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Radioactive Effluents from Nuclear Power Plants

Annual Report 2009

Final Report

Office of Nuclear Reactor Regulation

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Abstract

There are 104 commercial nuclear power plants on 65 sites in the United States. Each year, each power reactor sends a report to the NRC that identifies the radioactive liquid and gaseous effluents discharged from the facility. In 2009, these effluent reports comprised about 10,000 pages of information, which described the radioactive materials discharged, as well as the resulting radiation doses to the general public. This report summarizes that information and presents it in a format intended for both nuclear professionals and the general public.

The reader can use this report to quickly characterize the radioactive discharges from any nuclear power plant in the United States in 2009. The effluents from one reactor can be compared with other reactors. The results can also be compared with typical (or median) effluents for the industry, including short-term 3-year trends and long-term 34-year trends.

Reference information is included so the reader can compare the doses from nuclear power plant effluents with the doses the general public receives from other sources of radiation, such as medical procedures, industrial devices, and natural materials in the environment.

Although all NPPs released some radioactive materials in 2009, all effluents were within the NRC safety limits, NRC design objectives, and the licensees' system operating limits for radioactive effluents. Additionally, the doses from radioactive effluents were much less than the doses from other sources of natural radiation that are commonly considered safe. This indicates radioactive effluents from NPPs in 2009 had no significant impact on the health and safety of the public or the environment.

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Abbreviations

ALARA	as low as is reasonably achievable
ARERR	Annual Radioactive Effluent Release Report
Bq	becquerel
BWR	boiling water reactor
CFR	Code of Federal Regulations
Ci	curie
GBq	gigabecquerels
mCi	millicurie
MFAP	mixed fission and activation products
mrem	millirem
mSv	millisievert
NCRP	National Council on Radiation Protection and Measurements
NPP	nuclear power plant
NUREG	A nuclear regulatory document prepared by or for the NRC, which includes reports or brochures on regulatory decisions, results of research, results of incident investigations, and other technical and administrative information (See Glossary)
ODCM	Offsite Dose Calculation Manual
PWR	pressurized water reactor
RG	Regulatory Guide
SI	International System of Units (abbreviation is from the French: *Le Système International d'Unités*)
Sv	sievert
USGS	United States Geological Survey
(U.S.) NRC	United States Nuclear Regulatory Commission

1 Introduction

1.1 Purpose

This report describes radioactive effluents from commercial nuclear power plants (NPPs) in the United States during calendar year 2009. It is based on an extensive amount of information submitted to the Nuclear Regulatory Commission (NRC) by all U.S. NPP licensees. The original information was submitted by the NPPs in their Annual Radioactive Effluent Release Reports (ARERRs) and comprises several thousand pages of data. The ARERRs may be viewed in their entirety on the NRC Web site (http://www.nrc.gov/about-nrc/radiation.html).

For the years between 1972 and 1993, this type of annual information was condensed in a tabular format and published as a large volume of raw information (Refs. 1-22). An evaluation of the practice of generating tabular annual reports revealed the need for a more concise summary report that presented the information in a more intuitive, graphic format (Ref. 23). As a result, this report was created. This report joins a series of previous reports on radioactive effluents presented in the new graphical format (Refs. 24, 25).

The purpose of this report is to condense an extremely large volume of technical information into a few tables and figures from which the reader can quickly, if broadly, characterize the effluents from any operating U.S. NPP. These tables and figures are designed to provide easily understandable information for the public at large, while also providing experienced professionals with enough information to evaluate trends in industry performance and to identify potential performance issues for individual power plants. Those users wanting more extensive and detailed information are encouraged to retrieve the original ARERRs from the NRC Web site.

1.2 Scope

This report summarizes data from all NPPs in commercial operation between January 1, 2009 and December 31, 2009. The list of NPPs included in this report is provided in Table 1.1. The NPP type—boiling water reactor (BWR) or pressurized water reactor (PWR)—is indicated in the table.

Some of the shutdown reactors were totally dismantled during the decommissioning process. As a result, for some shutdown reactors, no visible structures or facilities may be present at the locations listed in Table 1.1.

Table 1.1
Nuclear Power Plants, 2009

Plant Name	Type	Full Plant Name	Location
Arkansas 1, 2	PWR	Arkansas Nuclear One (ANO), Units 1, 2	Russellville, AR
Beaver Valley 1, 2	PWR	Beaver Valley, Units 1, 2	Shippingport, PA
Braidwood 1, 2	PWR	Braidwood Generating Station, Units 1, 2	Braceville, IL
Browns Ferry 1, 2, 3	BWR	Browns Ferry Nuclear Plant, Units 1, 2, 3	Decatur, AL
Brunswick 1, 2	BWR	Brunswick Steam Electric Plant, Units 1, 2	Southport, NC
Byron 1, 2	PWR	Byron Generating Station, Units 1, 2	Byron, IL
Callaway	PWR	Callaway Plant, Unit 1	Callaway, MO
Calvert Cliffs 1, 2	PWR	Calvert Cliffs Nuclear Power Plant, Units 1, 2	Lusby, MD
Catawba 1, 2	PWR	Catawba Nuclear Station, Units 1, 2	York, SC
Clinton	BWR	Clinton Power Station	Clinton, IL
Columbia	BWR	Columbia Station	Richland, WA
Comanche Peak 1, 2	PWR	Comanche Peak Steam Electric Station, Units 1, 2	Glen Rose, TX
Cook 1, 2	PWR	Donald C. Cook Nuclear Plant, Units 1, 2	Bridgman, MI
Cooper	BWR	Cooper Nuclear Station	Brownville, NE
Crystal River 3	PWR	Crystal River, Unit 3	Crystal River, FL
Davis-Besse	PWR	Davis-Besse Nuclear Power Station, Unit 1	Oak Harbor, OH
Diablo Canyon 1, 2	PWR	Diablo Canyon, Units 1, 2	Avila Beach, CA
Dresden 2, 3	BWR	Dresden Generating Station, Units 2, 3	Morris, IL
Duane Arnold	BWR	Duane Arnold Energy Center	Palo, IA
Farley 1, 2	PWR	Joseph M. Farley Nuclear Plant, Units 1, 2	Ashford, AL
Fermi 2	BWR	Fermi 2 Nuclear Power Plant	Newport, MI

Table 1.1 (continued)
Nuclear Power Plants, 2009

Plant Name	Type	Full Plant Name	Location
FitzPatrick	BWR	James A. FitzPatrick Nuclear Power Plant	Lycoming, NY
Ft. Calhoun	PWR	Ft. Calhoun Station, Unit 1	Ft. Calhoun, NE
Ginna	PWR	R.E. Ginna Nuclear Power Plant, Unit 1	Ontario, NY
Grand Gulf	BWR	Grand Gulf Nuclear Station, Unit 1	Port Gibson, MS
Harris	PWR	Shearon Harris Nuclear Power Plant, Unit 1	New Hill, NC
Hatch 1, 2	BWR	Edwin I. Hatch Nuclear Plant, Units 1, 2	Baxley, GA
Hope Creek	BWR	Hope Creek Generating Station, Unit 1	Hancocks Bridge, NJ
Indian Point 2, 3	PWR	Indian Point Energy Center, Units 2, 3	Buchanan, NY
Kewaunee	PWR	Kewaunee Power Station	Kewaunee, WI
LaSalle 1, 2	BWR	LaSalle County Generating Station, Units 1, 2	Marseilles, IL
Limerick 1, 2	BWR	Limerick Generating Station, Units 1, 2	Saratoga, PA
McGuire 1, 2	PWR	McGuire Nuclear Station, Units 1, 2	Huntersville, NC
Millstone 2, 3	PWR	Millstone Power Station, Units 2, 3	Waterford, CT
Monticello	BWR	Monticello Nuclear Generating Plant	Monticello, MN
Nine Mile Point 1, 2	BWR	Nine Mile Point Nuclear Station, Units 1, 2	Lycoming, NY
North Anna 1, 2	PWR	North Anna Power Station, Units 1, 2	Mineral, VA
Oconee 1, 2, 3	PWR	Oconee Nuclear Station, Units 1, 2, 3	Seneca, SC

Table 1.1 (continued)
Nuclear Power Plants, 2009

Plant Name	Type	Full Plant Name	Location
Oyster Creek	BWR	Oyster Creek Nuclear Generating Station	Forked River, NJ
Palisades	PWR	Palisades Nuclear Plant	Covert, MI
Palo Verde 1, 2, 3	PWR	Palo Verde Nuclear Generating Station, Units 1, 2, 3	Phoenix, AZ
Peach Bottom 2, 3	BWR	Peach Bottom Atomic Power Station, Units 2, 3	Delta, PA
Perry	BWR	Perry Nuclear Power Plant, Unit 1	Perry, OH
Pilgrim	BWR	Pilgrim Nuclear Power Station, Unit 1	Plymouth, MA
Point Beach 1, 2	PWR	Point Beach Nuclear Plant, Units 1, 2	Two Rivers, WI
Prairie Island 1, 2	PWR	Prairie Island Nuclear Generating Plant, Units 1, 2	Welch, MN
Quad Cities 1, 2	BWR	Quad Cities Generating Station, Units 1, 2	Cordova, IL
River Bend	BWR	River Bend Station, Unit 1	St. Francisville, LA
Robinson 2	PWR	H. B. Robinson Steam Electric Plant, Unit 2	Hartsville, SC
Salem 1, 2	PWR	Salem Nuclear Generating Station, Units 1, 2	Hancocks Bridge, NJ
San Onofre 2, 3	PWR	San Onofre Nuclear Generating Station, Units 2, 3	San Clemente, CA
Seabrook	PWR	Seabrook Station, Unit 1	Seabrook, NH
Sequoyah 1, 2	PWR	Sequoyah Nuclear Plant, Units 1, 2	Soddy-Daisy, TN
South Texas 1, 2	PWR	South Texas Project Electric Generating Station, Units 1, 2	Wadsworth, TX
St. Lucie 1, 2	PWR	St. Lucie Nuclear Plant, Units 1, 2	Ft. Pierce, FL
Summer	PWR	Virgil C. Summer Nuclear Station, Unit 1	Jenkinsville, SC
Surry 1, 2	PWR	Surry Power Station, Units 1, 2	Surry, VA
Susquehanna 1, 2	BWR	Susquehanna Steam Electric Station, Units 1, 2	Berwick, PA

Table 1.1 *(continued)*
Nuclear Power Plants, 2009

Plant Name	Type	Full Plant Name	Location
Three Mile Island 1	PWR	Three Mile Island Generating Station, Unit 1	Harrisburg, PA
Turkey Point 3, 4	PWR	Turkey Point Nuclear Plant, Units 3, 4	Princeton, FL
Vermont Yankee	BWR	Vermont Yankee Nuclear Plant, Unit 1	Vernon, VT
Vogtle 1, 2	PWR	Vogtle Electric Generating Plant, Units 1, 2	Waynesboro, GA
Waterford 3	PWR	Waterford Steam Electric Station, Unit 3	Killona, LA
Watts Bar	PWR	Watts Bar Nuclear Plant, Unit 1	Spring City, TN
Wolf Creek	PWR	Wolf Creek Generating Station, Unit 1	Burlington, KS
Reactors No Longer In Commercial Operation			
Big Rock Point	BWR	Big Rock Point Restoration Project	Charlevoix, MI
Dresden 1	BWR	Dresden Generating Station, Unit 1	Morris, IL
Haddam Neck	PWR	Haddam Neck Nuclear Plant Site	Haddam Neck, CT
Humboldt Bay	BWR	Humboldt Bay Power Plant, Unit 3	Eureka, CA
Indian Point 1	PWR	Indian Point Energy Center, Unit 1	Buchanan, NY
La Crosse	BWR	La Crosse Boiling Water Reactor	Genoa, WI
Maine Yankee	PWR	Maine Yankee	Bath, ME
Millstone 1	PWR	Millstone Power Station, Unit 1	Waterford, CT
Rancho Seco	PWR	Rancho Seco, Unit 1	Herald, CA
San Onofre 1	PWR	San Onofre Nuclear Generating Station, Unit 1	San Clemente, CA
Three Mile Island 2	PWR	Three Mile Island Nuclear Station, Unit 2	Middletown, PA
Trojan	PWR	Trojan Nuclear Plant, Unit 1	Portland, OR
Yankee-Rowe	PWR	Yankee Nuclear Power Station	Franklin Co., MA
Zion 1, 2	PWR	Zion Generating Station, Units 1, 2	Warrenville, IL

This report contains information about all routine and abnormal releases from these facilities. Since 2006, there has been increased interest in radionuclides entering the groundwater due to spills and leaks at nuclear power plants. A spill or a leak is considered an abnormal release, and that information is included in this report.

The NRC uses the information on radioactive releases, along with other information collected during routine inspections of each facility, to ensure NPPs are operated within regulatory requirements. One of those requirements includes maintaining radiation doses from radioactive effluents as low as is reasonably achievable (ALARA). For this summary report, only information submitted with regard to NRC reporting requirements and guidance is included. Information not related to the NRC requirements for radioactive effluents or the NRC guidance on radioactive effluents is not included in this summary report. Additionally, information on non-radioactive waste is not included in this report.

Some reactors are no longer operating. For the 2009 data shown in the tables and figures of this report, those reactors are treated as follows. The Big Rock Point, Haddam Neck, Humboldt Bay, La Crosse, Maine Yankee, Rancho Seco, Trojan, Yankee-Rowe, Zion 1, and Zion 2 reactor sites are shutdown and are not collocated with an operating reactor. The data from these shutdown reactors are not included in this report. The Millstone 1 and Three Mile Island 2 reactors are shutdown and are collocated with one or more operating reactors. For these shutdown reactors, the licensee reports data for the shutdown unit separately from the operating units, and the results from these shutdown reactors are not included in this report. For the Dresden 1, Indian Point 1, and San Onofre 1 reactor sites, which are shutdown and collocated beside two operating units, the licensee reports the sum of the effluents from the shutdown unit with one or both of the operating units. For these shutdown reactors, the effluent data are included with (and attributed to) one or more of the operating units in this report.

The historical data from all reactors, including the reactors that are no longer operating, are included in Figures 3.15 and 3.18, which depict long-term trends of radioactive effluents.

1.3 Source of Data

Each commercial nuclear power plant in the United States is authorized by the NRC to release small amounts of radioactive materials to the environment as specified in the licensing documents for the plant. NRC regulations require each NPP to establish and maintain a program for monitoring radioactive effluents (per Title10 of the Code of Federal Regulations (CFR) Part 50.36 and 10 CFR 50, Appendix I, Section IV.B) and to report these effluents in an Annual Radioactive Effluent Release Report (per 10 CFR 50.36a) (Ref. 26). In accordance with the regulatory framework, licensees submit their reports to the NRC in a format outlined by Regulatory Guide 1.21 (Ref. 27), or an equivalent format.

The information included in this document was obtained from the licensees' ARERRs. Individual licensee reports are available through the NRC Public Document Room, One White Flint North, 11555 Rockville Pike (first floor), Rockville, Maryland 20852, phone 1-800-397-4209 or 301-415-4737 and directly from the NRC's public Web site at http://www.nrc.gov/reactors/operating/ops-experience/tritium/plant-info.html.

The data from these reports are entered into a database that is maintained by the NRC. The public may access this database through an NRC Web site (http://www.reirs.com/effluent/). The data are entered into the database as they are reported by each site.

1.4 Limitations of the Data

Some NPPs have more than one reactor unit located at a site. If the licensee reports data separately for each reactor unit, those data are reflected in this report as reported by the licensee. Because some licensees are allowed to operate multi-unit sites with a common radioactive waste processing system, the NRC allows these licensees to report total effluents from the site instead of reporting the totals from each reactor unit. This complicates the task of presenting the effluent information in a manner that allows both (1) a direct comparison of one reactor unit with another, and (2) a direct comparison of each reactor unit with NRC limits and regulations.

For purposes of presentation in this report, the data are normalized on a per-unit basis. For multi-unit sites where the effluents are from a common radioactive waste system, the effluents are divided equally between the units in operation during that year. For example, Calvert Cliffs has two units (1 and 2) with a common radioactive waste processing system. For this report, the total effluents for Calvert Cliffs were split equally between Unit 1 and Unit 2. For other multi-unit sites, the effluent activity is not divided equally between the units. For example, in the case of Beaver Valley, the licensee reports gaseous effluents from 4 sources: Unit 1, Unit 2, a common plant vent, and a common building vent. In this case, the releases from the common vents are split equally between Unit 1 and Unit 2, and the totals for each unit then are calculated. This method of splitting the data has been applied to radionuclide activity data and radiation dose data at some multi-unit sites. The affected NPPs and the type of data affected are listed in Table 1.2.

Although there are other methods of normalizing effluent data (e.g., on the basis of thermal or electrical power generation), the unit-based method selected for this report (1) is most intuitive, (2) is most directly comparable with the NRC required design objectives, and (3) is easily derived from the effluent data supplied by the licensee. This approach satisfies a primary objective for this report: to allow the reader to quickly formulate reasonable comparisons between reactors and with the regulatory limits. It should be noted, however, that for some multi-unit sites, the actual contributions from each unit might be different than the equal distributions calculated with this approach, such as when a plant is undergoing a major or extended outage.

Table 1.2
Reactors for Which the NRC Has Normalized Data on a Unit-Specific Basis

Boiling Water Reactors (BWRs)	Pressurized Water Reactors (PWRs)
Browns Ferry 1, 2, 3 (R, D)	Beaver Valley 1, 2 (R)
Brunswick 1, 2 (R, D)	Calvert Cliffs 1, 2 (R, D)
Dresden 1, 2, 3 (R)	Catawba 1, 2 (R, D)
LaSalle 1, 2 (R, D)	Comanche Peak 1, 2 (R, D)
Limerick 1, 2 (R, D)	Cook 1, 2 (R, D)
Nine Mile Point 1, 2 (D)	Diablo Canyon 1, 2 (R, D)
Peach Bottom 2, 3 (R, D)	Indian Point 1, 2 (R, D)
Quad Cities 1, 2 (R, D)	McGuire 1, 2 (R, D)
Susquehanna 1, 2 (R)	North Anna 1, 2 (R, D)
	Oconee 1, 2, 3 (R, D)
	Point Beach 1, 2 (R, D)
	Prairie Island 1, 2 (R, D)
	San Onofre 1, 2, 3 (R, D)
	Sequoyah 1, 2 (R, D)
	Surry 1, 2 (R, D)

Notes:

R = Radionuclide Data, D = Dose Data

Care has been taken to assure the information contained in this report accurately reflects the information provided by the licensees. The report may include licensees' corrections submitted to the NRC up to the time of publication. If a licensee submits amended data in accordance with NRC regulatory guidance, the NRC reserves the right to update the data in future reports. For the most current data, the reader should use the NPPs' ARERRs and this NUREG, all of which are available on the NRC Web site.

2 Description of the Data

2.1 Introduction

Radioactive materials may be disposed of in one of three forms: solid, liquid, or gas. This report summarizes the disposal of radioactive materials in liquid and gaseous effluents from commercial nuclear power plants. As described in Section 1.3, owners and operators of NPPs are required to report the radioactive effluents from their facilities to the NRC. The two basic characteristics most often used to describe radioactive effluents are activity and radiation dose. Radiation dose will simply be referred to in this document as dose.

Activity is a term used to describe how often a substance emits radiation. The activity of any given radionuclide increases in direct proportion to the amount of the radionuclide present. This report lists the amounts of various radionuclides present in radioactive effluents. For this report, activity can be thought of as the amount of radioactive material present in radioactive effluents. The units for measuring activity are described in more detail in Section 2.2. The actual activities of various radionuclides in radioactive effluents from NPPs are presented in Sections 3.1 through 3.5.

Although radionuclide activity is an important, inherent characteristic that helps to describe radioactive effluents, it is not—by itself—a good indicator of the potential health effects from exposure to radiation. Health effects are dependent on many factors, such as the radionuclide, the activity of the radionuclide, the type of radiation emitted by the radionuclide, the energy of the radiation, the uptake of the radionuclide into the human body, and the metabolism of the radionuclide by the human body. To properly describe the potential health effects from exposure to radioactive materials, a measure that accounts for all of these differences is needed.

Dose is a measure of how much radiation energy is absorbed by organs or tissues of the body. Dose is a good indicator of the potential health effects from exposure to radiation. The units for measuring dose are described in more detail in Section 2.3. The dose from radioactive effluents is discussed in Section 2.4. The actual doses due to radioactive effluents from NPPs are presented in Section 3.6.

Radiation is around us all of the time. The human body—each of us—contains some natural radioactive materials such as radioactive carbon and radioactive potassium. Natural radioactive materials are in rocks, in soil, in the air we breathe, and in the food we eat. As a result, humans have been exposed to radiation since the dawn of man. Over the last 100 years, man has developed new radioactive materials and new machines that create additional sources of radiation. These new sources include radioactive materials used in medicine, research, industry, and nuclear power plants. Section 2.5 contains basic information on the doses received by the average member of the U.S. population each year from all sources of radiation, including commercial NPPs.

2.2 Measuring Activity in Radioactive Effluents

Activity is reported in various units. In the United States, the traditional unit for reporting activity is the curie (Ci). One curie is equal to 37,000,000,000 (37 billion) radioactive atoms decaying (disintegrating) in one second. In this document, activity will be reported as curies and millicuries (mCi). A curie is equal to one thousand millicuries. In countries that have adopted the International System of Units (or SI units), activity is reported in units of becquerels (Bq). One Bq is one atomic decay (or disintegration) per second. One curie equals 37,000,000,000 becquerels, which may be expressed in scientific notation as 3.7E+10 becquerels or 3.7×10^{10} becquerels. One curie is sometimes expressed as 37 gigabecquerels or simply 37 GBq.

Activity is the number of atoms that decay in a given period of time. One curie of cobalt-60 and one curie of hydrogen-3 have the same activity; however, when an atom of cobalt-60 decays, the atomic transformations that occur typically produce one moderately energetic beta particle and two highly energetic gamma rays. By contrast, when an atom of hydrogen-3 decays, it emits a single, low-energy beta particle. Sensitive instruments can detect and measure the decay products, which are unique to each radionuclide. Cobalt and hydrogen are just two examples of elements that can be radioactive. Other examples are shown in tables 2.1 and 2.2.

Table 2.1
Radionuclides in Gaseous Effluents

Gaseous Effluent Category	Some Common Radionuclides in this Category	Radionuclides Included in this Report
Fission and Activation Gases (sometimes referred to as Noble Gases)	Krypton (85, 85m, 87, 88) Xenon (131, 131m, 133, 133m, 135, 135m) Argon (41)	Kr-85 Xe-133 Xe-135 All (Sections 3.2, 3.3, and 3.6)
Iodines/Halogens	Iodine (131, 132, 133, 134, 135) Bromine (82)	I-131 All (Section 3.6)
Particulates	Cobalt (58, 60) Cesium (134, 137) Chromium (51) Manganese (54) Niobium (95)	Co-58 Co-60 Cs-134 Cs-137 All (Section 3.6)
Tritium	Hydrogen (3)	H-3
Gross Alpha	Total alpha activity from all alpha emitters	Not Presented in this Report

Radioactive waste contains at least one radionuclide. The radionuclides in liquid and gaseous wastes are sometimes grouped into categories (Ref. 27). Each category contains one or more radionuclides. These categories are described in Tables 2.1 and 2.2.

In order to present the liquid and airborne (gaseous) effluent data in a manner that is both useful and concise, only selected radionuclides are included in some of the tables and figures in this report. The radionuclides chosen for inclusion in this report are shown in Tables 2.1 and 2.2.

The radionuclides highlighted in this report are good indicators of total radioactive releases from the site, and they can provide additional information about operational practices at the site. For example, although Table 2.1 lists 11 radionuclides in the category called "fission and activation gases," only 3 radionuclides (Kr-85, Xe-133, and Xe-135) were selected for inclusion in section 3.1 of this report. These 3 were chosen because as their activities increase, the activities of other fission and activation gases typically increase as well. Conversely, if the activities of these 3 radionuclides are very low, the activities of other fission and activation gases tend to be low also. All noble gas radionuclides are included in sections 3.2, 3.3, and 3.6 of this report.

Table 2.2
Radionuclides in Liquid Effluents

Liquid Effluent Category	Some Common Radionuclides in this Category	Radionuclides Included in this Report
Mixed Fission and Activation Products	Iron (55) Cobalt (58, 60) Cesium (134, 137) Chromium (51) Manganese (54) Zirconium (95) Niobium (95) Iodine (131, 133, 135)	Fe-55 Co-58 Co-60 Cs-134 Cs-137 I-131 All (Sections 3.4, 3.5, and 3.6)
Tritium	Hydrogen (3)	H-3
Dissolved and Entrained Noble Gases	Krypton (85, 85m, 87, 88) Xenon (131, 133, 133m, 135, 135m)	Not Presented in this Report
Gross Alpha	Total alpha activity	Not Presented in this Report

Much information about the operation of plant systems can be obtained from the radionuclides present in radioactive effluents. Additionally, the ratios of the activities of selected radionuclides can provide insights into fuel integrity, radioactive waste system operation, and general radioactive waste handling practices at a site. The interested reader wanting to see the activities of all radionuclides released from NPPs is encouraged to review the detailed, site-specific ARERRs on the NRC Web site.

Laboratory instruments can identify which radionuclides are present in radioactive effluents. They can also measure the activities (curies or becquerels) of the radionuclides. As a result, many discussions about radioactive effluents focus on the curies (or becquerels) released. Although activity measures the rate of atomic disintegrations, it does not provide a direct measure of the health effects from exposure to radionuclides. When discussing health effects or potential health effects, the concept of dose is used. Radiation dose is discussed in more detail in the following paragraphs.

2.3 Dose Units and Limits

The traditional unit for reporting radiation dose in the United States is the rem. Small exposures are often reported as millirem (mrem) or as fractions of a mrem. One thousand mrem equals one rem. Other countries report radiation dose in units of sieverts (Sv). One sievert equals 100 rem. One millirem equals 0.00001 sievert or 0.01 millisievert (mSv). The number 0.00001 can be represented in scientific notation as 1×10^{-5} or 1E-05.

Radioactive effluents from NPPs are controlled by regulations. NRC regulations (10 CFR 20.1301) specify that the dose to any member of the public from all liquid and gaseous effluents discharged in a year shall be limited to 100 mrem (1 millisievert) (Ref. 28). Typically, the dose from radioactive effluents is so low (usually less than 1 mrem in a year) that the dose cannot be measured directly. As a result, doses are typically calculated based on the activities of the radionuclides contained in radioactive effluents.

2.4 Radiation Dose to the Public

Each licensee calculates the dose from radioactive effluents to ensure compliance with the requirements of 10 CFR 50, Appendix I (Ref. 26). The dose calculations are based on the measurements and models listed below.

- actual measurements of the radioactive materials released to the environment,
- models of how radionuclides are dispersed and diluted in the environment,
- models of how radionuclides are incorporated into animals, plants, and soil, and
- biokinetic models of human uptake and metabolism of radioactive materials.

The models are designed to calculate the dose to a real (or hypothetical) individual closest to the NPP or to an individual who may be exposed to the highest concentrations of radioactive materials from radioactive effluents. This person is often referred to as the maximum exposed individual. The parameters and assumptions used in these dose calculations typically include conservative assumptions that tend to overestimate the calculated exposures. As a result, the actual doses received by real individuals are often much less than those calculated. Guidance for these calculations is provided in NRC Regulatory Guide 1.109 (RG 1.109), and licensees have incorporated this guidance into their Offsite Dose Calculation Manuals (ODCM) (Ref. 28). ODCMs are available through the NRC Public Document Room. The interested reader may refer to these documents for additional information about dose calculations performed at each reactor site.

Once the doses are calculated, they are compared with the system operating limits for the NPP. Licensees have established operating limits for plant systems to control the amounts of radioactive materials released from NPPs. The NRC requires these system operating limits to be established in accordance with the design objectives in 10 CFR 50, Appendix I (Ref. 26). These system operating limits are designed to ensure radioactive effluents from NPPs are kept ALARA. It should be understood that system *operating* limits are design objectives for plant systems, not *safety* limits. If a system operating limit is exceeded, the licensee is required to take corrective actions to ensure the plant systems are functioning as designed. Maintaining the design functions of plant systems is critical to ensure radioactive releases do not exceed the dose limits in 10 CFR 20, which are federal *safety* limits (Ref. 28). For purposes of comparison, the system operating limits are set to a small fraction (typically about 3%) of the federal safety limits. Licensees have incorporated several different system operating limits into their ODCMs, as required by their Technical Specifications, to satisfy NRC regulatory requirements. The system operating limits have been included in the applicable tables and figures in this report.

Annual organ doses and annual total body doses are included in this report, but other doses are also calculated by each facility. If you wish to see all the doses calculated by a licensee, they are in the NPPs ARERRs, available on the NRC Web site.

2.5 Other Sources of Radiation Dose to the U.S. Population

Doses from NPP effluents were discussed in the previous sections. This section discusses the doses that the average American typically receives each year from naturally occurring background radiation and all other sources of radiation. With the information presented in this section, the reader can compare the doses received from NPP effluents with the doses received from natural, medical, and other sources of radiation. This comparison provides some context to the concept of radiation dose effects.

