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Interagency Steering Committee on Radiation Standards

Final Report

ISCORS Assessment of Radioactivity in Sewage Sludge: Recommendations on Management of Radioactive Materials in Sewage Sludge and Ash at Publicly Owned Treatment Works

ISCORS Technical Report 2004-04

This document resulted from interagency discussions. The Interagency Steering Committee on Radiation Standards, Sewage Sludge Subcommittee, is composed of representatives from the Environmental Protection Agency (EPA), Nuclear Regulatory Commission (NRC), Department of Energy, Department of Defense, State of New Jersey, the city of Cleveland and the county of Middlesex, New Jersey. This document has not been approved by the respective agencies and does not represent the official position of any participating agency at this time.

ISCORS Assessment of Radioactivity in Sewage Sludge: Recommendations on Management of Radioactive Materials in Sewage Sludge and Ash at Publicly Owned Treatment Works

Developed by the Sewage Sludge Subcommittee

United States Nuclear Regulatory Commission

United States Department of Energy

United States Environmental Protection Agency

State of New Jersey Department of Environmental Protection

Middlesex County Utilities Authority

Northeast Ohio Regional Sewer District

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ACKNOWLEDGMENTS

The Sewage Sludge Subcommittee of the Federal Interagency Steering Committee on Radiation Standards (ISCORS) (1) conducted a survey to collect information concerning radioactive materials in sewage sludge and ash from Publicly Owned Treatment Works (POTWs), (2) performed dose modeling to help with the interpretation of the results of the survey, and (3) developed a guidance on radioactive materials in sewage sludge and ash for POTW owners and operators. The guidance is based primarily upon the results of the ISCORS survey and dose modeling. The following are Sewage Sludge Subcommittee members who actively participated in the development of the three reports associated with this project:

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PREFACE

The Sewage Sludge Subcommittee of the Interagency Steering Committee on Radiation Standards (ISCORS) has prepared this report to supplement reports describing the ISCORS Sewage Sludge Survey and Dose Assessment. This report has not been approved by the respective agencies and does not necessarily represent the official position of any participating agency at this time.

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ABSTRACT

In the United States, there are no identified cases in which radioactive materials in sewage systems are a threat to the health and safety of POTW workers or the general public. However, there have been a small number of facilities where elevated levels of man-made radioactive materials were detected. Based upon this past experience, there is a concern that radioactive material could concentrate in sewage sludge and ash and could pose a threat to the health and safety of workers or the public.

As a result of Congressional interest, the Sewage Sludge Subcommittee of the Interagency Committee on Radiation Standards (ISCORS) conducted a survey of radioactive material in sewage sludge and ash and performed dose modeling of the survey results to address these concerns and to estimate typical levels of radioactive materials in POTWs around the country. The Subcommittee also developed this report for use by POTW operators in evaluating whether the presence of radioactive materials in sewage sludge or ash could pose a threat to the health and safety of POTW workers or the general public. The levels of radioactive materials detected in sewage sludge and ash in the ISCORS survey indicate that, at most POTWs, radiation exposure to workers or to the general public, including from land application of sludge for growing food crops, is very low and consequently, is not likely to be a concern.

The survey obtained sewage sludge and incinerator ash samples from 313 POTWs across the country. A total of 45 radionuclides were detected, with 8 radionuclides (Be-7, Bi-214, I-131, K-40, Pb-212, Pb-214, Ra-226, and Ra-228) reported in more than 200 samples. The highest concentrations were observed for I-131, Tl-201, and Sr-89 (all short half-lived medical isotopes). Many samples contained radium and uranium. The survey results represent a single sampling event at the 313 POTWs, and therefore, do not account for seasonal or episodic fluctuations in radionuclide levels. The POTWs participating in this survey were specifically selected for their potential for finding elevated levels of radioactive materials in their sewage sludge or ash. Consequently, the survey results should be considered conservative, and may not necessarily represent typical levels occurring in POTWs across the country. The dose modeling effort involving both worker and end use/disposal (including land application) exposure scenarios made it clear that while some scenarios and radionuclides give rise to very low doses, there are other radionuclide-scenario combinations that may be of concern.

