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Background Information on Sources of Low-Level Radionuclide Emissions to Air

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September 1983

Prepared for the U.S. Environmental Protection Agency under the U.S. Department of Energy's Related Services Contract DE-AC06-76RLO 1830

Pacific Northwest Laboratory
Operated for the U.S. Department of Energy
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ABSTRACT

The Office of Radiation Programs of the U.S. Environmental Protection Agency (EPA) has requested that the Pacific Northwest Laboratory (PNL)[a] provide background information on various source categories of radionuclide emissions to the atmosphere. This report provides a general description and reported emissions for eight low-level radioactive source categories, including facilities that are licensed by the Nuclear Regulatory Commission (NRC) and Agreement States, and non-Department of Energy (DOE) federal facilities.[b] The eight categories of low-level radioactive source facilities covered by this report are: research and test reactors, accelerators, the radiopharmaceutical industry, source manufacturers, medical facilities, laboratories, naval shipyards, and low-level commercial waste disposal sites. Under each category five elements are addressed: a general description, a facility and process description, the emission control systems, a site description, and the radionuclides released to air (from routine operations).

(a) Pacific Northwest Laboratory is operated for the U.S. Department of Energy by Battelle Memorial Institute.

(b) Accelerators are exempt from licensing, and are in some cases used to generate radionuclides for use by other source categories.

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1.0 INTRODUCTION

The Office of Radiation Programs of the U.S. Environmental Protection Agency (EPA) has sponsored a series of studies with the Pacific Northwest Laboratory (PNL)[a] to provide background information on various source categories of radionuclide emissions to the atmosphere. These studies are intended to support emission standards to be issued by EPA under the Clean Air Act.

This report provides a general description and reported emissions for eight low-level radioactive source categories (Sections 2.0 through 9.0), including facilities that are licensed by the Nuclear Regulatory Commission (NRC) and Agreement States, and non-Department of Energy (DOE) federal facilities[b]. The eight categories of low-level radioactive source facilities covered by this report are:

- Research and Test Reactors
- Accelerators
- Radiopharmaceutical Industry
- Source Manufacturers
- Medical Facilities
- Laboratories
- Naval Shipyards
- Low-Level Commercial Waste Disposal Sites.

Under each category five elements are addressed: 1) a general description, 2) a facility and process description, 3) emission control systems, 4) a typical site description, and 5) the radionuclides released to air (from routine operations).

(a) Pacific Northwest Laboratory is operated for the U.S. Department of Energy by Battelle Memorial Institute.
(b) Accelerators are exempt from licensing, and are in some cases used to generate radionuclides for use by other source categories.

The data base for this report was compiled primarily from license applications and periodic licensee reports of radionuclide emissions to the atmosphere. Lists of licensees were initially obtained from the NRC and 26 Agreement States, and then were assigned to a category.

Facilities that use only sealed radioactive sources are excluded from this report. Sources of naturally occurring radionuclides (e.g., uranium and coal mines, fossil-fuel power plants, the phosphate industry, power plants producing electricity, and Department of Energy (DOE) facilities) are not included in this report.

2.0 RESEARCH AND TEST REACTORS

2.1 GENERAL DESCRIPTION

This chapter addresses low-level radioactive airborne emissions from research and test reactors. For the purposes of this report, the term "research and test reactor" includes all those nuclear reactors that are operated by colleges and universities, private industry, the federal government, and research institutions for purposes other than electric power generation and sale. The DOE reactors and naval propulsion units are excluded.

There are 70 research and test reactors currently licensed to operate in the United States; 53 are operated by colleges or universities, 11 by private industry, and 6 by the federal government. The majority of these reactors are used primarily as educational or training tools. As such, these reactors provide facilities for reactor operator training, reactor laboratory classes, and graduate- and undergraduate-level research projects. The research applications include activation analysis, isotope production, neutron scattering analysis, neutron dosimetry, neutron spectroscopy, and neutron and gamma irradiations. Most of the privately operated research and test reactors are used in commercial applications such as isotope production, reactor fuels research, reactor instrument development, and other types of industrial research. The six government-operated reactors provide services such as activation analysis, neutron standards and dosimetry, and forensic analysis. Table 2.1 shows the number of reactors by state within the United States (U.S. DOE 1981). Within each state, the location of research and test reactors generally parallels that of major universities.

2.2 FACILITY AND PROCESS DESCRIPTION

Research and test reactors have been divided into seven categories based on reactor core configuration and/or the type of moderation employed. These categories, their corresponding power ranges, and the approximate number of reactors in each category are shown in Table 2.2.

TABLE 2.1. Number of Licensed Reactors Per State Within the United States

Number of Reactors						
1	2	3	4	5	6	10
Alabama	Georgia	Illinois	Maryland	Virginia	New York	California
Arizona	Kansas	Massachusetts				
Colorado	Missouri	Michigan				
District of Columbia	New Mexico	Oregon				
	Utah	Texas				
Florida	Washington					
Idaho						
Indiana						
Iowa						
Nebraska						
New Mexico						
North Carolina						
Ohio						
Oklahoma						
Pennsylvania						
Rhode Island						
Tennessee						
Utah						
Wisconsin						

TABLE 2.2. Categories of Research and Test Reactors

Category	Power, kW_t	Number
10-MW tank	10,000	1
Heavy water moderated	5,000-10,000	3
Pool	0-5,000	14
TRIGA[(a)] or modified TRIGA	10-1,500	26
Graphite/water	10-100	5
Homogeneous	1	13
"Unique"	0.0001-200	8
TOTAL		70

(a) Training, Research, Isotope, General Atomic.

Eight of the research and test reactors, because of their unique design or extensive modification, do not fit readily into one of the first six categories. However, these "unique" reactors release a small percentage (<0.1) of the total airborne emissions from all research and test reactors. Based on Table 2.2, university-owned and operated (TRIGA (Training, Research, Isotope, General Atomic) reactors are considered the most common type of research and test reactor.

Common to all TRIGA reactors is their use of a uranium-zirconium hydride fuel-moderator combination that provides the reactor with a prompt negative temperature coefficient of reactivity. The TRIGA reactors are thus inherently capable of safely undergoing large, sudden insertions of reactivity. The fuel in TRIGA reactors is typically clad in stainless steel and often arranged in a hexagonal configuration. Control rods contain borated graphite. The reactor core is typically centrally located in an aluminum-lined pool of water that is surrounded by a thick, concrete biological shield. The reactor assembly is usually located in a confinement facility that is equipped with appropriate ventilation and waste processing equipment.

2.3 EMISSION CONTROL SYSTEMS

Ten representative Final Safety Analysis Reports (FSARs) for research and test reactors were reviewed for systems used to control releases of radioactive materials to air. In general, the commonly employed control technologies may be summarized in three words: filtration, dilution, and dispersion.

Four out of the ten FSARs reviewed stated that the ventilation system effluent was filtered before release to the atmosphere. Filter systems typically consist of approximately 5 μm "roughing" filters in series with 0.3 μm "absolute" filters.[a] At one facility, a charcoal filter is also provided.

All of the sites reviewed utilize some form of dilution and dispersion to minimize the concentration of airborne radionuclides in their ventilation system effluents in the environs. Typically, reactor building exhaust is mixed with

(a) Not clearly identified, but should be HEPA filters in accordance with nuclear industry standards.