In March 2009, the National Council on Radiation Protection and Measurements (NCRP) published Report No. 160 as an update to the 1987 NCRP Report No. 93, *Ionizing Radiation Exposure of the Population of the United States* (Refs. 30, 31). Report No. 160 describes the doses to the U.S. population from all sources of ionizing radiation for 2006, the most recent data available at the time the NCRP report was written. The NCRP report also includes information on the variability of those doses from one individual to another. The NCRP estimated that the average person in the United States receives about 620 mrem of radiation dose each year. NCRP Report No. 160 describes each of the sources of radiation that contribute to this dose, including:

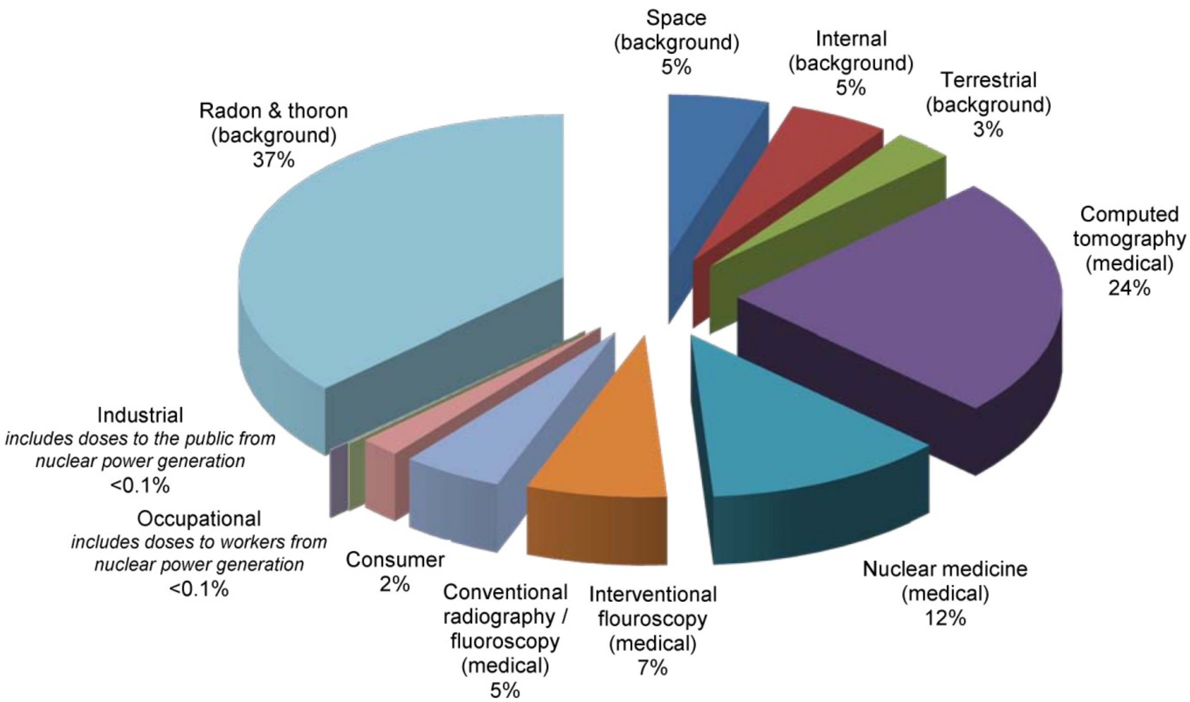
- Naturally occurring sources (natural background) such as cosmic radiation from space, terrestrial radiation from radioactive materials in the earth, and naturally occurring radioactive materials in the food people eat and in the air people breathe;
- medical sources from diagnosis and treatment of health disorders using radioactive pharmaceuticals and radiation-producing equipment;
- consumer products (such as household smoke detectors);
- industrial processes, security devices, educational tools, and research activities; and
- exposures of workers that result from their occupations.

Figure 2.1 is a pie chart showing the relative contributions of these sources of radiation to the dose received by the average American. Larger contributors to dose are represented by proportionally larger slices of the pie. Doses to the public from NPPs are included in the industrial category; doses to workers from nuclear power generation are included in the category of occupational dose.

Doses to the public due to effluents from NPPs are less than 0.1% (one-tenth of one percent) of what the average person receives each year from all sources of radiation. Doses to workers from occupational exposures, including those received from work at NPPs, also are less than 0.1% of the average dose to a member of the public from all sources.

Figure 2.1

Sources of Radiation Exposure to the U.S. Population



The chart above shows the contribution of various sources of exposure to the total collective effective dose and the total effective dose per individual in the U.S. population for 2006. Values have been rounded to the nearest 1%, except for those <1 % [less than 1%]. *Credit: Modification to image courtesy of National Council on Radiation Protection and Measurements.*

3 Effluent Data

3.1 Radioactive Materials in Liquid and Gaseous Effluents

The activities of selected radionuclides in liquid and gaseous effluents for 2009 are shown in Tables 3.1 through 3.12*.* The data from these tables are illustrated graphically in Figures 3.1 through 3.12. The tables and figures are organized by the two types of reactors used in the United States: boiling water reactors (BWRs) and pressurized water reactors (PWRs). The tables and figures are further subdivided into liquid and gaseous effluents. Finally, the data are subdivided into the radionuclide categories listed in Tables 2.1 and 2.2. These tables and figures allow a detailed comparison of one reactor's effluents with another.

As described in Section 2.2, only selected radionuclides are included in the tables and graphs of Section 3.1. Nuclides not included in the tables and graphs of Section 3.1, like strontium-90, are included in other sections of this report, most notably Section 3.6, "Doses."

For comparison purposes, median values are included on some tables and figures. The median is a statistical estimate of the midpoint of the data. Releases from half of the power plants will be greater than the median and half will be lower than the median. The median is a method of estimating a central or typical value while avoiding bias caused by extremely high or low values in the data set. All sites are included when calculating the medians, even those sites for which no measurable release of a particular radionuclide is reported. If the majority of reactors did not detect a radionuclide, the median will be zero (and the corresponding table entry will be blank).

If no value is listed for a particular radionuclide in a table, it is because the licensee indicated the radionuclide was not detected at that NPP. In those cases, the corresponding graph will not contain information on that radionuclide at that NPP.

On the following pages, the tables are presented first. In general, on each table, the information is organized in order of increasing activity. The facilities discharging the least activity are shown near the top of each table, while the facilities discharging the most activity are shown toward the bottom of each table. The median is shown in the middle of each data set.

The figures are shown following the tables. In general, on each figure, the information is organized in order of decreasing activity. The facilities discharging the most activity of the selected radionuclides are shown near the top of the figure, while the facilities discharging the least activity of the selected radionuclides are shown toward the bottom of each figure. The median is shown in the middle of each data set.

Figures with information on more than one radionuclide contain two graphs, shown side by side on a single page. Such a figure is referred to as a dual graph in this report. For example, Figure 3.1 is a dual graph. In figures with dual graphs, the total activity of the selected radionuclides is shown on one graph, while the relative contribution of each radionuclide to the total activity is shown on the other graph. The relative contributions of each nuclide are shown—in multiple colors—as a percent of the total activity. A dual graph allows the reader to compare not only the activity but also the distribution of selected radionuclides released by the various facilities. Dual graphs contain two separate scales. The total activity is shown on a logarithmic scale, while the radionuclide distributions are shown on a linear scale.

Table 3.1

BWR Gaseous Releases — Selected Fission and Activation Gases, 2009

BWR Facility	Kr-85 (Ci)	Xe-133 (Ci)	Xe-135 (Ci)
Browns Ferry 1			
Browns Ferry 2			
Browns Ferry 3			
Clinton			
Susquehanna 1			
Susquehanna 2			
Vermont Yankee			
Fermi 2		1.72E-01	7.18E-02
Perry		1.61E-02	3.20E-01
Hatch 1		9.72E-01	9.86E-01
Hatch 2		9.72E-01	9.86E-01
Quad Cities 1		1.31E+00	2.10E+00
Quad Cities 2		1.31E+00	2.10E+00
Duane Arnold			3.79E+00
Hope Creek	1.59E-01	8.06E-01	4.56E+00
Dresden 2		1.79E+00	4.36E+00
Dresden 3		1.79E+00	4.36E+00
Limerick 1	4.76E-01	2.80E+00	3.18E+00

BWR Facility	Kr-85 (Ci)	Xe-133 (Ci)	Xe-135 (Ci)
Limerick 2	4.76E-01	2.80E+00	3.18E+00
BWR Median Release		**1.31E+00**	**3.79E+00**
Columbia			7.69E+00
Pilgrim		1.28E+00	7.01E+00
Nine Mile Point 1		6.07E+00	3.17E+00
Oyster Creek			1.54E+01
FitzPatrick		1.59E+01	2.20E-01
Grand Gulf		7.60E+00	2.02E+01
Cooper	8.97E-01	1.70E+01	1.32E+01
River Bend		5.24E+00	4.65E+01
Brunswick 1		1.37E+01	4.34E+01
Brunswick 2		1.37E+01	4.34E+01
Nine Mile Point 2		1.01E+02	9.19E+00
Peach Bottom 2		1.12E+02	1.17E+01
Peach Bottom 3		1.12E+02	1.17E+01
Monticello		2.88E+02	9.46E+01
LaSalle 1		6.77E+02	1.76E+02
LaSalle 2		6.77E+02	1.76E+02

Table 3.2
BWR Gaseous Releases — Iodine, 2009

BWR Facility	I-131 (Ci)
Susquehanna 1	
Susquehanna 2	
Limerick 1	4.39E-05
Limerick 2	4.39E-05
Vermont Yankee	5.38E-05
Duane Arnold	5.97E-05
Columbia	9.42E-05
Clinton	1.29E-04
Hatch 2	1.39E-04
Hatch 1	1.51E-04
Oyster Creek	1.61E-04
Perry	1.98E-04
FitzPatrick	2.12E-04
Grand Gulf	2.58E-04
Cooper	3.17E-04
Browns Ferry 1	4.50E-04
Browns Ferry 2	4.50E-04
Browns Ferry 3	4.50E-04

BWR Facility	I-131 (Ci)
BWR Median Release	**4.50E-04**
Dresden 2	4.75E-04
Dresden 3	4.75E-04
Nine Mile Point 1	6.00E-04
Quad Cities 1	1.67E-03
Quad Cities 2	1.67E-03
Fermi 2	1.69E-03
Peach Bottom 2	2.06E-03
Peach Bottom 3	2.06E-03
Pilgrim	4.23E-03
Nine Mile Point 2	5.11E-03
Hope Creek	7.06E-03
River Bend	7.68E-03
Monticello	1.35E-02
Brunswick 1	2.14E-02
Brunswick 2	2.14E-02
LaSalle 1	2.64E-02
LaSalle 2	2.64E-02

Table 3.3
BWR Gaseous Releases — Selected Particulates, 2009

BWR Facility	Co-58 (Ci)	Co-60 (Ci)	Cs-134 (Ci)	Cs-137 (Ci)
FitzPatrick				
Perry				
Vermont Yankee				
Hatch 2				1.15E-07
Clinton		4.94E-06		
Grand Gulf	5.45E-06	5.34E-06		3.62E-07
Limerick 1		1.19E-05		
Limerick 2		1.19E-05		
Peach Bottom 2	3.33E-07	3.13E-05		9.33E-07
Peach Bottom 3	3.33E-07	3.13E-05		9.33E-07
Browns Ferry 1	5.66E-06	3.08E-05		3.40E-06
Browns Ferry 2	5.66E-06	3.08E-05		3.40E-06
Browns Ferry 3	5.66E-06	3.08E-05		3.40E-06
Susquehanna 1		7.91E-05		
Susquehanna 2		7.91E-05		
River Bend		9.21E-05		
Pilgrim	6.01E-06	7.36E-05		1.82E-05
Hatch 1	4.08E-05	6.17E-05		1.15E-07
BWR Median Release	**5.45E-06**	**9.21E-05**		**3.62E-07**

Table 3.3 *(continued)*

BWR Gaseous Releases — Selected Particulates, 2009

BWR Facility	Co-58 (Ci)	Co-60 (Ci)	Cs-134 (Ci)	Cs-137 (Ci)
Oyster Creek		1.27E-04		
Hope Creek		1.63E-04		
Duane Arnold	4.27E-05	1.36E-04		3.70E-07
Dresden 2	4.05E-06	1.83E-04		1.31E-06
Dresden 3	4.05E-06	1.83E-04		1.31E-06
Columbia	1.98E-05	1.99E-04		2.60E-06
Brunswick 1	3.47E-05	1.98E-04		1.60E-06
Brunswick 2	3.47E-05	1.98E-04		1.60E-06
Cooper	6.06E-06	2.50E-04		2.58E-07
Quad Cities 1	7.45E-06	4.23E-04		4.26E-06
Quad Cities 2	7.45E-06	4.23E-04		4.26E-06
Fermi 2	2.93E-04	2.87E-04		
Monticello	2.72E-06	3.86E-04		2.52E-04
LaSalle 1	6.80E-05	1.11E-03		
LaSalle 2	6.80E-05	1.11E-03		
Nine Mile Point 1	1.61E-04	2.98E-03		1.03E-04
Nine Mile Point 2	3.96E-04	3.09E-03	8.21E-07	9.27E-06

Table 3.4
BWR Gaseous Releases — Tritium, 2009

BWR Facility	H-3 (Ci)
Perry	
Vermont Yankee	1.75E+00
Oyster Creek	5.48E+00
Dresden 2	6.74E+00
Dresden 3	6.74E+00
Cooper	1.14E+01
Grand Gulf	1.16E+01
Monticello	1.51E+01
Hope Creek	1.64E+01
Limerick 1	1.67E+01
Limerick 2	1.67E+01
Peach Bottom 2	1.68E+01
Peach Bottom 3	1.68E+01
River Bend	1.74E+01
FitzPatrick	1.79E+01
Susquehanna 1	1.88E+01
Susquehanna 2	1.88E+01
Hatch 2	1.96E+01

BWR Facility	H-3 (Ci)
BWR Median Release	**1.96E+01**
Columbia	2.01E+01
Hatch 1	2.94E+01
LaSalle 1	2.95E+01
LaSalle 2	2.95E+01
Browns Ferry 1	3.18E+01
Browns Ferry 2	3.18E+01
Browns Ferry 3	3.18E+01
Duane Arnold	3.61E+01
Nine Mile Point 1	3.63E+01
Clinton	4.94E+01
Quad Cities 1	6.04E+01
Quad Cities 2	6.04E+01
Pilgrim	6.77E+01
Fermi 2	7.36E+01
Nine Mile Point 2	1.06E+02
Brunswick 1	1.19E+02
Brunswick 2	1.19E+02

Table 3.5

PWR Gaseous Releases — Selected Fission and Activation Gases, 2009

PWR Facility	Kr-85 (Ci)	Xe-133 (Ci)	Xe-135 (Ci)
Farley 2		3.52E-04	2.35E-04
Seabrook		3.21E-02	4.34E-03
Beaver Valley 2		4.71E-02	4.44E-03
Point Beach 1	4.33E-03	2.72E-02	2.15E-02
Point Beach 2	4.33E-03	2.72E-02	2.15E-02
Beaver Valley 1		7.14E-02	3.11E-03
McGuire 1	1.47E-02	5.15E-02	1.65E-02
McGuire 2	1.47E-02	5.15E-02	1.65E-02
Crystal River 3		9.13E-02	
Kewaunee		1.12E-01	6.32E-03
Robinson 2	3.06E-02	9.53E-02	6.99E-05
St. Lucie 1		2.53E-03	3.27E-01
Wolf Creek	1.94E-02	2.70E-01	4.83E-02
Diablo Canyon 1	2.02E-01	1.52E-01	2.37E-05
Diablo Canyon 2	2.02E-01	1.52E-01	2.37E-05
Catawba 1	4.05E-03	3.77E-01	3.32E-02
Catawba 2	4.05E-03	3.77E-01	3.32E-02
Summer	1.13E-01	3.56E-02	2.72E-01
Indian Point 3	8.06E-03	3.64E-01	1.79E-01
Prairie Island 1	5.50E-01	9.74E-04	1.12E-05
Prairie Island 2	5.50E-01	9.74E-04	1.12E-05
Byron 2		5.56E-01	2.52E-02
Salem 2		5.96E-01	1.94E-03
Farley 1		6.17E-01	3.79E-02
Surry 1		6.19E-01	4.07E-02
Surry 2		6.19E-01	4.07E-02
Palo Verde 2	1.68E-01	6.07E-01	
Sequoyah 1	2.23E-02	7.89E-01	4.11E-02
Sequoyah 2	2.23E-02	7.89E-01	4.11E-02
Palo Verde 1		2.18E-01	7.23E-01
Arkansas 1	9.45E-01	2.16E-04	
South Texas 2		1.48E+00	
Indian Point 2		1.51E+00	1.26E-01
Three Mile Island 1	1.37E-01	1.94E+00	9.41E-03
Comanche Peak 1	2.24E+00	4.44E-02	1.31E-02
Comanche Peak 2	2.24E+00	4.44E-02	1.31E-02

Table 3.5 *(continued)*

PWR Gaseous Releases — Selected Fission and Activation Gases, 2009

PWR Facility	Kr-85 (Ci)	Xe-133 (Ci)	Xe-135 (Ci)
PWR Median Release	**2.23E-02**	**7.89E-01**	**3.79E-02**
Cook 1	2.18E+00	1.81E-01	3.92E-03
Cook 2	2.18E+00	1.81E-01	3.92E-03
Harris	1.18E-03	2.65E+00	
St. Lucie 2		2.64E+00	6.58E-02
Ginna		2.64E+00	1.32E-01
South Texas 1		2.96E+00	1.63E-03
Ft. Calhoun	1.75E-03	3.19E+00	5.82E-02
Braidwood 1	2.21E-01	3.79E+00	4.72E-01
Watts Bar	4.92E-03	3.62E+00	1.13E+00
Braidwood 2	2.21E-01	5.18E+00	4.72E-01
Oconee 1	1.73E+00	4.98E+00	8.57E-02
Oconee 2	1.73E+00	4.98E+00	8.57E-02
Oconee 3	1.73E+00	4.98E+00	8.57E-02
Millstone 3	4.15E+00	4.51E+00	1.93E-02
Byron 1	1.05E+01	8.90E-01	2.56E-02
Palo Verde 3		1.64E+01	5.87E+00
North Anna 1	9.57E+00	1.63E+01	1.06E-01
North Anna 2	9.57E+00	1.63E+01	1.06E-01
Salem 1		2.79E+01	
Palisades	1.89E-03	3.31E+01	6.03E-01
Millstone 2	2.60E+01	9.80E+00	1.57E-01
San Onofre 2	8.38E-01	5.10E+01	1.76E-03
San Onofre 3	8.38E-01	5.10E+01	1.76E-03
Calvert Cliffs 1	3.42E+01	8.27E+01	1.20E+00
Calvert Cliffs 2	3.42E+01	8.27E+01	1.20E+00
Turkey Point 4	1.13E+00	1.24E+02	2.40E-01
Turkey Point 3	2.10E+00	1.58E+02	2.86E-01
Davis-Besse	1.01E+02	7.43E+01	9.86E-02
Callaway	3.72E-01	1.95E+02	4.97E+00
Vogtle 1		2.53E+02	6.22E+00
Arkansas 2	1.16E+01	2.86E+02	1.19E+01
Vogtle 2	6.36E-01	7.31E+02	1.53E+01
Waterford 3	4.19E+01	3.41E+03	8.38E+01

Table 3.6
PWR Gaseous Releases — Iodine, 2009

PWR Facility	I-131 (Ci)
Catawba 1	
Catawba 2	
Comanche Peak 1	
Comanche Peak 2	
Farley 2	
Harris	
Indian Point 2	
Indian Point 3	
Kewaunee	
Palo Verde 1	
Prairie Island 1	
Prairie Island 2	
South Texas 1	
Wolf Creek	
Salem 1	5.68E-14
Surry 1	1.18E-08
Surry 2	1.18E-08
Point Beach 1	2.97E-08
Point Beach 2	2.97E-08
South Texas 2	3.11E-08
Cook 1	1.34E-07
Cook 2	1.34E-07
Beaver Valley 1	1.77E-07
Vogtle 2	3.35E-07
St. Lucie 1	7.34E-07
Beaver Valley 2	8.29E-07
Three Mile Island 1	1.21E-06
Callaway	1.97E-06
Robinson 2	2.34E-06
Salem 2	2.53E-06
Ginna	4.05E-06
Ft. Calhoun	4.16E-06
McGuire 1	4.21E-06
McGuire 2	4.21E-06
Arkansas 1	5.20E-06

PWR Facility	I-131 (Ci)
PWR Median Release	**5.20E-06**
Farley 1	6.48E-06
Sequoyah 1	6.88E-06
Sequoyah 2	6.88E-06
Crystal River 3	7.83E-06
Millstone 3	1.11E-05
Seabrook	1.18E-05
Byron 1	1.30E-05
Summer	2.07E-05
Palo Verde 2	2.10E-05
Braidwood 2	2.73E-05
Palo Verde 3	2.95E-05
Diablo Canyon 1	4.62E-05
Diablo Canyon 2	4.62E-05
St. Lucie 2	6.29E-05
Millstone 2	6.47E-05
Byron 2	8.85E-05
Braidwood 1	9.93E-05
Davis-Besse	1.20E-04
Oconee 1	1.25E-04
Oconee 2	1.25E-04
Oconee 3	1.25E-04
San Onofre 2	1.49E-04
San Onofre 3	1.49E-04
Watts Bar	1.88E-04
Vogtle 1	4.33E-04
Palisades	4.77E-04
North Anna 1	4.95E-04
North Anna 2	4.95E-04
Arkansas 2	6.62E-04
Waterford 3	9.15E-04
Calvert Cliffs 1	2.21E-03
Calvert Cliffs 2	2.21E-03
Turkey Point 4	2.24E-02
Turkey Point 3	2.39E-02

Table 3.7
PWR Gaseous Releases — Selected Particulates, 2009

PWR Facility	Co-58 (Ci)	Co-60 (Ci)	Cs-134 (Ci)	Cs-137 (Ci)
Arkansas 1				
Arkansas 2				
Braidwood 1				
Byron 1				
Callaway				
Catawba 1				
Catawba 2				
Comanche Peak 1				
Comanche Peak 2				
Cook 1				
Cook 2				
Davis-Besse				
Farley 2				
Ginna				
Indian Point 3				
Kewaunee				
Palo Verde 1				
Summer				
Turkey Point 4				
Vogtle 2				
Wolf Creek				
Calvert Cliffs 1		4.88E-09		
Calvert Cliffs 2		4.88E-09		
Robinson 2		1.08E-07		
Millstone 3		1.86E-07		
Millstone 2	2.70E-07			9.50E-08
Palisades	2.38E-07	1.54E-07		1.31E-08
Farley 1	1.09E-07	2.74E-07		2.41E-08
Oconee 1				4.38E-07
Oconee 2				4.38E-07
Oconee 3				4.38E-07
Ft. Calhoun	6.43E-07			
Byron 2	8.68E-07			
Point Beach 1	2.79E-07	7.35E-07		1.13E-08
Point Beach 2	2.79E-07	7.35E-07		1.13E-08
PWR Median Release	**2.70E-07**			

Table 3.7 *(continued)*

PWR Gaseous Releases — Selected Particulates, 2009

PWR Facility	Co-58 (Ci)	Co-60 (Ci)	Cs-134 (Ci)	Cs-137 (Ci)
Prairie Island 1	3.36E-06			
Prairie Island 2	3.36E-06			
South Texas 2	3.39E-06			
Salem 1		2.27E-13	1.14E-13	3.57E-06
St. Lucie 2	7.08E-07	2.52E-07		3.78E-06
McGuire 1	6.26E-06			
McGuire 2	6.26E-06			
Braidwood 2	7.20E-06			
North Anna 1	3.56E-06	3.89E-06		6.39E-07
North Anna 2	3.56E-06	3.89E-06		6.39E-07
Indian Point 2				9.32E-06
Crystal River 3	4.91E-06	2.73E-06		2.51E-06
Salem 2		4.11E-06	3.28E-06	4.89E-06
Turkey Point 3	1.12E-05	3.69E-06		
St. Lucie 1		1.71E-05		3.77E-06
Surry 1	2.51E-05			4.95E-06
Surry 2	2.51E-05			4.95E-06
Waterford 3	1.56E-05	3.86E-06	6.83E-06	8.75E-06
South Texas 1	4.77E-05	6.20E-06		
Palo Verde 2	6.64E-05	3.86E-06		
Watts Bar	8.41E-06	6.94E-05		
Beaver Valley 2	7.08E-05	9.84E-06		6.11E-07
Vogtle 1	7.71E-05	8.81E-06		
Palo Verde 3	8.28E-05	6.95E-06		1.13E-06
Sequoyah 1	9.85E-05	3.57E-06		
Sequoyah 2	9.85E-05	3.57E-06		
Diablo Canyon 1	9.23E-05	1.88E-05		
Diablo Canyon 2	9.23E-05	1.88E-05		
San Onofre 2	6.88E-05	3.15E-05	1.73E-06	1.28E-05
San Onofre 3	6.88E-05	3.15E-05	1.73E-06	1.28E-05
Harris	4.53E-06	1.34E-04		
Beaver Valley 1	2.11E-04	1.31E-05		6.11E-07
Seabrook	7.79E-04			
Three Mile Island 1	7.73E-03	5.25E-04		9.67E-05

Table 3.8

PWR Gaseous Releases — Tritium, 2009

PWR Facility	H-3 (Ci)
Summer	1.39E+00
Turkey Point 4	1.87E+00
Calvert Cliffs 1	2.33E+00
Calvert Cliffs 2	2.33E+00
St. Lucie 1	2.48E+00
St. Lucie 2	3.89E+00
Prairie Island 1	5.20E+00
Prairie Island 2	5.20E+00
Beaver Valley 1	6.12E+00
Beaver Valley 2	6.12E+00
Robinson 2	6.27E+00
Ft. Calhoun	6.53E+00
North Anna 1	8.56E+00
North Anna 2	8.56E+00
Turkey Point 3	8.78E+00
Crystal River 3	1.10E+01
Indian Point 2	1.21E+01
Vogtle 2	1.64E+01
Oconee 1	1.89E+01
Oconee 2	1.89E+01
Oconee 3	1.89E+01
Farley 2	1.91E+01
Arkansas 1	1.92E+01
Indian Point 3	1.93E+01
Surry 1	2.02E+01
Surry 2	2.02E+01
Sequoyah 1	2.27E+01
Sequoyah 2	2.27E+01
Farley 1	2.34E+01
Comanche Peak 1	2.81E+01
Comanche Peak 2	2.81E+01
Millstone 2	3.13E+01
Callaway	3.49E+01
Arkansas 2	3.58E+01
Point Beach 1	4.08E+01

PWR Facility	H-3 (Ci)
Point Beach 2	4.08E+01
PWR Median Release	**4.08E+01**
Palisades	4.11E+01
San Onofre 2	4.28E+01
San Onofre 3	4.28E+01
Wolf Creek	4.40E+01
Kewaunee	4.59E+01
Millstone 3	4.67E+01
Davis-Besse	4.90E+01
Byron 2	5.17E+01
Byron 1	5.30E+01
Vogtle 1	5.33E+01
Watts Bar	5.36E+01
Ginna	6.13E+01
South Texas 2	6.28E+01
South Texas 1	6.65E+01
Waterford 3	6.74E+01
Three Mile Island 1	7.13E+01
McGuire 1	8.32E+01
McGuire 2	8.32E+01
Braidwood 2	8.75E+01
Cook 1	9.06E+01
Cook 2	9.06E+01
Diablo Canyon 1	9.84E+01
Diablo Canyon 2	9.84E+01
Salem 2	1.09E+02
Seabrook	1.37E+02
Catawba 1	1.62E+02
Catawba 2	1.62E+02
Harris	2.12E+02
Salem 1	2.36E+02
Braidwood 1	2.44E+02
Palo Verde 1	3.11E+02
Palo Verde 3	5.35E+02
Palo Verde 2	7.44E+02

Table 3.9

BWR Liquid Releases — Selected Fission and Activation Products, 2009

BWR Facility	Co-58 (Ci)	Co-60 (Ci)	Cs-134 (Ci)	Cs-137 (Ci)	Fe-55 (Ci)	I-131 (Ci)
Clinton						
Columbia						
Duane Arnold						
Fermi 2						
FitzPatrick						
LaSalle 1						
LaSalle 2						
Monticello						
Nine Mile Point 2						
Oyster Creek						
Vermont Yankee						
Cooper	3.37E-05	1.93E-04				
Pilgrim	1.96E-05	1.95E-04	2.26E-06	2.33E-05		
Nine Mile Point 1		3.45E-04			1.83E-05	
River Bend		9.34E-04				
Limerick 1	2.69E-05	1.21E-03	1.13E-06	1.24E-05		1.13E-06
Limerick 2	2.69E-05	1.21E-03	1.13E-06	1.24E-05		1.13E-06
Dresden 2	9.80E-06	5.65E-04		3.14E-05	1.41E-03	
Dresden 3	9.80E-06	5.65E-04		3.14E-05	1.41E-03	
BWR Median Release	**1.19E-05**	**6.59E-04**		**1.24E-05**		
Hatch 1	3.08E-05	6.59E-04		2.02E-04	1.17E-03	
Hatch 2	8.13E-06	1.07E-04		2.97E-05	2.29E-03	
Quad Cities 1	1.19E-05	8.53E-04		5.58E-04	2.74E-03	
Quad Cities 2	1.19E-05	8.53E-04		5.58E-04	2.74E-03	
Susquehanna 1	5.28E-04	3.69E-03				
Susquehanna 2	5.28E-04	3.69E-03				
Brunswick 1	1.26E-04	4.50E-03	8.48E-06	1.37E-04		3.58E-04
Brunswick 2	1.26E-04	4.50E-03	8.48E-06	1.37E-04		3.58E-04
Browns Ferry 1	3.50E-05	1.73E-03	3.12E-04	3.20E-03	1.91E-04	
Browns Ferry 2	3.50E-05	1.73E-03	3.12E-04	3.20E-03	1.91E-04	
Browns Ferry 3	3.50E-05	1.73E-03	3.12E-04	3.20E-03	1.91E-04	
Perry	2.59E-04	1.06E-02		1.80E-04	1.96E-04	
Grand Gulf	1.22E-05	6.43E-03		8.42E-05	1.61E-02	1.52E-04
Hope Creek	3.88E-03	1.81E-02	2.83E-03	4.76E-03	8.51E-03	7.82E-08
Peach Bottom 2	5.37E-04	4.65E-02	1.57E-04	3.46E-04	1.02E-03	
Peach Bottom 3	5.37E-04	4.65E-02	1.57E-04	3.46E-04	1.02E-03	

Table 3.10

BWR Liquid Releases — Tritium, 2009

BWR Facility	H-3 (Ci)
Clinton	
Columbia	
Fermi 2	
LaSalle 1	
LaSalle 2	
Nine Mile Point 2	
Monticello	1.21E-05
Duane Arnold	1.98E-04
FitzPatrick	2.64E-02
Nine Mile Point 1	4.69E-02
Vermont Yankee	4.00E-01
Pilgrim	1.98E+00
Cooper	3.32E+00
Quad Cities 1	6.12E+00
Quad Cities 2	6.12E+00
Dresden 2	6.53E+00
Dresden 3	6.53E+00
Hope Creek	9.28E+00

BWR Facility	H-3 (Ci)
BWR Median Release	**9.28E+00**
Limerick 1	1.12E+01
Limerick 2	1.12E+01
Susquehanna 1	1.14E+01
Susquehanna 2	1.14E+01
Hatch 2	1.15E+01
Hatch 1	1.55E+01
Peach Bottom 2	1.90E+01
Peach Bottom 3	1.90E+01
Browns Ferry 1	2.81E+01
Browns Ferry 2	2.81E+01
Browns Ferry 3	2.81E+01
Perry	3.86E+01
River Bend	4.91E+01
Oyster Creek	6.81E+01
Grand Gulf	7.46E+01
Brunswick 1	1.05E+02
Brunswick 2	1.05E+02