Three overall conclusions that arose included the following: (1) Elevated levels of radioactive materials were found in some sewage sludge and ash samples, but did not indicate a wide-spread problem; (2) Estimated doses to potentially exposed individuals are generally well below levels requiring radiation protection actions; and (3) For limited POTW worker and onsite resident scenarios, doses above protective standards could occur. This was primarily due to indoor radon generated as a decay product of naturally occurring radionuclides, such as Ra-226 and Th-228. This report for POTW owners and operators, which includes a summary of the information produced by the survey and modeling efforts, is designed to alert POTW authorities to the possibility of radioactive materials concentrating in sewage sludge and incinerator ash. It was also intended to inform them how to determine if there are elevated levels of radioactive materials in their sewage sludge or ash, and to assist them in identifying actions for reducing potential radiation exposure from sewage sludge and ash. A flow chart is provided to assist the reader in using this report.

This report presents recommendations, but not a complete description of all aspects of environmental or occupational radiation protection. Chapter 1 describes the meaning of "elevated levels of radioactive materials" and highlights some examples of concentrated levels of radionuclides in sludge at various POTWs. Chapter 2 outlines the purpose of this report. Chapter 3 identifies the sources of radioactive material that may enter a POTW and describes potential pathways of human exposure. Chapter 4 provides an overview of existing regulatory agency responsibilities regarding radiation protection. Chapter 5 contains recommendations for the POTW operator in determining whether there is any reason to suspect that elevated levels of radioactive materials may be present in the POTW, and whether there is any need to sample sewage sludge or ash for radioactive materials, or monitor air within the POTW for radon. Chapter 6 contains a process for evaluating sewage sludge or ash sampling and monitoring results and determining whether any further action by the POTW operator is warranted. Chapter 7 contains some suggestions for reducing levels of radiation exposure, should the POTW operator choose to do so. Various appendices include more detailed information on radiation, on existing Federal and State radiation protection regulatory agencies along with agency contacts, and on various analyses that could be used to evaluate levels of radioactive materials detected in sewage sludge or ash, as well as in indoor air.

This report recommends further actions that may be taken by a POTW operator when elevated levels of radionuclides are detected. In general, there is no need for further action when estimated doses, using screening calculations, are below 10 mrem/year. If doses are estimated to be 10 mrem/year or greater, the POTW operator is advised to consult with its State regulatory agency to determine if additional analyses should be conducted or if any response actions need to be considered. The 10 mrem/year criterion is not a limit, does not include radon, and is not intended to suggest that higher dose levels are unacceptable.[1] It is merely a guide for determining when advice from radiological specialists should be considered. This report advises the POTW operator to contact the State radiation control agency, the Federal Nuclear Regulatory Commission, the Environmental Protection Agency, or a radiation protection professional, such as a health physicist, for assistance when designing radiation sampling or monitoring programs, site-specific surveys, or changes in management practices to reduce radiation exposures.

This report does not constitute rulemaking or formal guidance from any participating agency in this study. The recommendations provided result from ISCORS observations while conducting the ISCORS Survey and Dose Assessment. Decisions on whether to conduct further nationwide sludge surveys, develop more detailed technical guidance, or issue specific regulations addressing radioactive materials in sewage sludge or ash will be made by the appropriate Federal or State agencies with legislative authority to address concerns related to radiation protection of the public and the environment.

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[1] To place the 10 mrem/year criterion in perspective, the International Commission on Radiological Protection (ICRP) has recommended that the acceptable upper limit for public exposure for a member of the public from all controllable sources of radiation should be 100 mrem/year. Most Federal and State regulatory agencies have also set constraints on individual sources of exposure to the general public that are a fraction of 100 mrem/year, and limit occupational exposures to 5 rem/year or less.