"clean" location exhaust in a ratio varying from 1:4 to 1:10 before the mixed effluent is released to the atmosphere. Release elevations are also variable, ranging from building roof height to approximately 60 m, depending on the facility design. The typical stack height (for those reactors with stacks) is approximately 25 m. Stack flow rates range from 2,000 to 40,000 cfm.

It is widely recognized in the research and test reactor community that most of the argon-41 released to the atmosphere is the consequence of a small inleakage of air into areas with high neutron flux. The natural argon-40 in the ambient air is activated to argon-41 by the addition of a neutron. Although very little information has been published on methods to reduce argon-41 releases, a review of the annual reports from the licensees to the NRC indicates that the only control technology being practiced is to reduce air inleakage. This can be done by sealing leaks or by blanketing with inert gases those locations with large volumes of ambient air subject to high neutron flux.

2.4 SITE DESCRIPTION

Demographic data was taken from five of the research and test reactor FSARs and is summarized in Table 2.3. Approximately 75% of all research and test reactors are located within 80 km of major population centers. The majority of university-owned research and test reactors are located on the main campus of the individual unversity or college. As a result, the distance to the closest residence is typically 400 to 800 m. The same generalization is also true of the majority of private-and government-operated reactors.

TABLE 2.3. Population in the Vicinity of Research and Test Reactors, Specific Examples

Power, kW_t	Population Within 1.6-km Radius	Date
10,000	~6,800	1980
10,000	5,700	1972
5,000	30,000	1967
5,000	~560	1980
1,500	46,000	1967

2.5 RADIONUCLIDE RELEASES TO AIR

Table 2.4 summarizes the data available from the licensees' annual reports to the NRC on releases of radionuclides by reactor power level. The data are not necessarily all from the same year but are average values. These data show that more than 99% of the radioactive materials released to the air, from research and test reactors, is argon-41 which has a half-life of 1.8 hr.

Table 2.5 shows the relative argon-41 contributions to air from the seven defined categories of research and test reactors. The "Lowest, Average and Maximum Curies Per Year," and "Percent of Total Releases," refer only to those reactors for which data was available. Averages were calculated by summing the release data available for each category and dividing by the number of reactors in that category. Again, the most common class of reactors is the TRIGAs; however, the 26 TRIGAs account for less than one percent of the argon-41 released from the 70 reactors. Three heavy-water reactors and one 10-MW tank reactor contribute about 94% of the total annual argon-41 releases. The total airborne release of argon-41 (1.8 hr half-life) from all 70 research reactors included in this review is approximately 15,000 Ci/yr at the points of release.

TABLE 2.4 Research and Test Reactor Radionuclide Releases to Air

Type	Power (kW_t)	Nuclide	Average Concentration (μCi/mL)	Ci/yr
1. Heavy water	10,000	^{41}A ^{3}H		465 155
2. 10-MW tank	10,000	^{41}Ar ^{3}H	3×10^{-6}	2504 16
3. Heavy water	5,000		5×10^{-6}	NDA[a]
4. Heavy water	5,000	^{41}Ar ^{3}H	4×10^{-8} 2×10^{-7}	8,560 22
5. Pool	5,000	^{41}Ar		350
6. Pool	2,000	^{41}Ar		247
7. Pool	2,000	Noble gases Radio iodines Gross Particulates	8.9×10^{-8} 3.4×10^{-11} 6.6×10^{-13}	47 0.021 0.01
8. Pool	2,000			NDA
9. Pool	2,000	^{41}Ar		6
10. TRIGA[b]	1,500	^{41}Ar		0.09
11. TRIGA	1,500	^{41}Ar ^{3}H	6.6×10^{-8}	2.1 0
12. Pool	1,000			NDA
13. TRIGA	1,000	^{41}Ar		9.2
14. TRIGA	1,000	^{41}Ar		7
15. TRIGA	1,000	^{41}Ar	3.3×10^{-9}	2.9
16. Pool	1,000	^{41}Ar	6.3×10^{-8}	14
17. Pool	1,000	^{41}Ar	6.7×10^{-8}	10
18. TRIGA	1,000	^{41}Ar	2.8×10^{-7}	41
19. TRIGA	1,000	^{41}Ar Particulate	2.23×10^{-8} 1.39×10^{-4}	2 0.001
20. TRIGA	1,000	^{41}Ar	6.1×10^{-8}	2.6
21. TRIGA	1,000	^{41}Ar	2.5×10^{-6}	1.8
22. TRIGA	1,000	^{41}Ar		1.2
23. TRIGA	1,000	^{41}Ar		1.0
24. TRIGA	250	^{41}Ar		0.003

a) No data available.
b) Training, Research, Isotope, General Atomic (reactors).

TABLE 2.4. (continued)

	Type	Power (kW_t)	Nuclide	Average Concentration (μCi/mL)	Ci/yr
25.	TRIGA[b]	250	^{41}Ar		0.016
26.	TRIGA	250	No releases	0	0
27.	TRIGA	250	^{41}Ar	$<1 \times 10^{-9}$	0.06
28.	TRIGA	250			NDA[a]
29.	TRIGA	250			NDA
30.	TRIGA	250	No releases	0	0
31.	TRIGA	250	^{41}Ar	1.9×10^{-10}	0.002
32.	TRIGA	250			NDA
33.	TRIGA	250	^{3}H ^{41}Ar	4×10^{-8}	0.002
34.	TRIGA	250		<MDL[c]	<MDL
35.	Pool	200	^{41}Ar		3.1
36.	Graphite/water	100	^{41}Ar	1.65×10^{-5}	33.0
37.	Light water	100	Gross beta	1.4×10^{-13}	NDA
38.	TRIGA	100	^{41}Ar		0.001
39.	TRIGA	100			NDA
40.	Graphite/water	100	^{41}Ar	1.21×10^{-9}	68
41.	Graphite/water	100	^{41}Ar		113
42.	Graphite/water	100	^{41}Ar	10^{-8}	17
43.	TRIGA	18	^{41}Ar		0.3
44.	SRTR[d]	10	No releases	0	0
45.	TRIGA	10	No releases	0	0
46.	Graphite/water	10			NDA
47.	Pool	10	Beta Gamma	1×10^{-12} 1×10^{-11}	NDA NDA
48.	Pool	10			NDA
49.	Pool	10			NDA
50.	Homogeneous	3	No releases	0	0

a) No data available.
b) Training, Research, Isotope, General Atomic (reactors).
c) Minimum detection level.
d) Special research and test reactor.

TABLE 2.4. (continued)

	Type	Power (kW_t)	Nuclide	Average Concentration (uCi/mL)	Ci/yr
51.	Pool	1.0			NDA[a]
52.	SRTR[b]	1.0			NDA
53.	SRTR	0.1	No releases	0	0
54.	Tank	0.1			NDA
55.	Homogeneous	0.015	No releases	0	0
56.	Homogeneous	0.01	No releases	0	0
57.	Homogeneous	0.01	^{85}Kr		3×10^{-8}
58.	Homogeneous	0.006			NDA
59.	Homogeneous	0.005	No releases	0	0
60.	Homogeneous	0.005	No releases	0	0
61.	Homogeneous	0.0001	No releases	0	0
62.	Homogeneous	0.0001			NDA
63.	Homogeneous	0.0001	No releases	0	0
64.	Tank	0.0001			NDA
65.	Homogeneous	0.0001	No releases	0	0
66.	Homogeneous	0.0001			NDA
67.	Homogeneous	0.0001			NDA
68.	Pool	0.0001			NDA
69.	Pulse	-	No releases	0	0
70.	Pulse	-	^{41}Ar		13

a) No data available.
b) Special research and test reactor.