Table 3.11

PWR Liquid Releases — Selected Fission and Activation Products, 2009

PWR Facility	Co-58 (Ci)	Co-60 (Ci)	Cs-134 (Ci)	Cs-137 (Ci)	Fe-55 (Ci)	I-131 (Ci)
Palo Verde 1						
Palo Verde 2						
Palo Verde 3						
Three Mile Island 1	9.36E-06	7.46E-05		1.29E-04		
Cook 1	5.74E-04	5.50E-04	1.33E-06	1.07E-05		
Cook 2	5.74E-04	5.50E-04	1.33E-06	1.07E-05		
Crystal River 3	3.85E-04	2.96E-04	2.12E-07	3.86E-04	2.33E-04	
Comanche Peak 1	1.10E-03	2.07E-04				
Comanche Peak 2	1.10E-03	2.07E-04				
Ft. Calhoun	8.86E-04	2.38E-04	2.18E-05	5.08E-04		4.91E-04
Robinson 2	5.53E-04	1.36E-03	6.77E-07	1.76E-05	4.59E-04	
South Texas 2	4.38E-04	1.57E-03	1.53E-04	2.49E-04	1.72E-03	
Ginna	4.32E-03	1.82E-04		1.05E-06	2.25E-04	
Oconee 1	5.15E-03	1.60E-04	3.87E-05	2.53E-05		4.33E-05
Oconee 2	5.15E-03	1.60E-04	3.87E-05	2.53E-05		4.33E-05
Oconee 3	5.15E-03	1.60E-04	3.87E-05	2.53E-05		4.33E-05
Summer	3.75E-04	3.80E-03	2.11E-04	5.39E-04	7.45E-04	9.26E-05
Indian Point 3	1.15E-03	3.97E-03		8.50E-05	7.26E-04	
San Onofre 2	2.45E-03	9.85E-04		2.79E-05	2.77E-03	4.56E-06
San Onofre 3	2.45E-03	9.85E-04		2.79E-05	2.77E-03	4.56E-06
Davis-Besse	1.33E-03	5.61E-04	2.06E-04	4.00E-04	4.45E-03	3.54E-06
Vogtle 1	1.88E-03	8.93E-04	9.74E-06	2.66E-04	3.82E-03	9.03E-05
Sequoyah 1	4.48E-03	2.08E-03	3.71E-07	8.78E-05	1.43E-03	5.86E-05
Sequoyah 2	4.48E-03	2.08E-03	3.71E-07	8.78E-05	1.43E-03	5.86E-05
Farley 1	3.86E-03	2.85E-03		8.96E-05	1.39E-03	7.02E-06
Surry 1	3.00E-03	3.63E-03		1.68E-03		5.11E-06
Surry 2	3.00E-03	3.63E-03		1.68E-03		5.11E-06
Kewaunee	1.47E-03	1.13E-03			5.81E-03	
Byron 1	7.28E-03	1.50E-03		2.52E-06		1.34E-06
Byron 2	7.28E-03	1.50E-03		2.52E-06		1.34E-06
South Texas 1	1.30E-03	4.06E-03	7.97E-06	3.16E-04	3.72E-03	
Farley 2	3.41E-03	4.24E-03		8.34E-04	1.17E-03	1.16E-05
Harris	6.27E-03	2.67E-03		4.00E-05	1.05E-03	
Seabrook	5.51E-03	4.09E-04		1.58E-05	4.24E-03	2.57E-05
McGuire 1	5.81E-03	4.27E-03	4.08E-05	2.28E-04		
McGuire 2	5.81E-03	4.27E-03	4.08E-05	2.28E-04		

Table 3.11 *(continued)*

PWR Liquid Releases — Selected Fission and Activation Products, 2009

PWR Facility	Co-58 (Ci)	Co-60 (Ci)	Cs-134 (Ci)	Cs-137 (Ci)	Fe-55 (Ci)	I-131 (Ci)
PWR Median Release	**5.14E-03**	**2.08E-03**	**1.58E-06**	**2.10E-04**	**1.39E-03**	**1.34E-06**
Calvert Cliffs 1	4.18E-03	6.57E-04	1.28E-04	2.10E-04	5.66E-03	6.11E-05
Calvert Cliffs 2	4.18E-03	6.57E-04	1.28E-04	2.10E-04	5.66E-03	6.11E-05
Diablo Canyon 1	5.14E-03	2.74E-03		5.30E-06	3.75E-03	4.76E-08
Diablo Canyon 2	5.14E-03	2.74E-03		5.30E-06	3.75E-03	4.76E-08
North Anna 1	8.98E-03	2.15E-03	9.50E-05	5.86E-04		
North Anna 2	8.98E-03	2.15E-03	9.50E-05	5.86E-04		
St. Lucie 1	5.31E-03	1.51E-03	2.95E-06	5.58E-05	5.18E-03	2.31E-06
St. Lucie 2	5.31E-03	1.51E-03	2.95E-06	5.58E-05	5.18E-03	2.31E-06
Palisades	3.49E-03	9.04E-03		4.95E-05	9.27E-06	2.67E-06
Salem 2	9.09E-03	3.42E-03	2.41E-04	2.83E-03		
Arkansas 1	7.34E-03	1.51E-03	7.86E-04	3.18E-03	3.48E-03	3.39E-05
Millstone 3	1.44E-03	7.73E-03	3.85E-04	3.78E-04	6.43E-03	
Salem 1	8.91E-03	5.57E-03	1.02E-04	2.16E-03		
Vogtle 2	5.06E-03	3.09E-03	6.68E-05	1.19E-03	7.94E-03	
Waterford 3	1.21E-02	2.43E-03	4.37E-04	3.28E-04	2.87E-03	1.13E-03
Indian Point 2	6.62E-05	2.50E-04	3.69E-04	1.95E-02		
Point Beach 1	6.78E-03	1.08E-02		1.22E-03	2.31E-03	
Point Beach 2	6.78E-03	1.08E-02		1.22E-03	2.31E-03	
Catawba 1	1.58E-02	8.82E-03	9.60E-07	1.22E-04		
Catawba 2	1.58E-02	8.82E-03	9.60E-07	1.22E-04		
Arkansas 2	7.87E-03	5.68E-04	1.00E-03	1.25E-03	2.20E-02	3.83E-04
Turkey Point 3	1.07E-02	5.27E-03	3.82E-03	4.38E-03	8.78E-03	4.13E-04
Turkey Point 4	1.07E-02	5.27E-03	3.82E-03	4.38E-03	8.78E-03	4.13E-04
Wolf Creek	2.07E-02	7.82E-04	2.24E-05	1.57E-03	1.21E-02	
Callaway	2.27E-02	1.32E-02	2.71E-04	1.20E-03		2.97E-06
Millstone 2	1.18E-02	9.83E-03	7.51E-05	4.74E-04	3.15E-02	2.11E-05
Beaver Valley 1	5.19E-02	1.00E-02		1.01E-03	1.22E-02	3.08E-05
Beaver Valley 2	5.19E-02	1.00E-02		1.01E-03	1.22E-02	3.08E-05
Watts Bar	1.75E-02	1.99E-03	1.58E-06	2.06E-05	5.95E-02	1.67E-06
Prairie Island 1	5.57E-02	9.75E-03	3.59E-06	2.13E-05	5.49E-02	7.06E-06
Prairie Island 2	5.57E-02	9.75E-03	3.59E-06	2.13E-05	5.49E-02	7.06E-06
Braidwood 1	1.10E-01	1.09E-02	9.35E-04	1.07E-03	6.82E-03	
Braidwood 2	1.10E-01	1.09E-02	9.35E-04	1.07E-03	6.82E-03	

Table 3.12

PWR Liquid Releases — Tritium, 2009

PWR Facility	H-3 (Ci)
Palo Verde 1	
Palo Verde 2	
Palo Verde 3	
Kewaunee	9.63E+01
Vogtle 1	1.07E+02
St. Lucie 1	1.80E+02
St. Lucie 2	1.80E+02
Ft. Calhoun	2.21E+02
Robinson 2	2.30E+02
Catawba 1	2.41E+02
Catawba 2	2.41E+02
Oconee 1	2.42E+02
Oconee 2	2.42E+02
Oconee 3	2.42E+02
Prairie Island 1	2.59E+02
Prairie Island 2	2.59E+02
Harris	2.70E+02
Palisades	2.97E+02
Arkansas 1	3.13E+02
Point Beach 1	3.19E+02
Point Beach 2	3.19E+02
Farley 1	3.33E+02
Ginna	3.34E+02
North Anna 1	3.88E+02
North Anna 2	3.88E+02
Turkey Point 3	4.28E+02
Turkey Point 4	4.28E+02
Salem 2	4.92E+02
Farley 2	5.09E+02
Millstone 3	5.26E+02
San Onofre 2	5.29E+02
San Onofre 3	5.29E+02
Braidwood 1	5.29E+02
Braidwood 2	5.29E+02
Millstone 2	5.56E+02

PWR Facility	H-3 (Ci)
PWR Median Release	**5.56E+02**
Cook 1	5.75E+02
Cook 2	5.75E+02
Salem 1	6.24E+02
Calvert Cliffs 1	6.33E+02
Calvert Cliffs 2	6.33E+02
Davis-Besse	6.52E+02
Surry 1	6.95E+02
Surry 2	6.95E+02
Callaway	7.08E+02
Crystal River 3	7.15E+02
McGuire 1	7.48E+02
McGuire 2	7.48E+02
Arkansas 2	7.56E+02
Waterford 3	7.69E+02
Three Mile Island 1	7.87E+02
Beaver Valley 1	7.94E+02
Beaver Valley 2	7.94E+02
Comanche Peak 1	8.11E+02
Comanche Peak 2	8.11E+02
Summer	8.56E+02
Indian Point 2	8.85E+02
Byron 1	9.07E+02
Byron 2	9.07E+02
Sequoyah 1	9.07E+02
Sequoyah 2	9.07E+02
South Texas 2	9.17E+02
Indian Point 3	9.74E+02
Diablo Canyon 1	1.05E+03
Diablo Canyon 2	1.05E+03
Vogtle 2	1.12E+03
Seabrook	1.38E+03
Wolf Creek	1.40E+03
South Texas 1	1.43E+03
Watts Bar	2.07E+03

