DEVELOPING A DATA PROTOCOL FOR COLLECTING MATERIAL FLOW DATA FOR COMMERCIAL RADIOISOTOPES IN THE UNITED STATES: CASE STUDY OF COBALT 60

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CENTER FOR RESPONSIBLE ENVIRONMENTAL STRATEGIES

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I. Background

Beginning in 2003, the Radiation Protection Division (RPD) of the US Environmental Protection Agency (USEPA) conducted a study of the material flow of a specific radioisotope, Cesium 137 (^{137}Cs), in the US economy. Encouraged by the findings of that study, in 2004, the RPD, a part of USEPA's Office of Air and Radiation, initiated a pilot project to conduct a material flow assessment for another radionuclide, Cobalt 60, which also enjoys significant commercial use in the US economy. The objective of the second phase of the RPD project was to 1) establish a standardized protocol for collecting data on commercially used radioisotopes over the commercial life cycle and to 2) provide estimates of how much Cobalt 60 enters the US economy annually, how it is used, and how much of it exits the economy by being returned to manufacturers or sent to permanent disposal. The long term goal of this effort is to provide a basis for better environmental management of commercial radionuclides in the United States.

One specific management objective is to improve the management and safe disposition of Orphaned Radioactive Sources. According to the International Atomic Energy Agency (IAEA), an Orphaned Source refers to a source of radioactive material that is not, but should be subject to regulatory control; a source subject to regulatory control, but has been abandoned, lost or misplaced; or a source that is subject to regulatory control, but has been stolen or removed without proper authorization.[1] Orphan sources pose a potential threat to public health, a looming financial risk for operators in the secondary metals industry, and raise national security concerns. According to a study conducted by The Henry L. Stimson Center[2] only 9 grams of Cobalt 60 (with a specific activity 1100 Curies per gram) are required to make a make a radiological explosive device or "dirty bomb" able to cause mass disruption.

Material Flow Analysis (MFA) was employed in order to better understand and control the use of radionuclides in commercial applications throughout the US economy. MFAs track materials over the commercial life cycle, through market transactions, into capital stock, and as they leave the economy and enter the environment. The accounts have been used to inform policy development for better managing material flows of toxic heavy metals such as cadmium and lead, base metals such as copper, nutrients such as nitrogen and phosphorus, and man made organic substances such as CFCs.[3]

The objective of developing MFAs for radionuclides is to achieve a complete material balance of the inputs and outputs from the US Economy. A schematic presentation of the Material Flow of Cobalt 60 is shown in Figure 1.

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[1] International Atomic Energy Agency (IAEA), 2000, *Categorization of Radiation Sources*. International Atomic Energy Agency, Vienna, Austria

[2] Kuchibhotla K., and McKinzie M. (2003). Nuclear Terrorism and Nuclear Accidents in South Asia. The Henry L. Stimson Center, Washington, D.C.

[3] Baccini, P. and Brunner, P.H. (1991) *Metabolism of the Anthroposphere*, Springer-Verlag, Berlin.