TABLE 2.5 Research and Test Reactor Annual ^{41}Ar Releases to Air by Type

Reactor Type	Number Units Reporting	^{41}Ar Releases to Air			
		Lowest Ci/yr	Average Ci/yr	Maximum Ci/yr	Percent of Total Releases Per Type
Heavy water	2	465	4,500	8,560	77
10-MW tank	1	2,500	2,500	2,500	17
Pool	7	3.1	97	350	5
Graphite/water	4	17	58	113	2
TRIGA[a)]	22	0	4	42	0.4
Unique	4	0	3	13	<0.1
Homogenous	9	0	0	0	0.1

a) Training, Isotope, General Atomic (reactors).

3.0 ACCELERATORS

3.1 GENERAL DESCRIPTION

The number of accelerators in the United States in 1980 was 1,289 as reported by the U.S. Bureau of Radiological Health (1980). The number of accelerators are listed by state in Table 3.1. This list does not include federal government-owned machines.

TABLE 3.1 Estimates of Particle Accelerators by State

State	Number of Accelerators	State	Number of Accelerators
Alabama	16	Montana	5
Alaska	0	Nebraska	11
Arizona	48	Nevada	1
Arkansas	9	New Hampshire	4
California	215	New Jersey	39
Colorado	10	New Mexico	4
Connecticut	12	New York	52
Delaware	10	North Carolina	7
District of Columbia	8	North Dakota	4
Florida	62	Ohio	33
Georgia	21	Oklahoma	13
Hawaii	2	Oregon	27
Idaho	5	Pennsylvania	94
Illinois	63	Rhode Island	6
Indiana	36	South Carolina	36
Iowa	7	South Dakota	2
Kansas	16	Tennessee	31
Kentucky	10	Texas	80
Louisiana	20	Utah	14
Maine	1	Vermont	0
Maryland	24	Virginia	18
Massachusetts	53	Washington	20
Michigan	57	West Virginia	7
Minnesota	26	Wisconsin	21
Mississippi	11	Wyoming	1
Missouri	13	Puerto Rico	4
		TOTAL	1,289

Accelerators use electric fields to impart high kinetic energies to either positively or negatively charged particles. The accelerated particles travel in an evacuated tube or enclosure until they impinge on gaseous or metallic targets. The interactions of the particles with the target produce secondary radiations which may include photons, neutrons, and many other particles. The secondary radiations, with their high associated energies, have useful practical applications such as industrial radiography, x-ray therapy, and radionuclide production.

In some accelerator designs, the target is enclosed within the evacuated acceleration tube. When the target is not enclosed, the particle beam leaves the tube via a foil window and travels through the air for an appreciable distance before reaching the target. As a result, air activation products such as carbon-11, oxygen-15, nitrogen-13, tritium, and argon-41 are produced. If released to air, these activation products become a routine airborne source term.

The two most important mechanisms by which radioactivation of air atoms may occur as a consequence of accelerator operation are: 1) exposure of air to secondary radiation from the target, and 2) direct exposure of air to the primary beam, if the beam passes from the accelerator tube vacuum into the atmosphere. In addition, radioactive gases may be produced within the target and subsequently escape to the local environment (if the target is external to the vacuum). In some instances, the target may contain inherently radioactive material (e.g., tritium). In general, the identities of the radionuclides generated by air activation and their rates of generation depend on several factors, including the type, energy, and intensity of the primary beam and the nature of the target.

3.2 FACILITY AND PROCESS DESCRIPTION

Accelerators are usually categorized according to the means used to achieve the desired particle velocity or kinetic energy. The majority of accelerators fall into the three main classes: constant field machines, incremental acceleration machines, and magnetic field accelerators. They are described in 3.2.1 through 3.2.3.

3.2.1 Constant Field Machines

This design class includes the Cockcroft-Walton and the Van de Graaff machines. Accelerators in this class share the feature of a constant DC electric field through which the charged particles are accelerated. The Dynamitron and the insulated cone transformer (ICT) accelerators are also in this class, since design is based on the Cockcroft-Walton machine.

Van de Graaff accelerators constitute 18% of all accelerators, and are the most common machine type in this design class. Together the Cockcroft-Walton and ICT accelerators make up 15% of all U.S. accelerators.

3.2.2 Incremental Acceleration Machines

In machines of this design class, the particles are accelerated by time-varying electric fields. This causes the particle velocity to increase in a stepwise rather than a continuous manner. The majority of accelerators in this class are linear accelerators (linacs) or cyclotrons.

The electron linac, the most common type of accelerator in the United States, constitutes 54% of all accelerators. These machines also show the highest growth rate, since they are used to replace older medical therapy devices. Cyclotrons constitute only 5% of all accelerators used in the United States. However, they have the potential to produce a larger percentage of the total airborne radioactivity due to their typically higher energy and power characteristics.

3.2.3 Magnetic Field Accelerators

Machines in this class employ a time-varying electric field to continuously accelerate the particles. The betatron is the only type of accelerator in this class which accelerates electrons, and represents 8% of all accelerators in the U.S. The betatron is similar to the linac in terms of radiation characteristics and applications.

3.3 EMISSION CONTROL SYSTEMS

The primary means of controlling radioactive air emissions from accelerators is containment, with or without additional treatment. Containment

removes radionuclides from the exhaust stream prior to atmospheric release either permanently (i.e., particulates) or temporarily to permit decay to releasable levels.

Ventilation practices vary widely according to the mode of operation of the accelerator and the physical layout of the facility. However, all ventilation practices direct the effluent into an exhaust system and thence to a controlled release point. Hoods, wall fans, and vent stacks are used as air collecting and directive devices. The airflow through the hoods and wall fans also permit dilution of radioactive effluents within the facility boundaries. The vent stack provides rapid dispersion of most of the effluents due to the elevated release point and high effluent velocity.

The treatment of exhaust streams prior to release is usually accomplished by high-efficiency particulate air (HEPA) filters, preceded by prefilters. In some cases, adsorptive filters are necessary for the removal of specific types of gases. Examples include activated charcoal and molecular sieves, which are usually preceded (in line) by a particulate filter.

In the case of tritium, a more elaborate system of air cleaning is necessary. Tritium exhaust treatment systems generally consist of a preheater, a catalytic recombiner, and a regenerable molecular sieve bed. Such systems, however, are not normally used in accelerator facilities (Dames and Moore 1979).

3.4 SITE DESCRIPTION

The majority of accelerator facilities (about 80%) are located in urban areas. Three of these facilities were used to develop the population distribution common to most accelerator facilities (Teknekron 1979). This population distribution is shown in Figure 3.1. Use of urban area population statistics for all accelerators will tend to maximize estimates of population dose.

3.5 RADIONUCLIDE RELEASES TO AIR

Emissions have been estimated for three common accelerators, the 6 MeV Van de Graaff, the 18 MeV electron linac, and the 100 MeV cyclotron.