Figure 3.1
BWR Gaseous Releases — Selected Fission and Activation Gases

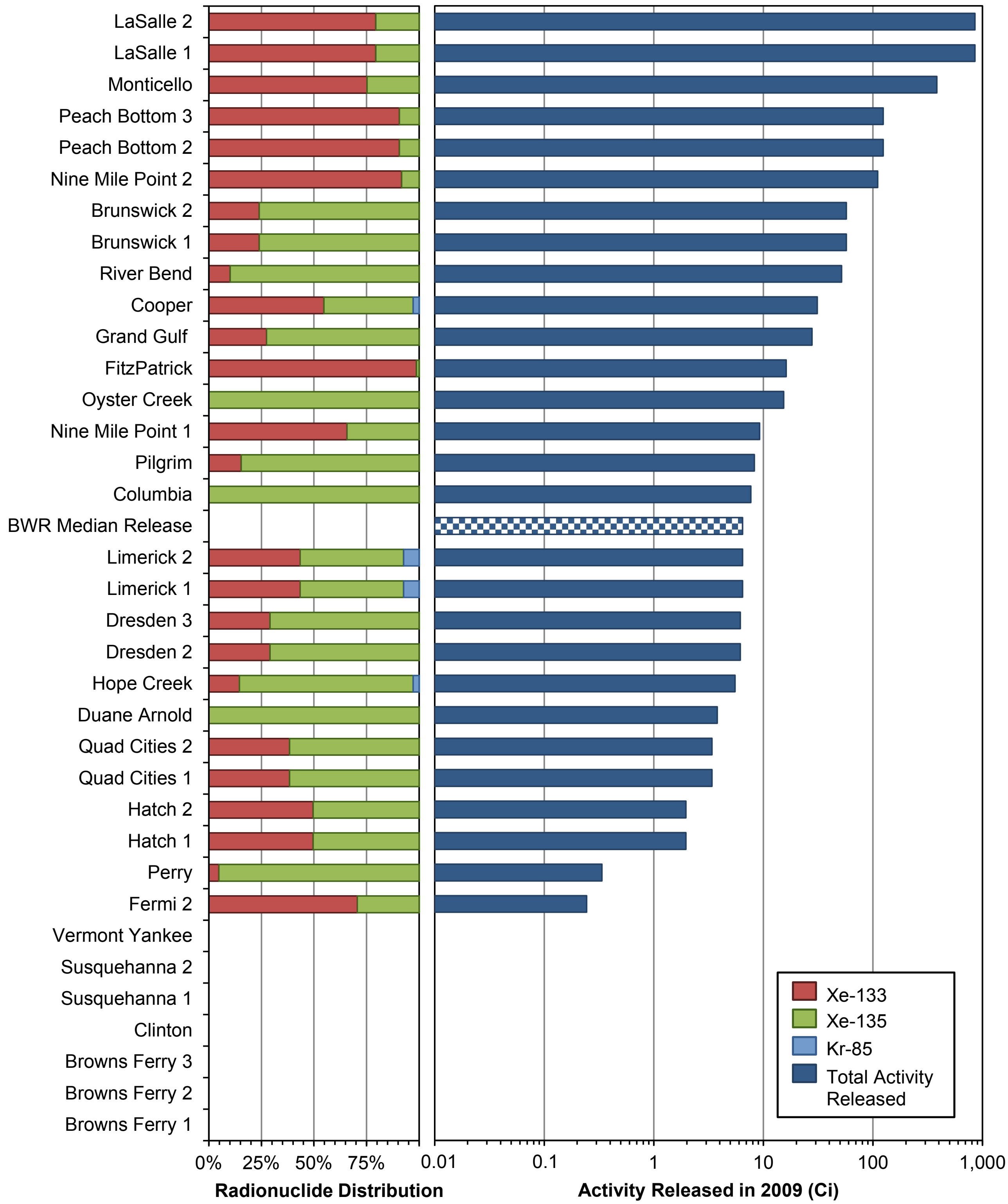


Figure 3.2
BWR Gaseous Releases — Iodine

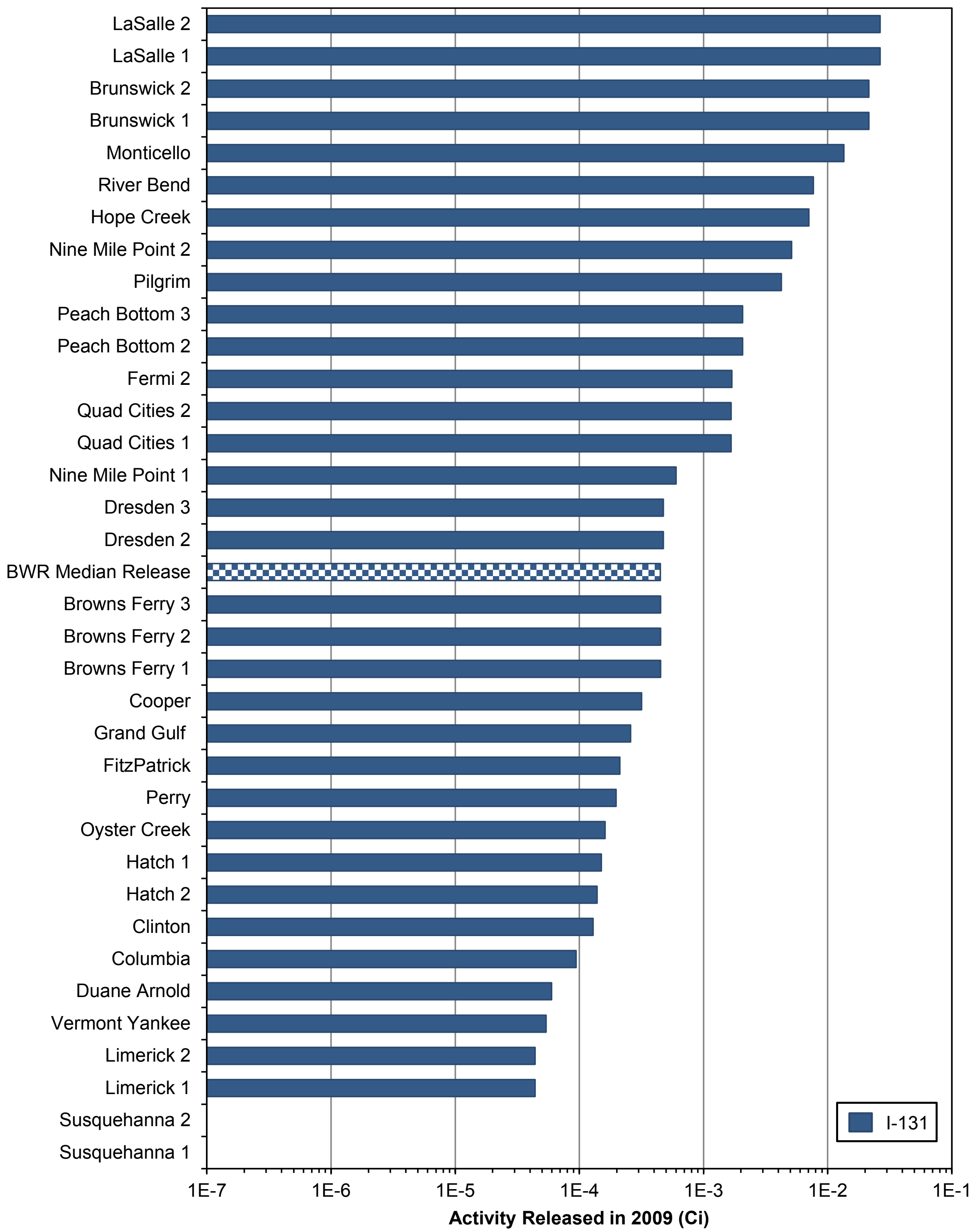


Figure 3.3

BWR Gaseous Releases — Selected Particulates

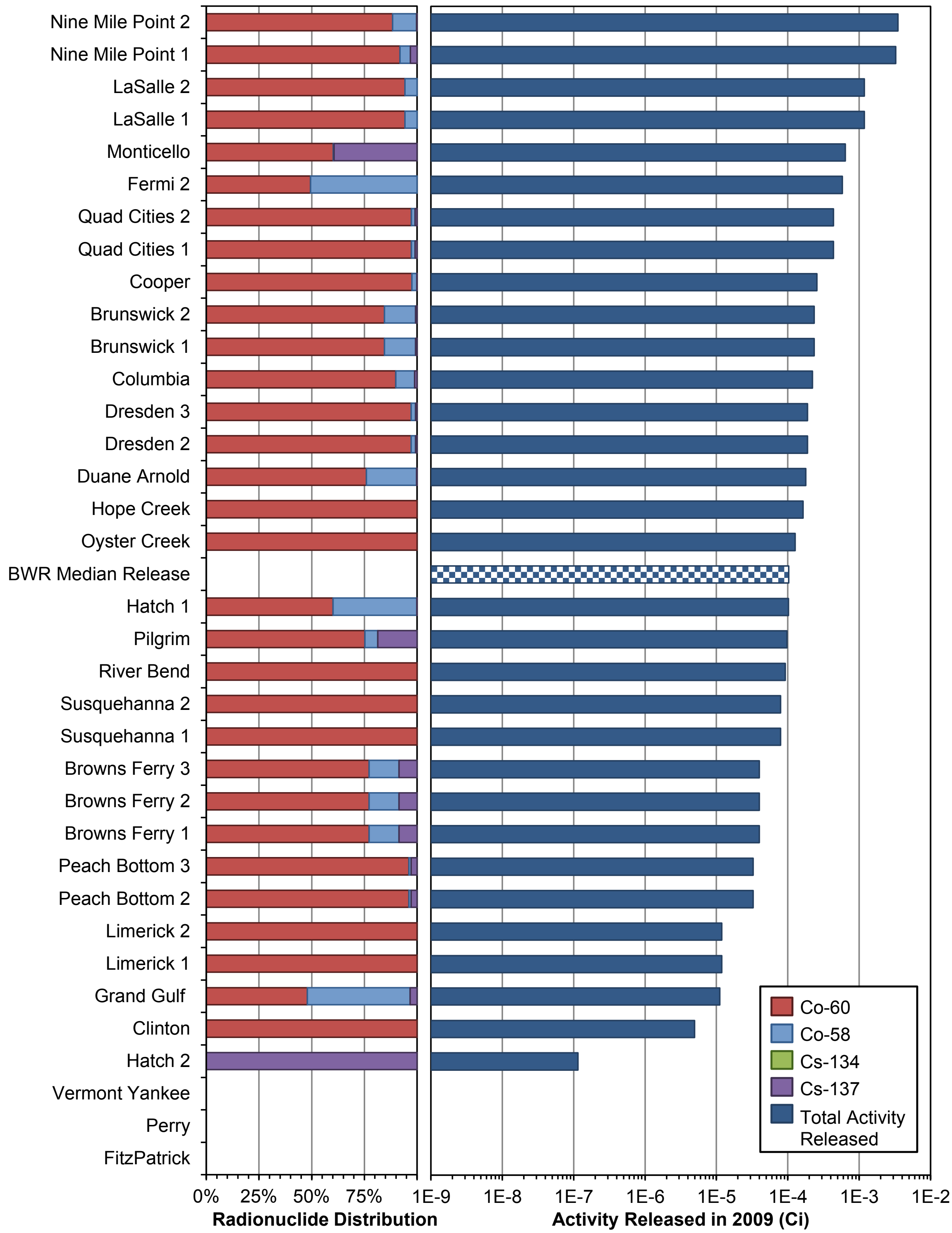


Figure 3.4
BWR Gaseous Releases — Tritium

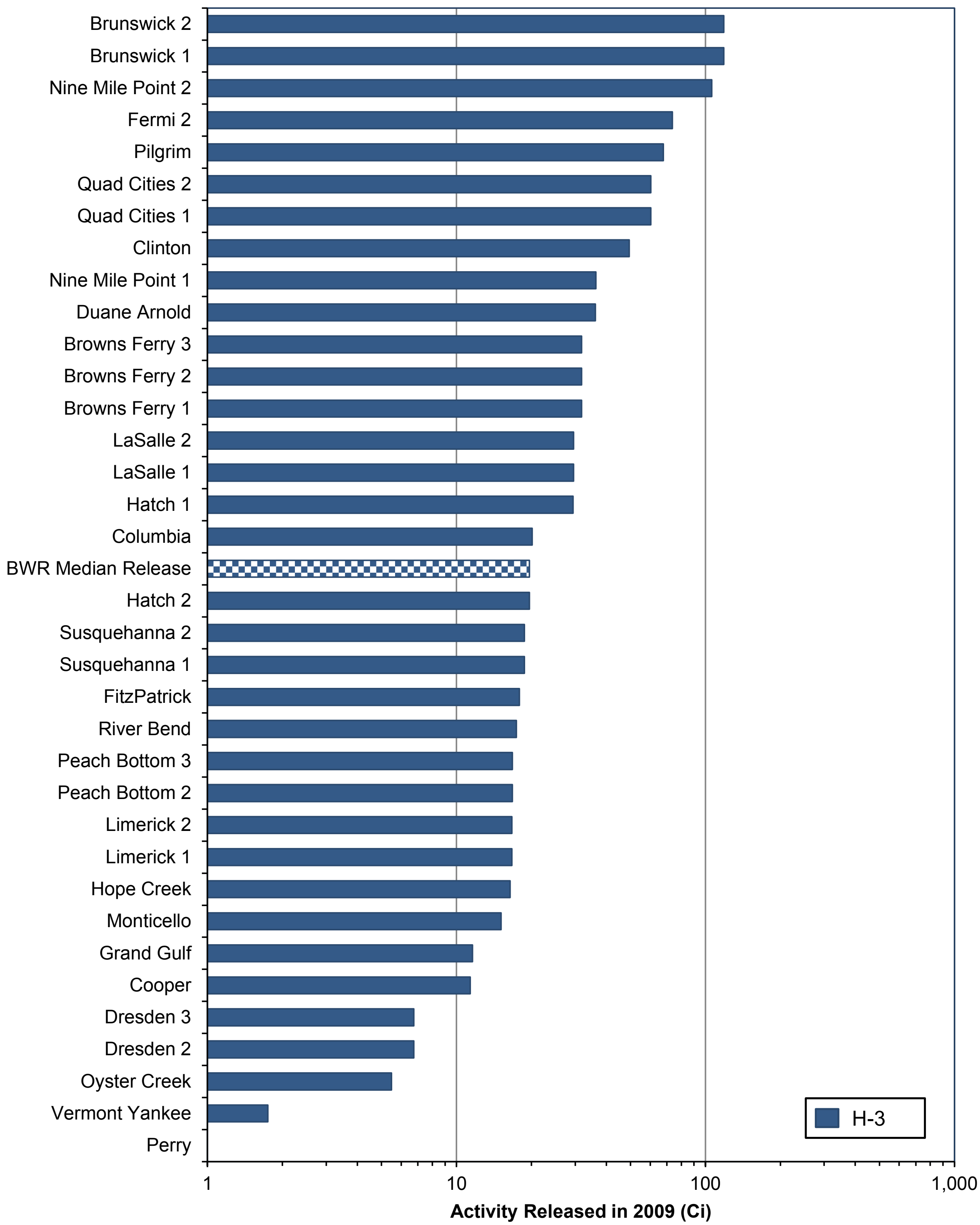


Figure 3.5

PWR Gaseous Releases — Selected Fission and Activation Gases

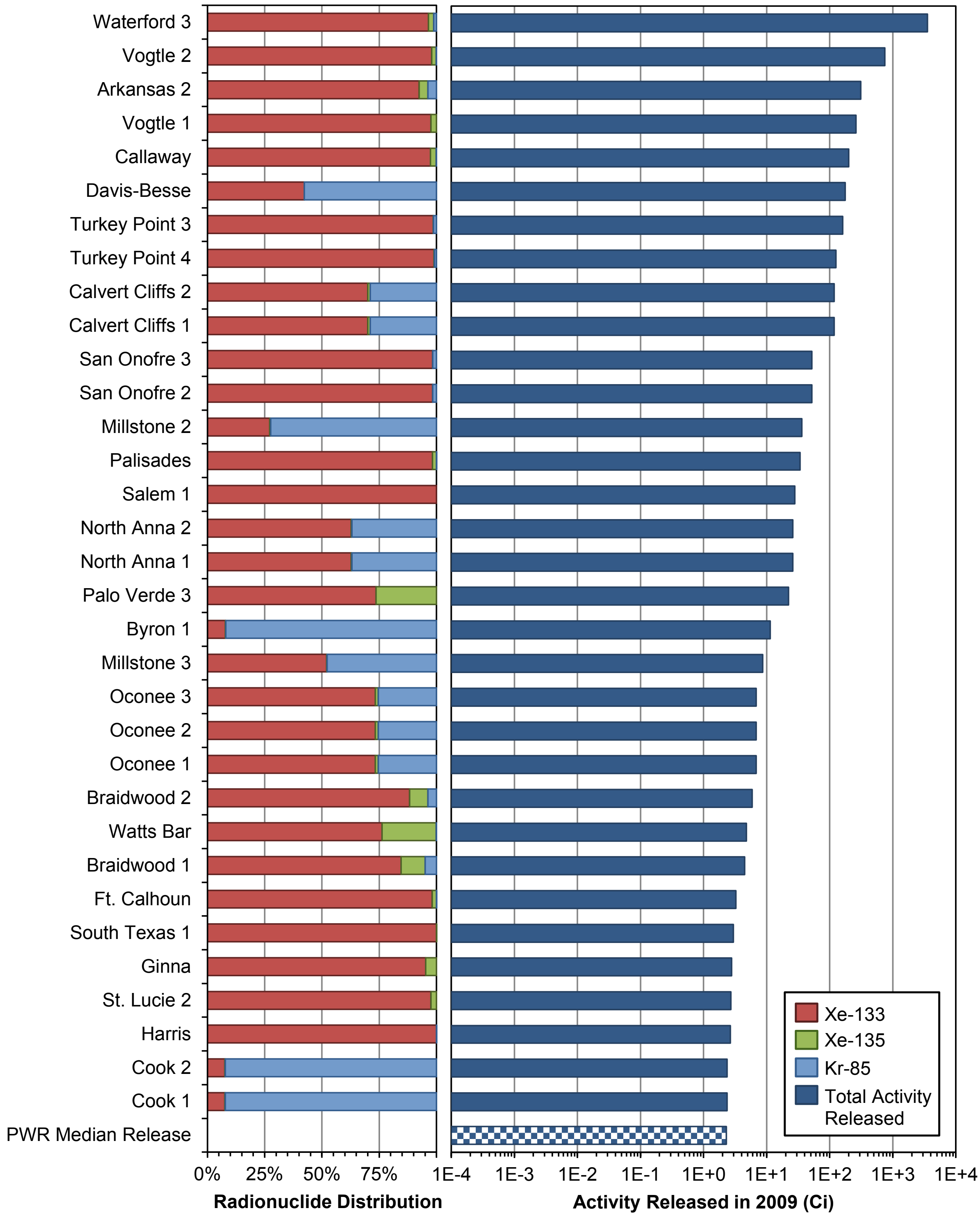


Figure 3.5 *(continued)*

PWR Gaseous Releases — Selected Fission and Activation Gases

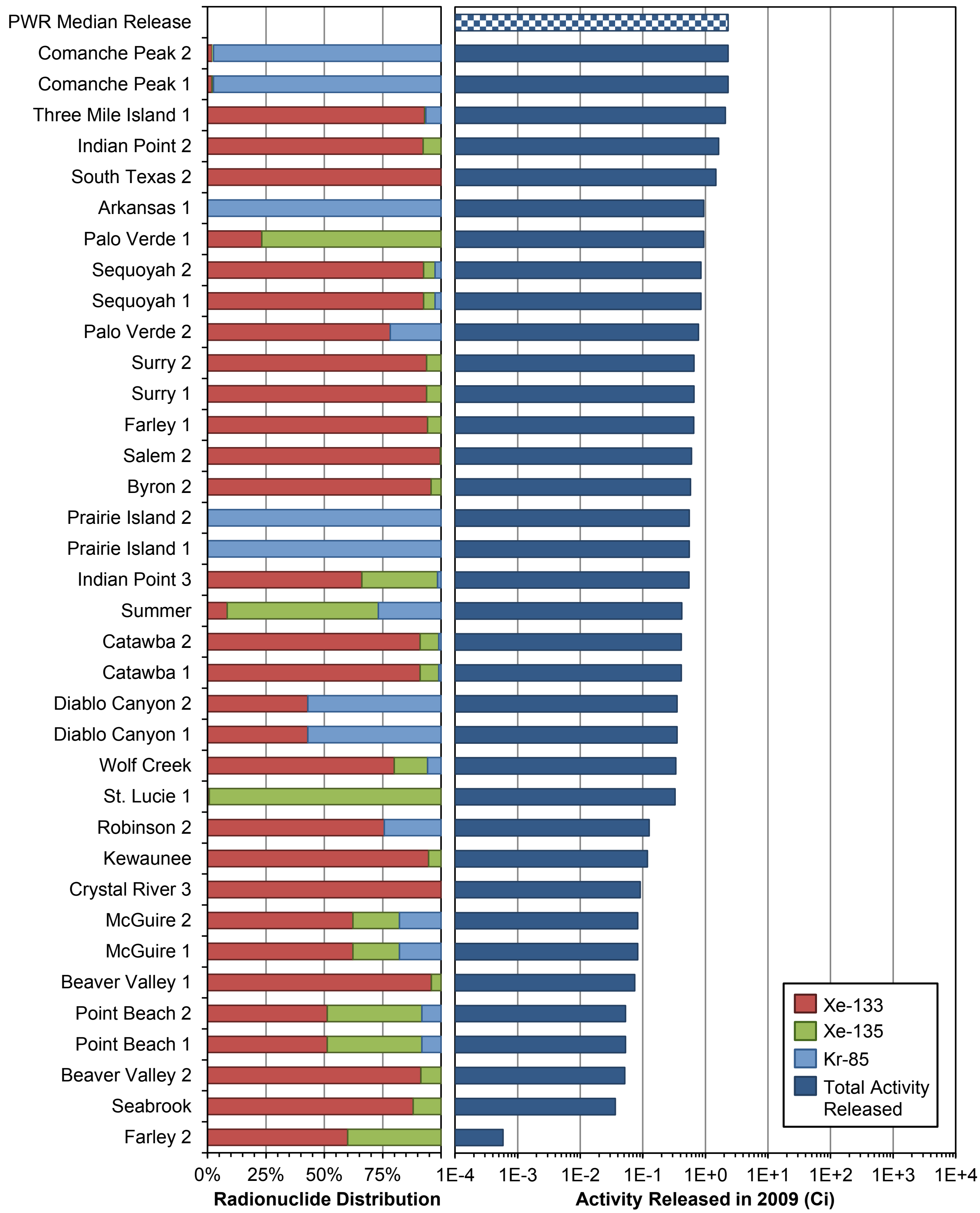


Figure 3.6
PWR Gaseous Releases — Iodine

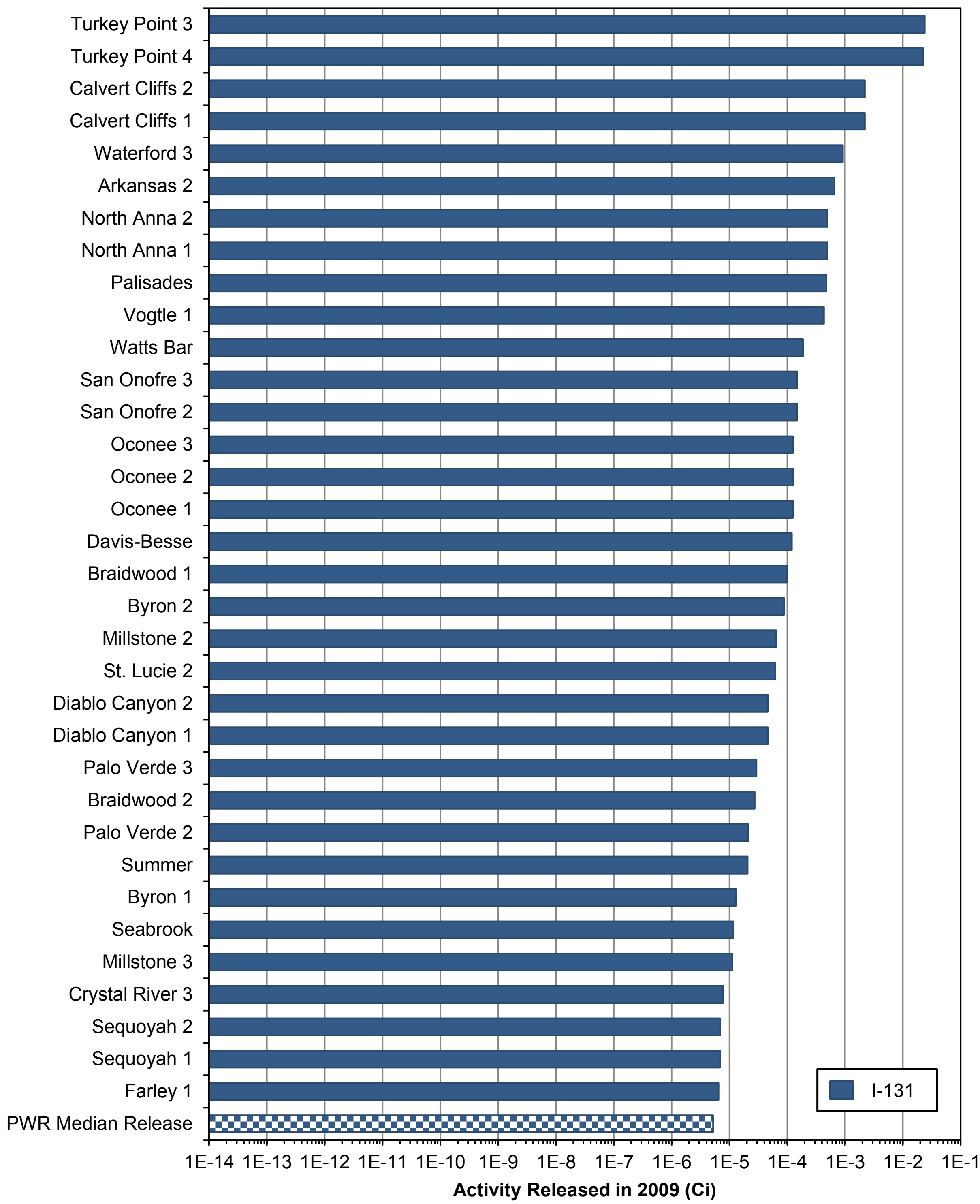


Figure 3.6 *(continued)*
PWR Gaseous Releases — Iodine

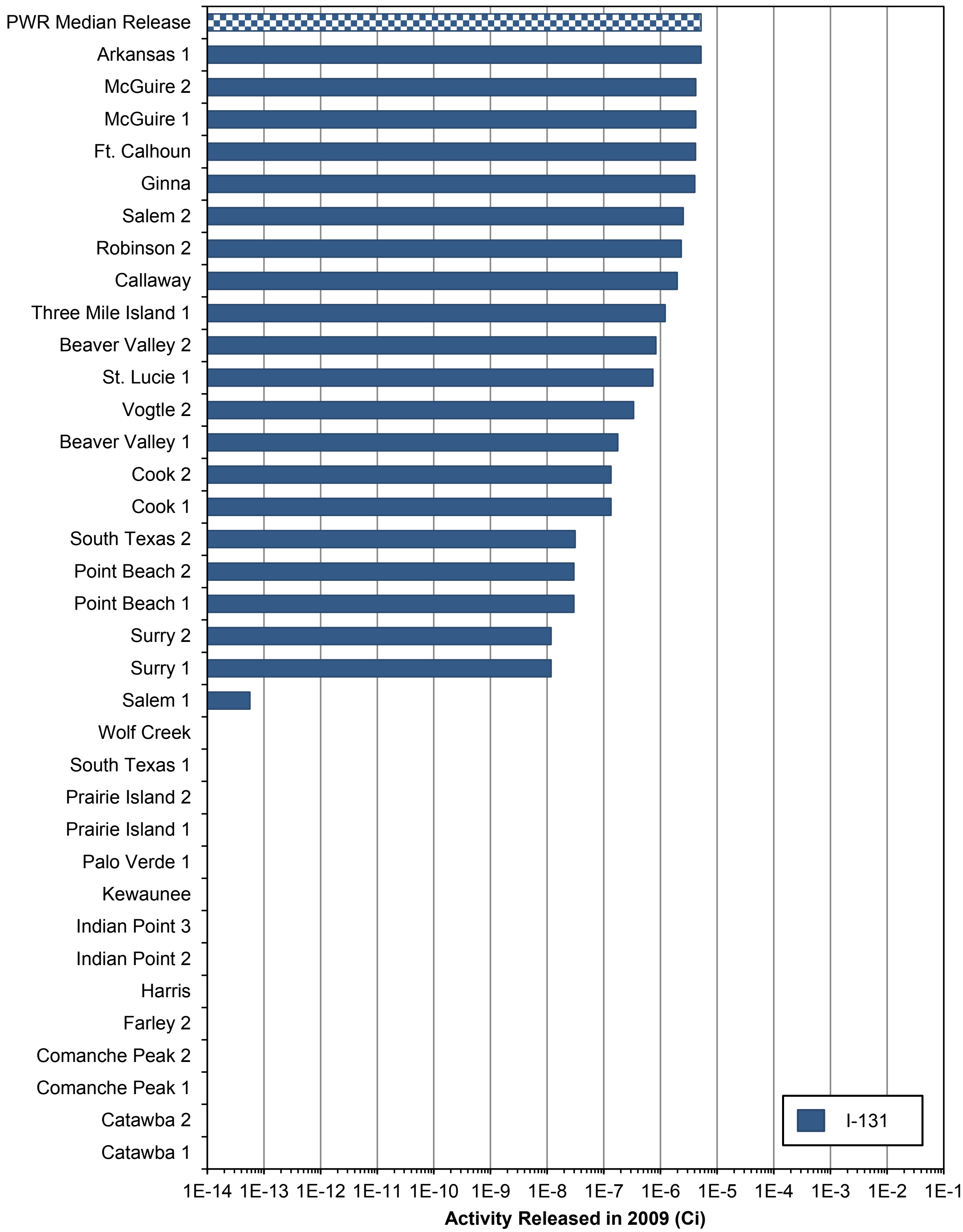


Figure 3.7
PWR Gaseous Releases — Selected Particulates

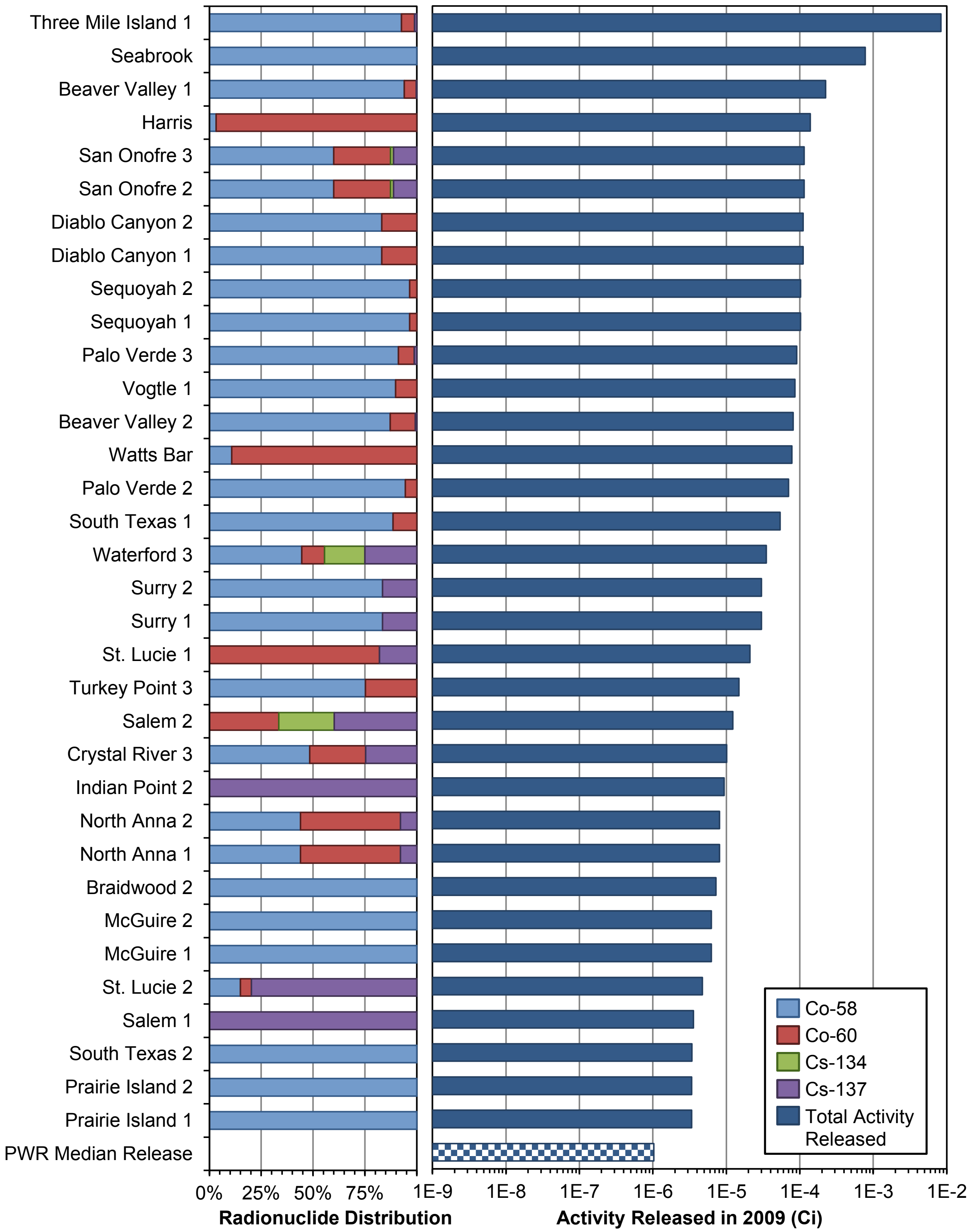


Figure 3.7 *(continued)*

PWR Gaseous Releases — Selected Particulates

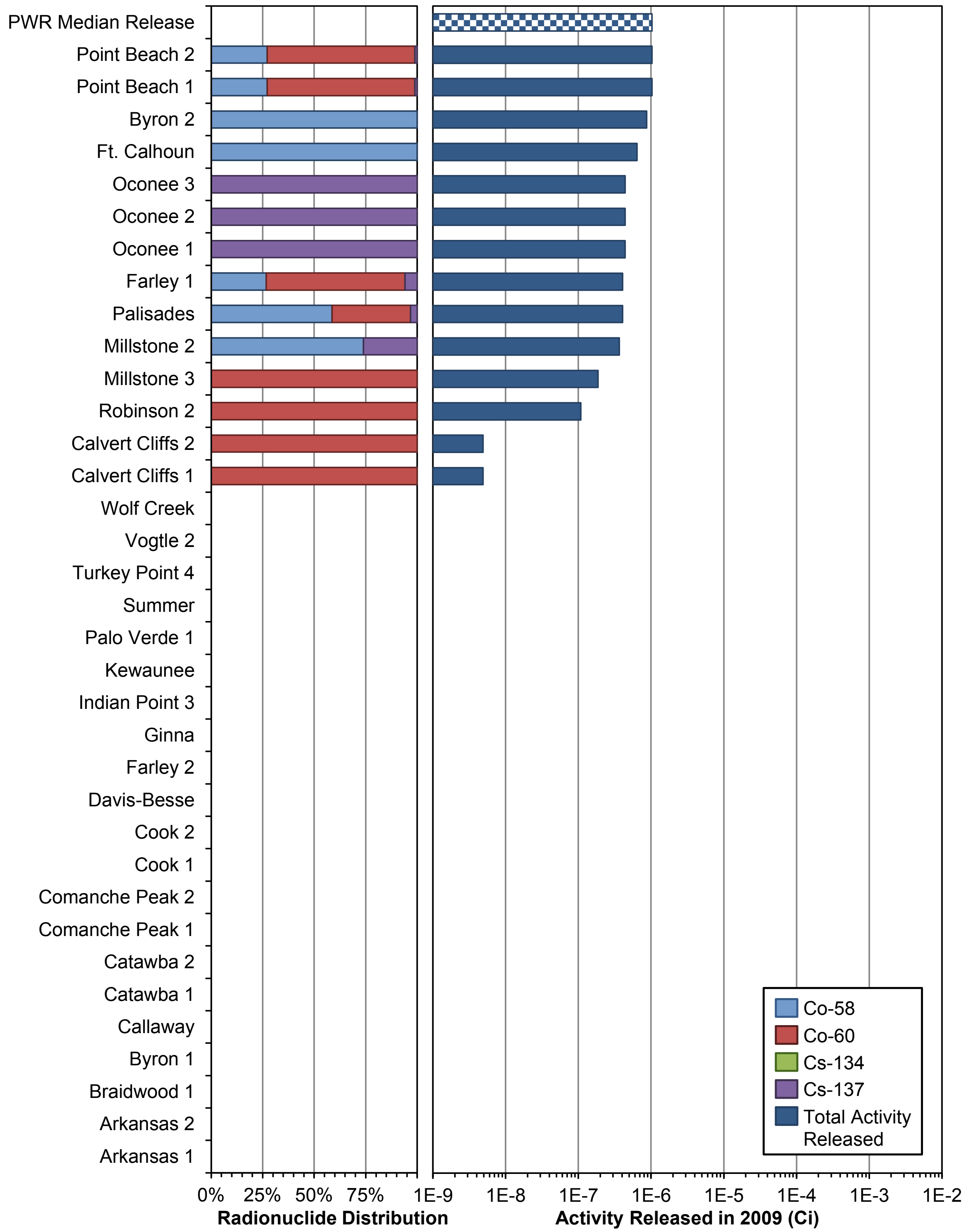


Figure 3.8
PWR Gaseous Releases — Tritium

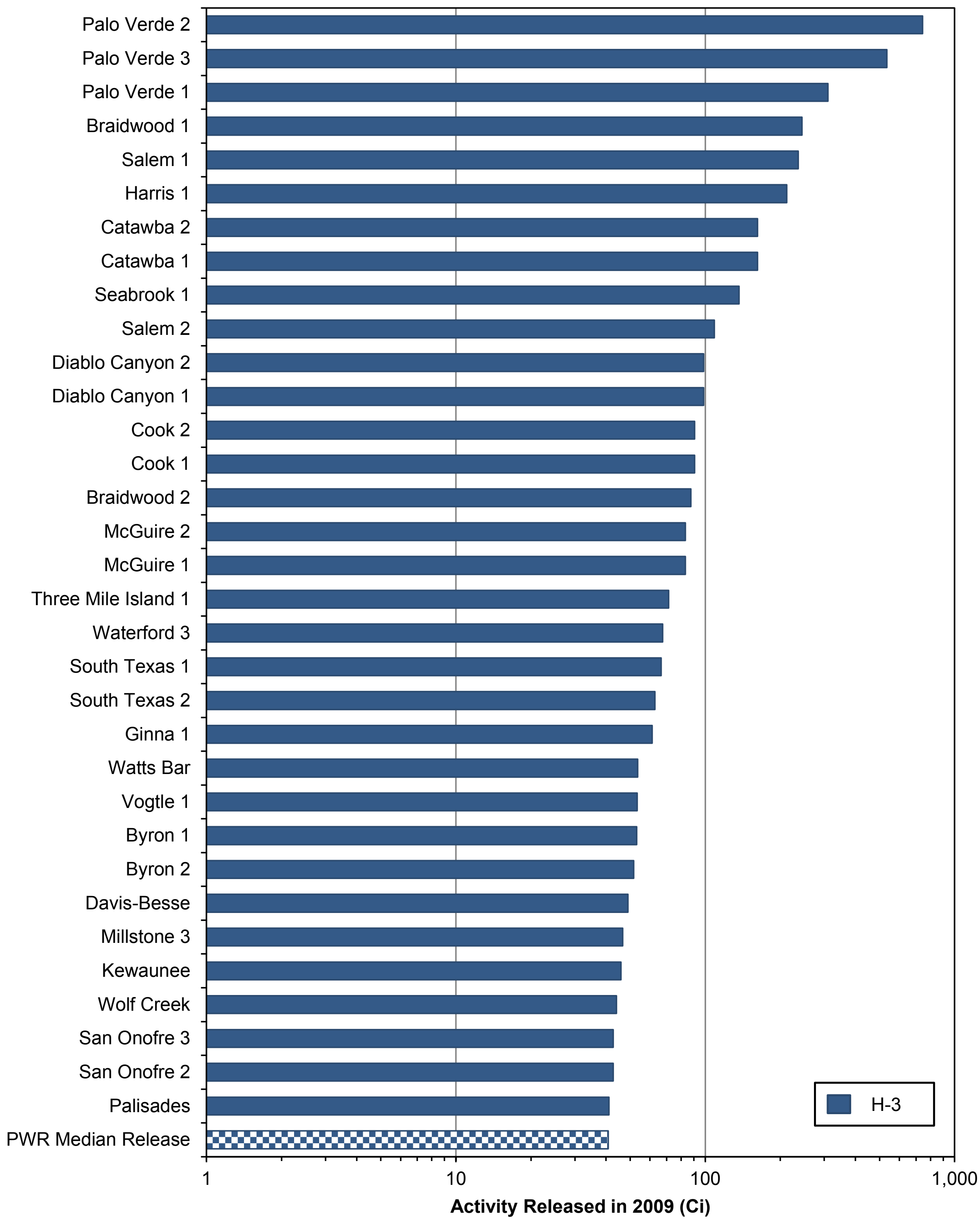


Figure 3.8 *(continued)*

PWR Gaseous Releases — Tritium

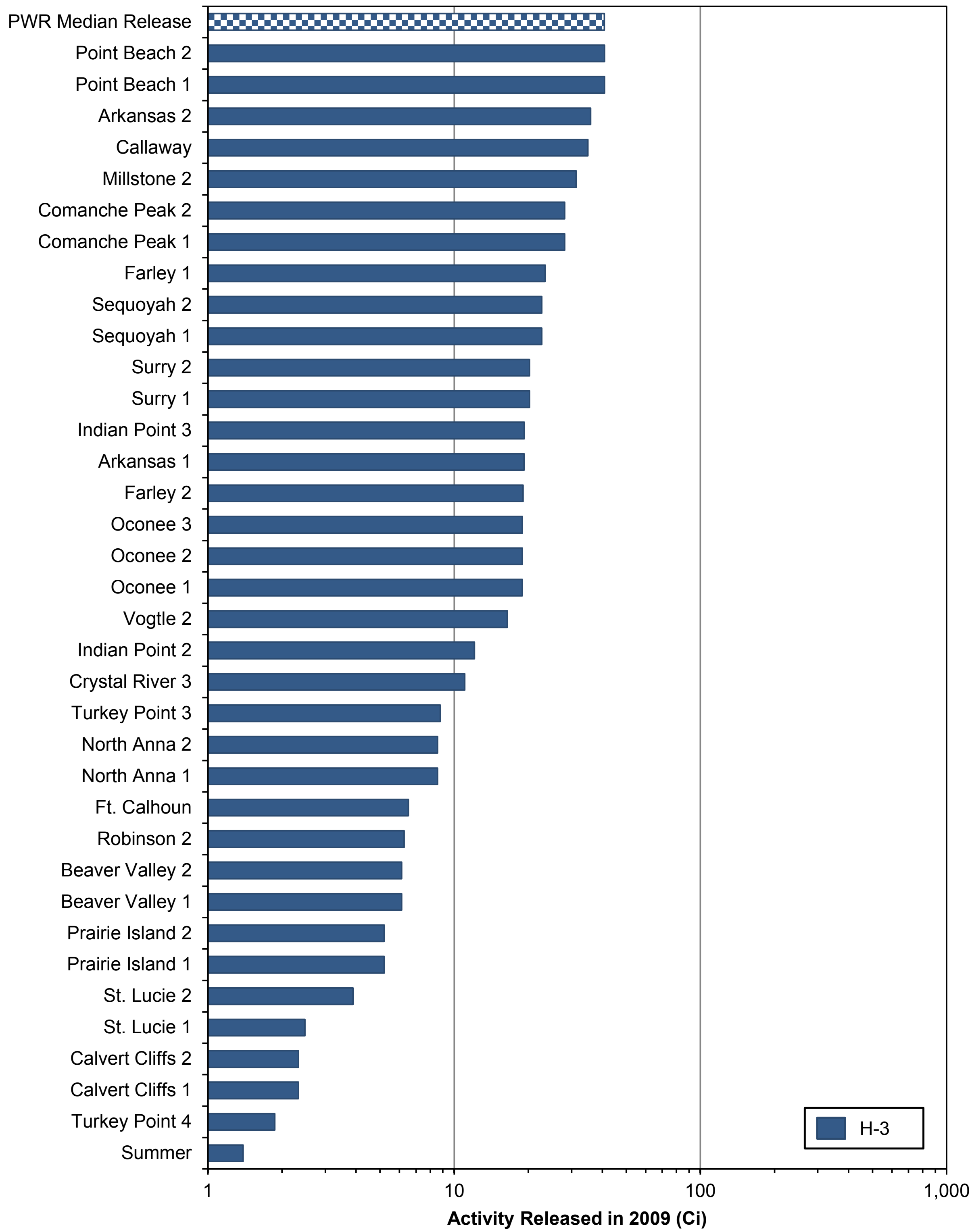


Figure 3.9

BWR Liquid Releases — Selected Fission and Activation Products

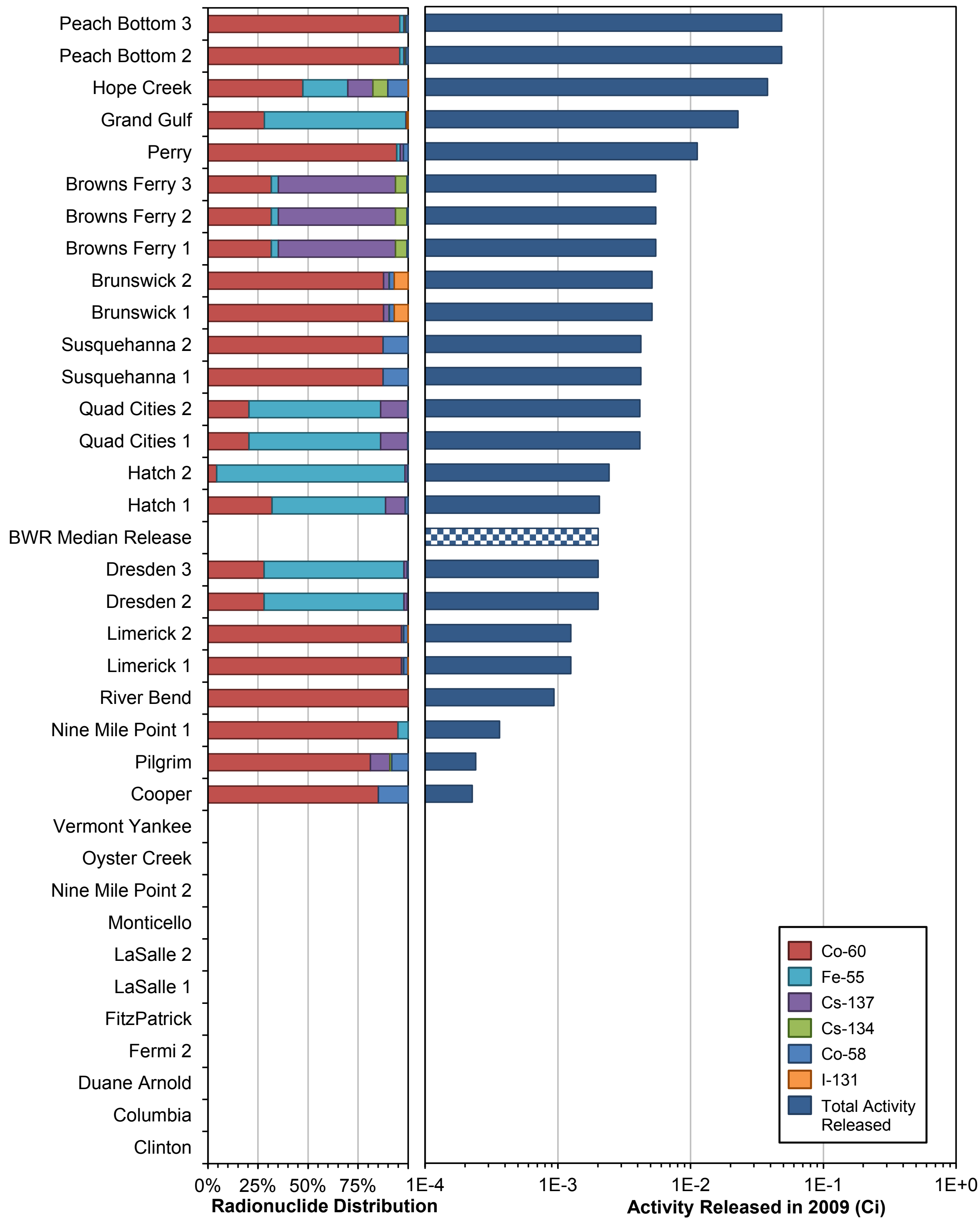


Figure 3.10
BWR Liquid Releases — Tritium

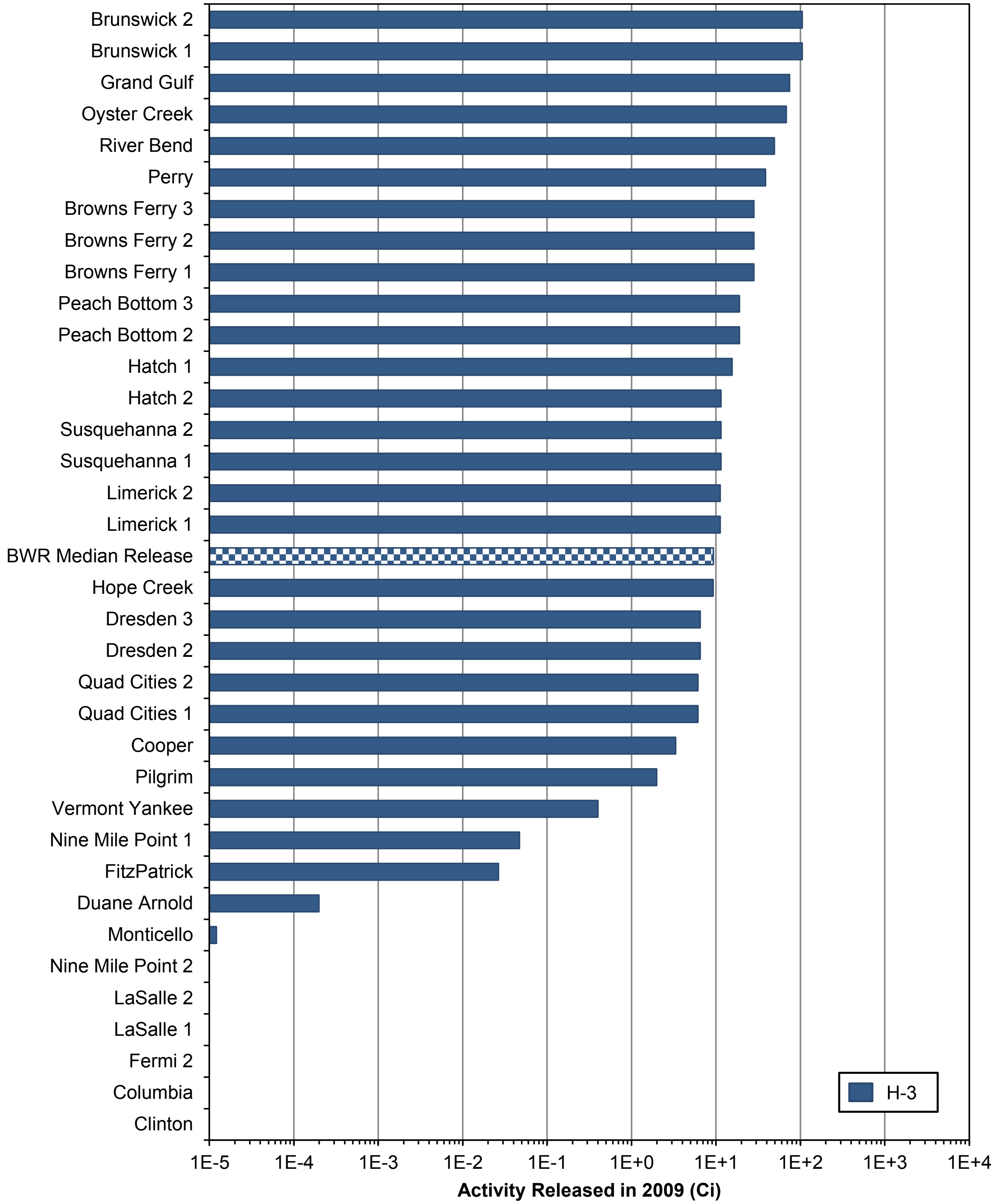


Figure 3.11

PWR Liquid Releases — Selected Fission and Activation Products

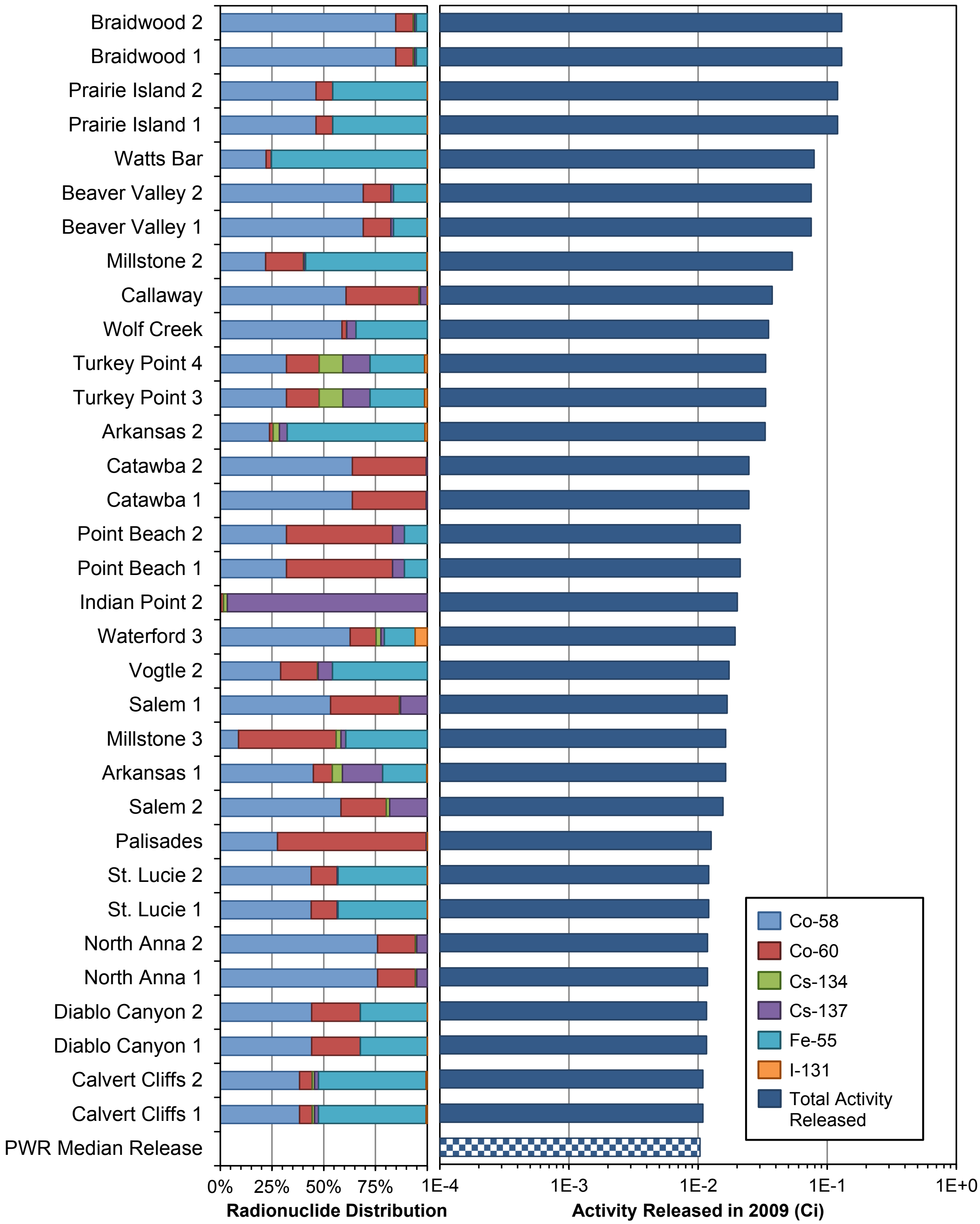


Figure 3.11 *(continued)*

PWR Liquid Releases — Selected Fission and Activation Products

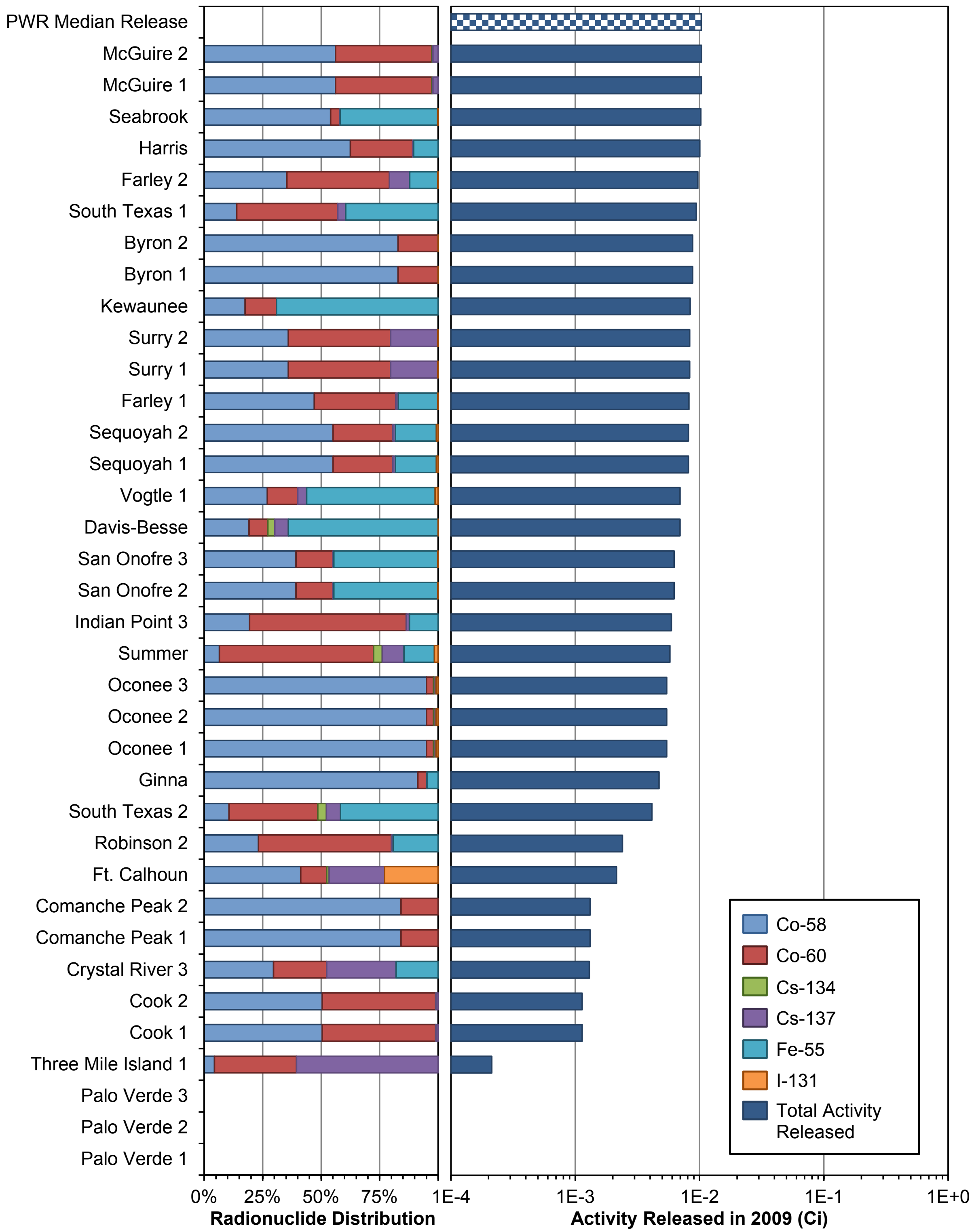


Figure 3.12
PWR Liquid Releases — Tritium

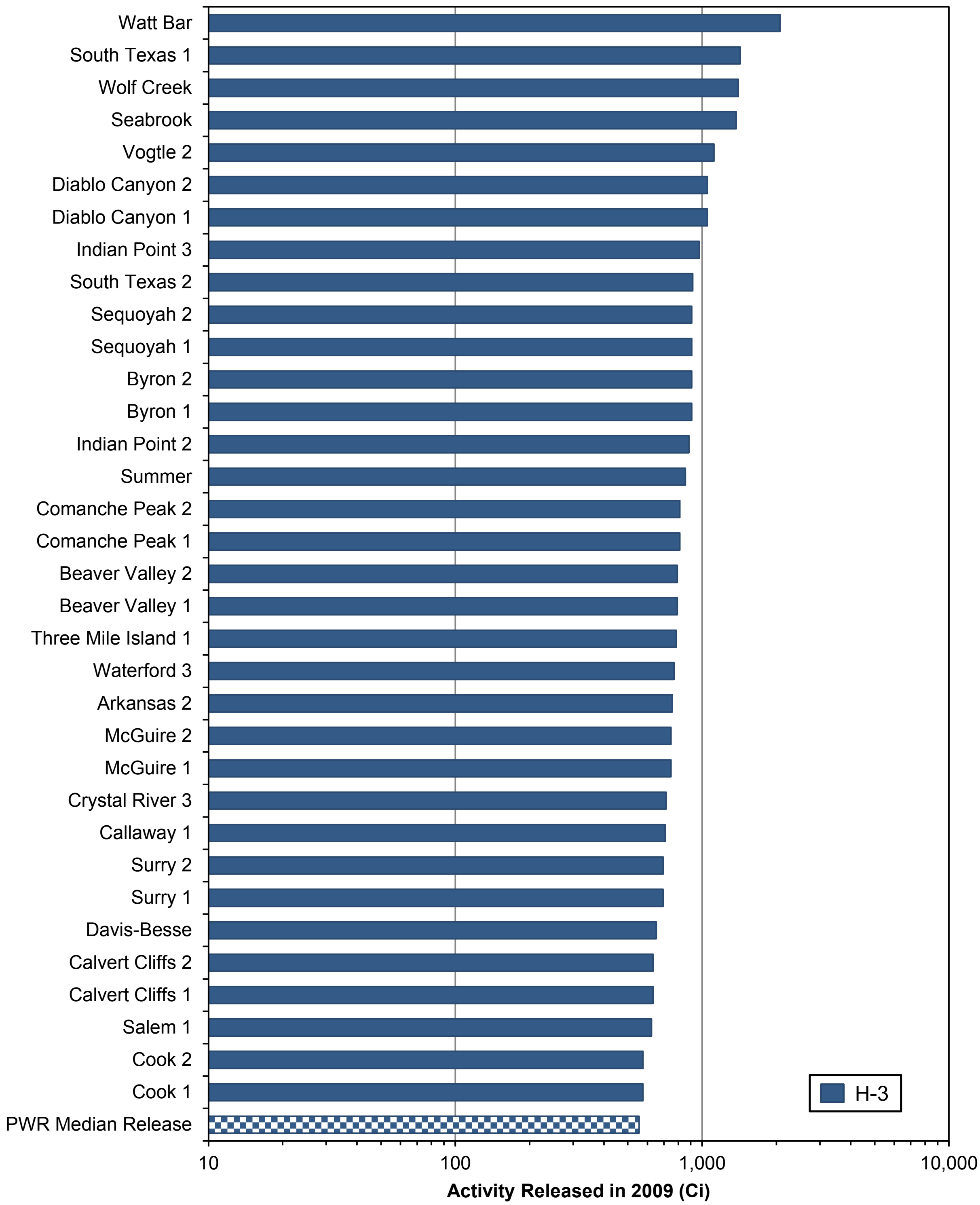
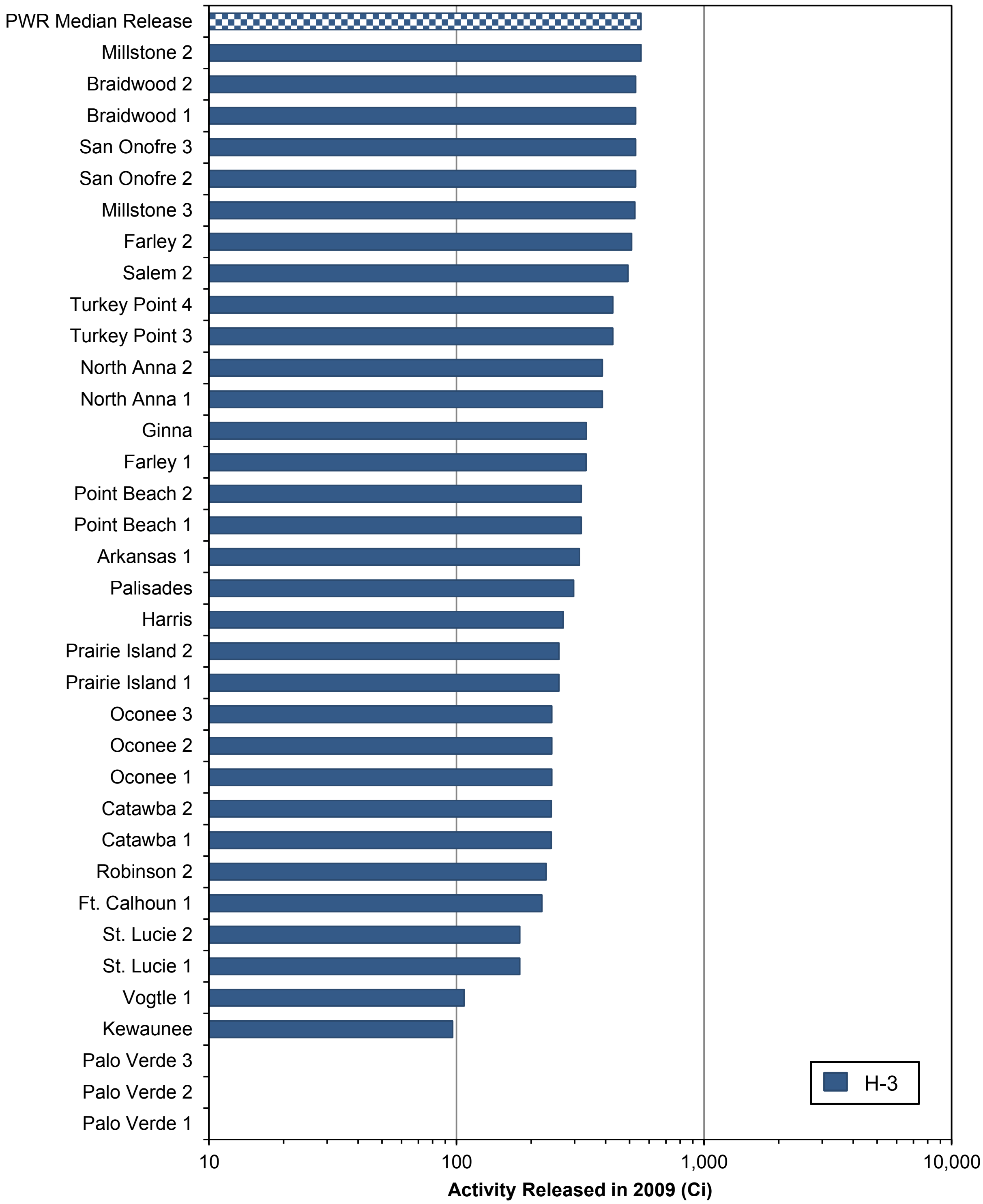


Figure 3.12 *(continued)*
PWR Liquid Releases — Tritium



3.2 Three-Year Trends in Gaseous Effluents

In the previous section, only a few radionuclides from each of the categories in Table 2.1 were shown in the tables and figures. Although particular focus on a few selected radionuclides yields useful information, many radionuclides other than those shown in the previous section are typically present in radioactive gaseous effluents. This section provides the reader with a tool to gain a better understanding of the total releases of gaseous effluents from a facility.

A long-standing, historical measure of the licensee's ability to control gaseous effluents is based on the activities of noble gases discharged in gaseous effluents. This category of radionuclides—noble gases—is described in Table 2.1. The noble gases category includes all radionuclides in gaseous effluents except iodines, particulates, tritium, and radionuclides emitting alpha radiation. Noble gases provide a wealth of information about gaseous waste. Although the doses from noble gases are generally small, other radionuclides (such as iodines and alpha emitters) will generally only be elevated if noble gases are elevated. As a result, noble gases are sometimes used as a primary indicator of the overall control and handling of radioactive gaseous effluents at a site.

Tables 3.13 and 3.14 list the total activities for the last 3 years of all noble gases in gaseous effluents for BWRs and PWRs, respectively. In these tables, no noble gas radionuclides are left out. For each reactor unit, the activities of all noble gases are added together. In this way, the yearly total of all noble gases in gaseous effluents from a reactor is represented by a single number. That number gives the total activity (as curies) of noble gases discharged in gaseous effluents at each reactor for each of the years listed.

Table 3.13, for example, lists a separate column for each year from 2007 to 2009. Within each of these columns are the names of the facilities and the corresponding total activities of noble gases released during each of these 3 years. In each year, the facilities are ranked in order, with the facility discharging the least amount of activity at the top of each column, and the facility discharging the most activity at the bottom of each column. Additionally, within each column, the facilities are organized into four groups, called quartiles. Each group, or quartile, contains about 25% (or one-fourth) of the total number of reactors. For example in 2009, the facilities at the top of the table (highlighted in green on Table 3.13) represent those reactors that discharged the least amount of noble gas activity in that year. The reactors highlighted in green in 2009 are in the first quartile for that year. Similarly, those facilities in the fourth quartile (shown in light blue), represent the 25% of reactors that discharged the most noble gases in each of the years listed.

This ranking of nuclear facilities into four groups is referred to as quartile rankings. These quartile rankings, particularly the second quartile (or median), have historically been used in the United States as one general measure of effluent control for the entire fleet of power plants.

These rankings should be viewed in the proper context. For example, it should be emphasized that the effluents from those facilities in the fourth quartile do not represent any challenge to the federal safety limits for radioactive effluents. As a result, these quartile rankings are not necessarily linked to potential health effects. Instead, they are more closely linked to the concepts of configuration, operation, control, optimization, and implementation. When viewed in the proper context, the quartile rankings of activities may, among other things, provide insights regarding one or more of the following:

- configuration of plant systems,
- operation of plant systems,
- control of plant processes,
- optimization of plant procedures, and
- implementation of operating practices.

As a result, quartile rankings, while not particularly useful for predicting potential health effects from radioactive effluents, can provide some insights that may be useful when evaluating a number of operational and design issues. Some of these insights may include the impact of 2-year fuel cycles, the condition of the fuel cladding, the gaseous radioactive waste processing capabilities, whether best industry practices are adopted, and the analytical capabilities of the radioactive effluent control program.

The quartile rankings for noble gases discharged in gaseous effluents from BWRs are shown in Table 3.13. The numbers have been rounded for clarity. Inspection of Table 3.13 indicates the discharges of noble gases from all BWRs in 2009 ranged from a low of 0 curies to a maximum of 2,003 curies. Additionally, it can be seen that the actual discharges from facilities in the first quartile ranged from 0 to 2.9 curies; the second quartile ranged from 9.8 curies to 30.7 curies; the third quartile ranged from 53.0 to 115 curies; and facilities in the fourth quartile discharged more than 182 curies in 2009.

