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^{60}Co Contamination in Iron and Steel

RPM Cargo Report

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

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Any requests to share this information outside your agency should be addressed to the Domestic Nuclear Detection Office (DNDO) Joint Analysis Center (JAC) at the following e-mail address: dndo.jac2@dhs.gov

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What is Iron?

- Iron is an element with the symbol Fe. It is the fourth most common metal found in the Earth's crust with a myriad of industrial and consumer uses.
- Fresh iron metal is silvery-gray. Over time iron oxidizes to form iron oxides that flake off and expose more iron.
- Iron ores almost always consist of iron oxide. The two primary ores are magnetite (Fe_3O_4) and haematite (Fe_2O_3). Iron ores contain Naturally Occurring Radioactive Material (NORM).
- Iron ore is the primary source of pig iron. Pig iron is the intermediate product of smelting iron ore with coke (or charcoal or anthracite) and usually limestone as flux. Pig iron has very high carbon content , 3.5 - 4.5 %, and is very brittle.
- The density of iron metal is 7.874 g/cm^3.
- Iron is not naturally radioactive, but can contain radioactive contaminants.

Pure Iron Chips

Source: Alchemist-hp (talk) (www.pse-mendelejew.de

Pig Iron

Source: Mfields1 at en.wikipedia.

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What is Steel?

- **Steel is an alloy of iron and carbon in quantities of less than 2.1% by weight. Many elements are present in steel as impurities including manganese, phosphorus, sulfur, silicon, oxygen, and nitrogen.**
- **Many elements are added to steel to improve its properties including manganese, nickel, chromium, vanadium, molybdenum, tungsten, cobalt, and titanium.**
- **The density of steel varies between 7.75 and 8.5 g/cm^3 depending on the alloy.**

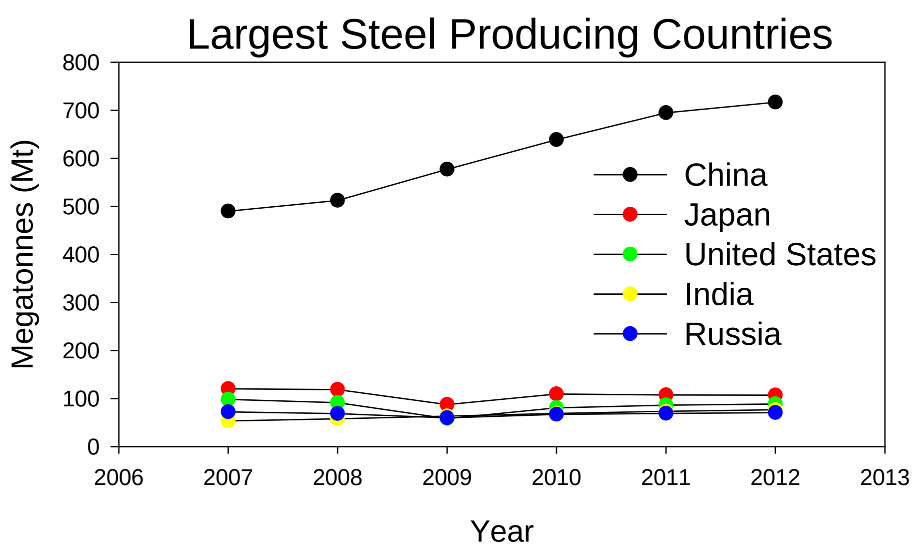
Steel Wire Rope

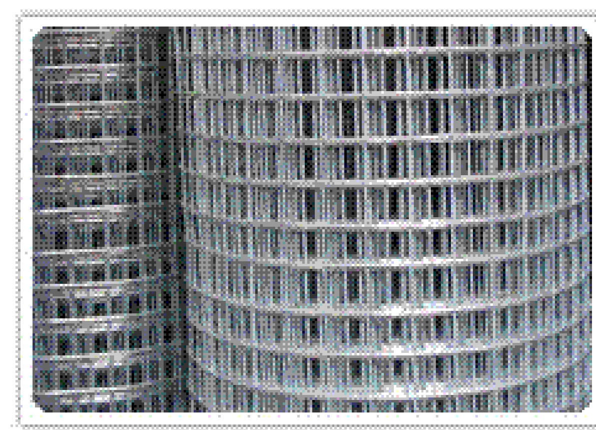
Source: Steel_wire_rope.png: Johannes Hemmerlein Derivative work: Materialscientist (talk)