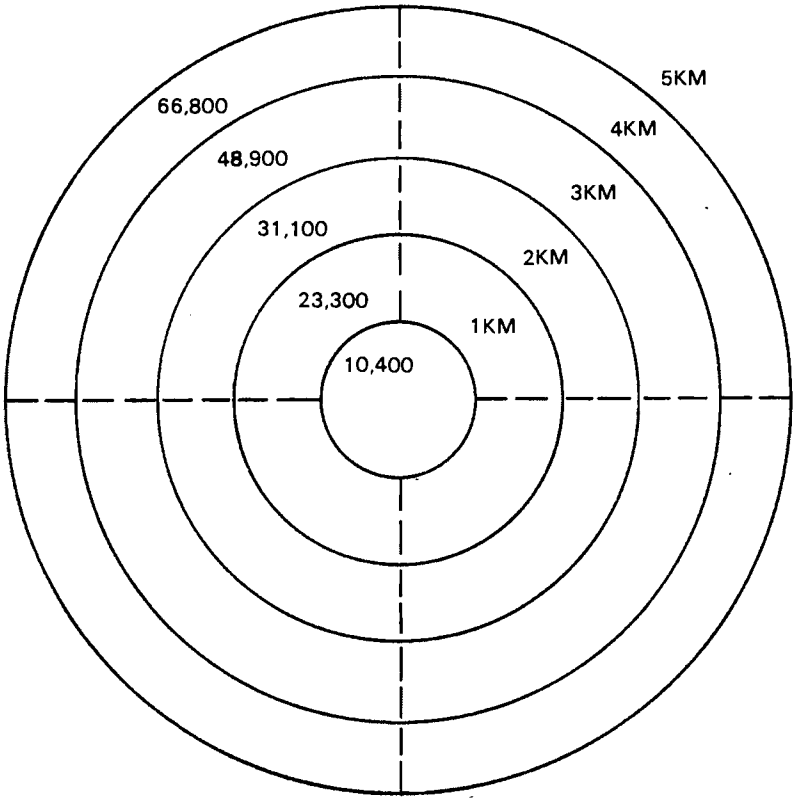

FIGURE 3.1. Population Distribution Around a Generic Accelerator Facility

Table 3.2 lists the estimates of the annual releases of radionuclides from these machines. The nuclides are all in a gaseous form. The chemical forms are largely unknown; however, carbon-11 is most likely released as carbon dioxide and tritium is most likely released as tritiated water vapor. All of the nuclides are released with the building ventilation system's exhaust air, except for tritium which may be released via the fume hood exhaust. For purposes of population exposure analysis, the release height of these radionuclides can be assumed to be at ground level.

TABLE 3.2. Estimated Annual Emissions from Three Typical Accelerator Facilities[a]

Radionuclide	Half-Life	100 MeV Cyclotron (Ci/yr)	18 MeV Electron Linac (Ci/yr)	6 MeV Van de Graaff (Ci/yr)
^{3}H	12 yr			1.0
^{11}C	20 min	2.0×10^{-3}		
^{13}N	10 min	4.0×10^{-2}		
^{14}C	5,600 yr		1.0×10^{-9}	
^{15}O	2 min	1.0		
^{41}Ar	1.8 hr		1.0×10^{-4}	

a) Source: Teknekron (1979).

4.0 RADIOPHARMACEUTICAL INDUSTRY

4.1 GENERAL DESCRIPTION

The radiopharmaceutical industry converts radioactive chemicals into forms that are suitable for use in medicine and research, and repackages them for distributors. The industry is composed of manufacturers and radiopharmacies. The geographical distribution by state is indicated in Table 4.1.

The manufacturing segment of the radiopharmaceutical industry obtains radionuclides that are produced in reactors or accelerators. Reactor and accelerator releases were covered in Sections 2.0 and 3.0 respectively. These radionuclides are processed by chemical and physical means, and the products are radiopharmaceuticals or radioimmunoassay kits. The radiopharmacy portion of the industry obtains bulk amounts of the radiopharmaceuticals and repackages them for distribution.

Data from the Agreement States indicates that the numbers of manufacturers and pharmaceutical facilities within the radiopharmaceutical industry are approximately equal. However, the major sources of releases of radionuclides to air are the manufacturers, since they handle quantities of radionuclides up to a thousand times larger in their production processes than do radiopharmacies.

4.2 FACILITY AND PROCESS DESCRIPTION

The radioactive material flow charts are similar for all the radiopharmaceutical manufacturers; however, process capacities vary a great deal. The manufacturing and radiopharmacy processes are different and are covered below in separate subsections.

4.2.1 Radiopharmaceutical Manufacturers

Several types of radiopharmaceuticals are produced in the manufacturers' facilities. These include radioisotope generators (mainly molybdenum-99/technetium-99m), reagent and radioimmunoassay kits, and therapeutic or in-vivo radiopharmaceuticals.

TABLE 4.1. Radiopharmaceutical Facilities by State[a]

State	Number of Facilities	State	Number of Facilities
Alabama	2	Missouri	3
California	27	Nebraska	1
Colorado	2	New Jersey	6
Florida	14	New Mexico	2
Georgia	3	New York	3
Illinois	4	North Carolina	1
Indiana	3	Ohio	1
Kentucky	2	Oregon	2
Louisiana	2	Texas	10
Massachusetts	6	Utah	1
Michigan	1	Virginia	1
Minnesota	1	Washington	1
Mississippi	1		
TOTAL			100

(a) This listing is representative, not comprehensive.

Unsealed radiochemicals are handled at each stage of the manufacturing process. Within the facility are specific areas for the following activities: storage of radioactive raw materials, dilution and filling of product vials, packaging of final products, processing of raw materials into radioactive bulk intermediates, storage of bulk radiopharmaceuticals, storage of radiopharmaceuticals during product testing and sales life, final packaging for distribution of radiopharmaceuticals and nonradioactive accessory products, and waste handling and storage. These activities may be carried out in separate buildings at large manufacturing sites. Often in the radiopharmaceutical industry, the manufacturing facility is part of a larger complex, which may produce other radiochemicals or contain other related facilities.

In a typical facility, radiochemicals are mixed with other materials within a hot cell or glove box designated for the procedure being performed and diluted to the desired radioactive concentration. This diluted bulk is

drawn by vacuum through a filter into another glove box where it is apportioned into prelabeled vials. The filled and capped vials are removed from the glove box in the appropriate shielded containers and packaged into Department of Transportation (DOT) cartons to meet the required specifications. These are monitored for external radiation prior to the required shipment.

Manufacturing facilities typically will process thousands of curies of radionuclides annually. The nuclides processed in the greatest quantities are molybdenum-99/technetium-99m, xenon-133, iodine-131, and iodine-125. Low levels of these nuclides are released to the atmosphere from stacks and vents at roof height.

4.2.2 Radiopharmacies

The radiopharmacies operate on a much smaller scale than the radiopharmaceutical manufacturers. They are generally small facilities employing 5-20 persons as compared to perhaps 300 employees at a large manufacturing facility. A few radiopharmacies are located within hospitals as part of the nuclear medicine departments.

Typical production activities include processing, mixing or compounding, and distributing prepared radiopharmaceuticals. Actual production of pharmaceuticals is fairly limited, but does frequently include the production of technetium pertechnate from molybdenum-99/technetium-99m generators.

Annual quantities of radionuclides handled are typically in the microcurie to millicurie range, and the largest licensed quantity is usually 50 Ci of molybdenum-99/technetium-99m. Again, the radionuclides of concern are molybdenum-99/technetium-99m, xenon-133, iodine-131, and iodine-125.

4.3 EMISSION CONTROL SYSTEMS

The radiopharmaceutical industry employs control techniques to ensure that emissions are maintained below the NRC's concentration guides. Control of emissions within the facilities is provided by glove boxes and fume hoods and frequently through the use of hot cells in the larger manufacturing facilities.