So far, the discussion of industry quartiles has been limited to the grouping of facilities into four quartiles so that each quartile contains approximately the same number of facilities. However, Table 3.13 has 9 facilities in the first quartile in 2007, while it has 10 facilities in the first quartile in 2009. This is not arbitrary. To ensure the quartile groupings are assigned in a fair and objective manner, the numerical boundaries that define the four quartiles are calculated using standard mathematical formulas. For this report, the quartiles were calculated using a commonly available software package, Microsoft® Excel® 2010. Although several different formulas are available for calculating quartiles, the use of Excel®-based formulas allows the reader to replicate the calculations using commonly available software.

The quartile boundaries for gaseous effluents, calculated with the assistance of the software package described above, are shown graphically in Figures 3.13 (BWRs) and 3.14 (PWRs).

Figure 3.13 indicates that, for the 3 years between 2007 and 2009, the second quartile (or median) for gaseous effluents at BWRs decreased from 37.2 curies to 30.7 curies. This median value is important because it represents the “typical” noble gas effluents for BWRs. Approximately half of the reactors discharged more activity than the median, and approximately half of the reactors discharged less activity than the median value in any particular year. Figure 3.13 demonstrates that typical (or median) noble gas activity in gaseous effluents from BWRs has decreased (i.e., improved) for the 3 years shown. This decrease for BWRs represents more than an 17% reduction in noble gas effluents during that 3-year period.

Figure 3.14 indicates a slight increase in the median for PWR noble gas effluents from 2007 to 2008, but an overall decrease in 2009. It is interesting to note that the reduction over the 3-year period for PWRs is approximately 20%. This continues the longer-term trend described in the next section.

Table 3.13

Noble Gases in Gaseous Effluents, BWRs

3-Year Trend, Quartile Rankings

	2007		2008		2009	
	Facility	Ci	Facility	Ci	Facility	Ci
First Quartile	Browns Ferry 1	0	Browns Ferry 1	0	Browns Ferry 1	0
First Quartile	Browns Ferry 2	0	Browns Ferry 2	0	Browns Ferry 2	0
First Quartile	Browns Ferry 3	0	Browns Ferry 3	0	Browns Ferry 3	0
First Quartile	Clinton	0	Hatch 1	0	Clinton	0
First Quartile	Fermi 2	0	Hatch 2	0	Susquehanna 1	0
First Quartile	Vermont Yankee	0	Susquehanna 1	0	Susquehanna 2	0
First Quartile	Hatch 1	0.046	Susquehanna 2	0	Vermont Yankee	0
First Quartile	Hatch 2	0.046	Vermont Yankee	0	Perry	1.2
First Quartile	Oyster Creek	13.4	Clinton	0.0011	Hatch 1	2.9
Second Quartile	Limerick 1	24.3	Nine Mile Point 1	0.33	Hatch 2	2.9
Second Quartile	Limerick 2	24.3	Hope Creek	1.2	Nine Mile Point 1	9.8
Second Quartile	Duane Arnold	27.3	Perry	2.4	Duane Arnold	11.4
Second Quartile	Perry	27.4	Oyster Creek	7.6	Limerick 1	14.1
Second Quartile	Cooper	27.9	Duane Arnold	11.4	Limerick 2	14.1
Second Quartile	Hope Creek	34.3	Cooper	14.3	Fermi 2	14.4
Second Quartile	Susquehanna 1	36.8	Fermi 2	15.4	Oyster Creek	15.4
Second Quartile	Susquehanna 2	36.8	Limerick 1	36.7	Hope Creek	22.8
Second Quartile	Nine Mile Point 1	37.2	Limerick 2	36.7	Dresden 2	30.7
Third Quartile	Columbia	60.3	Dresden 2	82.1	Dresden 3	30.7
Third Quartile	Quad Cities 1	73.0	Dresden 3	82.1	FitzPatrick	53.0
Third Quartile	Quad Cities 2	73.0	Quad Cities 1	85.6	Cooper	54.8
Third Quartile	Dresden 2	157	Quad Cities 2	85.6	Quad Cities 1	85.8
Third Quartile	Dresden 3	157	Columbia	91.4	Quad Cities 2	85.8
Third Quartile	Monticello	199	FitzPatrick	189	Columbia	90.0
Third Quartile	Peach Bottom 2	269	River Bend	204	River Bend	99.2
Third Quartile	Peach Bottom 3	269	Peach Bottom 2	303	Pilgrim	115
Fourth Quartile	River Bend	343	Peach Bottom 3	303	Grand Gulf	182
Fourth Quartile	Nine Mile Point 2	413	Pilgrim	311	Brunswick 1	349
Fourth Quartile	Grand Gulf	622	Nine Mile Point 2	359	Brunswick 2	349
Fourth Quartile	FitzPatrick	623	Grand Gulf	443	Nine Mile Point 2	448
Fourth Quartile	Brunswick 1	744	LaSalle 1	791	Peach Bottom 2	511
Fourth Quartile	Brunswick 2	744	LaSalle 2	791	Peach Bottom 3	511
Fourth Quartile	LaSalle 1	1,315	Brunswick 1	846	Monticello	1,503
Fourth Quartile	LaSalle 2	1,315	Brunswick 2	846	LaSalle 1	2,003
Fourth Quartile	Pilgrim	1,553	Monticello	1,059	LaSalle 2	2,003

Table 3.14
Noble Gases in Gaseous Effluents, PWRs
3-Year Trend, Quartile Rankings

Quartile	2007 Facility	2007 Ci	2008 Facility	2008 Ci	2009 Facility	2009 Ci
First Quartile	Seabrook	0.047	Beaver Valley 1	0.057	Beaver Valley 2	0.053
	Prairie Island 1	0.049	Indian Point 3	0.071	Crystal River 3	0.091
	Prairie Island 2	0.049	Kewaunee	0.083	Kewaunee	0.12
	Kewaunee	0.079	Seabrook	0.25	Seabrook	0.15
	Beaver Valley 2	0.19	Prairie Island 1	0.27	Robinson 2	0.24
	Byron 2	0.24	Prairie Island 2	0.27	Point Beach 1	0.52
	Beaver Valley 1	0.27	Harris	0.28	Point Beach 2	0.52
	Byron 1	0.31	Palo Verde 3	0.34	Prairie Island 1	0.55
	Point Beach 1	0.33	Three Mile Island 1	0.37	Prairie Island 2	0.55
	Point Beach 2	0.33	Surry 1	0.54	Byron 2	0.63
	Vogtle 1	0.34	Surry 2	0.54	Surry 1	0.67
	Salem 1	0.45	Point Beach 1	0.55	Surry 2	0.67
	Palo Verde 1	0.60	Point Beach 2	0.55	Indian Point 3	0.68
	Diablo Canyon 1	0.80	Salem 1	0.59	Salem 2	0.80
	Diablo Canyon 2	0.80	North Anna 1	0.70	Wolf Creek	0.92
	Wolf Creek	0.93	North Anna 2	0.70	Diablo Canyon 1	1.4
	Surry 1	0.99	Palo Verde 1	0.85	Diablo Canyon 2	1.4
	Surry 2	0.99	Wolf Creek	0.91	McGuire 1	1.6
Second Quartile	Robinson 2	1.0	Salem 2	0.94	McGuire 2	1.6
	Salem 2	1.0	McGuire 1	1.1	St. Lucie 1	1.7
	Summer	1.0	McGuire 2	1.1	Summer	1.7
	McGuire 1	1.1	Vogtle 1	1.3	Palo Verde 2	1.7
	McGuire 2	1.1	Summer	1.4	Indian Point 2	1.8
	Ginna	1.2	Beaver Valley 2	1.7	Catawba 1	1.9
	Indian Point 2	1.4	Catawba 1	1.8	Catawba 2	1.9
	South Texas 1	1.5	Catawba 2	1.8	Three Mile Island 1	2.2
	Harris	1.6	St. Lucie 2	2.3	Sequoyah 1	2.4
	Millstone 2	1.9	Crystal River 3	3.3	Sequoyah 2	2.4
	Palo Verde 3	2.2	Byron 1	3.6	Comanche Peak 1	2.5
	Catawba 1	2.3	Watts Bar	3.8	Comanche Peak 2	2.5
	Catawba 2	2.3	Ft. Calhoun	3.8	South Texas 2	2.6
	Ft. Calhoun	2.8	Ginna	4.6	Harris	2.7
	Farley 2	3.1	Sequoyah 1	4.7	Cook 1	2.7
	Three Mile Island 1	4.3	Sequoyah 2	4.7	Cook 2	2.7
	Crystal River 3	4.4	Oconee 1	5.9	Ft. Calhoun	3.5
Third Quartile	Cook 1	4.9	Oconee 2	5.9	Ginna	3.5
	Cook 2	4.9	Oconee 3	5.9	South Texas 1	3.9
	St. Lucie 1	6.0	Farley 2	5.9	Braidwood 1	5.2
	Turkey Point 4	6.1	Byron 2	7.9	Watts Bar	5.4
	Turkey Point 3	6.1	St. Lucie 1	7.9	St. Lucie 2	5.8
	Comanche Peak 1	7.0	Palisades	12.1	Braidwood 2	6.0
	Comanche Peak 2	7.0	South Texas 1	15.4	Oconee 1	6.9