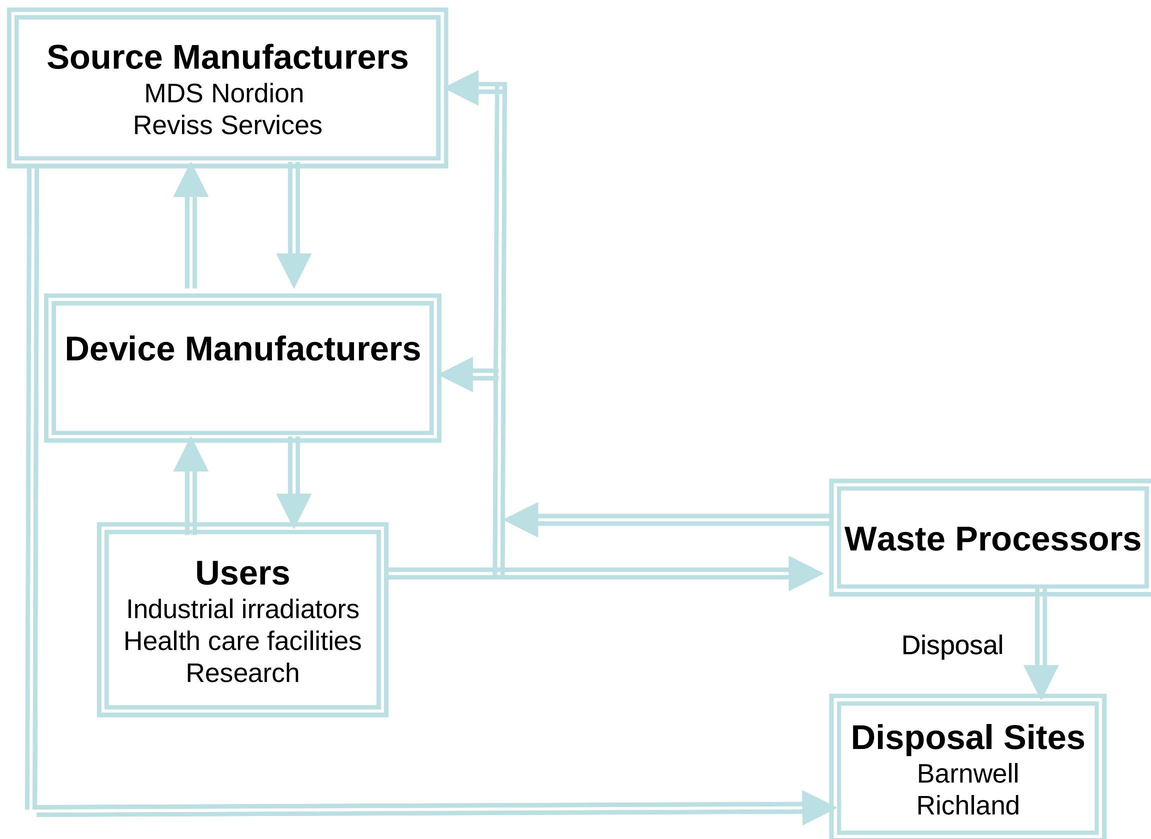


Figure 1. Material Flow Diagram for Cobalt 60

The need for better data during all stages of the commercial life cycle of radionuclides is accentuated by the fact that no single agency in the US government is currently responsible for managing, or even overseeing, these materials over the commercial life cycle from manufacture to disposal. In particular, the mix of reporting requirements and regulatory approaches exacerbates problems for managing orphaned sources, or sources without ownership or accountability, at the national level. More generally, the fragmented agency oversight results in large gaps in the data on use and disposition. MFAs provide an organizing principle for:

1) Consolidating existing data sources
2) Identifying data gaps, and
3) Establishing new reporting protocols to fill the gaps.

II. Cobalt 60

Cobalt is a hard and brittle metal, gray in color with a bluish tint. Under normal conditions of pressure and temperature, Cobalt 60 is a solid. Its magnetic properties are similar to those of iron. Common Cobalt is found in two forms: (i) In a non-radioactive stable form Cobalt-59 that occurs naturally, and (ii) As radioactive Cobalt, the most common isotope of Cobalt is Cobalt 60. Cobalt 60 is produced by exposing the stable form of Cobalt, Cobalt-59, to neutron bombardment in a nuclear reactor for 1 to 1.5

year. In this process, a portion of the Cobalt-59 atoms absorb neutrons and are transformed into Cobalt 60. Unlike Cesium-137, which is produced as a by-product of nuclear fission of uranium in commercial power reactors[4] , Cobalt 60 is the product of deliberate manufacture and is produced for commercial purposes.[5]

Cobalt 60 has a half-life of 5.27 years and emits a beta particle with two high-energy gamma rays 1.2 and 1.3 million electron volts (MeV). The high activity rate and high energy gamma rays emitted make Cobalt commercially valuable for applications requiring high energy deposition over a short period of time.