Control of atmospheric releases is provided by charcoal and HEPA filters in varying numbers and sizes depending upon the specific need. Stack heights

vary from 1 to 20 m above roof height, but are typically in the 1- to 5-m range. For purposes of population exposure analysis, the releases can be assumed to be at ground level.

Supplemental systems to those already in use include several kinds of adsorption beds such as charcoal filters, molecular sieves, alumina traps, and resin beds (Dames & Moore 1979). They are primarily used to remove organic and inorganic radioiodines and other halogens, but they also exhibit some small adsorption capability for noble gases.

4.4 SITE DESCRIPTION

Typical facilities and site features are different for the radiopharmaceutical manufacturers and radiopharmacies; the manufacturers occupy larger facilities and process a greater amount of radiochemicals than the pharmacies. The following site description is a composite of two of the larger radiopharmaceutical manufacturers derived from information contained in the licensees' Radiological Contingency Plan. This radiopharmaceutical manufacturing facility is located in a suburban area close to a large metropolitan center. The facility is situated on approximately 20 ha and consists of several major structures for manufacturing radiopharmaceuticals. Other buildings on the site are devoted to support activities or related manufacturing. The manufacturing facilities are surrounded by a security fence, and site access is restricted.

The composite site is adjacent to light industrial and commercial firms on two sides of the site. The other site boundaries are adjacent to open land, which separates the site from residential areas. No residence is immediately adjacent to the facility fenceline. The population, within a radius of 1.6 km of the facility, is 4,000. The closest residence to the manufacturing plant is 200 m from the facility fenceline.

The much smaller radiopharmacy facilities also tend to be located in light industrial or commercial areas. Those facilities associated with hospitals or universities generally have a somewhat higher surrounding population than the composite manufacturing site described above.

4.5 RADIONUCLIDE RELEASES TO AIR

A summary of airborne emissions from radiopharmaceutical manufacturers and radiopharmacies is presented in Table 4.2. The data includes information contained in two surveys of by-product users (Cook 1981; SAI 1983) and in several reports of specific facilities (Rocco 1982a, b; Frame 1982; Cole 1982). Because of large releases from a single manufacturing facility, the average release shown in Table 4.2 should not be considered typical.

TABLE 4.2. Summary of Annual Airborne Releases from Radiopharmaceutical Facilities

Number of Facilities Reporting	Radionuclide	Half-Life	Lowest Ci/yr	Average Ci/yr	Maximum Ci/yr	Total Ci/yr	Percent of Total
4	^{3}H	12 yr	3×10^{-3}	4×10^{-1}	1.0	1.1	0
1	^{83m}Kr	1.9 hr	6.1×10^{2}	6.1×10^{2}	6.1×10^{2}	6.1×10^{2}	1.8
4	^{85}Kr	11 yr	0	2.6	8.2	10.5	0
1	^{85m}Kr	4.5 hr	1.7×10^{3}	1.7×10^{3}	1.7×10^{3}	1.7×10^{3}	4.9
1	^{87}Kr	1.3 hr	1.6×10^{2}	1.6×10^{2}	1.6×10^{2}	1.6×10^{2}	0.5
5	^{99}Mo	66 hr	2×10^{-4}	3×10^{-2}	9×10^{-2}	9×10^{-2}	0
3	^{99m}Tc	6 hr	3×10^{-1}	3×10^{-1}	3×10^{-1}	6×10^{-1}	0
3	^{123}I	13 hr	7×10^{-5}	5×10^{-2}	1×10^{-1}	1×10^{-1}	0
8	^{125}I	60 d	7×10^{-6}	3×10^{-1}	2.3	2.3	0
13	^{131}I	8 d	0	5×10^{-1}	3.4	3.4	0
6	^{133}Xe	5 d	4.8	6×10^{-3}	1.9×10^{4}	1.9×10^{4}	54.8
1	^{133m}Xe	2.2 d	2.2×10^{3}	2.2×10^{3}	2.2×10^{3}	2.2×10^{3}	6.3
1	^{135}Xe	9 hr	1.1×10^{4}	1.1×10^{4}	1.1×10^{4}	1.1×10^{4}	31.7

5.0 SOURCE MANUFACTURERS

5.1 GENERAL DESCRIPTION

Seventy-nine manufacturers of radiation sources other than radiopharmaceuticals and naturally occurring radionuclides in the United States have been identified to date. The term "radiation source" includes any quantity of radioactive material enclosed in a sealed container or other nondispersible matrix. Source manufacturers produce such products as sealed neutron and gamma-ray sources, smoke detector ionization chambers, heat sources, and self-luminous devices. Table 5.1 provides a list of the number of radiation source manufacturers by state.

TABLE 5.1. Sealed Radiation Source Manufacturers by State[(a)]

State	Number of Radiation Source Manufacturers	State	Number of Radiation Source Manufacturers
Arkansas	1	Nebraska	1
California	14	New Jersey	1
Colorado	3	New Mexico	1
Connecticut	2	New York	5
Florida	2	North Carolina	1
Illinois	2	Ohio	3
Kansas	2	Oklahoma	1
Kentucky	1	Pennsylvania	3
Louisiana	2	South Carolina	1
Maryland	1	Tennessee	1
Massachusetts	2	Texas	7
Michigan	3	Virginia	1
Minnesota	2	Washington	3
Missouri	1	State not identified	12
TOTAL			79

(a) Listing is representative, not comprehensive.

5.2 FACILITY AND PROCESS DESCRIPTION

Radiation source manufacturing facilities may be licensed to possess radioactive materials in quantities ranging from ten to several thousand curies. Inventories of some radionuclides (notably tritium) are occasionally permitted to be as high as 100,000 Ci. The inventories of licensed facilities may include transuranic elements.

In general, source manufacturers process bulk quantities of radioactive materials that are received from radionuclide production facilities such as accelerators or reactors. Shipments are transferred to hot-cell or glove-box facilities where they are unpacked and distributed to other process areas. These areas may include storage, isotope dispensing, source manufacturing, chemical separation, plating, and welding operations. Individual laboratories may be equipped with a variety of specialized equipment for handling radioactive materials, such as filtered fume hoods, glove boxes, and remote manipulators.

5.3 EMISSION CONTROL SYSTEMS

Radiation source manufacturers utilize a broad range of radionuclides in their operations. Many of these radionuclides have chemical or physical properties that require more than simple filtration to control their release. In general, emission-control systems utilize standard techniques to minimize radionuclide releases to air: HEPA filters, dilution with clean air, and dispersion from elevated stacks. Many systems are also designed to control the release of specific radionuclides. Facilities with large inventories of tritium, for example, are typically equipped with desiccant columns to remove tritiated water from their effluent streams. Some facilities use charcoal or triethylenediamine-impregnated charcoal filters to control radioiodine releases. Other facilities use cold traps to delay noble-gas releases until they have decayed (Dames & Moore 1979).

5.4 SITE DESCRIPTION

The site description given below is a composite of three licensee site descriptions. Data for two sites were obtained from the licensees' Environmental Reports and data for the third site were collected from the licensee's Radiological Contingency Plan.

Manufacturing sites tend to be located in light commercial or industrial areas near large cities. While the population distribution adjacent to a site may be higher than that of a rural setting, it is somewhat lower than the population density of the urban area. Typically, there are approximately 2,000 residents within a 1.6-km radius of source manufacturing facilities. The nearest residents to a typical facility exhaust stack tend to be about 400-m away. Stacks tend to be located on or very near the building being exhausted. Typically, the stacks are 10- to 20-m high.