Table 3.14 *(continued)*

Noble Gases in Gaseous Effluents, PWRs

3-Year Trend, Quartile Rankings

	2007		2008		2009	
	Facility	Ci	Facility	Ci	Facility	Ci
Third Quartile	Arkansas 2	7.4	Cook 1	18.5	Oconee 2	6.9
	Indian Point 3	7.7	Cook 2	18.5	Oconee 3	6.9
	North Anna 1	8.5	Millstone 2	19.0	Beaver Valley 1	7.4
	North Anna 2	8.5	South Texas 2	20.9	Arkansas 1	8.7
	Arkansas 1	8.6	Arkansas 1	21.9	Millstone 3	9.4
	Braidwood 2	8.6	San Onofre 2	25.0	Palo Verde 1	9.9
	Palo Verde 2	9.1	San Onofre 3	25.0	Byron 1	11.5
	Braidwood 1	9.2	Diablo Canyon 1	26.9	Farley 2	16.4
	St. Lucie 2	9.6	Diablo Canyon 2	26.9	Farley 1	17.8
	Sequoyah 1	16.5	Davis-Besse	27.0	Palo Verde 3	23.5
Fourth Quartile	Sequoyah 2	16.5	Farley 1	27.2	North Anna 1	27.4
	Watts Bar	18.0	Braidwood 1	30.4	North Anna 2	27.4
	Callaway	19.8	Indian Point 2	47.3	Salem 1	28.2
	Farley 1	22.4	Turkey Point 4	52.8	Palisades	34.3
	Davis-Besse	31.6	Turkey Point 3	60.0	Millstone 2	36.6
	Waterford 3	40.8	Millstone 3	61.8	San Onofre 2	52.9
	Millstone 3	46.0	Arkansas 2	74.1	San Onofre 3	52.9
	South Texas 2	50.6	Callaway	111	Turkey Point 4	126
	San Onofre 2	51.8	Palo Verde 2	131	Calvert Cliffs 1	134
	San Onofre 3	51.8	Robinson 2	156	Calvert Cliffs 2	134
	Vogtle 2	87.6	Calvert Cliffs 1	332	Turkey Point 3	162
	Oconee 1	113	Calvert Cliffs 2	332	Davis-Besse	178
	Oconee 2	113	Braidwood 2	370	Callaway	210
	Oconee 3	113	Comanche Peak 1	498	Vogtle 1	270
	Calvert Cliffs 1	315	Comanche Peak 2	498	Arkansas 2	321
	Calvert Cliffs 2	315	Waterford 3	526	Vogtle 2	760
	Palisades	341	Vogtle 2	645	Waterford 3	3,560

Figure 3.13
Gaseous Effluent Activity from BWRs
3-Year Trend of Industry Quartiles, 2007-2009

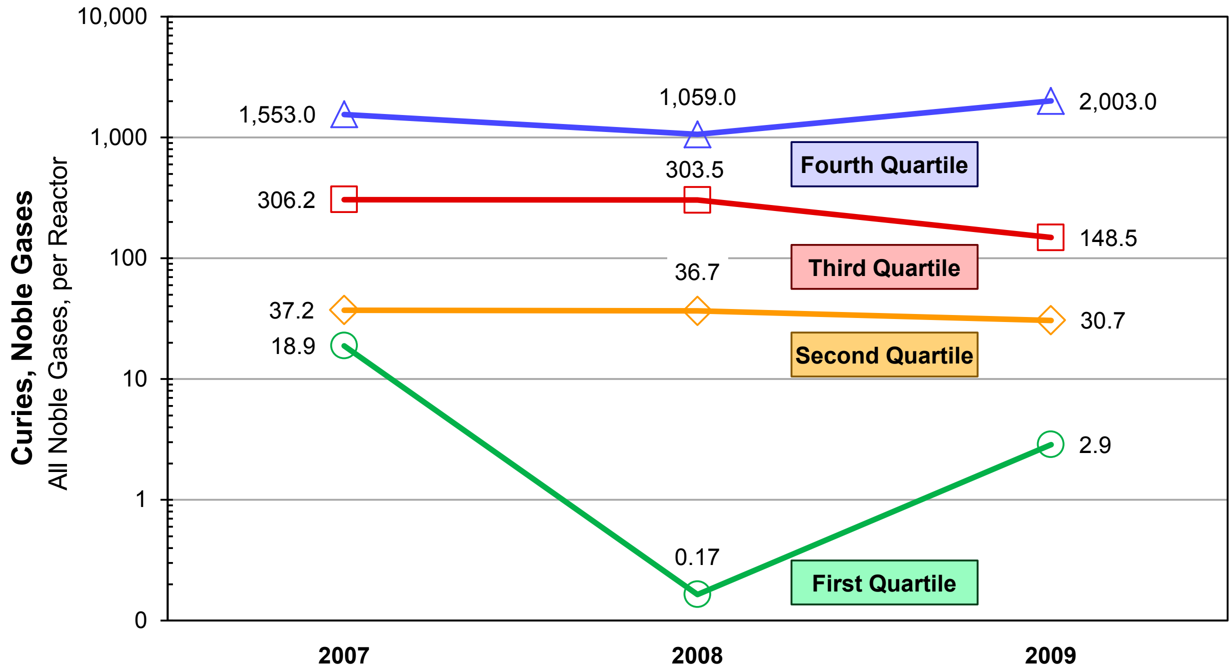
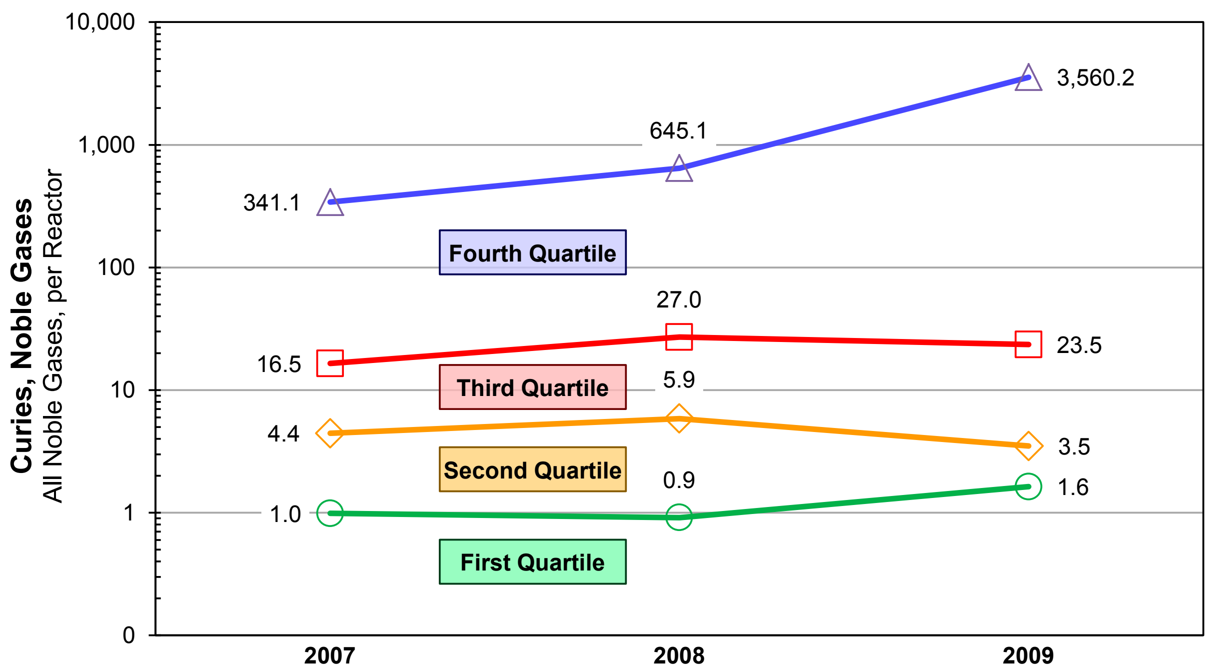


Figure 3.14
Gaseous Effluent Activity from PWRs
3-Year Trend of Industry Quartiles, 2007-2009



3.3 Long-Term Trend in Gaseous Effluents

In the previous section, short-term trends of noble gas activity in gaseous effluents were discussed. The trend of noble gases released from BWRs showed a decrease each year, while the trend for PWRs actually showed an increase in 2008, followed by a decrease in 2009. This section discusses the long-term trends of noble gases in gaseous effluents from nuclear power plants in the United States.

NRC regulations require radioactive effluents to be ALARA. As a result, the activity of radioactive effluents should ideally decrease over time. The trend in the median noble gas activity of gaseous effluents since 1975 is shown in Figure 3.15. This information comes from the Annual Radioactive Effluent Release Reports submitted by licensees and from information presented in previous NRC NUREGs (Refs. 2 thru 22). All power reactors that have operated in the United States, some of which are now shutdown, are included. Additionally, just as with Figures 3.13 and 3.14, no noble gas radionuclides have been excluded from Figure 3.15. As a result, Figure 3.15 is an extension of Figures 3.13 and 3.14, except that only the median activities are shown.

Figure 3.15
Long-term Trend in Gaseous Effluents
Noble Gases

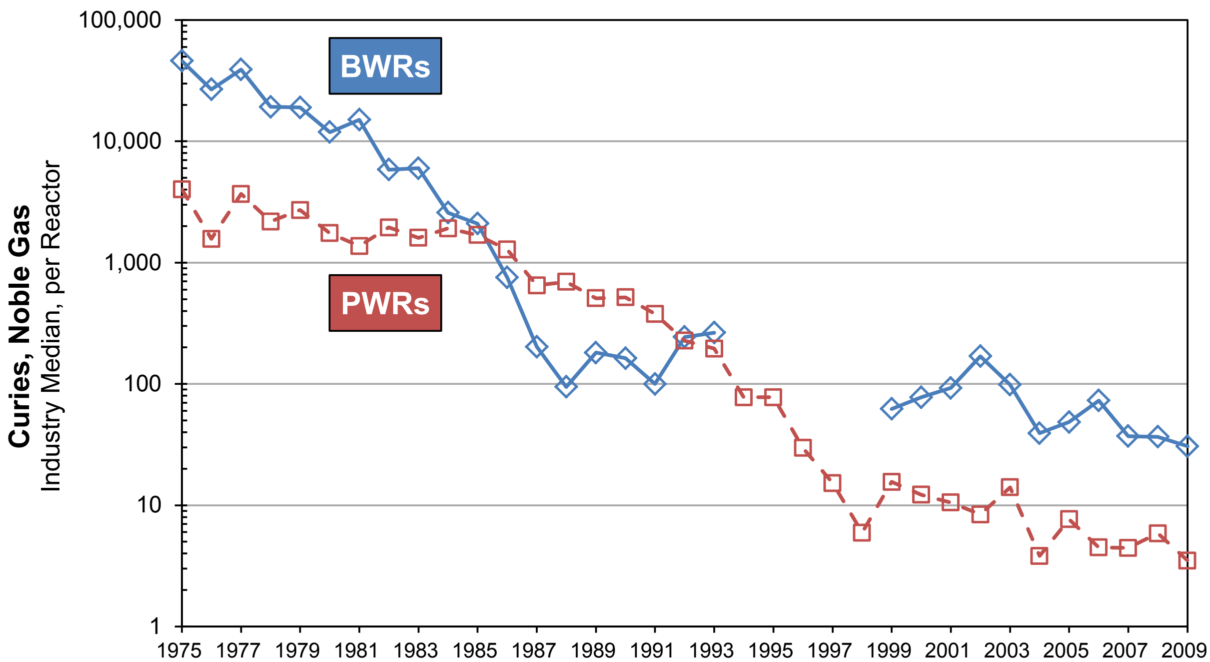


Figure 3.15 indicates a long-term downward trend in the amounts of noble gases in gaseous effluents from both BWRs and PWRs. The magnitude of the reduction is significant. For example, in 1975, the median release for BWRs was greater than 40,000 curies; however, in 2009, the median was 30.7 curies. That change corresponds to a 99.92% reduction in median noble gas effluents over the last 34 years. One of the primary contributors to the reduction in

noble gas effluents is improved fuel integrity in both BWRs and PWRs. The use of advanced off-gas systems in BWRs is also responsible for reductions in the BWR industry averages. Lastly, contributions from the operations, maintenance, chemistry, and health physics departments at the various facilities have improved the handling and processing of gaseous waste to further improve and optimize effluent performance.

Figure 3.15 contains a gap in the BWR data for the years 1994 to 1998. That data was not able to be compiled in time for publication in this report. That information is expected to be available in a future report. Even without all of the BWR data displayed, the overall long-term downward trend for both BWRs and PWRs is evident from Figure 3.15.

As discussed in the paragraphs above, Tables 3.13 and 3.14 and Figures 3.13, 3.14, and 3.15 focus on noble gases in gaseous effluents. Similar tables and figures can be prepared to show industry performance with respect to radioactive liquid effluents, which is discussed in the next section.

3.4 Three-Year Trends in Liquid Effluents

In Section 3.1, only a few radionuclides from each of the categories in Table 2.2 were shown in the tables and figures. Although particular focus on a few selected radionuclides yields useful information, many radionuclides other than those shown in Section 3.1 are typically present in radioactive liquid effluents. This section provides the reader with a tool to gain a better understanding of the total releases of liquid effluents from a facility.

A long-standing, historical measure of the licensee's ability to control liquid effluents is based on the activity of the mixed fission and activation products (MFAPs) discharged in liquid effluents. This category of radionuclides—MFAPs—is described in Table 2.2. It includes all radionuclides in liquid effluents except tritium, dissolved and entrained noble gases, and radionuclides emitting alpha radiation. MFAPs can be effectively reduced by liquid radioactive waste treatment systems installed in each NPP. As a result, MFAPs are sometimes used as a primary indicator of the overall control and handling of radioactive liquid effluents at a site.

Tables 3.15 and 3.16 list the total activities for the last 3 years of all MFAPs in liquid effluents for BWRs and PWRs, respectively. In these tables, no MFAP radionuclides are left out. For each reactor unit, the activities of all MFAPs are added together. In this way, the yearly total of all MFAPs in liquid effluents from a reactor are represented by a single number. That number gives the total activity (as millicuries) of MFAPs discharged in liquid effluents at each reactor for each of the years listed.

Table 3.15, for example, lists a separate column for each year from 2007 to 2009. Within each of these columns are the names of the facilities and the corresponding total activities of MFAPs released in liquid effluents during each of these 3 years. In each year, the facilities are ranked in order, with the facility discharging the least amount of activity at the top of each column, and the facility discharging the most activity at the bottom of each column. Additionally, within each column the facilities are grouped into four quartiles. Each group, or quartile, contains about 25% (or one-fourth) of the total number of reactors. For example, in 2009, the facilities at the top of the table (highlighted in green on Table 3.15) represent those reactors that discharged the least amount of MFAP activity in that year. The reactors highlighted in green in 2009 are in the first quartile for that year. Similarly, those facilities in the fourth quartile (shown in blue) represent the 25% of reactors that discharged the most MFAPs in each of the years listed.

These quartile rankings, particularly the second quartile (or median), have historically been used in the United States as one general measure of effluent control for the entire fleet of power plants. These rankings should be viewed in the proper context. As for the gaseous effluents previously discussed, those facilities in the fourth quartile do not represent any challenge to the federal safety limits for radioactive effluents. As a result, these quartile rankings are not necessarily linked to potential health effects. Instead, they are more closely linked to the concepts of configuration, operation, control, optimization, and implementation. When viewed in the proper context, the quartile rankings of activities may, among other things, provide insights regarding one or more of the following:

- configuration of plant systems,
- operation of plant systems,
- control of plant processes,
- optimization of plant procedures, and
- implementation of operating practices.

As a result, quartile rankings, while not particularly useful for predicting potential health effects from radioactive effluents, can provide some insights that may be useful when evaluating a number of operational and design issues. Some of these insights may include the impact of 2-year fuel cycles, the condition of the fuel cladding, the liquid radioactive waste processing capabilities, whether best industry practices are adopted, and the analytical capabilities of the radioactive effluent control program.

The quartile rankings for MFAPs discharged in liquid effluents from BWRs are shown in Table 3.15. The numbers have been rounded for clarity. Inspection of Table 3.15 indicates the discharges of MFAPs in liquid effluents from all BWRs in 2009 ranged from a low of 0 curies to a maximum of 11.6 curies per reactor (or 11,607 millicuries). Please note that the liquid effluent activity is listed in units of millicuries in Table 3.15 to eliminate exponential notation and to allow the numbers to be represented in their simplest form. One thousand millicuries is equal to 1 curie. Table 3.15 indicates that the actual discharges from facilities in the first quartile were all 0 mCi; the second quartile ranged from 0.36 to just less than 2.8 mCi; the third quartile ranged from 2.8 to 5.8 mCi; and facilities in the fourth quartile discharged more than 23.7 mCi in 2009.

So far, the discussion of industry quartiles has been limited to the grouping of facilities into four quartiles so that each quartile contains approximately the same number of facilities. However, Table 3.15 has 11 facilities in the first quartile in 2007, while it has 12 facilities in the first quartile in 2008. This is not arbitrary. To ensure the quartile groupings are assigned in a fair and objective manner, the numerical boundaries that define the four quartiles are calculated using standard mathematical formulas. For this report, the quartiles were calculated using a commonly available software package, Microsoft® Excel® 2010. Although several different formulas are available for calculating quartiles, the use of Excel®-based formulas allows the reader to replicate the calculations using commonly available software.

The quartile boundaries for liquid effluents, calculated with the assistance of the software package described above, are shown graphically in Figures 3.16 (BWRs) and 3.17 (PWRs).

Figure 3.16 indicates that the second quartile (or median) for liquid effluents at BWRs increased from 1.0 millicurie to 2.8 millicuries between 2007 and 2009. The median value is important because it represents the “typical” activity of MFAP effluents for BWRs. Approximately half of the reactors discharged more activity than the median, and approximately half of the reactors discharged less activity than the median value in any particular year. Figure 3.16 demonstrates that typical (or median) releases of MFAPs in liquid effluents from BWRs increased for the 3 years shown. Although the magnitude of the increase is small (i.e., an increase of 1.8 millicuries over 3 years), in relative terms, the release of MFAPs more than doubled during that 3-year period. A suggested explanation for this increase is discussed in Section 3.5. Even with this increase, median BWR releases of MFAPs in liquid effluents is approximately 5 times lower than such releases from PWRs.

Figure 3.17 demonstrates that typical (or median) MFAP activity in liquid effluents from PWRs has decreased (i.e., improved) for the 3 years shown. This decrease for PWRs represents more than a 40% reduction in MFAPs discharged during that 3-year period. The long-term trend for liquid effluent releases is described in the next section.

Table 3.15
Mixed Fission and Activation Products
In Liquid Effluents, BWRs
3-Year Trend, Quartile Rankings

	2007		2008		2009	
	Facility	mCi	Facility	mCi	Facility	mCi
First Quartile	Clinton	0	Clinton	0	Clinton	0
	Columbia	0	Columbia	0	Columbia	0
	Cooper	0	Duane Arnold	0	Duane Arnold	0
	Duane Arnold	0	Fermi 2	0	Fermi 2	0
	Fermi 2	0	FitzPatrick	0	FitzPatrick	0
	LaSalle 1	0	LaSalle 1	0	LaSalle 1	0
	LaSalle 2	0	LaSalle 2	0	LaSalle 2	0
	Nine Mile Point 1	0	Monticello	0	Monticello	0
	Nine Mile Point 2	0	Nine Mile Point 1	0	Nine Mile Point 2	0
	Oyster Creek	0	Oyster Creek	0	Oyster Creek	0
	Vermont Yankee	0	Pilgrim	0	Vermont Yankee	0
Second Quartile	Monticello	0.0010	Vermont Yankee	0	Nine Mile Point 1	0.36
	FitzPatrick	0.017	Dresden 2	0.085	Cooper	0.38
	Pilgrim	0.13	Dresden 3	0.085	River Bend	1.1
	Susquehanna 1	0.22	Quad Cities 1	0.89	Pilgrim	1.4
	Susquehanna 2	0.22	Quad Cities 2	0.89	Limerick 1	2.0
	Quad Cities 1	0.96	Susquehanna 1	1.2	Limerick 2	2.0
	Quad Cities 2	0.96	Susquehanna 2	1.2	Hatch 1	2.8
Third Quartile	Hatch 2	1.7	Nine Mile Point 2	3.1	Dresden 2	2.8
	Brunswick 1	2.9	Browns Ferry 1	3.8	Dresden 3	2.8
	Brunswick 2	2.9	Browns Ferry 2	3.8	Hatch 2	3.1
	Limerick 1	3.6	Browns Ferry 3	3.8	Quad Cities 1	4.2
	Limerick 2	3.6	Brunswick 1	4.0	Quad Cities 2	4.2
	Perry	4.7	Brunswick 2	4.0	Susquehanna 1	4.4
	Hatch 1	5.6	Cooper	4.7	Susquehanna 2	4.4
	River Bend	6.0	Hatch 2	8.3	Brunswick 1	5.8
Fourth Quartile	Dresden 2	19.1	River Bend	8.7	Brunswick 2	5.8
	Dresden 3	19.1	Perry	14.7	Perry	23.7
	Hope Creek	44.9	Hope Creek	16.6	Hope Creek	57.5
	Peach Bottom 2	387	Hatch 1	23.9	Grand Gulf	62.0
	Peach Bottom 3	387	Limerick 1	34.7	Peach Bottom 2	63.8
	Grand Gulf	420	Limerick 2	34.7	Peach Bottom 3	63.8
	Browns Ferry 1	2,457	Peach Bottom 2	127	Browns Ferry 1	11,607
	Browns Ferry 2	2,457	Peach Bottom 3	127	Browns Ferry 2	11,607
	Browns Ferry 3	2,457	Grand Gulf	371	Browns Ferry 3	11,607

Table 3.16

Mixed Fission and Activation Products
In Liquid Effluents, PWRs

3-Year Trend, Quartile Rankings

	2007		2008		2009	
	Facility	mCi	Facility	mCi	Facility	mCi
First Quartile	Byron 1	0	Byron 1	0	Palo Verde 1	0
	Byron 2	0	Byron 2	0	Palo Verde 2	0
	Palo Verde 1	0	Palo Verde 1	0	Palo Verde 3	0
	Palo Verde 2	0	Palo Verde 2	0	Three Mile Island 1	0.29
	Palo Verde 3	0	Palo Verde 3	0	Cook 1	1.7
	Braidwood 1	1.7	Three Mile Island 1	0.19	Cook 2	1.7
	Braidwood 2	1.7	Cook 1	4.5	Comanche Peak 1	1.9
	Cook 1	2.2	Cook 2	4.5	Comanche Peak 2	1.9
	Cook 2	2.2	Ginna	5.1	Ft. Calhoun	2.7
	Three Mile Island 1	2.5	Oconee 1	7.0	Robinson 2	2.9
	Salem 2	2.6	Oconee 2	7.0	Ginna	4.7
	Comanche Peak 1	3.8	Oconee 3	7.0	Salem 2	5.9
	Comanche Peak 2	3.8	Crystal River 3	7.4	South Texas 2	8.1
	Wolf Creek	5.3	Comanche Peak 1	7.6	Oconee 1	8.5
	Ft. Calhoun	5.3	Comanche Peak 2	7.6	Oconee 2	8.5
	Oconee 1	6.5	Salem 2	9.5	Oconee 3	8.5
	Oconee 2	6.5	South Texas 1	9.6	San Onofre 2	8.9
	Oconee 3	6.5	Ft. Calhoun	11.0	San Onofre 3	8.9
Second Quartile	Salem 1	7.9	Robinson 2	11.7	Vogtle 1	9.9
	Crystal River 3	10.1	South Texas 2	12.9	Sequoyah 1	10.2
	Indian Point 3	11.5	Surry 1	14.0	Sequoyah 2	10.2
	South Texas 1	12.3	Surry 2	14.0	Farley 1	10.9
	Robinson 2	13.5	Indian Point 3	14.3	Seabrook	10.9
	Davis-Besse	14.1	St. Lucie 1	14.3	Surry 1	11.0
	Surry 1	14.1	St. Lucie 2	14.3	Surry 2	11.0
	Surry 2	14.1	Diablo Canyon 1	14.5	Byron 1	11.1
	Calvert Cliffs 1	14.8	Diablo Canyon 2	14.5	Byron 2	11.1
	Calvert Cliffs 2	14.8	Davis-Besse	16.2	Kewaunee	11.4
	Summer	16.3	Farley 1	17.5	North Anna 1	12.2
	Vogtle 2	18.8	Palisades	17.6	North Anna 2	12.2
	St. Lucie 2	20.3	Salem 1	19.0	Davis-Besse	12.7
	St. Lucie 1	20.7	Harris	19.8	Calvert Cliffs 1	13.1
	Indian Point 2	42.4	San Onofre 2	20.0	Calvert Cliffs 2	13.1
	Ginna	22.0	San Onofre 3	20.0	Summer	14.6
	Seabrook	22.2	Catawba 1	22.2	South Texas 1	14.8
	Millstone 2	25.0	Catawba 2	22.2		

Table 3.16 *(continued)*

Mixed Fission and Activation Products
In Liquid Effluents, PWRs

3-Year Trend, Quartile Rankings

	2007		2008		2009	
	Facility	mCi	Facility	mCi	Facility	mCi
Third Quartile					Harris	15.7
	Arkansas 2	25.1	Kewaunee	22.8	McGuire 1	17.4
	Kewaunee	25.3	Summer	22.9	McGuire 2	17.4
	Catawba 1	27.2	Waterford 3	23.8	Salem 1	18.1
	Catawba 2	27.2	Seabrook	24.4	Farley 2	19.2
	San Onofre 2	27.5	Indian Point 2	54.6	Arkansas 1	21.2
	San Onofre 3	27.5	Vogtle 1	31.0	Diablo Canyon 1	21.6
	Diablo Canyon 1	28.2	Farley 2	33.8	Diablo Canyon 2	21.6
	Diablo Canyon 2	28.2	Calvert Cliffs 1	40.5	Indian Point 3	25.3
	Turkey Point 3	29.5	Calvert Cliffs 2	40.5	Crystal River 3	30.5
	Turkey Point 4	29.5	Sequoyah 1	40.8	Waterford 3	32.3
	McGuire 1	30.6	Sequoyah 2	40.8	Millstone 3	33.7
	McGuire 2	30.6	Arkansas 1	43.0	Catawba 1	34.4
	South Texas 2	32.5	Arkansas 2	47.2	Catawba 2	34.4
	Harris	34.3	Watts Bar	50.8	Indian Point 2	37.3
	Vogtle 1	36.7	Vogtle 2	50.8	Vogtle 2	37.7
	Palisades	36.7	Braidwood 1	51.6	Wolf Creek	46.8
	Point Beach 1	40.2	Braidwood 2	51.6	Point Beach 1	48.3
	Point Beach 2	40.2	McGuire 1	57.5	Point Beach 2	48.3
Fourth Quartile	Callaway	41.2	McGuire 2	57.5	Arkansas 2	50.2
	Arkansas 1	46.2	Turkey Point 3	58.8	St. Lucie 1	66.9
	Millstone 3	50.5	Turkey Point 4	58.8	St. Lucie 2	66.9
	Prairie Island 1	56.9	Point Beach 1	60.1	Callaway	70.2
	Prairie Island 2	56.9	Point Beach 2	60.1	Turkey Point 3	82.0
	Sequoyah 1	61.5	North Anna 1	61.3	Turkey Point 4	82.0
	Sequoyah 2	61.5	North Anna 2	61.3	Millstone 2	84.2
	Farley 1	68.3	Millstone 3	80.4	Watts Bar	88.8
	Beaver Valley 1	85.9	Wolf Creek	105	Beaver Valley 1	110
	Beaver Valley 2	85.9	Millstone 2	113	Beaver Valley 2	110
	Farley 2	92.4	Beaver Valley 1	199	Braidwood 1	136
	Watts Bar	98.2	Beaver Valley 2	199	Braidwood 2	136
	North Anna 1	128	Callaway	254	Prairie Island 1	204
	North Anna 2	128	Prairie Island 1	381	Prairie Island 2	204
	Waterford 3	174	Prairie Island 2	381	Palisades	217

Figure 3.16
Liquid Effluent Activity from BWRs
3-Year Trend of Industry Quartiles, 2007-2009

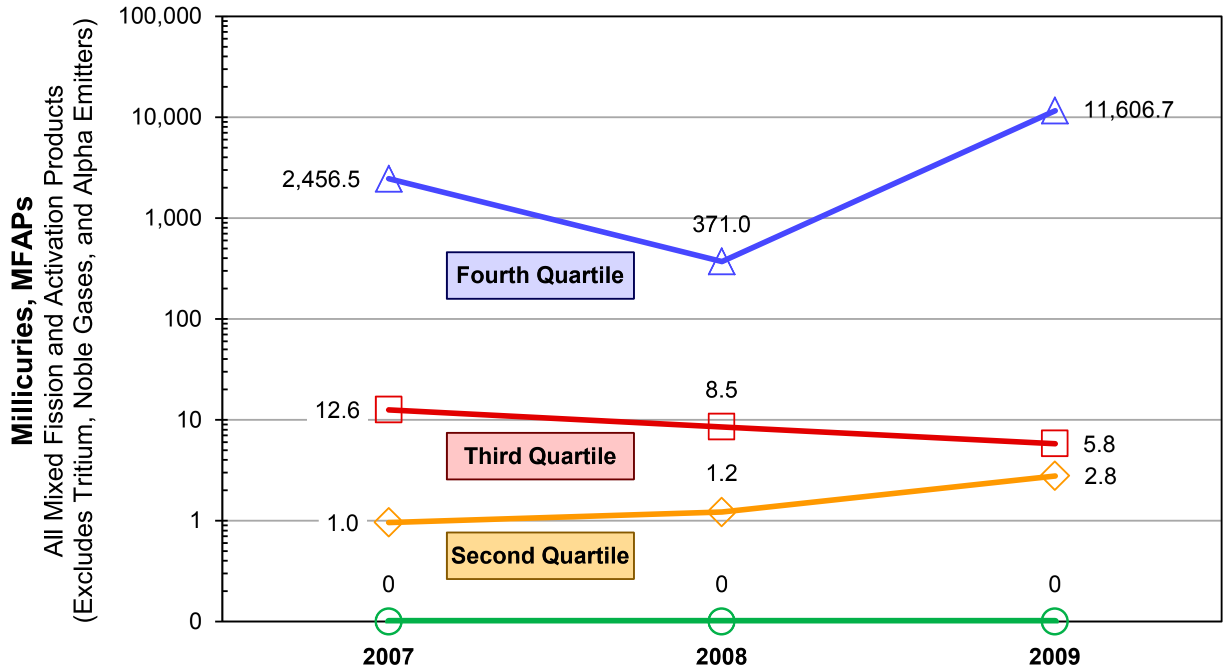
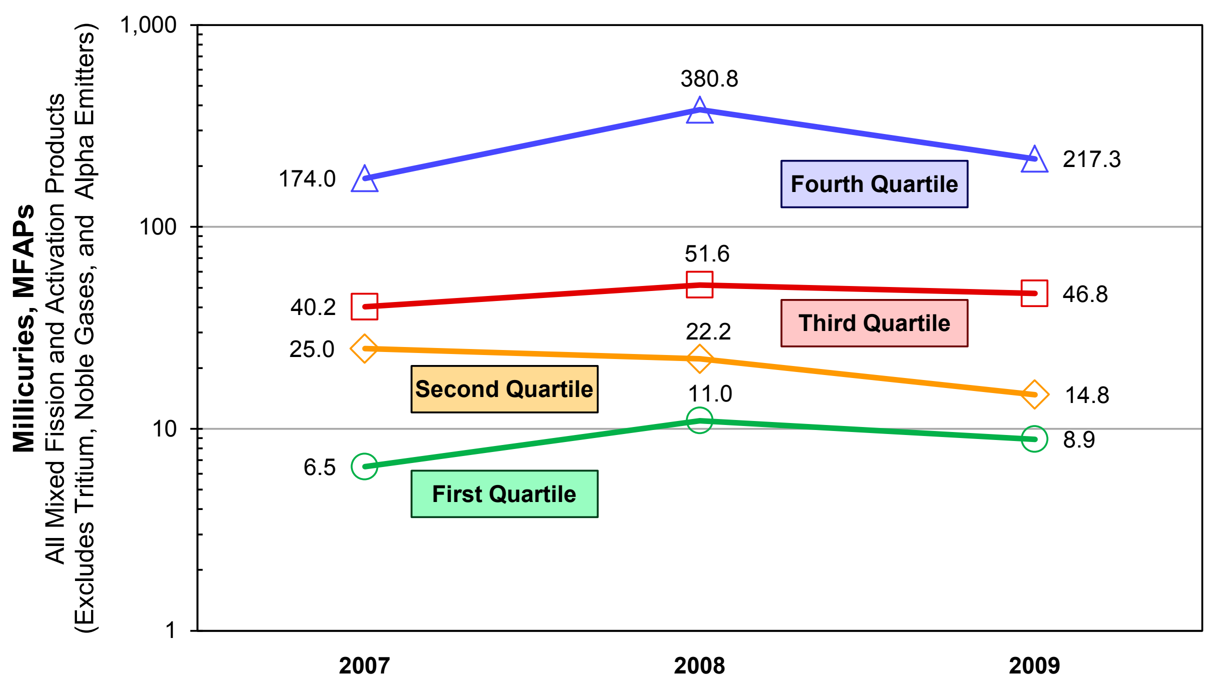


Figure 3.17
Liquid Effluent Activity from PWRs
3-Year Trend of Industry Quartiles, 2007-2009



3.5 Long-Term Trend in Liquid Effluents

In the previous section, short-term trends of MFAP activity in liquid effluents were discussed. The short-term, 3-year trend of MFAPs released from BWRs showed an increase in each of the 3 years, while PWRs showed a decrease each year. This section discusses the long-term trends in MFAPs in liquid effluents from nuclear power plants in the United States.