- **Around 98% of iron ore is used for making steel.**
- **Steel is not naturally radioactive, but may contain radioactive contaminants.**
- **Iron and steel are used in construction of large buildings, car bodies, concrete reinforcement, appliances, and many other products.**

Production of Iron and Steel

- **Iron ore is most heavily produced in China, Australia, Brazil, India, and Russia[1].**
- **In 2012, iron ore cost $101 per metric ton[1].**
- **The largest steel producing countries are China, Japan, United States, India, and Russia[2].**

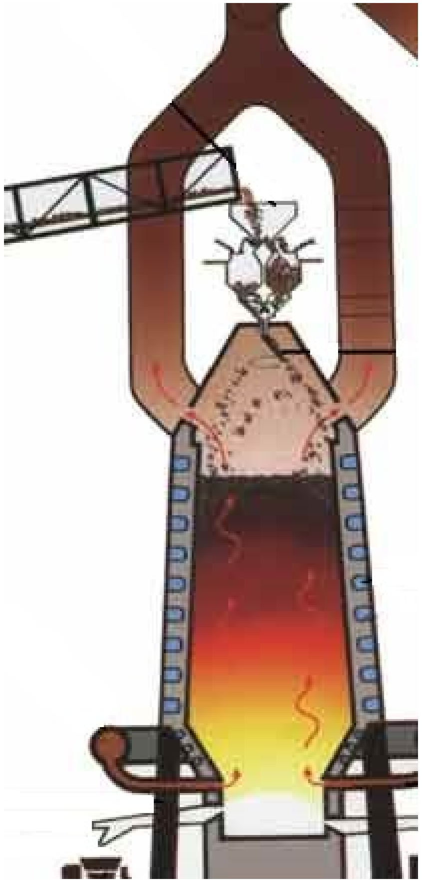




[1]"Iron Ore", U.S. Geological Survey, Mineral Commodity Summaries, January 2013.
[2]Worldsteel Association, January 22, 2013.

How Iron Metal is Produced

- **Iron ore is melted and combined with strengthening agents, generally coke and limestone, in a blast furnace.**
- **The blast furnace is a large structure about 30 meters high. It is lined with refractory firebricks that can withstand temperatures approaching 2000°C.**
- **The furnace gets its name from the method that is used to heat it. Pre-heated air at about 1000°C is blasted into the furnace through nozzles near its base.**
- **The production of iron in a blast furnace is a continuous process. The furnace is heated constantly and is re-charged with raw materials from the top while it is being tapped from the bottom. Production can continue up to ten years before the furnace linings have to be renewed.**



How Steel is Made

- **The majority of steel is made from two main processes. Steel production is not a continuous process, it is a batch process.**

1. **Basic Oxygen Steel Making (BOS)**
   - Steel is made from pig iron which is produced in a blast furnace and less than 30% scrap metal.
   - Before the 1950s, the Bessemer process was used until it was replaced by BOS. BOS produces better steel because it replaces regular air with pure oxygen, greatly reducing impurities including atmospheric ^{60}Co contamination.
2. **Electric Arc Furnace (EAF)**
   - EAF or mini-mill uses recycled scrap steel (90-100%) with a small amount of pig iron if needed.
   - Most ^{60}Co contamination originates with recycled scrap metal.
   - EAF is a very electricity intensive process.
   - Most specialty steels are made by EAF.
   - About 25% of steelmaking plants in the U.S are EAFs.

Source: https://en.wikipedia.org/wiki/File:ThyssenKrupp_Duisburg_016.jpg

70% of steel is made by BOS and 29% is made by EAF[1].