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ES.1 INTRODUCTION

Authorities that operate Publicly Owned Treatment Works (POTWs) have many areas of concern to address in the monitoring and daily operation of wastewater treatment plants. One of these is the potential for radioactive materials to become concentrated in the sewage sludge or ash produced by the treatment plant. Radioactive materials are typically not a major concern at POTWs; however, they are a component of the waste stream that is not well understood by POTW operators. A final draft of this report and associated dose modeling report were published for public comment on November 26, 2003 (68 FR 66503). Changes have been made to address comments received. This executive summary describes in brief the information provided in the main body of this report in Chapters 1–7 to follow. The reader is referred to those chapters for more detail than provided here.

The Nuclear Regulatory Commission (NRC) estimates that of the more than 22,000 regulated users of Atomic Energy Act (AEA) radioactive materials, about 9,000 users have the potential to release radioactive materials to sanitary sewer systems. In its 1994 report, *Nuclear Regulation: Action Needed to Control Radioactive Contamination at Sewage Treatment Plants*, the General Accounting Office (GAO) (renamed in 2004 as Government Accountability Office) described nine cases where contamination was found in sewage sludge or ash or the wastewater collection system, which have resulted in considerable cleanup expense to the POTW authority or specific industrial dischargers of wastewater to the POTW (GAO, 1994). There have been a few additional cases of radioactive materials detected in sludge that are still under investigation. Naturally Occurring Radioactive Materials (NORM) may also enter the sewer systems. (See Box 1.1.) In some situations, these radioactive materials may enter the wastewater treatment system and become concentrated in sewage sludge and ash. Previous sampling studies were limited in scope, but indicated that the following four radionuclides were most frequently reported in sewage sludge: iodine-131, radium-226, americium-241, and cesium-137. At the present time, there are no specific Federal regulations that limit the levels of radioactive material in sewage sludge and ash, although NRC and the Department of Energy (DOE) have requirements (NRC’s 10 CFR Part 20.2003, Disposal by Release into Sanitary Sewage, and DOE’s Order DOE 5400.5, Radiation Protection of the Public and the Environment) that control discharges to municipal sanitary sewer systems.

Box ES.1 Example of Naturally Occurring Radioactive Material Concentrating in Sewage Sludge

There are certain geographical areas of the United States where relatively high radium concentrations occur in ground water. Many public drinking water supplies depend upon ground water as their source of water, and some of these supplies have radium levels that exceed the drinking water standard for radioactive material. In treating these water supplies to remove the radium, a waste stream containing the removed radium may be created. If this waste stream is discharged to the sanitary sewer, the radium can be reconcentrated in the sewage sludge produced by the POTW. In some cases, the treated sewage sludge with elevated levels of radium is used as an organic soil conditioner or fertilizer by farmers and the general public. Several States have been aware of such situations and are in the process of evaluating the radium levels in these materials.

ES.2 PURPOSE

The NRC, EPA, and other agencies, in coordination with the Office of Science and Technology Policy (OSTP) and Office of Management and Budget (OMB), formed the Interagency Steering Committee on Radiation Standards (ISCORS) in 1995. ISCORS was created to address a need identified by the GAO and members of Congress related to inconsistencies, gaps, and overlaps in (then-) current radiation protection standards programs. In addition to NRC and EPA, ISCORS membership also includes senior managers from the Department of Defense (DOD), the Department of Energy (DOE), the Department of Labor's Occupational Safety and Health Administration (OSHA), the Department of Homeland Security (DHS), the Department of Transportation (DOT), and the Department of Health and Human Services (HHS). Representatives of OMB, OSTP, and the States are observers at meetings. ISCORS formed a Sewage Sludge Subcommittee (Subcommittee) to conduct the ISCORS sewage sludge and ash survey and to develop this POTW report.