NRC regulations require radioactive effluents to be ALARA. As a result, the activity of radioactive effluents should ideally decrease over time. The trend in the median MFAP activity of liquid effluents since 1975 is shown in Figure 3.18. This information comes from the Annual Radioactive Effluent Release Reports submitted by licensees and from information presented in previous NRC NUREGs (Refs. 2 thru 22). All power reactors that have operated in the United States, some of which are now shutdown, are included. Additionally, just as with Figures 3.16 and 3.17, no MFAPs have been excluded from Figure 3.18. As a result, Figure 3.18 is an extension of Figures 3.16 and 3.17, except that only the median activities are shown.

Figure 3.18
Long-term Trend in Liquid Effluents
Mixed Fission and Activation Products

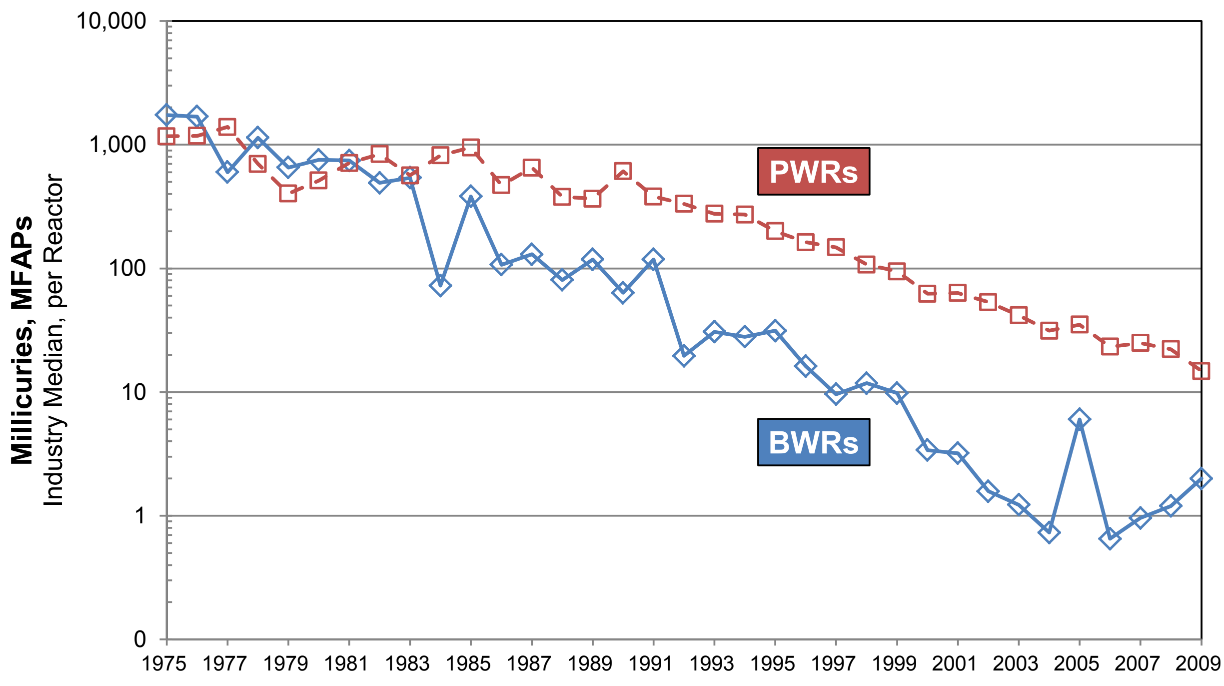


Figure 3.18 indicates a long-term downward trend in the amounts of MFAPs in liquid effluents from both BWRs and PWRs. The magnitude of the reduction is significant. For example, in 1978, the median activity of liquid effluents from BWRs was greater than 1000 millicuries; however, in 2009, the median was 2.8 millicuries. That corresponds to a 99.7% reduction in MFAPs in liquid effluents over the last 34 years. One of the primary contributors to the reduction in liquid effluents is improved fuel integrity in both BWRs and PWRs. Additionally, many BWRs recycle (or reuse) either some or all of the liquid waste. The recycling of liquid

waste at BWRs is one reason why effluents from BWRs are generally lower than from PWRs. Additionally, PWRs use boron in the reactor water, whereas BWRs do not. This also contributes to lower liquid releases in BWRs, particularly for tritium. The use of advanced liquid radioactive waste processing systems has also significantly lowered liquid effluents. Lastly, contributions from the operations, maintenance, chemistry, and health physics departments at the various facilities has improved the handling and processing of liquid waste to further improve and optimize effluent performance.

Figure 3.18 indicates that from 2007 to 2009 median liquid effluents from BWRs increased each year. This is also shown in Figure 3.16. An analysis of this increase in median MFAP activity of liquid effluents from BWR reveals important information about the control of liquid effluents at BWRs. For many decades, BWRs have embraced a “zero-release” strategy for radioactive liquid effluents. Such a strategy has cost advantages, because it is expensive to discharge very high quality water that could appropriately be reused in designated plant systems. Additionally, a zero-release strategy conserves the natural resources and virtually eliminates radioactive liquid effluents in those BWRs that adopt this strategy. This combination of factors makes a zero-release strategy very popular among BWRs. The zero-release strategy is partly responsible for the decreases in the median MFAP activity during the 1980s, 1990s, and beyond 2000, which can be seen in Figure 3.18. This strategy can be very effective in reducing both the activity and the dose from radioactive effluents. Within the last 10 years, it was recognized that, at some sites, the relative contribution of tritium to personnel exposure was increasing. This increase had the potential to affect plant workers and members of the public. This relative increase can be attributed to 4 factors:

- As waste water is recycled, the tritium concentration in the water increases over time.
- Over the last 20 years, improved fuel integrity, improved fuel loading pattern designs, and improved liquid waste processing capabilities effectively reduced the concentration of mixed fission and activation products in waste water.
- When all radioactive liquid releases are eliminated, tritium is released through the gaseous release points.
- The dose due to tritium discharged from a gaseous release point can, depending on plant design and site characteristics, be higher than the same amount of tritium discharged from a liquid release point.

As a result, for some sites, it was a mathematical certainty that doses could be lowered if more tritium was released in liquid effluents. Limited liquid releases containing tritium, along with very low levels of mixed fission and activation products, can shift the release of tritium from a gas release point to a liquid release point, thereby lowering doses due to effluents. This strategy can cause a slight increase in the activity of MFAPs in liquid effluents. This strategy to reduce doses from liquid effluents is partly responsible for the increases in the MFAP activity of liquid effluents at BWRs since about 2005, which can be seen in Figure 3.18.

This is an example of how the quartile rankings and medians discussed thus far can provide valuable insights regarding the optimization of the radioactive effluent control program. Such optimizations can minimize exposures to people and ensure radioactive effluents are ALARA. This also demonstrates that the activities of some radionuclides can increase in liquid effluents, while the dose from liquid and gaseous effluents decreases. Dose is discussed in the next section.

3.6 Radiation Doses from Liquid and Gaseous Effluents

The doses from liquid and gaseous effluents for 2009 are shown in Tables 3.17 through 3.20. The data from these tables are illustrated graphically in Figures 3.19 through 3.24. These tables and figures contain annual organ doses (for liquid and gaseous effluents) and annual total body doses (for liquid effluents). Doses measure the potential impact of NPP effluents on public health and the environment. Licensees are required to calculate these doses as described in 10 CFR 50 Appendix I and the licensing documents for each site (Ref. 26). The dose calculation methodology is described in RG 1.109 (Ref. 29).

In accordance with regulatory requirements and RG 1.109 methodology, the doses are calculated for the individuals receiving the highest whole body and organ doses. As a result, these doses are often referred to as the maximum whole body and the maximum organ doses. Additionally, licensees are required to calculate the organ doses for 6 separate organs in the human body: bone, liver, thyroid, kidney, lung, and intestines. Only the highest of the organ doses is shown in this report. This is often referred to as the critical organ for the maximum exposed individual. Because these doses are calculated for the individual receiving the highest dose from liquid and gaseous effluents, these individuals are typically located in close proximity to the facility. As a result, doses to other individuals, especially those located further away from the facility, are expected to be lower than those indicated in this report.

The doses shown in the tables and graphs of this section include contributions from all radionuclides in the type of effluent shown (i.e., liquid or gaseous). For example, any dose contributions from Sr-90, which can be a relatively significant contributor to dose, are included in the tables and graphs in this section.

The NRC design objectives (also called system operating limits in this report), discussed in Section 2.4, are included in the tables and figures. To allow the reader to compare one reactor with another in this report, the system operating limits are shown on a per-unit basis for multi-unit sites. The dose tables and figures are organized by the two types of reactors used in the United States: BWRs and PWRs. The tables and figures are further subdivided into liquid and gaseous effluents.

If the licensee does not report a dose, the corresponding table entry will be blank. A blank entry indicates that a particular dose is zero. A dose of zero implies either (1) no releases occurred (e.g., the NPP is a zero-discharge plant) or (2) no exposure pathway exists and it is not possible for a member of the public to receive a dose. Zeros are not included in the dose tables in order to make it easier for the reader to quickly identify the positive values.

For comparison purposes, median values are included in the tables and figures. The median is a statistical estimate of the midpoint of the data. Approximately half of the power plants will report doses greater than the median and approximately half will report doses lower than the median. The median is a method of estimating a central or typical value while avoiding bias caused by extremely high or low values in the data set. All sites are included when calculating the medians, even those sites for which no dose is reported. For example, in Table 3.17, the BWR median annual organ dose due to gaseous effluents from all BWRs is highlighted in yellow in the center of the table. In this case, the median is 0.0148 mrem. This represents the typical annual organ dose, due to all gaseous effluents, from all BWRs operating in the United States in 2009. The 2009 median organ dose is compared with the median organ doses from 2007 and 2008 in Figure 3.23. The organ doses due to gaseous effluents from PWR are also shown on Figure 3.23. Figure 3.23 indicates organ doses due to gaseous effluents from BWRs decreased between 2007 and 2009. The median organ doses for liquid effluents from PWRs also decreased between 2007 and 2009.

This information can be useful in a number of ways. For example, Figures 3.23 and 3.24 show that, in general, most of the dose from NPP effluents comes from the gaseous effluents. As a result, licensees wanting to lower doses may choose to focus additional efforts on reducing the radionuclides in gaseous effluents. Indeed, this was discussed at some length in Section 3.5. In Figure 3.18 of Section 3.5, it was noted that the activity of MFAPs in BWR liquid effluents increased from 2007 to 2009. As discussed in Section 3.5, this increase in MFAPs appears to be, at least partly, the result of an effort to reduce doses. Figures 3.23 and 3.24 indicate that even though the activity in BWR liquid effluents increased from 2007 to 2009 (as shown in Figure 3.18), the doses from BWR liquid and gaseous effluents decreased during the same period.

The evaluation of effluent data can be a key factor in understanding radioactive effluents. By gaining a better understanding of radioactive effluents, it is possible to exercise more control in reducing doses from such effluents. This helps to ensure radioactive effluents are ALARA.

The tables in this section indicate that the highest total body dose from all of the facilities was less than 0.4 mrem (Table 3.19), and the highest organ dose from all of the facilities was less than 0.9 mrem (Table 3.18). None of the doses from liquid or gaseous effluents exceeded 1 mrem. For purposes of comparison, 1 mrem is less than the radiation dose from any one of the following:

- the dose received in 1 week from skiing in the Rocky Mountains,
- the dose received in 4 weeks from the natural potassium in each person's body, or
- the dose received in 8 weeks by a homeowner residing in a brick or stone house.

The basis for each of these 3 values is discussed in the following paragraphs.

Based on information from the U. S. Geological Survey (USGS) (Ref. 32), people's exposure to cosmic rays at the high altitudes of Colorado would result in a dose of about 70 mrem per year. Additionally, the dose from rocks and soil in the mountains of Colorado would be about 40 mrem per year. The total of these two values is about 110 mrem per year for a person in the high elevations of Colorado. A person in Florida, who is typically at sea level and surrounded by the native Florida terrain, would receive about 40 mrem per year from rocks, soil, and cosmic radiation, based on USGS data. As a result, people living at the high altitudes of Colorado receive about 70 mrem per year more radiation dose than a person living in Florida. People from Florida skiing in the Rocky Mountains for a week would be expected to receive an additional dose—above what they might normally have received if they had stayed in Florida—of about 1.3 mrem.

According to a DOE report prepared by the Pacific Northwest National Laboratory (Ref. 33) the average 150-pound individual receives about 14 mrem per year from the natural potassium-40 that is incorporated into the human body. The dose for 4 weeks would be 1.1 mrem.

Report No. 95 issued by the NCRP (Ref. 34) indicates that the radiation exposure from living in a brick, stone, adobe, or concrete home is about 7 mrem per year. At this annual dose rate, the exposure received in 8 weeks would be about 1.1 mrem.

NPPs in the United States discharge small but measurable amounts of radioactive materials in radioactive effluents. All of these radioactive releases must comply with NRC requirements. These requirements are in place to ensure (1) the radwaste processing systems at NPPs are operating properly, (2) the doses to members of the public are within the safety limits, and (3) the doses to members of the public are ALARA. The information presented in this section indicates the maximum dose due to radioactive releases from NPPs was less than 1 mrem in 2009. The highest median dose was approximately 0.01 mrem. Additionally, the doses from radioactive effluents appear to be on a declining trend. Doses of these magnitudes are not expected to have a health impact on the public or the environment.

Table 3.17

BWR Gaseous Effluents — Maximum Annual Organ Dose, 2009

BWR Facility	Annual Organ Dose (mrem)
Perry	5.33E-05
Limerick 1	3.03E-04
Limerick 2	3.03E-04
Hope Creek	6.51E-04
Vermont Yankee	7.88E-04
Clinton	1.62E-03
FitzPatrick	3.37E-03
Dresden 2	3.44E-03
Browns Ferry 1	5.53E-03
Browns Ferry 2	5.53E-03
Browns Ferry 3	5.53E-03
Duane Arnold	6.05E-03
Oyster Creek	6.56E-03
Dresden 3	9.17E-03
Hatch 2	9.74E-03
Grand Gulf	1.37E-02
Hatch 1	1.44E-02
Peach Bottom 2	1.48E-02
Peach Bottom 3	1.48E-02
BWR Median Dose	**1.48E-02**
Columbia	1.84E-02
Nine Mile Point 1	2.97E-02
LaSalle 1	3.85E-02
LaSalle 2	3.85E-02
Cooper	3.90E-02
Pilgrim	6.19E-02
Monticello	6.24E-02
Fermi 2	6.96E-02
Nine Mile Point 2	1.13E-01
Quad Cities 1	1.47E-01
Quad Cities 2	1.47E-01
Susquehanna 1	1.48E-01
Susquehanna 2	1.98E-01
Brunswick 1	2.03E-01
Brunswick 2	2.03E-01
River Bend	3.48E-01
System Operational Limit	**15**

Table 3.18

PWR Gaseous Effluents — Maximum Annual Organ Dose, 2009

PWR Facility	Annual Organ Dose (mrem)
Salem 2	4.08E-05
Salem 1	1.04E-04
Vogtle 2	3.56E-04
Calvert Cliffs 1	4.00E-04
Calvert Cliffs 2	4.00E-04
St. Lucie 1	9.68E-04
Kewaunee	9.69E-04
Summer	1.14E-03
Diablo Canyon 2	1.28E-03
Davis-Besse	1.66E-03
Indian Point 2	2.10E-03
South Texas 2	2.27E-03
South Texas 1	2.36E-03
Farley 2	2.61E-03
Indian Point 3	3.18E-03
Vogtle 1	3.21E-03
Farley 1	3.33E-03
Ginna	4.30E-03
Millstone 3	6.21E-03
Callaway	9.03E-03
Byron 1	7.24E-03
San Onofre 2	7.44E-03
San Onofre 3	7.44E-03
Crystal River 3	7.68E-03
Palisades	8.39E-03
Millstone 2	8.93E-03
Oconee 1	9.17E-03
Oconee 2	9.17E-03
Oconee 3	9.17E-03
Arkansas 1	1.30E-02
Sequoyah 1	1.30E-02
Sequoyah 2	1.30E-02
Prairie Island 1	1.32E-02
Prairie Island 2	1.32E-02
Ft. Calhoun	1.48E-02
PWR Median Dose	**1.48E-02**

PWR Facility	Annual Organ Dose (mrem)
North Anna 1	1.55E-02
North Anna 2	1.55E-02
Point Beach 1	1.61E-02
Point Beach 2	1.61E-02
St. Lucie 2	2.14E-02
Beaver Valley 2	2.31E-02
Seabrook	2.51E-02
Byron 2	2.82E-02
Wolf Creek	3.11E-02
Comanche Peak 1	3.94E-02
Comanche Peak 2	3.94E-02
Braidwood 2	4.81E-02
Surry 1	4.89E-02
Surry 2	4.89E-02
Three Mile Island 1	5.59E-02
Diablo Canyon 1	7.55E-02
Watts Bar	8.36E-02
Cook 1	8.37E-02
Cook 2	8.37E-02
Robinson 2	8.67E-02
McGuire 1	9.90E-02
McGuire 2	9.90E-02
Palo Verde 1	1.11E-01
Beaver Valley 1	1.32E-01
Braidwood 1	1.61E-01
Arkansas 2	1.65E-01
Palo Verde 3	1.92E-01
Palo Verde 2	2.43E-01
Turkey Point 4	3.69E-01
Turkey Point 3	3.94E-01
Waterford 3	6.72E-01
Catawba 1	7.70E-01
Catawba 2	7.70E-01
Harris	8.47E-01
System Operational Limit	**15**

Table 3.19

BWR Liquid Effluents — Maximum Annual Total Body and Organ Dose, 2009

BWR Facility	Annual Total Body Dose (mrem)	Annual Organ Dose (mrem)
Clinton		
Columbia		
Fermi 2		
LaSalle 1		
LaSalle 2		
Monticello		
Nine Mile Point 2		
Oyster Creek		
Duane Arnold	4.56E-06	4.56E-06
FitzPatrick	1.66E-05	1.66E-05
River Bend	1.85E-05	4.09E-05
Dresden 2	2.72E-05	3.82E-05
Vermont Yankee	5.06E-05	5.06E-05
Dresden 3	7.12E-05	8.89E-05
Pilgrim	3.10E-05	2.10E-04
Hope Creek	8.32E-05	3.05E-04
Hatch 2	2.23E-04	2.83E-04
Perry	3.57E-04	3.61E-04
BWR Median Dose	**3.57E-04**	**3.61E-04**
Susquehanna 1	8.50E-04	1.28E-03
Susquehanna 2	8.50E-04	1.28E-03
Nine Mile Point 1	6.30E-04	1.95E-03
Browns Ferry 1	1.10E-03	1.55E-03
Browns Ferry 2	1.10E-03	1.55E-03
Browns Ferry 3	1.10E-03	1.55E-03
Peach Bottom 2	1.50E-03	2.36E-03
Peach Bottom 3	1.50E-03	2.36E-03
Hatch 1	8.78E-04	3.93E-03
Brunswick 1	2.24E-03	3.00E-03
Brunswick 2	2.24E-03	3.00E-03
Quad Cities 1	4.70E-03	7.45E-03
Quad Cities 2	4.70E-03	7.45E-03
Cooper	2.45E-02	2.49E-02
Grand Gulf	6.15E-02	1.21E-01
Limerick 1	3.88E-01	3.88E-01
Limerick 2	3.88E-01	3.88E-01
System Operational Limit	**3**	**10**

Table 3.20

PWR Liquid Effluents — Maximum Annual Total Body and Organ Dose, 2009

PWR Facility	Annual Total Body Dose (mrem)	Annual Organ Dose (mrem)	PWR Facility	Annual Total Body Dose (mrem)	Annual Organ Dose (mrem)
Palo Verde 1			Farley 1	6.10E-03	9.13E-03
Palo Verde 2			South Texas 1	8.19E-03	8.25E-03
Palo Verde 3			Davis-Besse	7.81E-03	9.67E-03
Robinson 2	4.23E-05	4.76E-05	Harris	5.87E-03	1.27E-02
Salem 2	2.72E-05	8.89E-05	Ginna	9.57E-03	9.62E-03
Salem 1	3.22E-05	8.60E-05	Farley 2	6.42E-03	1.61E-02
Crystal River 3	5.53E-05	1.14E-04	Watts Bar	1.13E-02	1.40E-02
Turkey Point 3	3.93E-04		Vogtle 1	1.18E-02	1.49E-02
Turkey Point 4	3.93E-04		Cook 1	2.22E-02	2.23E-02
Surry 1	1.55E-04	2.52E-04	Cook 2	2.22E-02	2.23E-02
Surry 2	1.55E-04	2.52E-04	Three Mile Island 1	2.77E-02	2.86E-02
Diablo Canyon 1	1.67E-04	4.20E-04	Ft. Calhoun	2.80E-02	3.06E-02
Diablo Canyon 2	1.67E-04	4.20E-04	Catawba 1	2.51E-02	3.54E-02
Indian Point 3	2.49E-04	4.59E-04	Catawba 2	2.51E-02	3.54E-02
Kewaunee	5.81E-04	7.25E-04	Oconee 1	2.04E-02	4.87E-02
Seabrook	8.17E-04	1.11E-03	Oconee 2	2.04E-02	4.87E-02
Calvert Cliffs 1	8.50E-04	1.40E-03	Oconee 3	2.04E-02	4.87E-02
Calvert Cliffs 2	8.50E-04	1.40E-03	St. Lucie 1	1.59E-02	5.61E-02
Indian Point 2	9.00E-04	1.71E-03	St. Lucie 2	1.59E-02	5.61E-02
Millstone 3	4.00E-04	2.26E-03	Braidwood 1	4.91E-02	5.72E-02
San Onofre 2	1.08E-03	2.74E-03	Braidwood 2	4.91E-02	5.72E-02
San Onofre 3	1.08E-03	2.74E-03	Vogtle 2	5.06E-02	5.65E-02
Prairie Island 1	9.55E-04	3.46E-03	Comanche Peak 1	6.45E-02	6.48E-02
Prairie Island 2	9.55E-04	3.46E-03	Comanche Peak 2	6.45E-02	6.48E-02
Arkansas 2	2.30E-03	2.80E-03	Beaver Valley 1	5.32E-02	9.34E-02
Arkansas 1	2.50E-03	3.40E-03	Beaver Valley 2	5.32E-02	9.34E-02
Point Beach 1	3.01E-03	3.51E-03	Byron 1	7.35E-02	9.05E-02
Point Beach 2	3.01E-03	3.51E-03	Byron 2	7.35E-02	9.05E-02
Millstone 2	8.29E-04	7.76E-03	McGuire 1	8.90E-02	9.00E-02
South Texas 2	5.26E-03	5.28E-03	McGuire 2	8.90E-02	9.00E-02
Sequoyah 1	5.35E-03	5.35E-03	North Anna 1	1.40E-01	1.52E-01
Sequoyah 2	5.35E-03	5.35E-03	North Anna 2	1.40E-01	1.52E-01
Waterford 3	6.16E-03	5.61E-03	Palisades	1.39E-02	3.70E-01
Summer	6.24E-03	6.33E-03	Wolf Creek	1.93E-01	2.03E-01
Callaway	5.67E-03	8.18E-03	**System Operational Limit**	**3**	**10**
PWR Median Dose	**6.10E-03**	**8.18E-03**			