[1]World Coal Association, http://www.worldcoal.org/coal/uses-of-coal/coal-steel/, July 2013.

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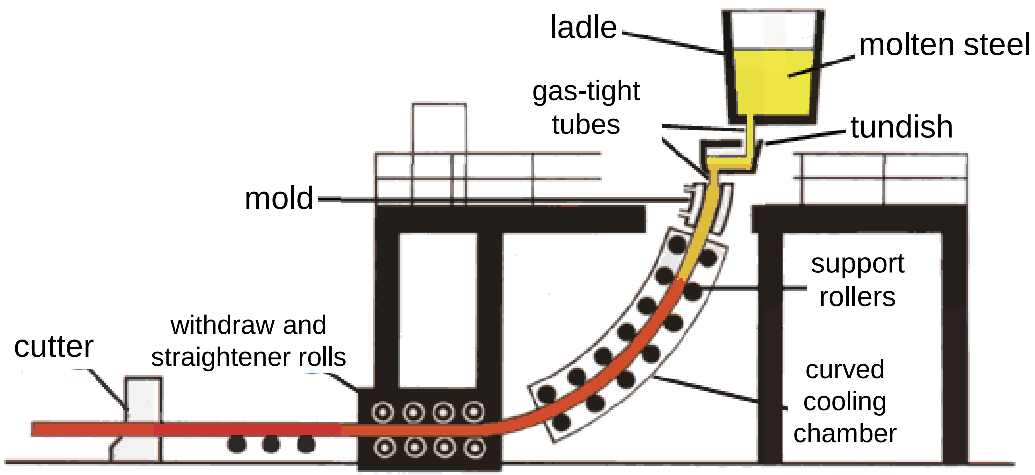
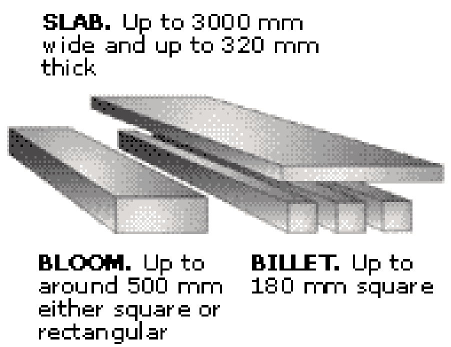
How Steel is Cast

- **Once steel of the correct composition is made, it is ready for casting. Casting structures the metal in the basic shape that the customer wants. Continuous casting may result in larger quantities of contaminated metal[1].**
- **Batch Casting**
  - Batch casting casts the steel in batches dictated by the size of the separate containers. Today batch casting is rarely used and only used for small specialized orders of steel.
- **Continuous Casting**
  - The modern steel industry uses continuous casting, which is more efficient. This technique allows molten steel from the ladle to be cast directly into the basic shape that the customer wants. By adjusting the water-cooled moulds in the continuous caster, steel sections can be produced in the three basic shapes shown on the right: slabs, blooms and billets.



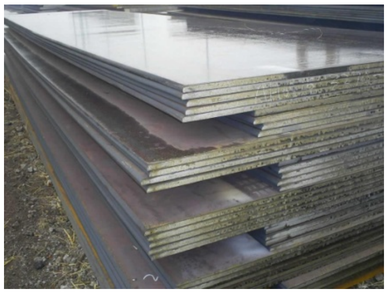


[1]Corus Group's Education Service, "The Chemistry of Steelmaking", http://resources.schoolscience.co.uk/corus/14-16/steel/index.html, July 2013.

How Steel is Shipped?

- **Steel is shipped as raw material or finished product:**
  - **Raw materials:**

Sheets



Source:
http://julongsteelpipes.en.made-in-china.com/product/BeJnYEjDJXri/China-Stainless-Steel-Sheet-202-Stainless-Steel-Plate.html

Spools of wire

Source:
http://www.cnartluck.com/products/search.html?keyword=high+carbon+steel+wire+rod

Logs, Ingots, and Bricks

Source:
http://www.ishwarispat.com/mild-steel-ingots.htm

Spools of Sheet Metal

Source:
http://www.steelfromchina.com/galvanized-steel-coil.html

  - **Finished products:**

Steel Products

Stainless Steel Products

Why is Some Steel Radioactive?

