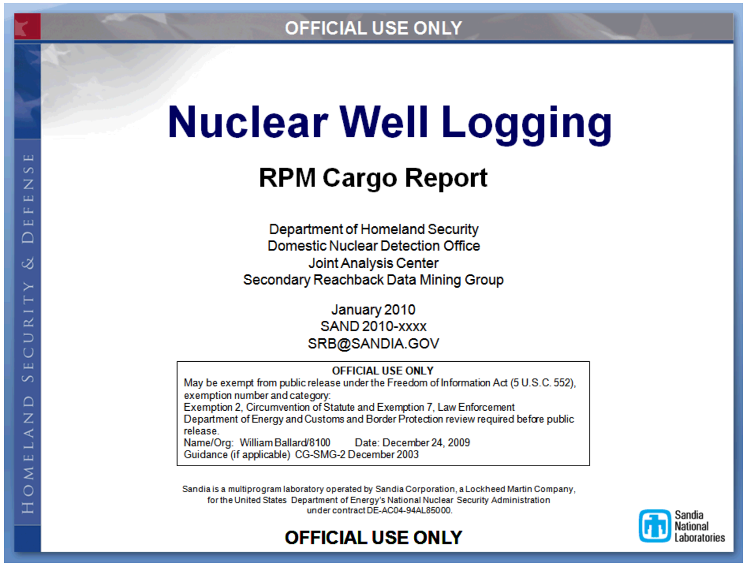
- Some industrial radionuclide uses are ubiquitous enough to be considered their own category and are not included in the catch-all "industrial sources"
- Examples are:
  - **Medical sources** – these include radionuclides used in therapy and diagnostics, radionuclides used in their generation, and any subsequent radioactive waste.
  - **Reactor materials** – for both power and research reactors this includes fuel production, current fuel, and spent fuel, as well as any fission or activation products.
  - **Research institution or laboratory** sources.
  - **Military** or other federal, state, territorial, tribal, or local (**FSTTL**) sources.
  - **NORM and TE-NORM** (i.e., NORM concentrated by human activities).
- Commercial accelerators (e.g. as used in the VACIS P7500), although capable of producing intense radiation, are not considered "industrial sources" because their radiation ceases when they are turned off.

Deep Well (Oil Well) Logging

- Well logging, also known as borehole logging, is the process of making a detailed record (a *well log*) of the geologic formations as a function of well depth.
- Radioactive sources are used in some down-hole logging tools.
  - Both gamma and neutron sources are used.
  - The U.S. NRC licenses and regulates all such sources.
  - Typical sources include ^{137}Cs, Am-Be, ^{252}Cf, and D-T accelerators.



Photograph of an Am-Be neutron source used in well logging (a) and a diagram of a probe mounted on a drill for logging while drilling (b). From W. Rhodes III, SNL.



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Nuclear Well Logging

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January 2010
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This companion report explains well logging sources in detail.

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Industrial Irradiators

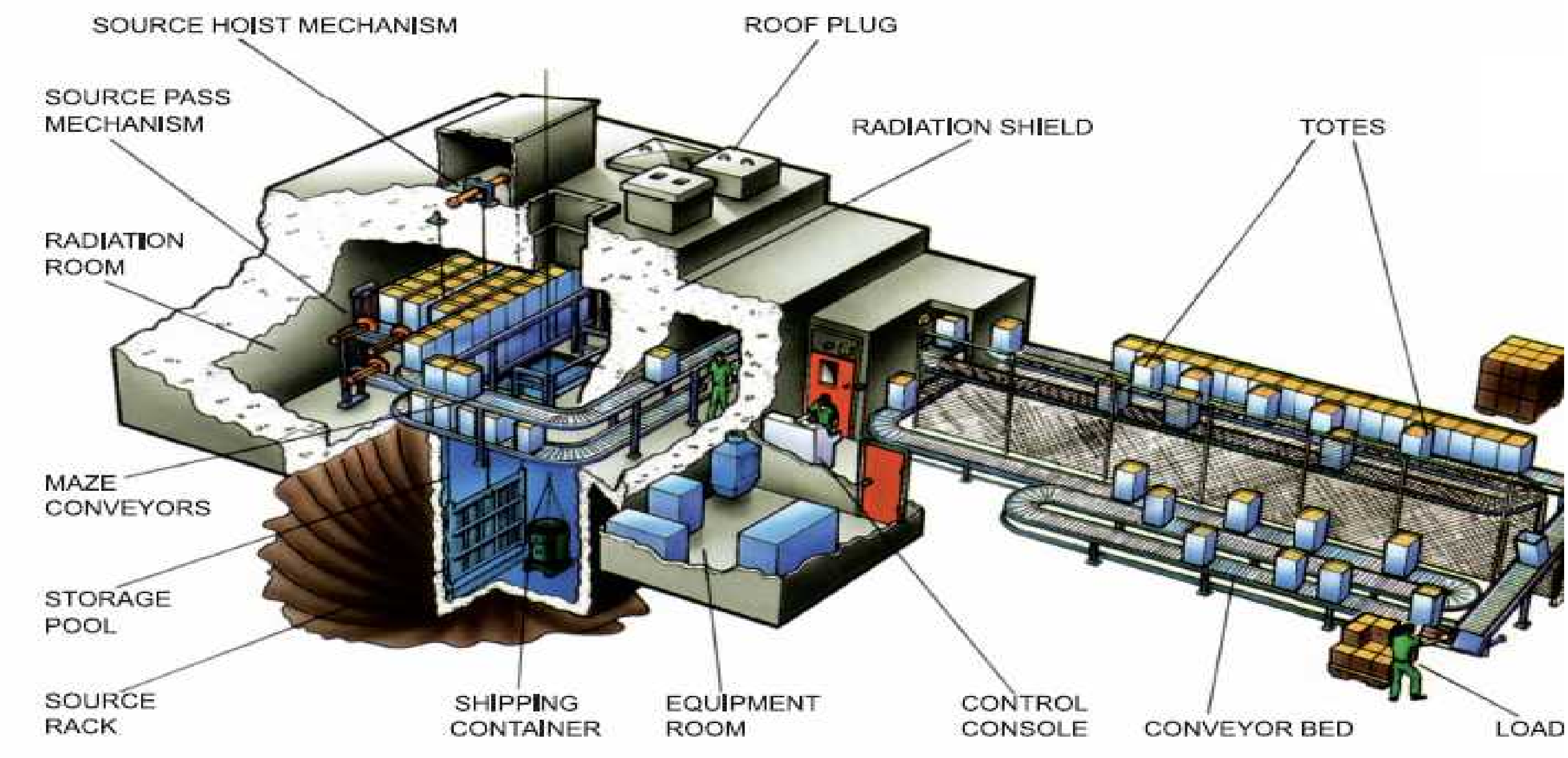
- An irradiator exposes a target to a large amount of gamma, neutron, or x-ray radiation, often for sterilization, calibration, or research.
- There are two types of irradiators: **self-contained** and **panoramic** – panoramic irradiators are discussed on the following slides.
- A self-contained irradiator:
  - Has a sealed source (most often ^{137}Cs) mounted in a dry container constructed of solid materials.
  - Prohibits by design human access to the source.
  - Shields the source at all times.
- Self-contained irradiators are often used for:
  - Blood irradiation for sterilization.
  - Biomedical and radiation research.
  - Calibration of high dose rate devices.
- Self-contained irradiators typically don't have "industrial source" applications.