The principal applications of Cobalt 60 are:

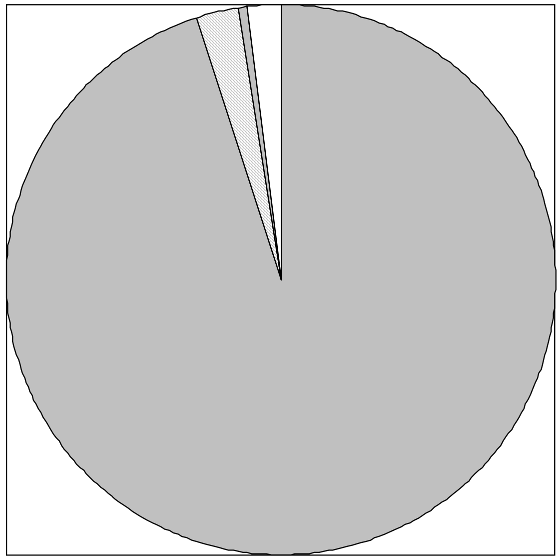
- Food Irradiation, i.e., sterilization of spices and foods where gamma rays kill bacteria and other pathogens, leaving the food unharmed
- Radiotherapy for cancer treatment in medical facilities
- Research and Development

Figure 2 shows the distribution of Cobalt 60 among uses in the United States. While values shown represent authorized amounts allowed by licensees and not actual use, we take these amounts as a proxy for market share. The figure clearly shows that use of this isotope is dominated by irradiation facilities, leaving a miniscule fraction to medical use and even less for academic and research use.

[4] Okumura, T. and T.E. Graedel, 2004, The Contemporary Materials Cycle for Radioactive Cesium-137 in the U.S., Center for Industrial Ecology, Yale University

[5] Radiation Information, USEPA (http://www.epa.gov/radiation/radionuclides/Cobalt.htm)

Figure 2 Percentage of uses for Cobalt 60: US 2000



Source: Nuclear Regulatory Commission Nuclear Material Events Database (NMED)

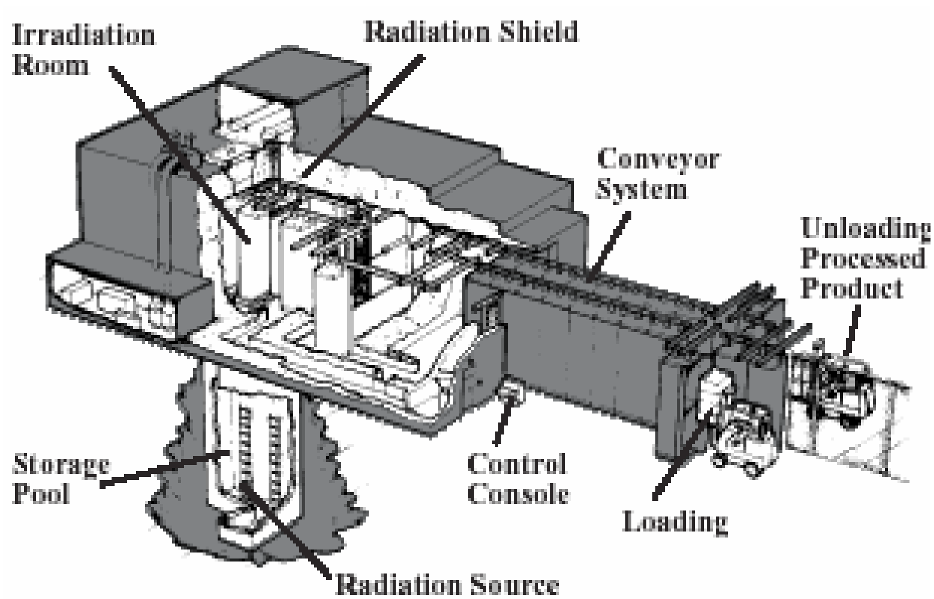
Because of its high activity and high energy emission, Cobalt 60 is the most common radiation source used for treating foods. Devices that employ Cobalt 60 typically seal the radioisotope in a stainless steel capsule, which is then incorporated into the final product. Legally, devices are supposed to be returned to the device manufacturer for disposal in an approved radioactive material disposal site, but for various reasons some are not recovered and recycled. Abandoned devices, of course, pose a potential risk of exposure or improper use. Globally, in 2002 large-scale facilities irradiated over 67 million metric tons (137 billion pounds) of food and operated in over 40 different countries. In the United States the market for Cobalt in food irradiation has grown in tandem with the greater use of this technology in the food processing industry as evidenced by expanding regulatory approval of food irradiation for different products. In 1992, the USDA approved the commercial irradiation of poultry, and in 1999, approved commercial irradiation of meat.[6]