- **Iron and steel are not naturally radioactive.**
- **The most common radioactive isotope found in contaminated steel is ^{60}Co.**
- **Iron and steel processing do not remove cobalt contamination**
  - Due to its similar bonding properties and melting point, cobalt readily combines with iron when smelted. Instead of separating with the melt slag like other radioactive elements, trace amounts of ^{60}Co remain in the iron and then contaminate the steel when contaminated iron is used to make steel.
  - Other isotopes remain in the iron and steel by-products: ^{137}Cs ends up in the dust and ^{226}Ra in the slag[1].
- **Cobalt, naturally 100 % ^{59}Co, is rarely used in stainless steel as a specific additive. However, there are a few specific uses:**
  - High carbon, high chromium cold work steel (5% Co)
  - Chromium hot work tool steel (4.25%)
  - Molybdenum high speed tool steel (5-12%)
  - Ultrahard high speed tool steel (5-9%)
  - Tungsten high speed tool steel (5-12%)

23 V 50.942	24 Cr 51.996	25 Mn 54.938	26 Fe 55.845	27 Co 58.933	28 Ni 58.693	29 Cu 63.546
41 Nb 92.906	42 Mo 95.96	43 Tc [97.91]	44 Ru 101.07	45 Rh 102.91	46 Pd 106.42	47 Ag 107.87

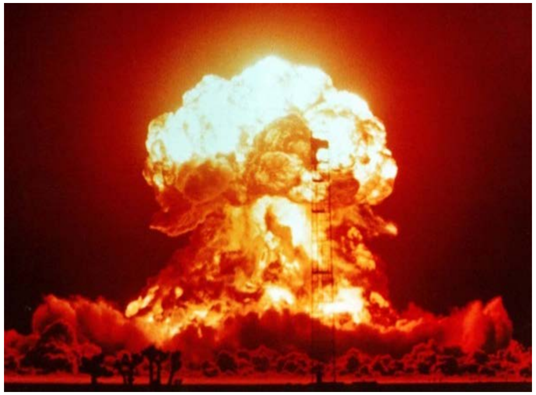
- **^{59}Co may be activate by neutrons to produce ^{60}Co.**

[1]NatSteel A Tata Steel Enterprise, Glossary – Radiation, http://www.natsteel.com.sg/node/180, July 2013.

How ^{60}Co Appears in Steel

- **There are four reasons why steel may contain ^{60}Co:**

1. **Production Contamination**
   - ^{60}Co is used to monitor the wear of the blast furnace lining.
2. **Scrap Metal Contamination**
   - ^{60}Co can be introduced from scrap metal fed into the process.
3. **Environmental Factors**
   - Nuclear weapons testing and nuclear power plant accidents can result in release of ^{60}Co to the environment.
4. **Neutron Activation**
   - Steel exposed to neutrons intentionally or unintentionally can activate ^{59}Co, if present in steel, changing it to ^{60}Co.



Source: www.un.org

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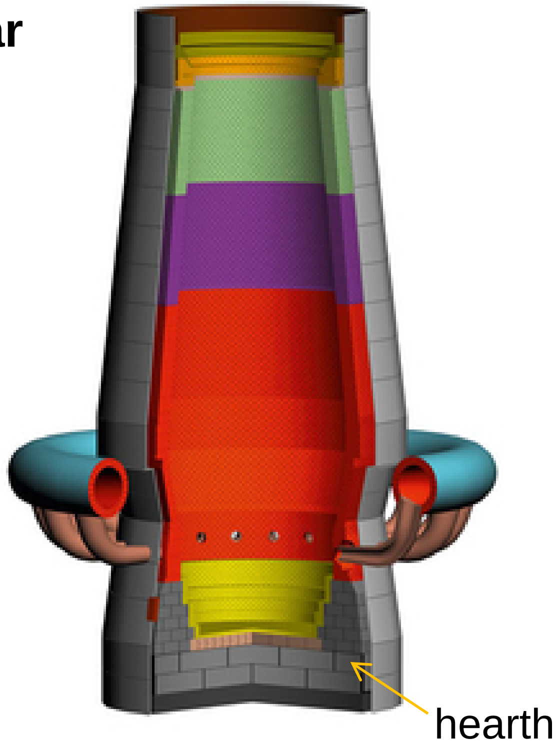
Production Contamination