Self contained irradiator, from www.mds.nordion.com

Panoramic Irradiators

- Panoramic irradiators are room to facility sized devices used to irradiate:
  - Single use medical devices and products for sterilization.
  - Food for sterilization.
  - Pharmaceuticals and cosmetics for sterilization.
  - Plastics for changing chemical characteristics.
  - Miscellaneous items, such as male insects for reproductive sterilization.
- **Dry source irradiators** have a dry sealed source that is fully shielded when not in use.
  - Also known as ANSI N43.20 Cat II.
  - Typically use ^{60}Co, but some older devices may have ^{137}Cs.
- **Wet source panoramic irradiators** have a source maintained in a storage pool (usually containing water).
  - Also known as ANSI N43.20 Cat IV.
  - Typically use ^{60}Co, sometimes in extremely large quantities (> 10^7 Ci).
- Besides radionuclides, irradiators may use electron beams or x-rays.

Wet Source Panoramic Irradiator Schematic



IAEA report – “Gamma Irradiators for Radiation Processing”

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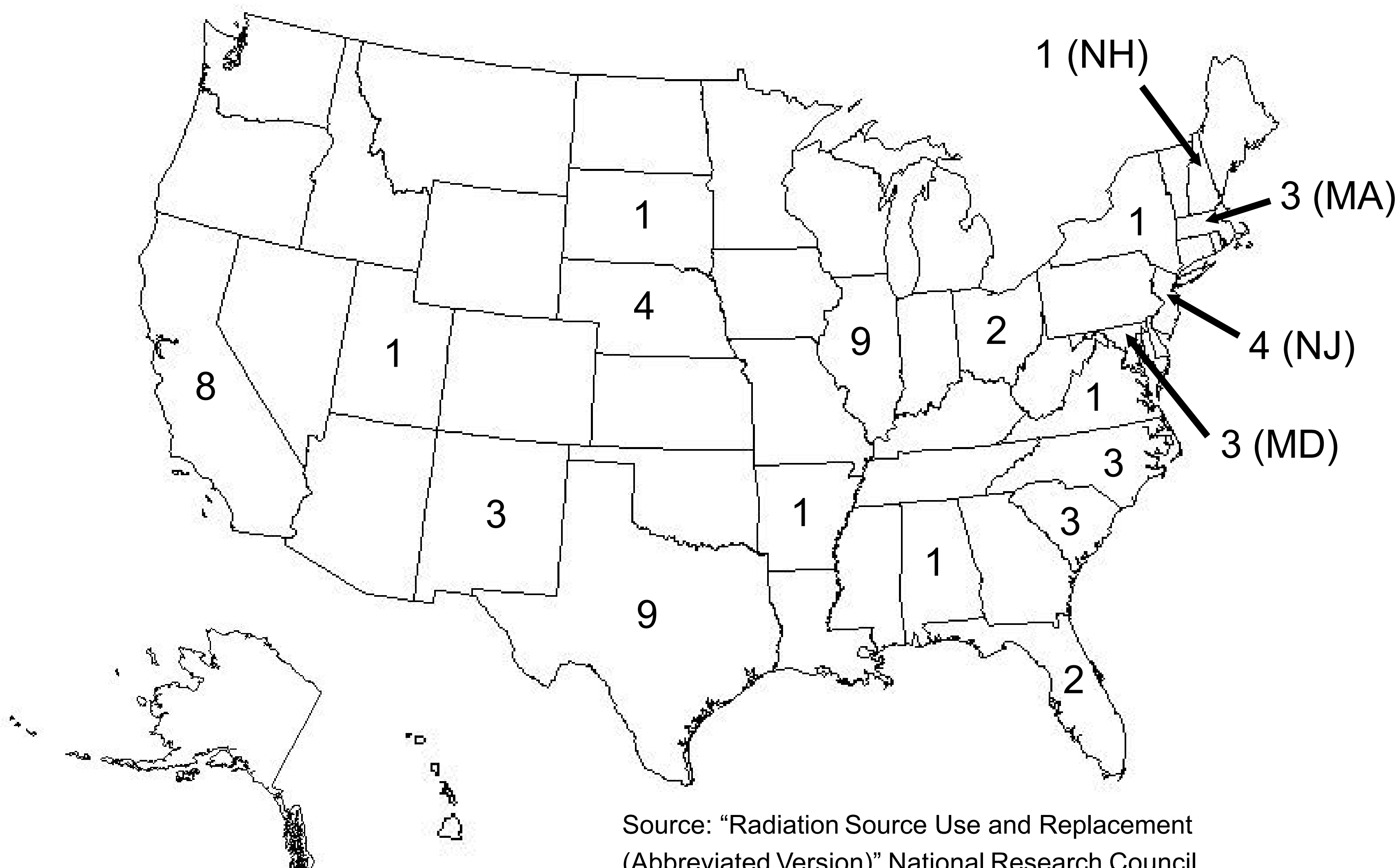
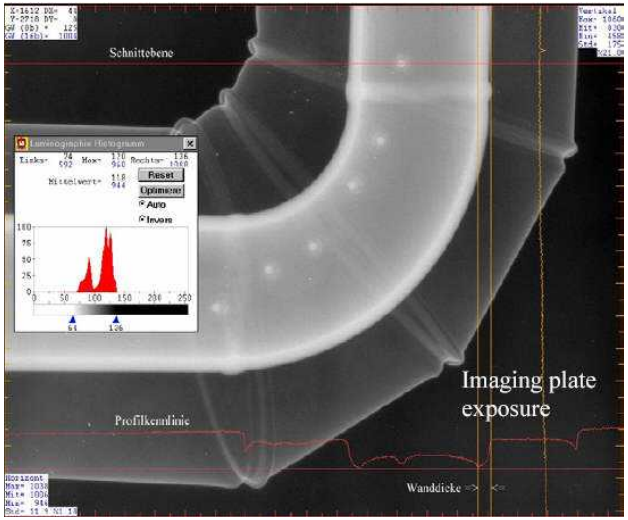
Estimated Number of Panoramic Irradiators



Source: “Radiation Source Use and Replacement (Abbreviated Version)” National Research Council

Industrial Radiography

- Radiography is a form of non-destructive inspection that uses x-rays or gamma rays (and occasionally neutrons) to detect defects such as voids, cracks, or imperfect welds.
