



ICE - Geometric Series

Radioactive waste is a serious problem in many countries, especially those with highly developed programs in nuclear energy and weapons. Figure 1¹ (below) shows some of the options that the British and United States government currently use. Note that the photographs presented in Figures 1(c) and 1(d) were made recently (1999) in South Carolina and Missouri.



Figure 1: Conventional methods for storage of highly radioactive waste. (a) Drums of waste are stored deep beneath Yucca Mountain Nevada. (b) Packages of highly radioactive material are stored in a pond in Sellafield, England. (c) Drums of material contaminated with uranium and plutonium are left outside near the Savannah River in South Carolina. (d) Rubble contaminated with uranium (from the demolition of an obsolete nuclear power plant) is left exposed to the elements in Weldon Spring, Missouri.

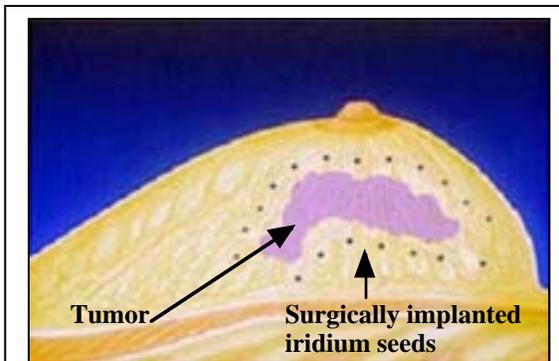


Figure 2: Schematic showing brachytherapy performed in the case of a cancerous growth in the breast tissue.

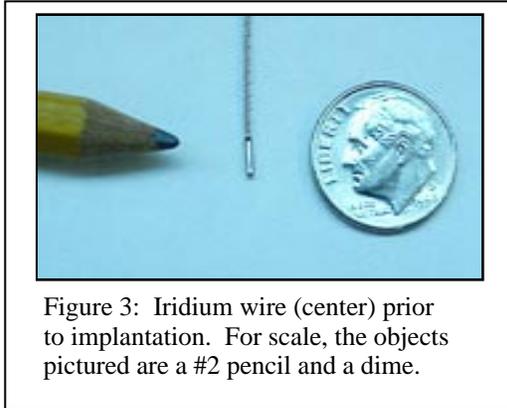
Even countries that do not have large facilities for generating nuclear power or nuclear weapons research programs often encounter difficulties with radioactive waste. For example, some medical procedures (many of those used in cancer treatments) involve exposing patients to radioactive material². When the treatment is complete, however, the (still) radioactive material must be disposed of in some way.

An example of such a medical procedure is called brachytherapy.

¹ Image sources: <http://www.crs4.it/~creas/Waste.html> <http://www.aber.ac.uk> and M. Datan. (1999) "Safe nuclear disarmament: Protecting health and the environment on the road to abolition." *Medicine and Global Survival*, 6: 12-17.

² Cancer cells are typically more susceptible to damage by ionizing radiation than normal somatic cells, although all body cells are susceptible to damage from radiation to some degree. The theory is that the cancer cells will be killed at a quicker rate than the patient's normal body cells. Ideally, such cancer treatments destroy the cancerous cells before they kill the patient.

This procedure is often used for the treatment of breast cancer and treatment of cancerous growths in the head. Figure 2³ shows a schematic diagram of a brachytherapeutic procedure performed in a case of breast cancer.



Brachytherapy consists of the insertion of small amounts of radioactive metal into or near to cancerous tumors. The radioactive material that is favored for this procedure is a radioactive isotope iridium-192 (Ir-192). Small sterile wires or “seeds” (see Figure 3⁴) of iridium are formed and then surgically implanted into the patient’s body. When examination suggests that the cancerous growth has been eliminated, the iridium is surgically removed from the patient and disposed of.

Radioactive material is highly toxic and cannot usually be disposed of by simply washing it down a drain⁵ or throwing it out with other trash⁶. Radioactive material must never be incinerated, as this simply releases the dangerous radioactive isotopes into the atmosphere exposing the population at large to a radiation hazard. In most countries, radioactive wastes from medical sources are usually stored in specific toxic waste dumps that follow strict procedures to try to contain the dangerous radiation.

In the European nation of Denmark (see Figure 4⁷) all radioactive material from medicine and industry is stored at the Radioactive Waste Plant of the Risø National Nuclear Laboratory (see Figure 5⁸), located near Copenhagen.



³ Image source: <http://www.radiotherapy.wisc.edu/>

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⁵ In fact, some radioactive material may be legally disposed of by flushing down a drain and into conventional waste water. The most common, medically important isotope that is often disposed of in this way is radioactive iodine (I-131) which is used to diagnose and treat cancers and diseases of the thyroid gland. Radioactive iodine is usually administered as a solution of sodium iodide and there are strict laws in many countries governing the concentration of the sodium iodide solution that may be disposed of by flushing down a drain.

⁶ Some solid, radioactive waste may be legally disposed of by inclusion with other bio-hazardous wastes. Things that fall into this category might include surgical instruments or clothing used during a procedure that involved radioactive material.

⁷ Image source: <http://www.ocdi.gov/cia/publications/factbook/index.html>

⁸ Image source: <http://www.risoe.dk/rd/>



Figure 5: (a) Danish Nuclear Laboratory at Risø. (b) The Nuclear Waste Processing and Storage center.