5.5 RADIONUCLIDE RELEASES TO AIR

A summary of airborne emissions from source manufacturer facilities is presented in Table 5.2 in terms of release range (lowest, average, maximum). The emission data was primarily obtained from two by-product user surveys (Cook 1981; SAI 1983). The two radionuclides, tritium and krypton-85, account for over 99% of all airborne releases from source manufacturers.

TABLE 5.2. Summary of Annual Airborne Releases From Source Manufacturer Facilities(a)

Number of Facilities Reporting	Radionuclide	Lowest Ci/yr	Average Ci/yr	Maximum Ci/yr	Total Ci/yr	Percent of Total
20	^{3}H	0	122	984	2,445	50.6
17	^{85}Kr	0	140	1,890	2,382	49.3
7	Other	0	0.7	4.3	4.6	0.1

(a) Listing is representative not comprehensive.

6.0 MEDICAL FACILITIES

6.1 GENERAL DESCRIPTION

The number of medical institutions in the United States licensed to use radioactive by-product materials exceeds 12,000, including both NRC and Agreement State licensees (U.S. EPA 1980). Data indicates that approximately 3,500 Agreement State licensees handle radioisotopes in an unsealed form within medical facilities. It is assumed that an equal number of NRC licensees handle unsealed radioisotopes resulting in a total number of 7,000 medical institutions that are possible sources of low-level radioactive airborne emissions. In addition to these various hospitals, clinics, and medical laboratories, municipal waste treatment facilities could release minute quantities of radionuclides during treatment of liquid wastes received from medical facilities.

6.2 FACILITY AND PROCESS DESCRIPTION

Medical facilities use radiopharmaceuticals for diagnostic, therapeutic, and research purposes. Diagnostic nuclear medicine can be further broken down into three major categories of usage:

- measurement for the radionuclide uptake of individual organs (thyroid uptake, cardiac circulation times, kidney functions)
- determination of the distribution of a radionuclide within an organ (lung scan, thyroid scan, detection of tumors)
- measurement of the components in biological samples (protein-binding sites and hormones in blood and urine).

For the first two uses, the radionuclides are given to the patient either orally or by injection. The third use is generally performed on samples within a laboratory.

Therapeutic uses of radiopharmaceuticals are principally for the treatment of diseases such as hyperthyroidism, cardiac dysfunction, leukemia, and selected carcinomas. These procedures use radionuclides internally, by injection or ingestion, or as implants and on the surface of the body, and in

devices external to the body. Radionuclides are also used in research studies to obtain and to develop diagnostic and therapeutic techniques for clinical use.

The amount of radionuclides used in diagnostic applications ranges from 10 μCi to 10 mCi and for therapeutic applications ranges from approximately 5 to 150 mCi per application. Table 6.1 lists the average quantities of radionuclides used for medical applications of various radionuclides. The radionuclides of interest for this study are those which could be vented to the atmosphere, including xenon-133, iodine-131, and iodine-125.

Radionuclides used in medical facilities are released into the sewer from the excreta of the treated patients, from diagnostic tests performed in laboratories, and from research laboratories. Municipal waste water treatment facilities have some small potential for airborne emissions of radionuclides. A study (Teknekron 1981) determined that treatment of approximately 20% of municipal waste waters includes sludge incineration.

6.3 EMISSION CONTROL SYSTEMS

A broad range of emission control systems can be found in medical facilities. Smaller facilities, with infrequent radiopharmaceutical administrations, generally use no controls other than retention of xenon for decay. Larger medical facilities may use activated charcoal traps for xenon and iodine retention from the effluent air, and fume hoods for preparation of dosages. Laboratories may employ HEPA-filtered fume hoods, glove boxes, and hot cells. Waste treatment facilities have no controls specifically designed for radionuclides, but generally have a cyclone separator and wet scrubber.

An advanced radioiodine control system entails use of a chamber that fits inside a typical fume hood. The chamber has portholes for easy access and provides containment and air-cleaning capabilities during dose preparation or experimental work. The exhaust air passes through a HEPA filter and an activated charcoal filter prior to exiting with the fume hood exhaust. This method has had initial collection efficiencies of 90-100% (Dames & Moore 1979).

TABLE 6.1. Average Quantities of Radionuclides Used Per Medical Application

Radionuclide	Medical Application	Activity per Application (μCi)
	Diagnostic	
^{51}Cr	Erythrocyte volume	100
^{85}Sr	Bone scan	100
^{87m}Sr	Bone scan	1,000
^{99m}Tc	Thyroid scan	1,000
	Bone scan	10,000
	Kidney scan	3,000
	Brain scan	10,000
	Spleen scan	1,500
	Liver scan	1,500
	Blood (plasma) volume	100
^{125}I	Radioimmunoassay	
^{131}I	Thyroid scan or function	25
	Kidney function	20
	Blood (plasma) volume	10
^{132}I	Thyroid function	25
^{133}Xe	Lung ventilation	20,000-30,000
^{133m}In	Liver scan	1,000
^{175}Se	Pancreas scan	200
^{197}Hg	Spleen scan	300
^{198}Au	Liver scan	150
^{203}Hg	Kidney scan	100
	Therapeutic	
^{32}P	Polycthemia Vera	4,000-8,000
^{131}I	Hyperthyroidism	
	Thyroid carcinoma	5,000-150,000
	Thyroid ablation	80,000
^{198}Au	Malignant effusions	100,000

The three typical methods of radioxenon control are: 1) the patient exhales into a standard fume hood, 2) the patient exhales into a collection bag which is then emptied into a fume hood or from the building roof, and 3) the exhaled air is retained in an activated charcoal xenon trap. The collection bag method also frequently allows time for reduction, by decay, of up to a factor of 1,000 (10 half-lives) for radioxenon prior to release to the atmosphere.

6.4 SITE DESCRIPTION

Medical facilities are typically located in urban settings. Large hospitals (>500 beds) are frequently located in a densely populated inner city area. Since the larger hospitals usually have the larger nuclear medicine programs, use of urban population statistics for all medical facilities will result in a conservative population estimate. The closest resident is frequently within 400 m of the facilities and a population of 100,000 is likely within a 1.6-km radius. Figure 6.1 shows the population distribution for a typical urban hospital, developed for a previous study (Teknekron 1979).