  - Radiography is used to inspect a wide variety of items, for example gas and oil pipelines, pipes and pressure vessels in chemical plants, reinforced concrete structures, vehicle and aircraft components, and submarine hull welds.
- Industrial radiography is similar to medical x-rays, except with more powerful sources in order to penetrate the larger, denser objects.
  - Radiation transmitted through the target forms a rather easily interpreted image on recording film or solid state detector.
  - Computer enhancement is often used, even producing 3D images.



Computed radiograph of an insulated pipe. The wall thickness can be measured and no corrosion is visible. From Uwe Ewert.

Industrial Radiography Sources

- Various source types are available, but radionuclides are often preferred as they are lighter, smaller, and require little or no power.
  - Linear accelerators can be used as moderate to high energy (few keV to few MeV) x-ray sources.
- The most commonly used radioactive sources are ^{192}Ir (80% of total) and ^{60}Co.
  - ^{60}Co has higher energy gamma rays and thus more penetrating power.
  - Other industrial source radionuclides include ^{75}Se and ^{169}Yb.

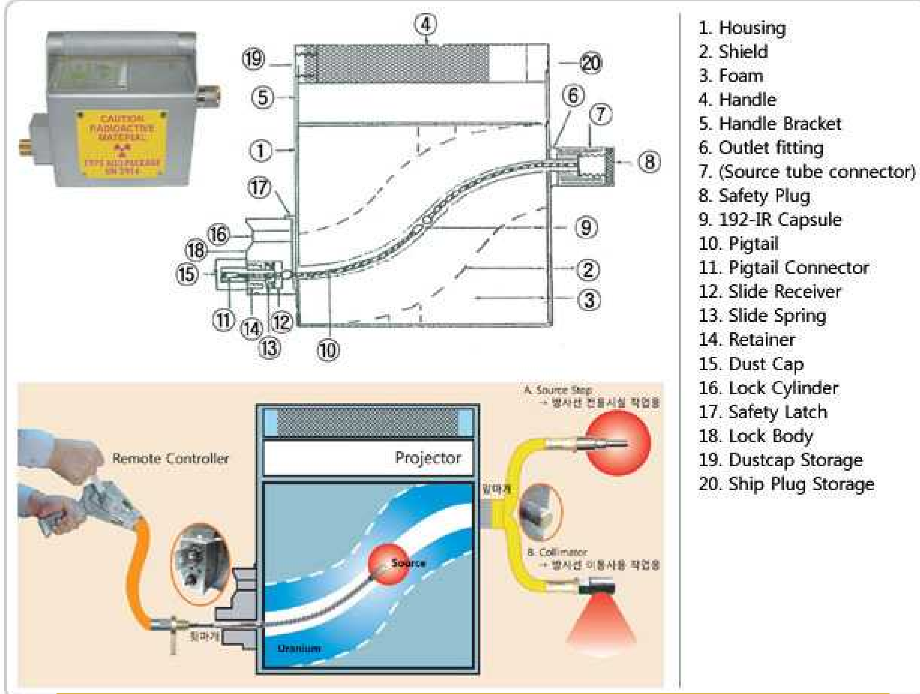
Nuclide	Half-life	Gamma Energy Range (keV)
^{60}Co	5.27 years	1170 – 1330
^{75}Se	120 days	66 – 401
^{169}Yb	31 days	8 – 308
^{192}Ir	74 days	206 – 612