Most of the information previously available on reconcentrating of radionuclides in sewage sludge and ash was due to unusual circumstances that triggered discovery of incidents in the course of other POTW operations. To better understand the occurrence of radionuclides in sewage sludge and ash, the Subcommittee conducted a survey to determine typical levels of radioactive materials in POTWs around the country, and performed dose modeling of the survey results. (See http://www.iscors.org/library.htm for the full survey report.) The survey, which included samples from POTWs with the greatest potential for elevated levels of radioactive materials, was undertaken by the Subcommittee to provide an estimate of radioactive materials that may be found in municipal sewage sludge and ash. The survey results indicated that the majority of samples with elevated radioactivity were attributable to naturally occurring radioactive materials rather than man-made sources. The levels of radioactivity detected in sewage sludge and ash in the ISCORS survey indicate that, at most POTWs, radiation exposure to workers or to the general public, including from land application of sludge for growing food crops, is very low and consequently, is not likely to be a concern. The dose modeling conducted by ISCORS suggests that the greatest potential for concern involves potential exposures of certain POTW workers and occupants of buildings constructed on long-term land application sites (see http://www.iscors.org/library.htm for the full dose modeling report).

ISCORS developed this recommendations report for use by POTW operators to evaluate whether the presence of radioactive materials in sewage sludge or ash could pose a threat to the health and safety of POTW workers or the general public. Based upon the information produced by the ISCORS survey and dose modeling efforts, this report has three major purposes: (1) to alert POTW operators and State and Federal regulators to the possibility of radioactive materials concentrating in sewage sludge and incinerator ash; (2) to inform POTW operators how to determine if, indeed, there are elevated levels of radioactivity in their sewage sludge and ash; and (3) to assist POTW operators in identifying actions for reducing potential radiation exposure from sewage sludge and ash.

ES.3 WHY IS THERE RADIOACTIVE MATERIAL IN SEWAGE SLUDGE AND ASH?

Radioactive materials are an ever-present component of the natural environment and are also produced through some human activities. Generally, the presence of radioactive materials is a concern only when concentrations become sufficiently elevated above background levels to pose a potential health risk or in cases where the ability of a POTW to use or dispose of the sewage sludge or ash is inhibited. There have not been many known occurrences of such elevated concentrations of radioactive materials in sewage sludge and ash since the 1980s.

There are three general sources of radionuclides in the environment that may enter sewage treatment systems: (1) natural sources, (2) natural sources concentrated or enhanced by human activity, and (3) man-made sources. The first of these sources, natural sources of radiation, include geologic formations and soils that contain uranium, radium, thorium, radon, and other nuclides that are radioactive. Water originating in or moving through these formations and soils may transport the radioactive materials either dissolved in the water itself, or attached to suspended solids in the water. Radon also is released to the atmosphere from soil and water and can enter any building, including POTW facilities, through ground contact openings in a concrete slab or foundation wall. The general advice EPA has provided to the public is that all homes, schools, and Federal workplaces be tested for radon. That advice also should be applicable to POTWs. Computerized maps are available that show counties with high radon concentrations that may be correlated with the location of a POTW. In addition, POTW operators should contact their State Radiation Control Program or the State Drinking Water Program for information specific to the area served by the POTW.

Levels of naturally-occurring radioactive materials can be enhanced by human activity and by technologies associated with extraction processes. These materials, when enhanced by human activity, are a second general source of radionuclides in the environment known as Technologically-Enhanced Naturally Occurring Radioactive Materials (TENORM). TENORM may be introduced to the sewage system from ground and surface water, plants and food, as well as from potential industrial discharges (e.g., water treatment plants, mining and petroleum industries, fertilizers, electronics, ceramics, foundries and paper/pulp mills).