In the area of food irradiation Cobalt 60 is less expensive than electron beams for annual volumes below 50 million pounds. For radiation source requirements above the equivalent of 1 million curies of Cobalt 60, electron beams are more economical. The amount of Cobalt 60 needed is directly related to the dose required and the amount of product that must be treated during a set amount of time. Given this fixed technological relationship, there are no production economics for the radiation source as the size of

[6] U.S. Nuclear Regulatory Commission, 2000, The Regulation And Use Of Radioisotopes In Today's World, NUREG/BR-0217 Rev. 1

the irradiator (hourly throughput) increases. Similarly, the power requirements for an electron accelerator are directly related to dose and hourly throughput. However, as the processing capacity of the accelerator rises, cost increases less than the power increases. Thus, machine irradiation exhibits more dramatic economies of size than Cobalt 60.[7] Figure 3 shows a typical arrangement of Cobalt 60 as used in an irradiation facility.

Figure 3 Typical Layout of A Commercial Food Irradiation Facility



As economies of scale are realized, wider consumer acceptance market may move away from Cobalt sources for radiation. This has been the case in the medical arena. As figure 2 shows, demand for Cobalt 60 for radiotherapy has become negligible compared to Cobalt used for food irradiation. The use of Cobalt 60 for delivering radiation to cancer patients in radiation oncology departments in the United States has fallen significantly in the face of competition from other radiation sources, primarily medical linear accelerators that provide an external beam of ionizing radiation for cancer therapy. Accelerators provide a tunable source of radiation that can reach much higher energies (e.g., 10-20 Mev) than Cobalt 60 that are able to treat a wider variety of tumors. Using accelerators also allows practitioners to avoid the problems of handling radioactive materials. A further advantage of using accelerators making Cobalt 60 less popular is the greater regulatory burden on possessing a Cobalt 60 unit as compared to operating an accelerator. For medical use, one needs an NRC (or Agreement State) license to possess and use Cobalt 60. While facilities are bound by state and local laws,

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[7] Rosanna Mentzer Morrison, 1989, An Economic Analysis of Electron Accelerators and Cobalt 60 for Irradiating Food, United States Department of Agriculture Economic Research Service, Technical Bulletin Number 1762

a U.S. Nuclear Regulatory Commission (NRC) license is not required operating an accelerator.

III. Data Collection for Cobalt 60

Compiling Material Flow Accounts for radionuclides in commercial sealed sources begins with gathering data from the institutions (i.e., federal and state agencies) that govern their manufacture and use. The NRC, the same agency charged with regulating nuclear power production, collects licensing data for commercial radioisotopes in the United States. In addition, information is provided by individual states that have reached an agreement with the NRC (The Agreement States) to develop an independent oversight system.

The current framework used by the NRC and the Agreement States for monitoring commercial sealed sources does not provide sufficient detail for constructing an MFA. As demonstrated in Figure 2 NRC licensing data documents maximum allowable amounts and do not provide information on the actual amounts possessed for a given licensee. Furthermore, each of the 32 Agreement States and the NRC itself maintain separate databases for monitoring transactions involving radioisotopes. As a result, there are now 33 databases, often with incompatible data structures, that currently track domestic movement.