880 Delta Series source projector – can house any of the four nuclides listed to the left, but with differing maximum activities.

Radiography Source Shielding

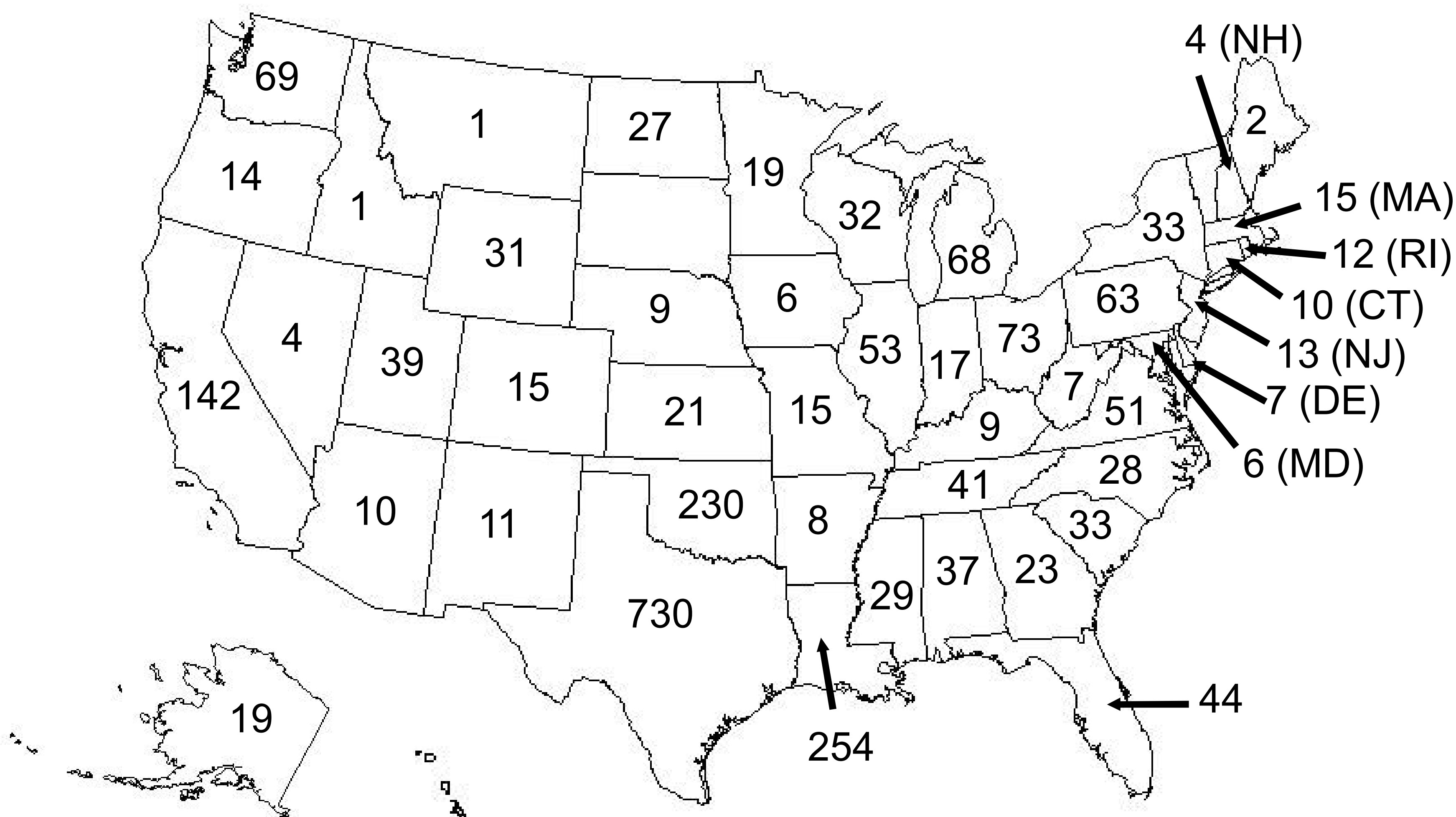
- Due to the high activity of radiography sources large amounts of shielding are typically required.
- Depleted uranium (DU) is a desirable shielding material due to its high density and atomic number.
  - DU itself is radioactive, but at a very low level relative to the source.
- Shielding adds considerable weight to the source.
  - 880 Delta Series pictured on last slide weighs 52 lb.
  - Ir-100 pictured here weighs 53 lb including 37 lb DU.
  - The GammaMat K100 (containing a ^{60}Co source) weighs 418 lb including 266 lb DU.