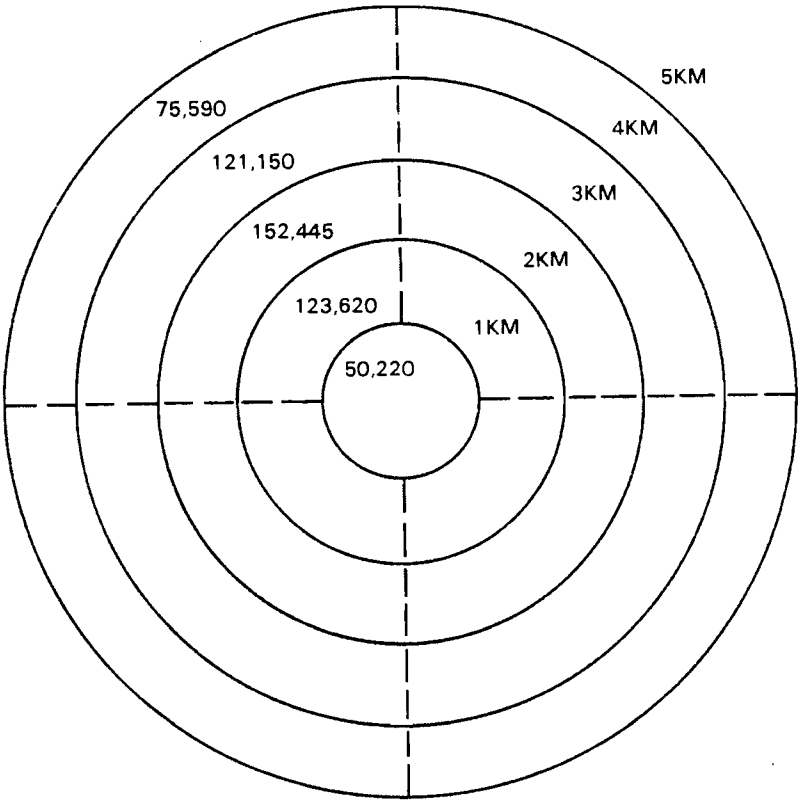

FIGURE 6.1. Population Distribution Around an Urban Hospital

6.5 RADIONUCLIDE RELEASES TO AIR

The radionuclides of major interest are xenon-133, iodine-131, and iodine-125 for medical facilities, because of the relative quantities and potential for population dose. These radionuclides are released intermittently to the air from stacks and vents at roof height. For purposes of population exposure calculations, such releases can be considered to be at ground level. It should be recognized, however, that building height, topography, and adjacent structures significantly affect the reliability of dose calculations.

Data for medical facilities were obtained from two by-product user surveys (Cook 1981; SAI 1983). A summary of annual radionuclide activity received and released by medical facilities is contained in Tables 6.2 and 6.3, respectively. Over 99% of the annual airborne releases from medical facilities are due to xenon-133. The average airborne release values in Table 6.3 include those facilities that reported zero released activity. The data (Cook 1981; SAI 1983) indicate that only 9% of those facilities receiving iodine-125 or iodine-131 reported releases to the air, and only 60% of those receiving xenon-133 reported releases.

Data indicate (Cook 1981; SAI 1983) that of the medical facilities that have unsealed sources of radionuclides, 51% receive xenon-133, 78% receive iodine-131, and 72% receive iodine-125. Applying these percentages to all medical institutions that use unsealed sources of radionuclides ($\sim$7,000 facilities) results in an estimate of 3,570 facilities that receive xenon-133, 5,460 facilities that receive iodine-131, and 5,040 facilities that receive iodine-125. The total activity released from these licensed medical facilities was extrapolated using the average release values obtained from Table 6.3. Table 6.4 summarizes the estimated annual releases of xenon-133, and iodine-131, and iodine-125 for the 7,000 medical facilities that have unsealed sources of radionuclides.

It has been estimated (Teknekron 1981) that 20% of the waste treatment facilities in the United States use sludge incineration. Further, only 0.1% of any radioiodine in the waste is released to the atmosphere. These percentages are assumed to be characteristic of all medical and waste treatment facilities for purposes of this report. Table 6.5 summarizes the estimated releases of radioactive iodines to the atmosphere from municipal waste treatment facilities.

TABLE 6.2. Summary of Annual Activity Received by Medical Facilities

Number of Facilities	Radionuclide	Lowest Ci/yr	Average Ci/yr	Highest Ci/yr	Total Ci/yr	Percent of Total
337	^{125}I	3×10^{-6}	0.077	5.7	26	1.2
516	^{131}I	1×10^{-5}	0.519	20	267.6	12.8
408	^{133}Xe	0	4.4	78	1,796	86.0

TABLE 6.3. Summary of Annual Airborne Releases from Medical Facilities

Number of Facilities	Radionuclide	Lowest Ci/yr	Average Ci/yr	Highest Ci/yr	Total Ci/yr	Percent of Total
337	^{125}I	0	8×10^{-5}	7.4×10^{-3}	2.8×10^{-2}	0.0
516	^{131}I	0	9×10^{-4}	2×10^{-1}	4.9×10^{-1}	0.3
408	^{133}Xe	0	3.9×10^{-1}	10	1.589×10^{2}	99.7

TABLE 6.4. Extrapolated Total Releases of Selected Radionuclides from All Licensed Medical Facilities

Number of Facilities	Radionuclide	Average Release (Ci/yr)	Total Release (Ci/yr
5,040	^{125}I	8×10^{-5}	0.4
5,460	^{131}I	9×10^{-4}	4.9
3,570	^{133}Xe	0.39	1,392

TABLE 6.5. Estimated Atmospheric Releases from Municipal Waste Treatment Facilities

Number of Facilities	Radionuclide	Activity Released to Liquid Waste (Ci/yr)(a)	Activity Incinerated (Ci/yr)(b)	Activity Released to Air (Ci/yr)(c)
5,040	^{125}I	15	3	0.003
5,460	^{131}I	80	16	0.016

(a) Based on liquid release data in Cook (1981).
(b) Based on 20% incineration (Teknekron 1981).
(c) Based on 0.1% release from incinerators (Teknekron 1981).

7.0 LABORATORIES

7.1 GENERAL DESCRIPTION

The general category of laboratories includes test, research, and development laboratories in industry, government agencies, and academic and research institutions. Approximately 700 laboratories are licensed by Agreement States to handle radioisotopes in an unsealed form. It is assumed that an equal number of NRC licensees handle unsealed radioisotopes, resulting in a total number of about 1,400 laboratories that are possible sources of low-level radioactive airborne emissions.

7.2 FACILITY AND PROCESS DESCRIPTION

Laboratory facilities at a single site vary from a small multipurpose single laboratory up to perhaps 300 individual laboratories, located within several buildings, at a major university. The smaller testing laboratories tend to specialize in the limited use of radionuclides for one purpose such as soil testing or weld testing. Both academic and industrial laboratories use by-product materials in basic research and development; frequently radioactively labeled chemicals are used to trace a metabolic or physical pathway through a system. Medical research laboratories conduct basic chemical and applied radionuclide research related to a broad spectrum of diseases and health problems. Government laboratories may focus on specific areas for the use of radionuclides such as food and drug testing, water and air quality, and ocean and fisheries monitoring. Thus, the testing and industrial laboratories tend to use larger quantities but a more limited variety of radionuclides than academic and other research laboratories.

A wide variety of radionuclides are found in laboratory work; the most frequently encountered nuclides are tritium, carbon-14, xenon-133, iodine-125, and iodine-131. The annual usage of any one radionuclide rarely exceeds 10 Ci, and typically is less than 0.5 Ci.

7.3 EMISSION CONTROL SYSTEMS

The primary airborne emission controls employed by laboratories are HEPA filters installed in fume hoods, hot cells, and glove boxes. Laboratories in which the usage of one radionuclide predominates will frequently have controls specific to that nuclide, such as activated charcoal traps for xenon and iodine removal.

Although its use may not be warranted by the expected minimal population doses, treatment technology does exist for carbon-14 and tritium. A catalytic recombiner followed by moisture removal is the principal technology for removal of gaseous tritium from airborne effluent streams. Chemical scrubbers may be used for removal of carbon-14 (Dames & Moore 1979).

7.4 SITE DESCRIPTION

Site characteristics of laboratories are as varied as the types of facilities. Industrial laboratories are commonly an integral part of a manufacturing facility and so are usually located in commercial or industrial areas of large cities. Academic laboratories and large research and development institutes are usually located in a campus setting. The distance to the closest residence from any of these facilities is typically 400 to 800 m, with a population of 4,000 people within a radius of 1.6 km.