At the international level, the International Atomic Energy Agency is charged with oversight of commercial radioisotopes. The IAEA estimates that millions of sources are currently in use worldwide in medical, research, and industrial applications, however, the IAEA is able to provide only rough estimates of the quantities involved in international trade or residing in individual countries. A 2003 study by Sandia National Laboratory[8] found that exporting countries typically do not notify receiving countries of incoming shipments of sources. The report also found that major importers such as the US do not require recipients to notify domestic agencies. The NRC assumes its oversight role only after manufacturers package the imported material as commercial sealed sources.

To obtain data directly from manufacturers questionnaires were developed for a voluntary reporting protocol for several target audiences (see Appendix A). A standard battery of questions was developed for collecting data to address the identified data gaps relying on information obtained directly from manufacturers as well as practitioners. The Center for Responsible Environmental Strategies developed a data collection protocol working with the Health Physics Society (HPS) nationally and in the state of Texas, as well as managers responsible for data collection within the Organization of Agreement States. The Nuclear Engineering Department at Texas A&M University provided guidance to help ensure the completeness of the pilot data template and the relevance of the battery of questions developed as part of the initial

[8] Cochran, John R. and Susan W. Longley, The Adequacy of Current Import and Export Controls on Sealed radioactive Sources, Sandia National Laboratory, 2003, SAND2003-3767.

data collection protocol. The objective of data obtained from the questionnaires and other sources was to populate a Material Flow Account, i.e., quantifying the flows represented by the arrows in Figure 1.

After establishing contacts with the major manufacturers of Cobalt 60 in North America, the questionnaire was distributed to MDS Nordion and Reviss Services that together control over 98% of the US market. Despite expectations of cooperation and data sharing from commercial source manufacturers, and contrary to experiences in the previous material flow assessment for Cesium-137, the project was unable to obtain data directly from manufacturers at this time. Manufacturers cited proprietary considerations as their main reservation in sharing data.

One possibility for the disparity in responses might be due to differences between the market for Cobalt 60 and Cs-137 in the US, namely, the fact that only two manufacturers dominate the market Cobalt 60 devices. A further possible reason for the difference in responses between this and the previous phase of the project might be due to new data requirements for manufacturers promulgated by the NRC as part of its recent National Tracking System (NTS) initiative.

In recognition of the inadequacy of the current framework, several government agencies have initiated programs for tracking sealed sources. In 2004, the NRC began working with the Organization of Agreement States and the Conference of Radiation Control Program Directors to develop a single national program for tracking commercial sources. The National Source Tracking (NST) initiative represents a new level of comprehensive data collection on the part of the NRC in response to security concerns that have been raised in light of the events of September 11. 2001.

The NST initiative by the NRC offers a substantial opportunity to obtain the data necessary for compiling a Material Flow Account for Cobalt 60. Conversely, the accounts offer significant benefits to the establishment of the NST system and will add to the utility of the data collected under the NST system by providing for external confirmation of the data collected under NST and coverage of sources currently missed under NST. For example, the NST will not collect data of radioactive source category 3 or above and would benefit from more comprehensive aggregated data.

As of July 2005 the NRC planned to collect the following data categories for commercial sources:

- Isotope
- Activity and Date
- Manufacturer
- Model Number
- Serial Number
- Date created
- Whether source is used in a device – voluntary

The EPA and CRES are currently engaged in requesting that the NRC collect additional data collection to augment the existing data collected under the NST. For example, collecting data on final disposal destination (e.g., return to manufacturers, Low Level Radioactive Waste (LLRW) facility) as well as data on the Industrial Function Category and the Commercial/Consumer Product Category codes from the US Department of Commerce to further characterize the sources during the use phase of the commercial life cycle. In Section IV of this report, some general estimates for Cobalt 60 use in the US economy will be offered. This section concludes with a brief discussion of the single largest holder of Cobalt 60 sources in the federal government, the US Department of Energy (USDOE).