- The life of a blast furnace is primarily dictated by the thinning of the hearth lining made of refractory bricks. It is costly to empty the molten material, so non-destructive assessment during processing is optimal.
- After the 1950s, ^{60}Co was used as a refractory wear indicator in the steel and iron production industry under a license granted by the Atomic Energy Commission. This practice has diminished, but is still in use in some places around the world.
- ^{60}Co pellets (1-5 mCi each) are embedded into the fire bricks at specific depths and locations in the blast furnace lining.
- A radiation detector outside the furnace monitors the amount of radiation emitted by the ^{60}Co in the furnace wall.
- The aggressive mechanical and chemical conditions in the blast furnace gradually erode the brick material that composes the furnace wall.



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Production Contamination cont.

- As the lining is burned away, the ^{60}Co pellets in the blast furnace walls drop into the molten metal.
- After the ^{60}Co pellets melt into the steel, the radiation levels recorded by the radiation detector drop, this reveals the erosion in the thickness of the furnace wall.
- Once a significant drop in the gamma ray emissions from the ^{60}Co is detected, the blast furnace is shut down to prevent a costly and dangerous burn-through.
- Using ^{60}Co to monitor furnace erosion causes trace amounts of ^{60}Co contaminate in significant portions of steel.
- Other non-destructive techniques may be used in lieu of the ^{60}Co pellets, some require removal of the molten metal from the furnace and, therefore, are less desirable.
  - Acousto ultrasonic-echo
  - Thermovision
  - Laser beam based profile measurement (removal of molten material is required)

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NRC Dose Estimates

- **The Nuclear Regulatory Commission (NRC) published NUREG-1717 "Systematic Radiological Assessment of Exemptions for Source and Byproduct Materials." Excerpts from pages 2-18,19:**

2.2.3.3 Steel Contaminated with ^{60}Co

Dose rates from external exposure to steel contaminated with ^{60}Co used in blast furnace refractory lining have been estimated by Leoben (NRC, Memoranda, 1996). External dose rates near a steel slab measuring 1.3 m × 1.3 m × 0.66 m were estimated based on a variety of measurements and calculations, and the results are summarized in Table 2.2.8.

Table 2.2.8 Estimates of External Dose Rates Near Steel Slab Contaminated With ^{60}Co [a]

Location	Dose-Equivalent Rate[b] (μrem/h per pCi/g)
Contact	2.3-6.3
Distance of 1 foot[c]	1.3-2.1

[a] Dose rates reported by Leoben (NRC, Memoranda, 1996) for a uniformly contaminated steel slab of dimensions 1.3 m × 1.3 m × 0.66 m; 1 μrem/h per pCi/g = 0.27 nSv/h per mBq/g.
[b] Range in estimated dose rates is based on differences among various calculations and measurements.
[c] Corresponds to a distance of about 0.3 meters.

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NRC Dose Estimates cont.

- **According to the Nuclear Regulatory Commission the exemption granted to the blast furnace industry was 19 Bq/g:**

NUREG-1717 excerpts from pages 2-18 and 19 continued from previous slide.

The exempt concentration for ^{60}Co is 19 becquerel (Bq)/g (500 picocurie (pCi)/g). Based on the results in Table 2.2.8, Leoben concluded that external exposure at locations near contaminated steel containing the exempt concentration of ^{60}Co could result in dose-equivalent rates on the order of 0.01 mSv/h (1 mrem/h), and that the resulting doses to members of the public from exposure to contaminated steel thus could be unacceptably high.