Man-made sources represent a third general source of radionuclides. These include materials produced for and as a result of the operation of nuclear reactors and fuel cycle facilities. Other man-made sources are produced from the operation of accelerators, industrial activities, scientific research, and medical applications. Man-made radionuclides may also be present in the environment due to accidents or fallout from weapons testing. These materials typically are considered to be part of background. NRC and Agreement States have licensed approximately 22,000 facilities to use radioactive materials and approximately 9,000 of these have the potential to release radioactivity to sanitary sewer systems. Nuclear power plants and nuclear fuel cycle facilities are not considered significant sources of radioactive materials in POTWs because almost all of these facilities maintain their own sewage treatment systems that are not directly connected to the POTWs. It is estimated that only 20% of NRC and Agreement State licensees actually discharge to the sewer system. For example, man-made radioactive materials used in the diagnosis and treatment of medical conditions are discharged to POTWs when excreted by human patients at licensed medical facilities and from homes and workplaces after the patient is released.

Radioactive materials reach POTWs by various sources and pathways other than wastewater discharges. Infiltration and inflow into sanitary sewers may contain radioactive materials. Radioactive material can also enter a POTW in chemicals and other materials used in wastewater treatment and sludge processing. Although it is unlikely that radionuclide levels in sewage sludges and ash at most POTWs across the country pose a concern for treatment plant workers or the general public, it is possible that radioactive material from natural and man-made sources could become concentrated in sewage sludge and ash produced by some POTWs. This could interfere with some POTW operations, including cost effective use or disposal of sewage sludge and ash. However, there are low amounts of radioactive materials, legally authorized under Federal and State laws and regulations, which can be disposed into the sanitary sewer system by NRC and Agreement State licensees.

Although there is a potential for radioactive materials to reconcentrate in the sewage sludges or ash produced by POTWs, there have only been limited surveys conducted addressing the radionuclide levels in sewage sludge or sludge products. A survey conducted by the Association of Metropolitan Sewerage Agencies (AMSA) as well as the ISCORS survey revealed the presence of both man-made radioactive material and NORM or TENORM at low levels in sewage sludges and ash. Based on what is known about the potential for reconcentrating radioactive material at POTWs, the three primary pathways for POTW workers and members of the public to be exposed to radiation from POTW operations include inhalation, ingestion, and direct exposure.

Human exposure to radiation sources (Table ES.1) is derived primarily from background natural radiation; however, a person's occupation, geographic location, time spent outdoors, need for diagnostic medical treatments and testing, time spent traveling in airplanes, and other activities can greatly impact the relative contributions of natural, man-made, and global fallout sources. On the average, 80% of human exposure to radiation comes from natural sources: radon gas, radionuclides in the human body, radiation coming from outer space, and that present in rocks and soil. The remaining 20% comes from man-made radiation sources, primarily X-rays. Radiation doses at POTWs are generally insignificant compared to background radiation under most conditions. However, under conditions at POTWs where elevated levels of radionuclides have been detected, there is the possibility that doses to POTW workers and to the general public could be of concern.

Table ES.1 Average Annual Exposure to Radiation

Source of Radiation	Average Exposure (mrem/yr)	Typical Range of Variability (mrem/yr)
Natural Sources		
Terrestrial	30	10–80
Radon	200	30–820
Cosmic	30	30–80
Internal	40	20–100
Man-Made Sources		
Medical	50	
Consumer products	10	
Other (Nuclear fuel cycle and occupational)	1	
Total	360	90–1080
Sources: NCRP 1987a, for average exposure values; Huffert et al. 1994; and Fisher 2003 for ranges of variability.		

The ISCORS Survey results provide an estimate of the range of concentrations of radionuclides that may be present in sewage sludge and ash. The ISCORS Dose Assessment project provides a means for estimating potential doses associated with these levels of radionuclides under various sludge management scenarios (see Table ES.2). The dose modeling results combined with the Survey measurements make it clear that while most scenarios and radionuclides give rise to very low doses, there are other radionuclide-scenario combinations that may be of concern (for example, see onsite resident scenarios for 50- and 100-years of application described in Chapter 6 and summarized in Table ES.2).