- **Cobalt 60 sources in US Department of Energy facilities**

Table 1shows an inventory of Cobalt 60 sources in USDOE facilities. These facilities are responsible for 1844 Cobalt 60 sources with a total Cobalt 60 radioactivity level of 455,460 Curies. Based on information provided, USDOE sponsored sites using Cobalt 60 categorize sources as “known” and as “unknown”. For the 23 DOE sponsored sites listed, about 96% of the Cobalt 60 radioactivity is accounted for and only 4% is unknown. While only a negligible fraction of the radioactivity is unaccounted for, only 9 grams of Cobalt 60 (specific activity 1100 Curies per gram) are required to make a make a radiological explosive device.

Table 1. Inventory of Co 60 sources in DOE facilities 2003

Site	Number of Sources	Total Cobalt 60 level (Curies) *
Argonne East	2	0.01
Argonne West	13	3.24
Brookhaven	57	7340
Fernald	20	0.01
Fermi	49	0.007
Hanford	49	0.01
Idaho	13	0.01
Kansas City	3	15.8
Los Alamos	97	8020
Lawrence Berkeley	41	437
Lawrence Livermore	110	554
Mound	2	372
New Brunswick	2	1.7 E-07
Nevada	110	9350
Oak Ridge ETTP	7	456
Oak Ridge Nat’l Lab	326	5700
Oak Ridge Y-12	13	6.23
Pantex	22	29.8
Pacific Northwest	79	61,900
Rocky Flats	60	276

Sandia	470	199,500
Savannah River	298	161,500
West Valley	1	1.6 E-07
TOTAL	**1844**	**455,460**

*Activity as of 10/28/03
Source: Personal communication, S. Hamlin (USEPA), 2004

Various USDOE offices, including the Office of Environmental Management and the Office of Security, have developed a prototype tracking system for tracking sources within DOE facilities, 'The Radiation Source Registry and Tracking System.' Among the stated objectives of the DOE system is that it should "Support Disposition Strategies" and help "Communicate with Stakeholders."[9] Though the current system is restricted to its own facilities, the DOE is considering expansion of the system to cover all transactions involving commercial sealed sources nationally. Ultimately, the DOE plans to host the national database on transactions involving sealed sources that would provide information to other federal agencies including US Department of Justice, Department of Commerce, USEPA and the Federal Emergency Management Agency.

IV. An Upper Limit Estimate on Cobalt 60 Flows in The United States

Nearly all of the Cobalt 60 used commercially in the US is manufactured in reactors outside the United States. MDS NORDION International Inc. (previously known as the Radiochemical Company, Atomic Energy of Canada Limited), a Canadian crown corporation, supplies almost 90 percent of the world's supply of Cobalt 60. The second largest distributor, Reviss Services obtains its material from the Mayak reactor facility located in Russia. As mentioned in the previous section, these manufacturers were not willing to make their production data public.

As an estimated upper limit on the total amount entering the US economy annually we can use the fact that over 97% of the Authorized licenses for Cobalt 60 are for irradiators. Furthermore, based on an estimate from the US Department of Agriculture these sources are replaced on average once every 8 years or a 12.5% annual replacement rate.[10] The activity of an 8 year old source is about 35% of the original. For the purposes of this estimate we will assume that the remaining 3% of the market for Cobalt 60 uses this same 12.5% rate. **Using these data we estimate that an upper limit on the amount of Cobalt 60 entering the US economy is 2.8 X 10E7 Curies annually.**

[9] Presentation by G.D Roberson, DOE radioactive Sources Stewardship Activities, January 2004, Woodrow Wilson Center, Washington DC.
[10] Rosanna Mentzer Morrison, 1989, An Economic Analysis of Electron Accelerators and Cobalt 60 for Irradiating Food, United States Department of Agriculture Economic Research Service, Technical Bulletin Number 1762

Based on data received from Low Level Radioactive Waste (LLRW) facilities in Richland ,Washington and Barnwell, South Carolina, fewer than 10,000 curies annually. We thus further **conclude that the vast majority of the Cobalt 60 is most likely returned to the manufacturer for final disposal.**

V. Conclusions

Existing sources reveal data fragmentation with large gaps in the data necessary for conducting a material flow assessment for commercial radioactive sources.