Nawoo Tech Ltd. Ir-100 radiography source.



A mechanism is required to expose the source in use and shield it when not. Here the Ir-100 **S-shaped channel** is detailed. Other designs include a **hinged section** of the shield to be opened to expose the source and a **rotating wheel** that shifts the source from exposed to shielded positions. From Nawoo Tech Ltd.

Estimated Number of Radiography Sources



Source: “Radiation Source Use and Replacement (Abbreviated Version)” National Research Council

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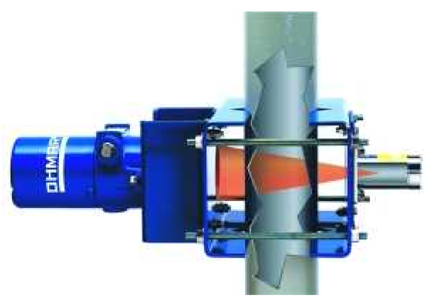
Radioactive Industrial Gauges

- Known absorption properties of x-ray, gamma, beta, and neutron radiation make it extremely useful for areal density measurements.
  - Areal density is the amount of material per unit area between the radioactive source and the detector.
  - Areal density = density (e.g. g/cm^3) × length (e.g. cm).
- Some example applications are the measurement of fluid density, metal sheet thickness, fluid level, moisture content, and earth compactions.
- Gauge source strengths are typically in the tens of mCi range – much smaller than irradiators.



Ohmart DSG – a compact radiation detector well-suited for a variety of density measurements. The cutaway view shows its application to slurry measurements.

From: http://www.vegacontrols.co.uk/product_details.asp?productID=205&fixedRangeID=06

Industrial Gauge Usage

Industry	Use	Types of Sources
• Manufacturing	• Measure: – Thickness of metal – Thickness of coatings – Moisture content in manufactured products	• Gamma emitters such as: – ^{133}Ba – ^{60}Co – ^{134}Cs and ^{137}Cs – ^{124}Sb – ^{75}Se – ^{90}Sr – ^{170}Tm
• Chemical processing	• Measure process characteristics: – Density – Thickness of coatings – Specific gravity – Level • Measure equipment parameters: – Density – 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: – Am-Be – Pu-Be – ^{252}Cf

Industrial Gauge Usage (continued)

Industry	Use	Types of Sources
• Mineral processing: – Measuring mineral levels in process streams	• Density gauges	• Gamma emitters such as: – ^{241}Am – ^{57}Co – ^{137}Cs
• Coastal engineering – Measuring environmental parameters	• Measure: – Levels of sediments in rivers and estuaries – Mobilization of sediment	• Gamma emitters such as: – ^{241}Am – ^{57}Co – ^{137}Cs
• Oil refining: – Refinery products	• Column scanning • Level measurement	• Gamma emitters (column scanning) • Neutron sources (level measurement) – Am-Be
• Coal fired boilers: – Electricity generation	• Measure: – Ash – Moisture content of coal	• Gamma emitters such as: – ^{241}Am (for ash content) – ^{137}Cs
• Agriculture: – Various crops • Hydrology: – Environmental assessments	• Measure: – Moisture content of soil	• Neutron sources such as: – Am-Be – Pu-Be – ^{252}Cf

Industrial Gauge Usage (continued)

Industry	Use	Types of Sources
• Materials processing: – Blown film – Cast film and sheet – Rubber – Vinyl – Coatings and laminations – Nonwovens – Textiles – Composites – Paper – Plastic pipe – Film thickness – Electroplating	• Measure: – Thickness or weight – Basis weight – Consistency – Moisture content	• Gamma emitters such as: – ^{241}Am • Beta emitters such as: – ^{147}Pr – ^{85}Kr – ^{90}Sr

A fixed gauge used in process control.

A portable gauge used to measure pavement.

Images from http://www.nrc.gov/materials/miau/industrial-uses/gauges.pdf

Calibration Sources

- Radioactive sources are used for instrument calibration, such as radiation detectors.
  - Typical activities are from a μCi (or less) to a few mCi.
  - They can be found wherever radiation detection instruments are used.
  - Self contained irradiators (discussed above) are also used for calibration (e.g. dosimeters).
- The small physical size of such sources allows for easy placement / misplacement around industrial work sites.
  - Although low in activity level, they can easily interfere with radiological searches for higher threat materials and/or background measurements.
- Typical radionuclides are ^{22}Na, ^{54}Mn, ^{57}Co, ^{60}Co, ^{65}Zn, ^{109}Cd, ^{137}Cs, ^{133}Ba, ^{152}Eu, and ^{226}Ra, ^{232}Th, although many others are possible.
- Small calibration sources can be purchased by anybody and do not require a NRC license.

A sampling of calibration sources sold by Cenco Physics.

A sampling of calibration sources sold by Images Scientific Instruments.

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Signage and Luminescent Applications

- Radioactive sources can be used for emergency or low light level illumination.
  - No external power source is required.
  - Typical uses include gauge dials and exit signs.
  - The half-life of the radioactive nuclide determines the useful life of the illumination source.
- Historically, radium has been used; more recently tritium.
  - Current trends favor elimination of radioactive illumination sources.
- The NRC regulates the handling, recordkeeping and disposal of tritium illumination sources.

A modern tritium exit sign and an old radium dial.