In practice, however, the presence of ^{60}Co in contaminated steel at levels approaching the exempt concentration of 19 Bq/g (500 pCi/g) is quite unlikely. For example, the data in Table 2.2.4 indicate that the concentrations of ^{60}Co in contaminated steel normally would be about three orders of magnitude less than the exempt concentration, and the external dose rates and doses to members of the public would be reduced accordingly. In addition, for a given concentration of ^{60}Co in steel, the dose rate from a large slab overestimates the dose rate from any smaller sources. Therefore, the dose rate would be reduced somewhat for steel products that are much less massive than the steel slab considered by Leoben (NRC, Memoranda, 1996), including, for example, appliances, furniture, and parts used in automobiles.

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Scrap Contamination

- **69% of steel in America is recycled from scrap metal [1]**
- **Today, most ^{60}Co contamination in steel is due to the use of contaminated scrap metal.**
- **The contaminating items are often medical sources (teletherapy units), radiography sources, and other intense sources that have been lost or abandoned.**
- **Other isotopes are often found in scrap metal, if processed in the furnace they are more likely found in the residue.**
  - ^{137}Cs
  - ^{192}Ir

Rusted medical source container:

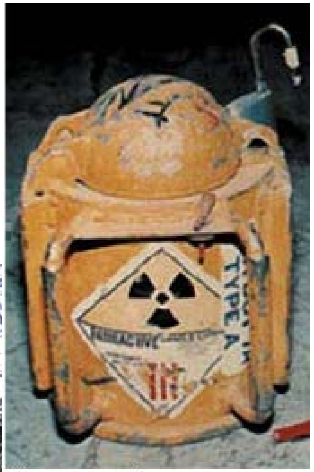

Photo: www.iaea.org

Crushed scrap metal:

Source: www.tradekorea.com

- **If ^{60}Co is embedded in the steel from a blast furnace or another source, it will be blended into the rest of the recycled batch**

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Example: Auburn Steel Company Accident

- **On February 21, 1983, a level gauge responded abnormally after a charge was ladled into the casting machine.**
- **The source of the ^{60}Co is unknown, but was most likely introduced to the scrap steel outside the facility.**
- **New York State Health Inspectors took measurements at the site:**
  - The steel contained approximately 4.2 x 10^5 pCi/g of ^{60}Co distributed over more than 100 tons of steel. It is estimated that the contamination resulted from the addition of 25 Ci or more of ^{60}Co to the scrap steel.
  - 700 pCi/g of ^{60}Co in a dust sample from the ventilation system,
  - 2900 pCi/g of ^{60}Co in a dust sample from inside the plant,
  - 540 pCi/g of ^{60}Co in a composite sample of wipes near the outlet vent of the ventilation system located on the plant roof.
- **The resulting cleanup shut the plant down for 28 days and cost more than $2 million.**

U.S. Nuclear Regulatory Commission, Office of Inspection and Enforcement, Washington D.C. 20555, SINNS No. 6825, In 83-16, March 30, 1983. http://www.nrc.gov/reading-rm/doc-collections/gen-comm/info-notices/1983/in83016.html

High Profile News on ^{60}Co in Steel

- **The vast majority of radioactive contaminated steel products are detected and contained by the many radiation detectors on scrap recycling plants, points of entry, and manufacturing companies.**
- **Most of the radiation levels detected in scrap metal are far under the amount of radiation absorbed from normal every day exposure from naturally occurring radioactive sources such as food [2].**
- **Occasionally, however, higher levels are detected and make the headlines. The NRC's national Nuclear Material Events Database contains numerous cases when contaminated steel has been detected and withheld or recalled. Many of these events were caused by highly radioactive medical, reactor, or industrial material being mistaken for scrap.**
  - In 1998, 430,000 pounds of steel laced with ^{60}Co made it to the U.S. from Brazil. Part of that load was used to make brackets for 1,000 La-Z-Boy recliners which would have given off a chest X-ray's worth of radiation every 1,000 hours, but never made it to stores or living rooms [3]

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High Profile News on ^{60}Co Steel cont.