Materials flows as well as voluntary manufacturer cooperation is dependent on the market structure for each individual isotope as evidenced by our differing experiences with Cesium 137 and Cobalt 60.

Cobalt 60 is mostly used in large applications – not really a source of concern due to highly centralized control.

Data cooperation from manufacturers was not forthcoming for Co60 as was the case for Cs137. Need to develop a confidentiality/proprietary agreement to protect the interests of the source manufacturers. Consideration should be given to creating a working group of source manufacturers to address their concerns about proprietary/confidentiality issues and articulate the parameters of a material flow account to see where they fit in.

New NRC initiative (NST) offers both an additional burden for manufacturers making them less likely to participate in a voluntary data reporting protocol as well as a new comprehensive data source for constructing material flow accounts.

What do we REALLY think?

APPENDIX A

Target Audiences/Sample Questions

Please provide all answers in curies

A. Source Manufacturers

1. Do you produce Cobalt 60?
   - 1a. If yes, how many curies do you produce annually?
   - 1b. If no, how many curies do you purchase annually? From who?
2. How many curies do you sell per year?
3. What is the physical form of your Cobalt 60 products? Sealed source? Wire? Plated?
4. Do you manufacture generally licensed sources? Specifically licensed sources?
5. Do you take back Cobalt 60? How much per year?
6. Do you recycle or reprocess Cobalt 60? How much per year?
7. Do you ship Cobalt 60 for reprocessing? How much per year?
8. Do you send Cobalt 60 out for disposal? How much per year?
9. Do you maintain a stock of Cobalt 60?
   - 9a. If yes, how much did your stock change last year?
10. Who are your primary customers? Device manufacturers, Industrial, Medical…
11. What is the breakdown of your sales domestic/international?
12. What are your projected sales this year? In 5yrs? In 10 yrs?
13. Would you participate in a voluntary reporting program?

B. Device manufacturers

1. How many curies of Cobalt 60 do you purchase annually?
   - 1a. From whom?
2. Do you take back Cobalt 60? How much per year?
3. Do you recycle or reprocess Cobalt 60? How much per year?
4. Do you maintain a stock of Cobalt 60?
   - 4a. If yes how much did your stock change last year?
5. Do you ship Cobalt 60 for reprocessing? How much per year?
6. Do you send Cobalt 60 out for disposal? How much per year?
7. What is the physical form of your Cobalt 60 products? Wire? Plated?
8. Do you manufacture generally licensed devices? Specifically licensed devices?
9. Who are your primary customers? Device manufacturers, Industrial, Medical…
10. What is the breakdown of your sales domestic/international?
11. What are your projected sales this year? In 5yrs? In 10 yrs?
12. Do you participate in the source and devices registry?
13. Would you participate in a voluntary reporting program?

C. Consumers

Generally licensed

1. How many curies of Cobalt 60 do you purchase per year?
2. How many curies of Cobalt 60 are in your possession?
3. For what application(s) do you use Cobalt 60 ?
4. Are all of your devices in use?
5. How many are in storage?
6. At the end of life, do you return devices to the manufacturer?
   - 6a. At the end of life, do you send to disposal?
   - 6b. At the end of life, do you store on site?
7. Do you use or ship sources overseas?
8. Do you participate in the source and devices registry?
9. Would you participate in a voluntary reporting program?

Specifically licensed

1. How many curies of Cobalt 60 do you purchase per year?
2. How many curies of Cobalt 60 are in your possession?
3. For what application(s) do you use Cobalt 60 ?
4. Are all of your devices in use?
5. How many are in storage?
6. At the end of life, do you return devices to the manufacturer?
   - 6a. At the end of life, do you send to disposal?
   - 6b. At the end of life, do you store on site?
7. Do you use or ship sources overseas?
8. Do you participate in the source and devices registry?
9. Would you participate in a voluntary reporting program?