From:
http://www.orau.org/ptp/collection/radioluminescent/radioluminescent.htm

Tritium gas is contained in sealed glass tubes. The insides of the tubes are lined with a phosphor. Low-energy beta particles emitted by the tritium bombard the phosphor, causing it to glow.

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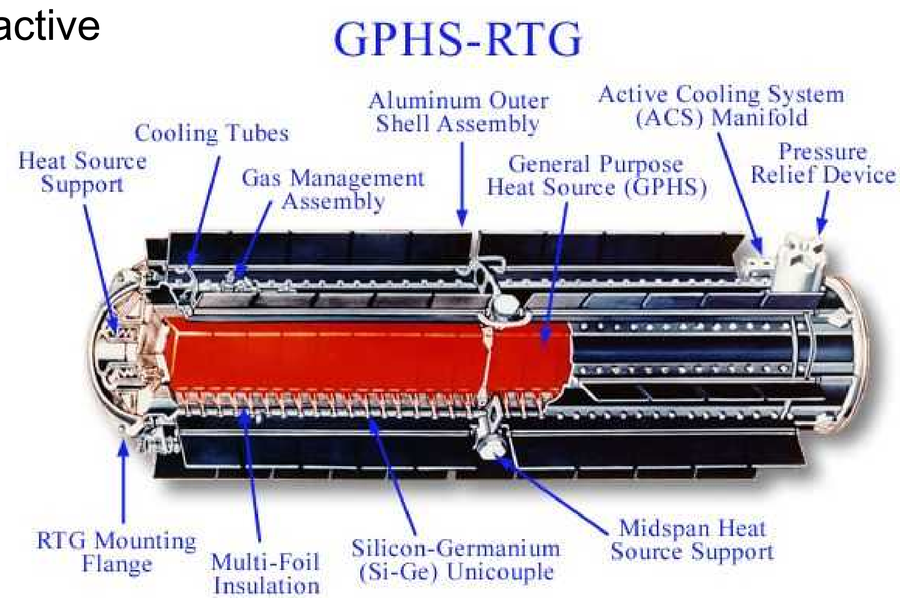
Radioisotope Thermoelectric Generators (RTGs)

- An RTG generates electricity from the heat released by radioactive decay.
  - The heat is converted to electricity by thermocouples.
- RTGs have some unique properties compared to other power sources:
  - Depending on size, produce 25-300 watts electrical power.
  - Degrade very slowly, and can still produce ~⅔ rated power after 20 years of use.
  - Require heavy shielding of the radioactive power source.
  - Require special handling of radioactive materials after decommissioning.
  - Are very expensive.
- Uses of RTGs include:
  - Space probes.
  - Satellites.
  - Lighthouses (esp. USSR)
  - Remote weather stations.
  - Navigation stations and buoys.
  - Heart pacemakers (early models).



From: http://saturn.jpl.nasa.gov/spacecraft/safety/

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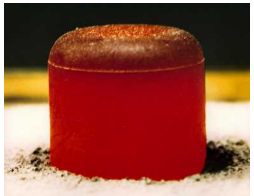
RTG Fuel

- There are several radionuclides that can be used for RTG fuel:
  - ^{238}Pu is the most commonly used because it is easily shielded and has a long half-life (87.7 years)
  - ^{90}Sr was used by the USSR in some lighthouses and the US in the arctic
    - ^{90}Sr cheaper than ^{238}Pu, but –
    - It is harder to shield, has a shorter half-life (28.5 years), and a lower power density.
  - Other possible fuel nuclides (including ^{210}Po and ^{244}Cm) have significant limitations.



A glowing pellet of $^{238}PuO_2$ to be used by NASA in a RTG for either the Cassini mission (Saturn) or the Galileo mission (Jupiter). Each pellet produces 62 watts of heat and when thermally isolated can glow brilliant orange because of the heat generated by the radioactive decay (primarily alpha) of the fuel. Picture provided by Los Alamos National Laboratory.

^{90}Sr fueled Soviet RTGs in dilapidated and vandalized condition on Kola peninsula. Picture provided by Finnmark region government.

IAEA Rating System

- The International Atomic Energy Agency (IAEA) rates sources according to their ability to cause injury.
  - **Category 1** – can cause death or permanent injury to those in close proximity after a short exposure (minutes to an hour).
  - **Category 2** – can cause death or permanent injury to those in close proximity after a longer exposure than category 1 (minutes to hours for injury, hours to days for death).
  - **Category 3** – can cause permanent injury to those in close proximity after a longer exposure than category 2 (hours for injury, days to weeks for possible but unlikely death).
  - **Category 4** – can cause temporary injury to those in close proximity after a longer exposure than category 3 (hours to weeks).
  - **Category 5** – unlikely to cause even minor injury.



Damage to hands from high dose x-ray exposure.

From: http://web.princeton.edu/sites/ehs/radiation/Xraytraining/RigakuMiniflexPrism.htm

Category 1 and 2 Industrial Sources in the U.S.