7.5 RADIONUCLIDE RELEASES TO AIR

Data for 168 laboratories; including industrial, academic, government, medical, and engineering was obtained from two surveys of by-product users (Cook 1981; SAI 1983). Table 7.1 summarizes the annual airborne releases reported by these facilities. For purposes of population exposure calculations, these releases can be assumed to be at ground level.

TABLE 7.1. Summary of Annual Airborne Releases from Laboratories[a)]

Number of Facilities	Radionuclide	Minimum Ci/yr	Average Ci/yr	Maximum Ci/yr	Total Ci/yr	Percent of Total
103	^{3}H	0	0.28	25	29	61.9
45	^{14}C	0	0.0069	0.11	0.31	0.7
9	^{85}Kr	0	0.16	1.4	1.4	3.0
35	^{125}I	0	0.004	0.042	0.14	0.3
35	^{131}I	0	0.0003	0.0059	0.011	0.0
20	^{133}Xe	0	0.8	10	16	34.1
	All				47	100

a) Source: Cook (1981) and SAI (1983).

8.0 NAVAL SHIPYARDS

8.1 GENERAL DESCRIPTION

The United States Navy services its nuclear-powered submarines and surface ships at 24 shipyards and submarine bases in 10 of the United States and Guam. This service includes construction, maintenance, overhaul, and refueling of the nuclear-powered fleet. Table 8.1 lists the number of facilities in each state or territory (McKee 1981).

TABLE 8.1. Geographical Distribution of Nuclear Navy Support Facilities

State or Territory	Number of Facilities
California	5
Connecticut	3
Florida	1
Georgia	1
Guam	1
Hawaii	3
Mississippi	1
New Hampshire	1
South Carolina	2
Virginia	4
Washington	2
All other states	0
TOTAL	24

8.2 FACILITY AND PROCESS DESCRIPTION

Air emissions are most likely to occur during maintenance operations such as shipboard filter changes and refueling. Permanent facilities are not usually used for these activities. Rather, temporary containment structures are set up during shipboard and dockside activities that may result in some release of airborne radionuclides.

8.3 EMISSION CONTROL SYSTEMS

Air exhausted from temporary containments during refueling operations is typically treated only by HEPA filters.

8.4 SITE DESCRIPTION

The Naval bases and shipyards tend to be located on inland bays. Areas surrounding the bases are commonly light industrial and commercial areas. The nearest resident tends to be located at least 600 m from any radiological operation.

8.5 RADIONUCLIDES RELEASED TO AIR

Table 8.2 summarizes the annual release data for radionuclides from nuclear shipyard operations. The data were obtained from the Navy's annual environmental report (McKee 1981). This report considers releases from 133 vessels within the ~19 km[(a)] territorial limit in addition to releases from their support facilities.

a) 12 miles.

TABLE 8.2. Annual Airborne Release of Radionuclides from all Naval Shipyards

Radionuclide	Annual Release (Ci/yr)
^{3}H	0.001
^{14}C	0.100
^{41}Ar	0.410
$^{58,60}Co$	0.001
^{83m}Kr	0.020
^{85}Kr	0.024
^{85m}Kr	0.001
^{87}Kr	0.050
^{88}Kr	0.020
^{131m}Xe	0.005
^{133}Xe	0.210
^{133m}Xe	0.010
^{135}Xe	0.250

9.0 LOW-LEVEL COMMERCIAL WASTE DISPOSAL SITES

9.1 GENERAL DESCRIPTION

Six commercial low-level radioactive waste disposal sites exist as of this date, but only three of the sites, located at Barnwell, South Carolina, Beatty, Nevada, and Richland, Washington, are operational. The remaining three, located at Maxey Flats, Kentucky, Sheffield, Illinois, and West Valley, New York, are no longer operational.

The operational sites accept low-level radioactive wastes in a stabilized form, but not special nuclear materials, transuranics, and spent reactor fuels. Wastes accepted for disposal by shallow-land burial must meet specific site acceptance criteria. The majority of these wastes come from three sources: power-reactor operations, laboratory research, and medical facilities.

9.2 FACILITY AND PROCESS DESCRIPTION

The disposal sites typically consist of a large fenced area of about 100 ha. Operations buildings for decontamination, maintenance, and waste preparation, are typically located at one end of the site.

Wastes are usually buried in the transport containers in which they arrive at the site. This aids in minimizing radionuclide releases to the atmosphere. However, some facilities do exist to provide containment of materials when the need arises to open the containers prior to burial.

9.3 EMISSION CONTROL SYSTEMS

Currently the operating burial sites rely on trench overburden to contain radioactive materials placed in the trenches. Despite having up to 2.4 m of overburden, some radionuclides may permeate through the cover and enter the atmosphere. These low-level releases may be in various chemical or physical forms. No emission controls, beyond use of overburden, are currently used to minimize such releases.

The potential exists for minor releases from two facilities commonly found at operational sites. The first is the equipment decontamination facility which uses sandblasting and a pressurized water spray to remove surface contamination from the equipment. Air-cleaning systems are usually employed in these buildings to control the release of radionuclides to the atmosphere.

The other facility of interest is the container inspection facility mentioned previously. Containers that are opened for inspection or for other reasons may release a portion of any volatile materials to the surrounding air. These facilities generally utilize a high-volume, open-ventilation hood to contain any airborne particulate contamination that may be released from opened containers. Air from the hood passes through a HEPA filter prior to being released to the atmosphere at roof level.

There is one additional source of airborne emissions. At one nonoperational burial facility, in order to reduce subsurface migration of radionuclides, the ground water is pumped from sump wells in the trenches to an evaporator. The water is evaporated and the vapor is exhausted from an unfiltered 10-m stack.

Recently adopted NRC rules (10 CFR 61) require improved containment capabilities for two of the three classes of near-surface disposable wastes. It is believed that the NRC rules will result in even lower atmospheric releases from burial grounds; currently these releases are normally less than 1% of 10 CFR 20 concentration guides.

9.4 SITE DESCRIPTION

Radioactive disposal sites have been located in both humid and arid regions. The area surrounding the site is typically rural or agricultural land.

The population density around the sites in the eastern U.S. is about 108 persons within a 1.6-km radius. The nearest resident from the site boundary is about 400 m. Disposal sites in the western U.S. are more isolated, with no permanent residents within a 1.6-km radius.

9.5 RADIONUCLIDES RELEASED TO AIR

Table 9.1 summarizes the available data (Teknekron 1981) on annual releases from a nonoperational low-level waste disposal site. No data on operational sites was available. As can be seen in Table 9.1, the primary radionuclide of interest is tritium, which is emitted from the trenchwater evaporation system that is described in the previous section.

TABLE 9.1. Radionuclides Released to Air from Nonoperational Low-Level Waste Disposal Sites

Radionuclide	From Trenches (Ci/yr)	From Evaporator (Ci/yr)
^{3}H	8.0×10^{1}	6.0×10^{3}
^{14}C	5.0×10^{0}	-
^{58}Co	-	1.9×10^{-4}
^{60}Co	-	5.8×10^{-4}
^{90}Sr	-	4.6×10^{-4}
^{134}Cs	-	2.1×10^{-4}
^{137}Cs	-	8.3×10^{-3}
^{238}Pu	-	1.1×10^{-4}
^{239}Pu	-	2.0×10^{-6}

10.0 REFERENCES

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