Figure 3.19
BWR Gaseous Effluents — Maximum Annual Organ Dose

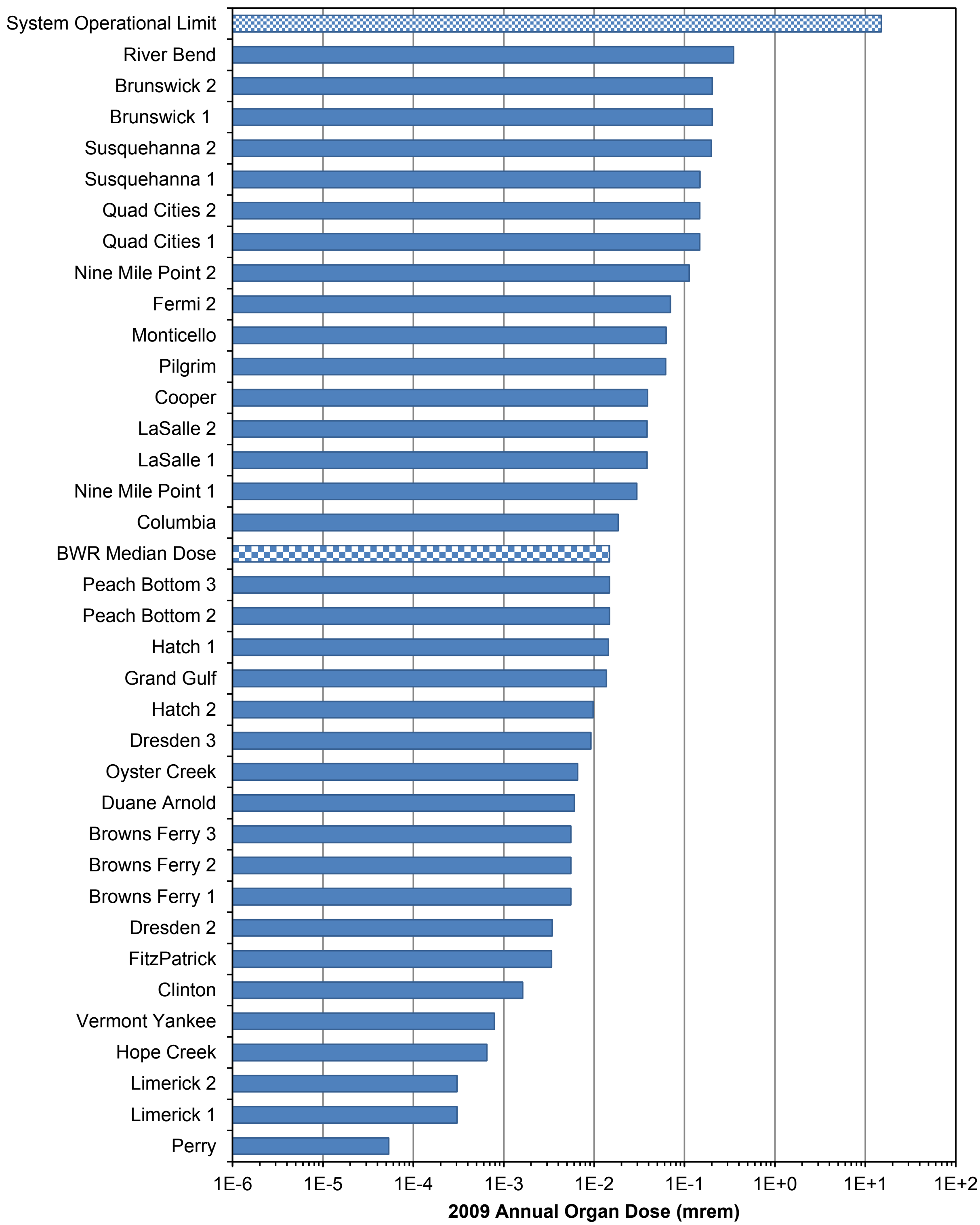


Figure 3.20

PWR Gaseous Effluents — Maximum Annual Organ Dose

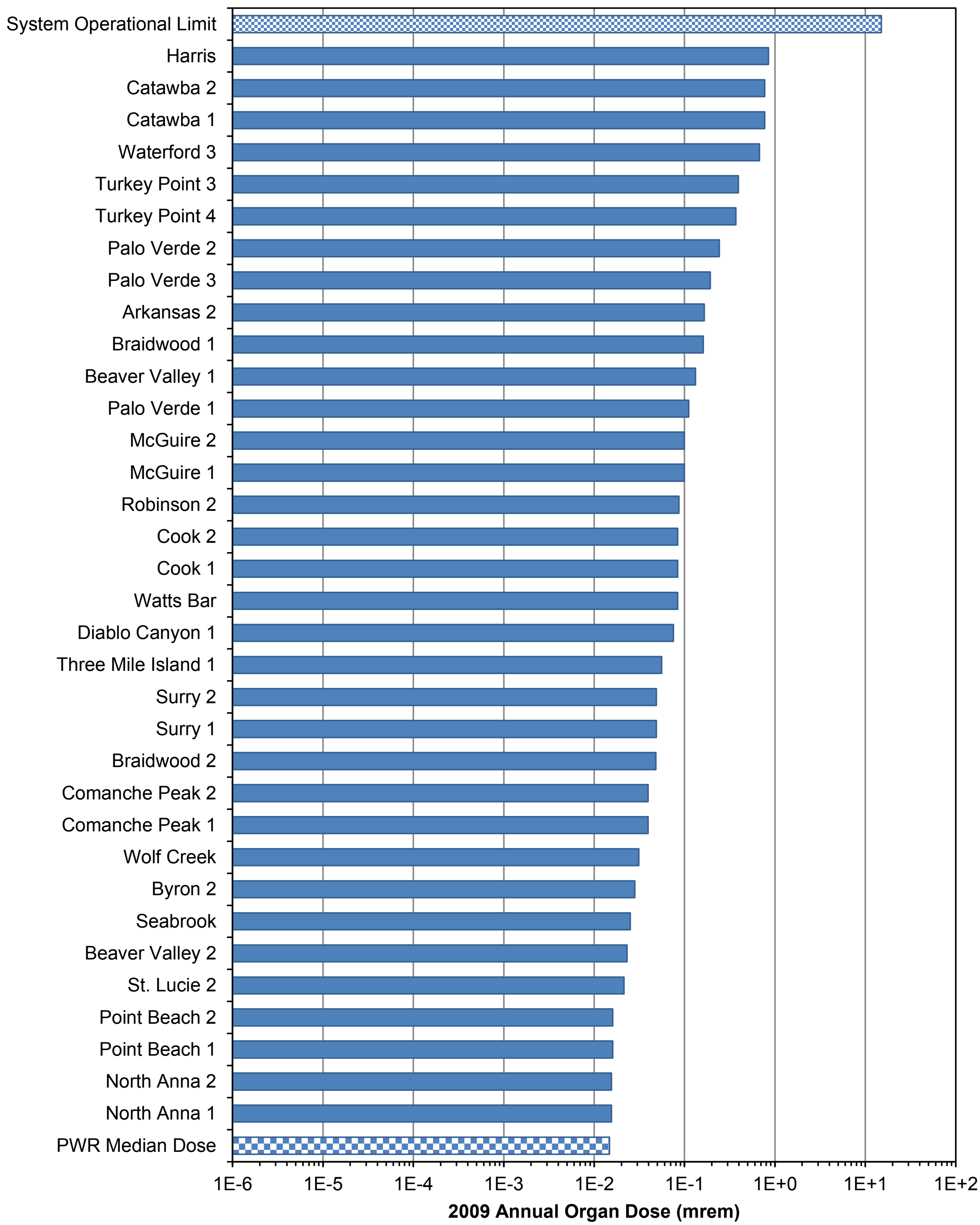


Figure 3.20 *(continued)*

PWR Gaseous Effluents — Maximum Annual Organ Dose

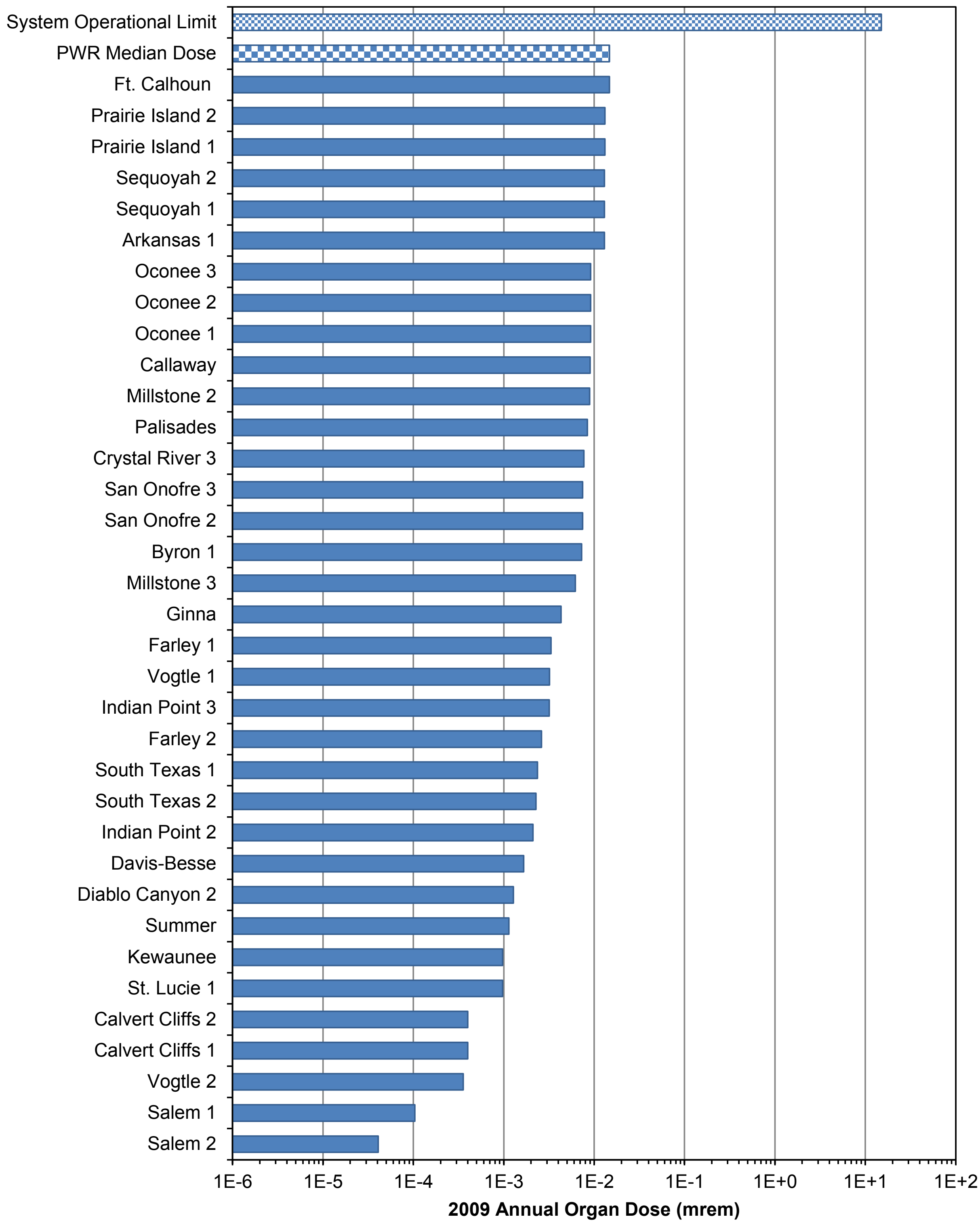


Figure 3.21

BWR Liquid Effluents — Maximum Annual Total Body and Organ Dose

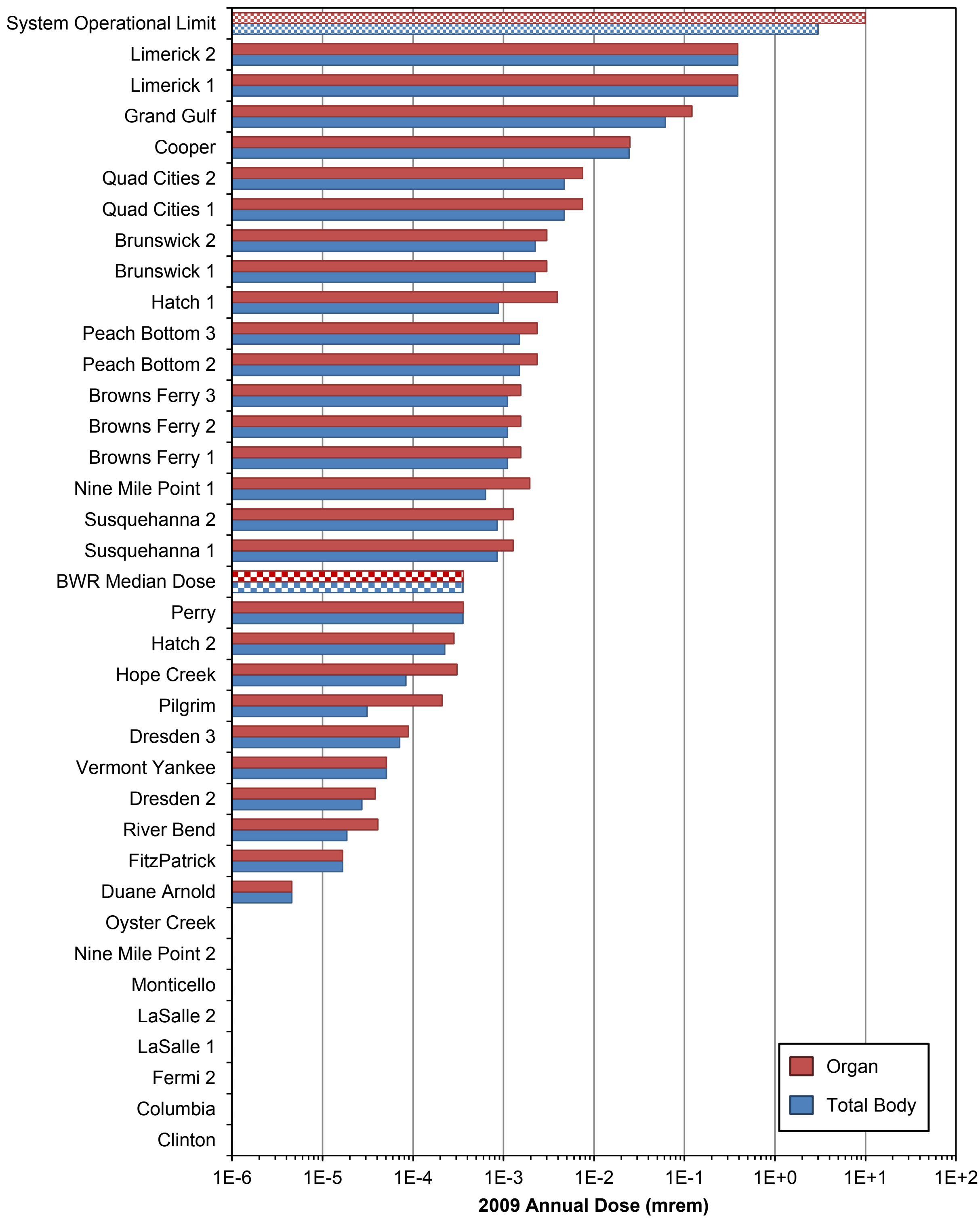


Figure 3.22
PWR Liquid Effluents — Maximum Annual Total Body and Organ Dose

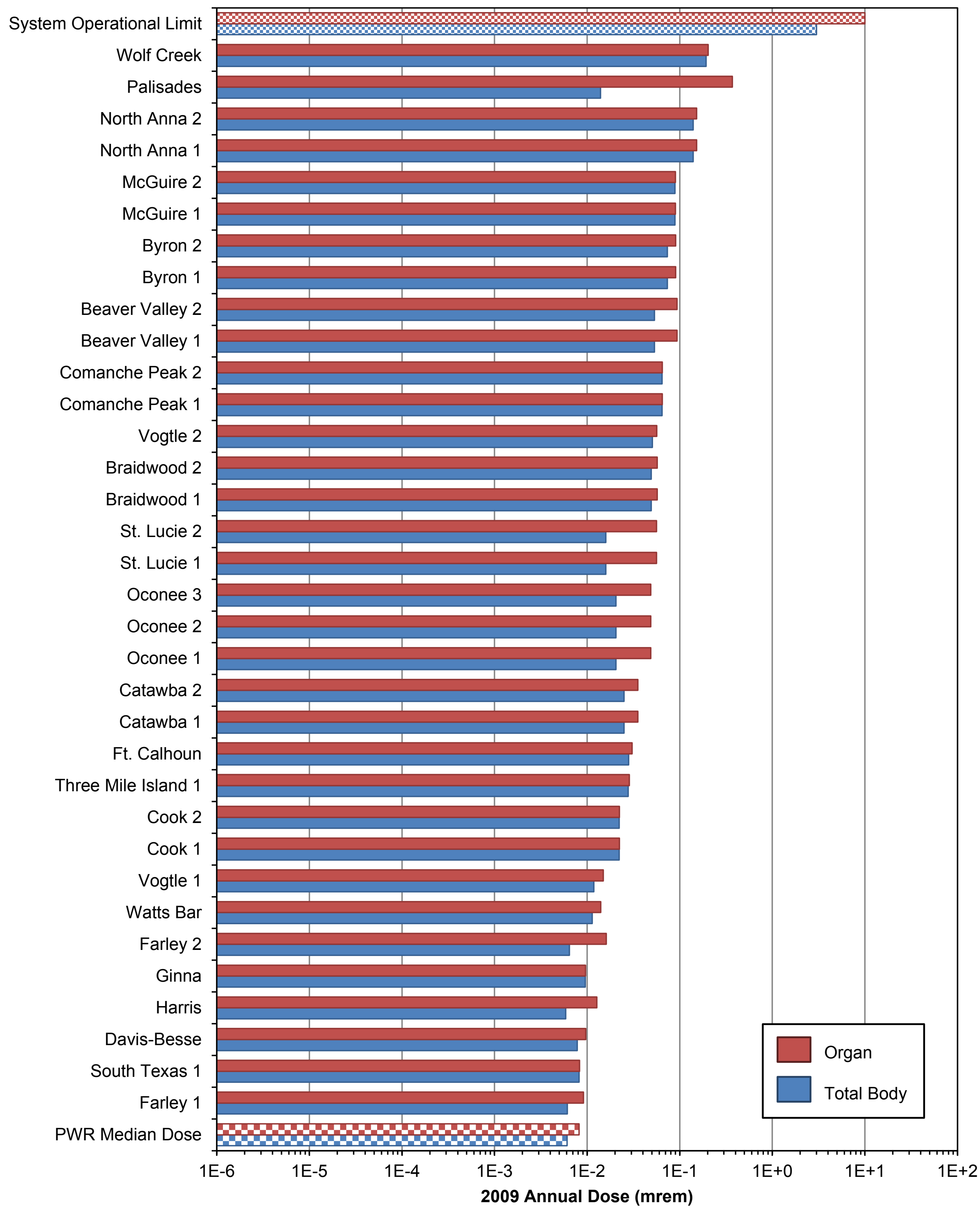


Figure 3.22 *(continued)*

PWR Liquid Effluents — Maximum Annual Total Body and Organ Dose

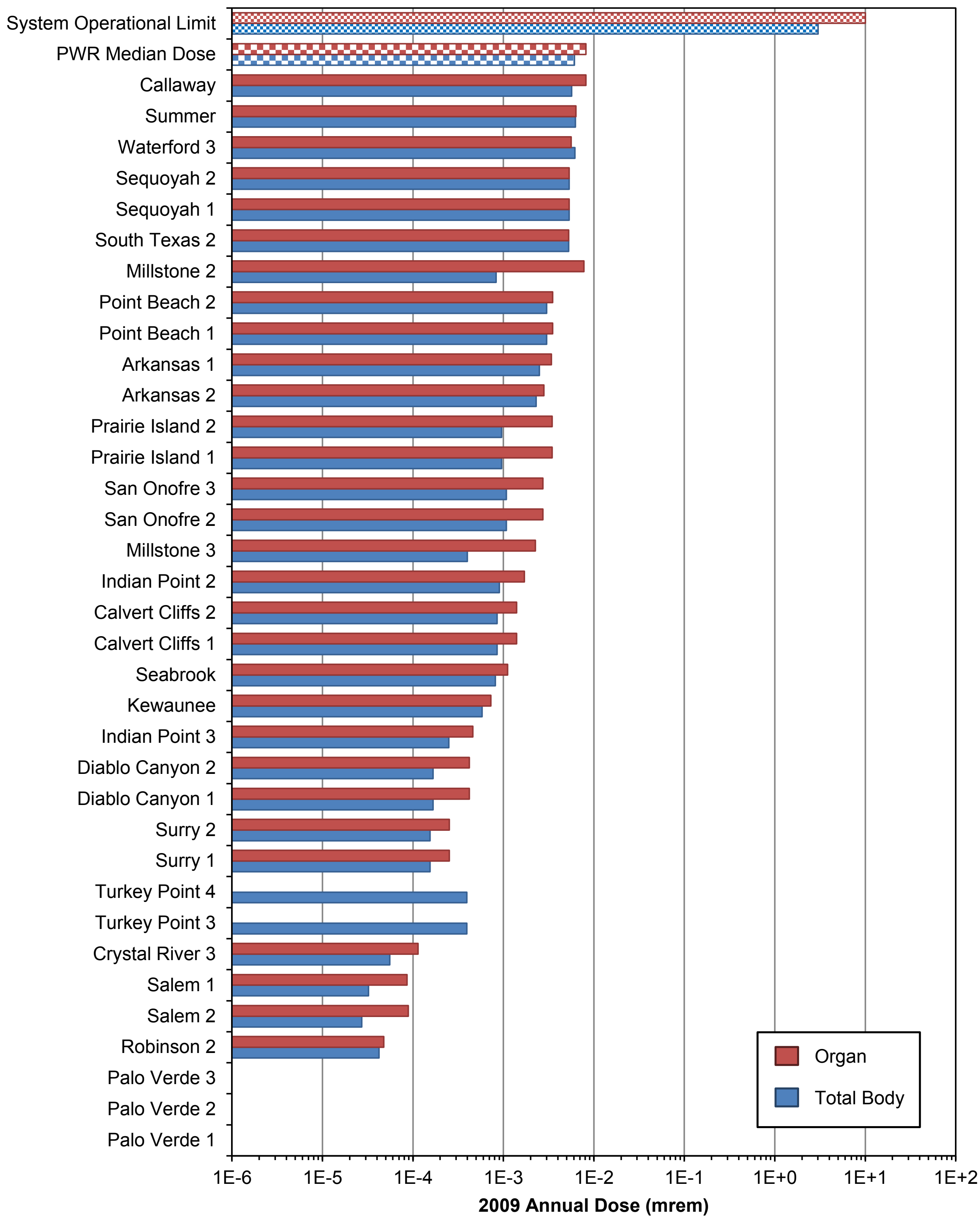


Figure 3.23

Median Maximum Annual Organ Dose, Gaseous Effluents

3-Year Trend, 2007-2009

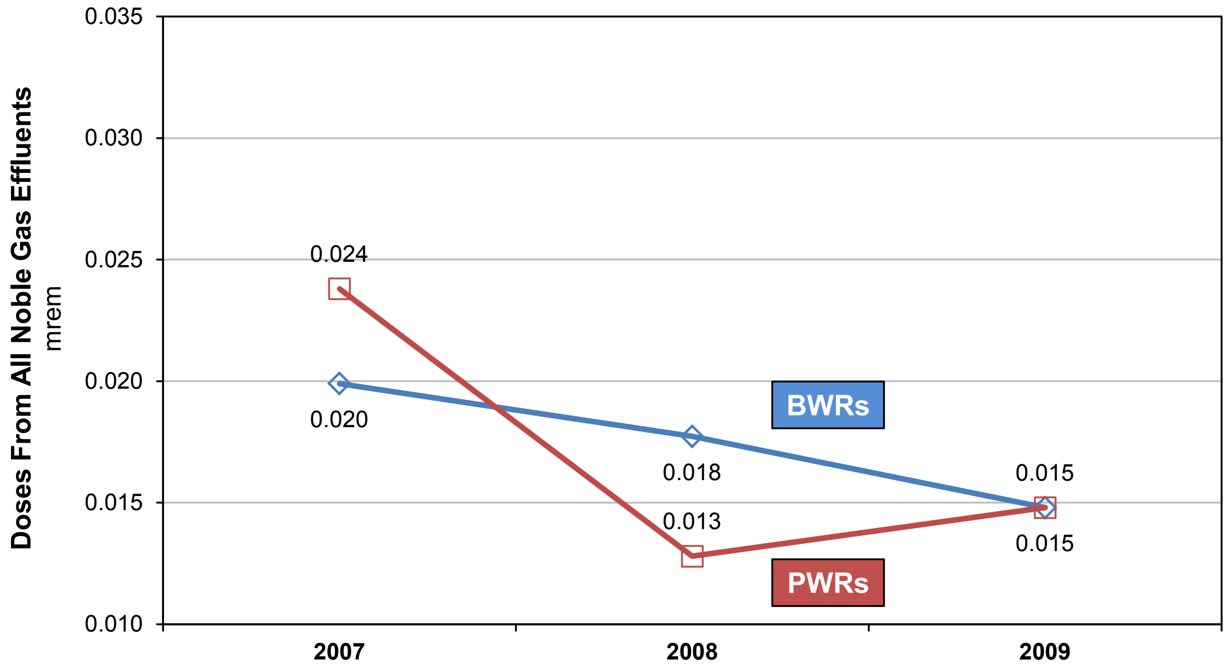
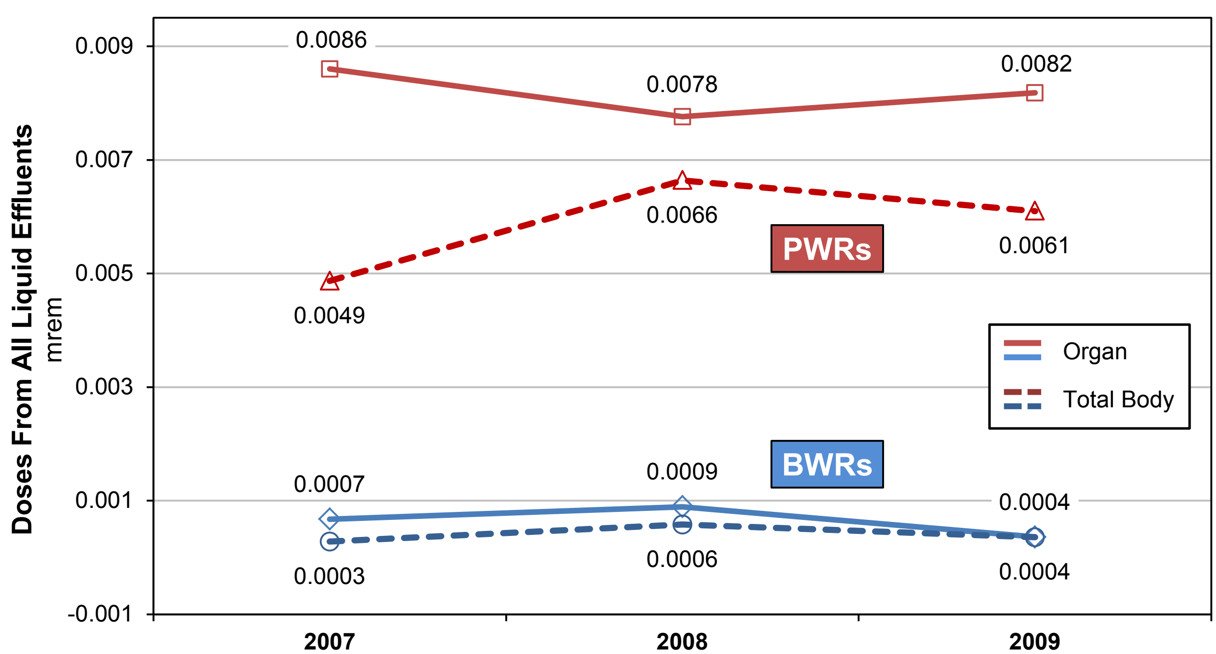


Figure 3.24

Median Maximum Annual Dose, Liquid Effluents

3-Year Trend, 2007-2009



4 Summary

The information contained in this report characterizes liquid and gaseous effluents from all United States nuclear power plants (NPPs) in commercial operation for calendar year 2009. Although all NPPs released some amount of radioactive materials in 2009, none of the effluents from any NPP exceeded:

- any NRC safety limit,
- any NRC design objective, or
- any of the licensees' system operating limits for radioactive effluents.

This report summarizes several thousand pages of reports submitted to the NRC by licensees in the United States. The radionuclides selected for inclusion in this report are either the most predominant in radioactive effluents or are particularly useful indicators of overall releases. The radionuclides selected also provide additional information about operational practices at a site. The data presented in this report show a significant decreasing trend in radioactive effluents (i.e., mixed fission and activation products in liquid effluents and noble gases in gaseous effluents) over the last 34 years.

The radiation doses in this report are those most directly associated with potential public health impact from radioactive effluents. People receive some radiation exposure from the radioactive effluents discharged from NPPs, but that exposure is very small. To provide some context, the dose from radioactive effluents to the maximum exposed individual living near any U.S. NPP is less than the dose from any one of the following:

- 1 week of skiing in the Rocky Mountains,
- 4 weeks from the natural potassium in each person's body,
- 8 weeks to a homeowner residing in a brick or stone house.

For additional context, the median activities for radioactive effluents, the system operating dose limits, the natural background sources of radiation, and other sources of radiation exposure to the U.S. population are provided in this report for comparison with the effluent data. Comparisons of the radioactive effluents between NPPs may indicate differences in fuel conditions, fuel cycle length, radioactive waste processing equipment, reactor types, reactor ages, electrical outputs, and operating conditions. Each of these factors can have an effect on radioactive effluents.

More complete and detailed information, including copies of the NPPs Annual Radioactive Effluent Release Reports (ARERRs), is available to the public on the NRC Web site.

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6 Glossary

Activity or radioactivity: The rate of radioactive decay of a radionuclide, measured in the traditional unit of the curie (Ci) or the international standard unit of the becquerel (Bq).

Background (radiation): Radiation from cosmic sources; naturally occurring radioactive material, including radon (except as a decay product of source or special nuclear material); and global fallout as it exists in the environment from the testing of nuclear explosive devices and from past nuclear accidents such as Chernobyl that contribute to background radiation and are not under the control of the licensee. Background radiation does not include radiation from source, byproduct, or special nuclear materials regulated by the Nuclear Regulatory Commission.

Effluent discharge, radioactive discharge: The portion of an effluent release that reaches an unrestricted area.

Effluent release, radioactive release: The emission of an effluent.

Exposure pathway: A mechanism by which radioactive material is transferred from the (local) environment to humans. There are three commonly recognized exposure pathways: inhalation, ingestion, and direct radiation.

Fission and activation gases: The noble (chemically non-reactive) gases formed from the splitting (fission) of the uranium-235 isotope in a nuclear reactor or the creation of radioactive atoms from non-radioactive atoms (activation) by the capture of neutrons or gamma rays that were released during the fission process.

Gaseous effluents: Airborne effluents.

Iodines/Halogens: The measured radioactive isotopes of iodine or of other non-metal elements in group 17 of the Periodic Table of Elements. Licensees might report any combination of the iodine isotopes I-131, I-132, I-133, I-134, and I-135, as well as other halogens such as bromine-82 (Br-82).

Maximum exposed individual: Individuals characterized as maximum with regard to food consumption, occupancy, and other usage of the region in the vicinity of the plant site. As such, they represent individuals with habits that are considered to be maximum reasonable deviations from the average for the population in general. Additionally, in physiological or metabolic respects, the maximum exposure individuals are assumed to have those characteristics that represent the averages for their corresponding age group in the general population.

Member of the public (10 CFR 20): Any individual except when that individual is receiving an occupational dose.

Monitoring: The measurement of radiation levels, concentrations, surface area concentrations or quantities of radioactive material and the use of results of these measurements to evaluate potential exposures and doses.

Noble gas: One of six noble gases (helium, neon, argon, krypton, xenon and radon) with an oxidation number of 0 that prevents it from forming compounds readily. All noble gases have the maximum number of electrons possible in their outer shell (2 for Helium, 8 for all others), making them unreactive.

NUREG: A publication by or for the NRC containing nonsensitive information related to NRC's mission that does not contain regulatory requirements and is published in a formal agency series to ensure the "…dissemination to the public of scientific and technical information related to atomic energy…" as mandated by the Atomic Energy Act of 1954, as amended. Each publication bears an agency designator (e.g., NUREG-number-year).

Particulates: Radioactive materials that are entrained in the gaseous effluents and are not included in any other effluent category.

Site boundary: That line beyond which the land or property is not owned, leased, or otherwise controlled by the licensee.

Tritium: The radioactive isotope of hydrogen (H-3).

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Office of Nuclear Reactor Regulation,
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555-0001

9. SPONSORING ORGANIZATION - NAME AND ADDRESS (If NRC, type "Same as above", if contractor, provide NRC Division, Office or Region, U. S. Nuclear Regulatory Commission, and mailing address.)

Same as above

10. SUPPLEMENTARY NOTES

11. ABSTRACT (200 words or less)

There are 104 commercial nuclear power plants on 65 sites in the United States. Each year, each power reactor sends a report to the NRC that identifies the radioactive liquid and gaseous effluents discharged from the facility. In 2009, these effluent reports comprised about 10,000 pages of information, which described the radioactive materials discharged, as well as the resulting radiation doses to the general public. This report summarizes that information and presents it in a format intended for both nuclear professionals and the general public.

The reader can use this report to quickly characterize the radioactive discharges from any nuclear power plant in the United States in 2009. The effluents from one reactor can be compared with other reactors. The results can also be compared with typical (or median) effluents for the industry, including short-term 3-year trends and long-term 34-year trends.

Although all nuclear power plants released some radioactive materials in 2009, all effluents were within the NRC safety limits, NRC design objectives, and the licensees' system operating limits for radioactive effluents. Additionally, the doses from radioactive effluents were much less than the doses from other sources of natural radiation that are commonly considered safe. This indicates radioactive effluents from nuclear power plants in 2009 had no significant impact on the health and safety of the public or the environment.

12. KEY WORDS/DESCRIPTORS (List words or phrases that will assist researchers in locating the report.)	
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