Radionuclide	Half-life	Major Applications	Typical Activity (Ci)	Physical or chemical form
^{241}Am	432.2 years	Well logging	13 – 22	Americium oxide as a pressed powder
^{252}Cf	2.645 years	Well logging	0.01	Metal oxide
^{137}Cs	30.17 years	Self-contained irradiators	2,000	Cesium chloride as a pressed powder
		High level calibrators	400	
^{60}Co	5.27 years	Panoramic irradiators	4,000,000	Metal slugs or pellets
		Self-contained irradiators	24,000	
		Radiography	100	
^{192}Ir	74 days	Radiography	100	Metal
^{238}Pu	87.7 years	RTG	15,000*	Metal oxide
		Fixed gauges	20	
^{75}Se	119.8 days	Radiography	75	Elemental or metal compound
^{90}Sr ^{90}Y	28.9 years	RTG	20,000	Metal oxide

* Based on 1 kg of oxide fuel

From – Radiation Source Use and Replacement: Abbreviated Version

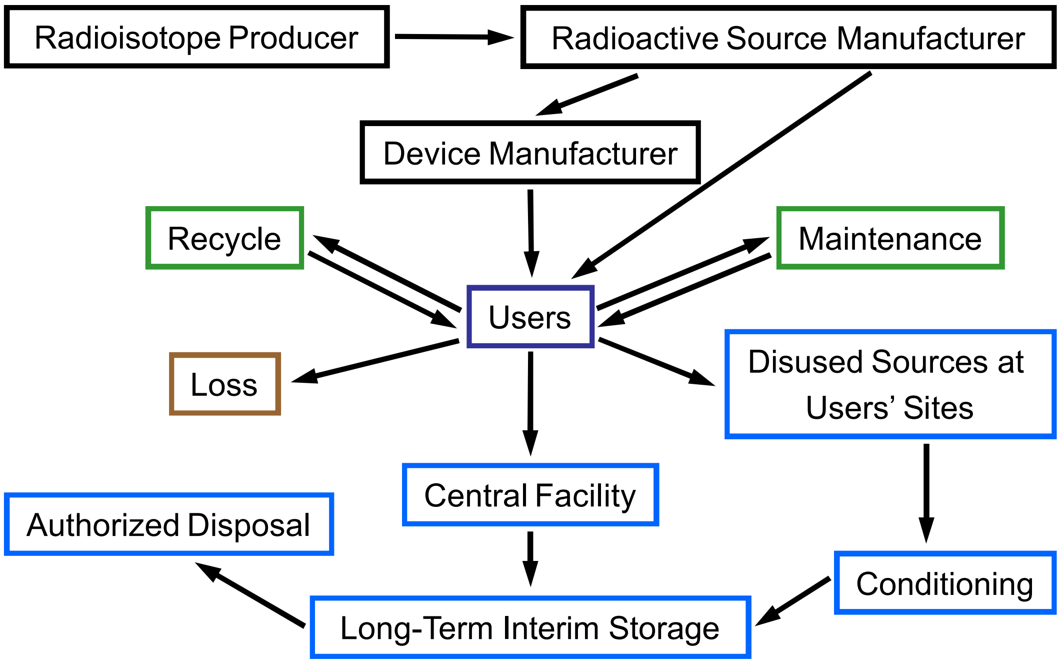
Other Common Industrial Radionuclides

Radionuclide	Half-life	Typical Use
Tritium (^{3}H)	12.3 years	Used in self-luminous exit signs, dials, and paint; used in geological prospecting and hydrology
^{14}C	5,700 years	Perform biological, pharmaceutical, agriculture, pollution and archeology research
^{24}Na	15 hours	Locate leaks in pipelines; perform oil well studies
^{35}S	87.5 days	Used in military and emergency management survey meters; used in cigarette manufacturing
^{55}Fe	2.7 years	Analyze electroplating solutions; detect sulfur in air
^{63}Ni	100 years	Detect explosives; used in voltage regulators and current surge protectors; used in gas chromatographs
^{85}Kr	10.7 years	Gauge thickness of thin plastics and sheet metal, rubber, textiles, and paper; measure dust and pollutant levels
^{109}Cd	453 days	Analyze metal alloys for checking stock and scrap sorting
^{147}Pm	2.62 years	Gauge thickness of thin plastics and sheet metal, rubber, textiles, and paper
^{169}Yb	30.7 days	Used as a radiography source
^{204}Tl	3.78 years	Measure dust and pollutant levels on filter paper; gauge thickness of plastics sheet metal, rubber, textiles, and paper
^{210}Po	138 days	Reduce static charge in the production of photographic film and other materials
^{226}Ra	1,600 years	Improve efficiency of lightning rods; when combined with Be, generate neutrons for well logging
^{229}Th	7,300 years	Used in fluorescent lights
^{230}Th	77,000 years	Provide coloring and fluorescence in glazes and glassware
Thoriated tungsten	1.4×10^{10} years	Used in electric arc welding rods
^{235}U	7.0×10^{8} years	Used in fluorescent glassware, glazes and wall tiles
^{244}Cm	18.1 years	Analyze material excavated in mining; analyze slurries in drilling operations