In 1972, the Risø National Nuclear Laboratory became the sole processor and storage facility for all high level radioactive waste generated in Denmark. At present, one of the major forms of waste this is actively stored at Risø is bio-hazardous iridium-192 from medical sources⁹.



Figure 6: Typical storage devices for high level radioactive waste.

According to the standard operating procedures of the Risø facility, radioactive iridium is collected from medical facilities once every two weeks¹⁰ (that is, once every 14 days). The iridium is stored in drums (see Figure 6¹¹) which are then stored within secure facilities on the grounds of the Risø facility. These drums have a nominal capacity of 220,000 cubic centimeters of storage space. However, as the radioactive material is normally encased in cement prior to storage, each drum holds approximately 110,000 cubic centimeters of radioactive waste.

Table 1 (below) gives some of the physical properties¹² of iridium-192 and Table 2 gives the current (as of February 2001¹³) assessment of both the amount of radioactive material stored at the Risø facility and the storage space that is still available.

⁹ Source: Director General for the Environment, Unit C-2, European Commission. (1999) "Nuclear safety and the environment. Management of radioactive waste arising from medical establishments in the European Union." Proceedings of European Commission Workshop, February 16-17, 1999. Brussels.

¹⁰ Source: Director General for the Environment, Unit C-2, European Commission. (1999) "Nuclear safety and the environment. Management of radioactive waste arising from medical establishments in the European Union." Proceedings of European Commission Workshop, February 16-17, 1999. Brussels.

¹¹ Image source: <http://deip.css.ua.edu/>

¹² Source: <http://www.webelements.com/>

¹³ Source: K. Lauridsen (ed.) (2001) *Decommissioning of the Nuclear Facilities at Risø National Laboratory. Descriptions and Cost Assessment*. Roskilde, Denmark: Risø National Laboratory.

Property	Value
Mass number	192.217
Atomic number	77
Half-life	74 days
Density of solid (at standard temperature and pressure)	22.56 grams per cubic centimeter

Table 1: Physical properties of iridium (Ir).

Building	Maximum storage capacity (drums)	Current inventory (drums)
212	80	0
244	5500	4700
231	195	0

Table 2: Storage capacities and current inventories of radioactive waste at Risø.

According to sources¹⁴, the amount of iridium that is collected from medical facilities is remarkably constant. Every two weeks, 13,314 grams of iridium-192 is delivered to the Risø facility for storage.

- **The first collection of radioactive material for the for the month of February 2001 occurred on February 3. Use the information given in the ICE to complete Table 3 (shown below).**

Number of weeks since February 3, 2001.	Amount of iridium-192 stored at the Risø facility since February 3, 2001.
0	
2	
3	
4	

Table 3: Use this table to work out how much iridium-192 has been stored.

¹⁴ Sources: (I) Director General for the Environment, Unit C-2, European Commission. (1999) "Nuclear safety and the environment. Management of radioactive waste arising from medical establishments in the European Union." Proceedings of European Commission Workshop, February 16-17, 1999.

(II) K. Lauridsen (ed.) (2001) *Decommissioning of the Nuclear Facilities at Risoe National Laboratory. Descriptions and Cost Assessment*. Roskilde, Denmark: Risoe National Laboratory.

(III) <http://www.risoe.dk/rd/>

• *Carefully examine the entries in Table 3. Can you see any patterns? If so, use these patterns to write down the amount of iridium-192 that has been stored $2 \cdot n$ weeks after February 3, 2001. (The symbol n represents a positive integer.)*

• *How long does it take to completely fill one drum with iridium-192?*

The Risø facility forms of radioactive waste other than iridium-192 from medical sources. Assuming that iridium-192 is the only radioactive waste accepted by the Risø facility is an over-simplification of the situation. However, this is not a bad assumption to start with¹⁵.

• *As soon as a drum has been filled with iridium-192, it is sealed and stored. Even though the iridium-192 inside a sealed drum will slowly decay, the drums are never re-opened once they have been sealed. Estimate how much longer the Risø facility will be able to continue to accept deliveries of radioactive waste. Do you think that your estimate is an over- or an under-estimate of the remaining lifetime of the storage facility?*

Epilogue:

As you will have calculated, the storage facilities at Risø will not last forever. At the time of writing¹⁶ there was no evidence to suggest that the Danish government had begun any serious planning activities directed towards establishing further storage facilities to augment those at Risø¹⁷.

¹⁵ When performing calculations to estimate or predict complicated phenomena such as the accumulation of radioactive waste for an entire country, it is not uncommon to “try the calculation out” with some simplifying assumptions you know to be unrealistic. When you have managed to work out the details of the calculation in a relatively simple case, it is often easier to then go back and adjust the calculation to incorporate more realistic assumptions.

¹⁶ Friday February 15, 2002.

¹⁷ This observation was explicitly made in 1999. Source: K. Broden. (1999) “Nordic cooperation on EIA for radioactive waste repositories.” *Proceedings from the 3rd Nordic EIA/SEA Conference*. (22-23 November 1999. It is possible that the Danish government has subsequently undertaken some kind of serious planning initiative in this area given that three years have elapsed. However, if such an initiative has been undertaken it does not appear to have been widely reported.