- In October 2008, the French nuclear safety authority (ASN) was informed about the detection of radioactivity in elevator buttons manufactured by a French company with metal from India[1]. The problem was throughout Europe. There were many measurements made, one button was 4 kBq (equivalent to 200 Bq/g) in the UK.
- In 2012, a ten year old China-made cheese grater was found at a scrap metal plant that was contaminated with the isotope ^{60}Co. Tests showed the gadget to be giving off the equivalent of a chest X-ray over 36 hours of use, according to NRC documents. The grater likely was four to five times more radioactive when it was new [3]
- In August, 2012, Petco recalled several models of steel pet food bowls after U.S. Customs and Border Protection determined that they were emitting low levels of radiation. The source of the radiation was determined to be ^{60}Co that had contaminated the steel [4]
- In May, 2013, a batch of metal-studded belts sold by online retailer Asos were confiscated and held in a U.S. radioactive storage facility after testing positive for ^{60}Co [5]

European ALARA Network, “The Management of the Co-60 Contamination in Lift Buttons in European Countries”, September 21, 2009. http://www.eu-alara.net/index.php/home-page-mainmenu-1/206.html

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Nuclear Age Contamination

- **^{60}Co has also contaminated steel products due to nuclear weapons tests and nuclear reactor accidents which deposit radioactive isotopes throughout our environment, including ^{60}Co.**
- **This type of contamination mostly occurs on the surface of the metal.**
  - In 1960, ^{60}Co was discovered in two 6” plates of steel.
  - The Environmental Survey Center in Las Vegas estimated the ^{60}Co surface contamination for the two plates to be 5 x 10^{-14} Ci/g of steel.
  - ^{60}Co surface contamination can be easily removed using blasting techniques or electro polishing.

Source: gajitz.com

- **It is possible that the hot air used in the blast furnace may be contaminated with very low levels of ^{60}Co from nuclear age contamination. The BOS process uses oxygen to make steel and would not have those contaminants.**
- **The quantity of ^{60}Co (which has a half-life of 5.3 years) in our atmosphere has lowered significantly since the end of atmospheric nuclear weapons testing**
- **Thus, this is not considered a significant source of ^{60}Co today.**

Why isn't Contaminated Steel Removed?

- **There are several reasons why contaminated steel is not removed from the recycling process:**
  - **Prevalence of Contaminated Steel**
    - Because blast furnaces produced so much low level contaminated steel and the US continually recycles enormous amounts of steel, traces of ^{60}Co have seeped into most of the world's steel supply. ^{60}Co is so prevalent in steel that sunken pre-1945 steel warships have become valuable as a shielding material eliminating background radiation for Department of Energy research [7]
  - **Lack of Responsibility**
    - The vast majority of steel contamination with harmful levels of radiation have been tragic accidents. However, to avoid fines and costly cleanup efforts, some recycling companies have been reported to pass radioactive materials on to manufacturers [3]
  - **Lack of Funds**
    - Even responsible recycling companies suffer from the added cost of purchasing and maintaining detection equipment, which costs roughly $50,000 per detector [3]

Neutron Activation

- **Iron or steel that is exposed to neutrons in large doses or for long periods of time may become activated.**
- **Whenever steel is used for structures or shielding material around an industrial source, it may become contaminated.**
  - Several types of steel contain between 4 to 12 % ^{59}Co.
  - When neutrons interact with ^{59}Co[1]:
    - $^{59}Co + n \rightarrow {}^{60m}Co$ (half-life = 10.5 m) $\rightarrow {}^{60}Co$
    - $^{59}Co + n \rightarrow {}^{60}Co$ (half-life = 5.3 y)
  - There are other possible paths, but they have a low probability of occurring and do not contribute significantly.
    - For example, $^{60}Ni + n \rightarrow {}^{60}Co + p$

[1]Handbook of Health Physics and Radiological Health, Third Edition, B. Shleien, L.A. Slaback, jr., B. K. Birky.

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