From – U.S. EPA, Radioisotopes Commonly Used in Devices by Industry

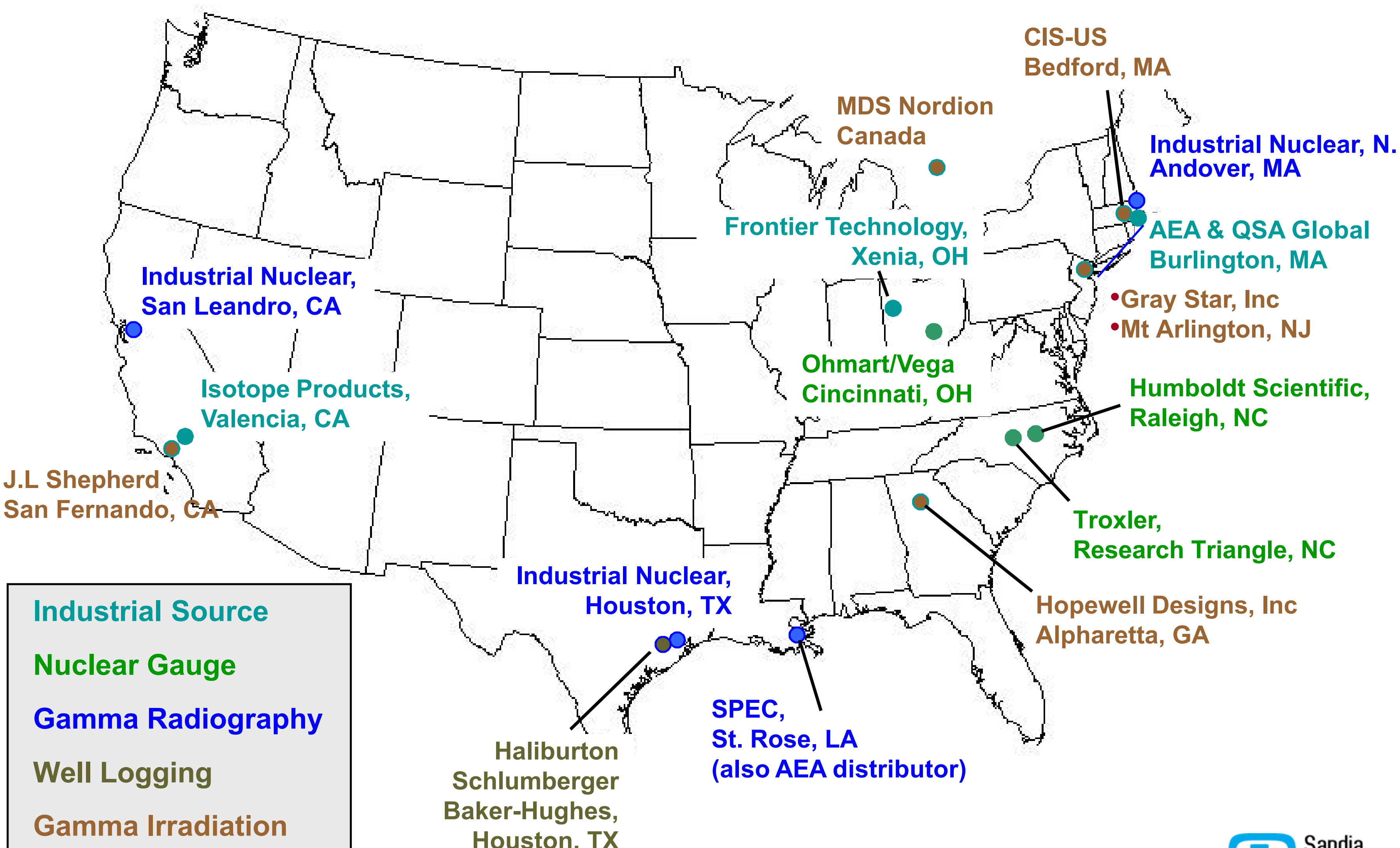
Transport of Industrial Sources

- During their lifecycle industrial sources may be transported several times, e.g. between:
  - The radioactive material manufacturer and the industrial source manufacturer.
  - The source manufacturer and the industrial user.
  - The radioactive material manufacturer and the industrial user during reloading.
  - Different locations by the industrial user.
  - The industrial user and the source manufacturer for calibration, refurbishment, reloading, and recycling.
  - Different industrial users when ownership is transferred.
  - The industrial user and a disposal site.



Adopted from "Commercial Radioactive Sources: Surveying the Security Risks"

Major Manufacturer and Distributor Locations



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Transportation of Radioactive Materials

- The U.S. Department of Transportation (DOT) regulates the shipment of all radioactive materials, including industrial sources.
  - Radioactive substances are **DOT Class 7**.
  - Refer to **U.S. Code of Federal Regulations Title 49 Section 172** for shipping regulations and proper shipping names of class 7 materials.
- Class 7 is subdivided by item properties; a few examples are (and these can have sub-subdivisions):
  - Fissile materials.
  - Low specific activity.
  - Natural uranium, thorium, or depleted uranium.
  - Surface contaminated objects.
- Class 7 may not be transported with Class 1, and with Class 2 only with packaging restrictions.

DOT Class	Description
1	Explosives
2	Gases
3	Flammable liquids
4	Flammable solids
5	Oxidizing agents and organic peroxides
6	Toxic and infectious substances
7	**Radioactive substances**
8	Corrosive substances
9	Miscellaneous

Below – placard displayed on trucks or train cars carrying DOT Class 7 materials.

References

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- U.S. EPA Radiation Protection; http://www.epa.gov/radiation/source-reduction-management/applications.html and http://www.epa.gov/radiation/source-reduction-management/radionuclides.html
- U.S. NRC Fact Sheet on Tritium Exit Signs; http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/fs-tritium.html
- Uwe Ewert, Upheaval in Industrial Radiology, http://www.ndt.net/article/ecndt02/414/414.htm
- VEGA Ohmart products; http://www.vegacontrols.co.uk/product_details.asp?productID=205&fixedRangeID=06
- Wikipedia; radioisotope thermoelectric generator

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