D. Waste Processors

1. How many curies of Cobalt 60 do you receive in your facility per year?
2. From whom do you receive your shipments? Medical? Industrial? Academic? Government? Mining?
3. What are the physical forms in which you receive? Is it ever mixed with other isotopes?
4. How much Cobalt 60 do you ship for reprocessing per year?
5. How much Cobalt 60 do you send out for disposal per year?
6. Do you recycle or reprocess Cobalt 60 on site? How much per year?
   - 6a. If you recycle, how much do you ship to source manufacturer?
   - 6b. How much to the device manufacturer?
7. Do you receive any Cobalt 60 from outside the US?
8. Would you participate in a voluntary reporting program?

E. Disposal Facilities

1. How many curies of Cobalt 60 do you receive in your facility per year?
2. Do you receive the majority from waste processors?
3. Do you receive from Medical? Industrial? Academic? Government? Mining?
4. What are the physical forms in which you receive Cobalt 60 ? Is it ever mixed with other isotopes?
5. Do you ship Cobalt 60 for reprocessing? If yes, how many curies per year?
6. Would you participate in a voluntary reporting program?

APPENDIX B

Interview with Ms. Agnes Barlow, Office of Environmental Health and Safety, Yale University, New Haven, CT

We started with a brief introduction about Cobalt 60, explaining why there were hardly any sources at Yale University and Yale-New Haven Hospital. Mike Varella of Yale-New Haven Hospital has specifically told Ms. Barlow that none of their medical therapy units use Cobalt 60 any longer. Blood irradiators in most hospitals and research facilities are Cesium-137.

Disadvantages in the usage of Cobalt 60

In comparison to the 30 year half life of Cesium-137, Cobalt 60 has a shorter half life of 5.2 years. This makes Cobalt 60 less favorable to facilities. One has to replace a Cesium-137 source less often than a Cobalt one. The primary reasons being:

- The cost of the replacement sources
- The downtime to "change out" a source
- The dose to vendor personnel from the "change out" source
- Shipment of sources back and forth

Also, for medical use, one needs an NRC (or Agreement State) license to possess and use Cobalt 60. However, if one replaces a Cobalt 60 therapy unit with a small linear accelerator (X-ray unit), the NRC license is not required (NRC has jurisdiction over byproduct material, but not electronic sources of radiation). Therefore, another reason that makes Cobalt 60 less popular is

- Greater regulatory burden on possessing a Cobalt 60 unit in comparison to possessing a linear accelerator

Advantages in the usage of Cobalt 60

There are also advantages in using or continuing to use Cobalt 60.

- It is easy to manufacture (irradiate stable Cobalt with neutrons)
- One can get high specific activity sources and small sources or many different shapes

Questions

1. How many sources of Cobalt 60 are in your possession? Is it in use or in storage?

There is no active use of Cobalt 60.

1. There is one very old source from 1950 which is obviously very weak now after several half lives. It is used solely for teaching purposes.
2. They have a few micro curies that had been bought in the 1970s. It is used for calibration purposes.

2. Do you return it to the manufacturer or dispose it?
They would have preferred recycling if possible. However, disposal is expensive and the vendor doesn't want it back. Since the sources are very old, it is stored.

3. Have you ever lost a source?
No

4. What are your uses of Cobalt 60?

1. Teaching in the Biology Department
2. Instrument calibration

5. What are your projected uses – 5 years? 10 years?

They do not anticipate buying in the next 5 or 10 years.

6. Where did you receive it from? Domestic? Overseas?

The first source came from Brookhaven National Lab in 1950. The small quantities in the 1970s came from Isotope Products Labs in California.

7. Would you participate in a voluntary reporting program?

They would volunteer with NRC if needed. They will not consider such a program with the EPA since they do not have jurisdiction.