Table ES.2 Calculated Total Peak Dose (Total Effective Dose Equivalent, or TEDE) (mrem/year) from Survey Samples: Summary Results for 95th-Percentile Sample With and Without Indoor Radon Contribution

Scenario	Subscenario	TEDE	TEDE w/o Rn	Dominant Radionuclide(s) [pathways]
S1–Onsite Resident	1 yr of sludge application	3	1	Ra-226 [indoor radon]*
	5 years application	14	4.9	Ra-226 [indoor radon]*
	20 years application	55	16	Ra-226 [indoor radon]*
	50 years application	130	37	Ra-226 [indoor radon]*
	100 years application	260	69	Ra-226 [indoor radon]*
S2–Recreational User	N/A	0.22	–	Ra-226 [external]
S3–Nearby Town	1 yr of sludge application	3.2e-03	–	Ra-226 [outdoor radon]
	5 years application	0.014	–	Ra-226 [outdoor radon]
	20 years application	0.045	–	Ra-226 [outdoor radon]
	50 years application	0.094	–	Ra-226 [outdoor radon]
	100 years application	0.17	–	Ra-226 [outdoor radon]
S4–Landfill	MSW — Sludge	0.027	0.01	Ra-226 [indoor radon]*
	MSW — Ash	0.041	0.014	Ra-226 [indoor radon]*
	Impoundment	1.2	0.36	Ra-226 [indoor radon]*
S5–Incinerator	N/A	7.7	–	multiple [multiple]
S6–Sludge Application Worker	1 yr of sludge application	0.15	–	Ra-226 [external]
	5 years application	0.77	–	Ra-226 [external]
	20 years application	3	–	Ra-226 [external]
	50 years application	7.4	–	Ra-226 [external]
	100 years application	15	–	Ra-226 [external]
S7–POTW Workers	Sampling (mrem/sample)	4.9e-07	–	Ra-226 [external]
	Transport (mrem/hr)	1.9e-04	5.6e-05	Th-228 [indoor radon, external]*
	Loading	17–70§	13	Ra-226, Th-228 [indoor radon]*

Notes:

All values rounded to two significant figures. DSRs of 95% are used in all total peak dose calculations. The symbol "–" denotes that indoor radon was not separately calculated. N/A denotes Not Applicable. MSW denotes Municipal Solid Waste. TEDE means Total Effective Dose Equivalent.

* The dominant radionuclide applies to doses that include radon. However, radon is typically controlled by concentration level (e.g., pCi/L or WL) and not by dose. The recommendations in Chapter 6 of this report use EPA's radon guidelines (4 pCi/L or 0.02 WL) as a metric for actions relating to indoor radon.

§ Range represents results from nine combinations of air exchange and room height (see Section 4.7.3 of ISCORS 2004-03).

The basic conclusions of the ISCORS Survey and Dose Assessment effort, which are considered somewhat conservative case situations, are as follows:

- None of the non-POTW scenarios shows a significant current widespread threat to public health.
- If agricultural land application is carried out for a long time into the future, then the potential exists for future radiation exposure primarily due to radon, if the land application site is converted to residential use.
- In specific cases of very high concentrations of radioactive materials (e.g., levels above the 95 percentile), there is the potential for localized radiation exposure.
- Within the POTW, little exposure is expected. Only when workers are in poorly ventilated areas with large quantities of sludge (e.g., for storage or loading) is there the potential for significant exposure, predominantly due to radon.
- Higher doses are generally attributable to the indoor radon pathway. Both for the Onsite Resident and the POTW Worker, exposures can be decreased significantly through the use of readily available radon testing and mitigation technologies

ES.4 WHAT ARE THE RELEVANT REGULATORY AGENCIES?

The regulatory framework for radioactive materials in wastewater is complex. There are many levels of authority and types of requirements. Regulations are issued and enforced by various agencies at different levels of government depending upon the type of radioactive material and the agreements arranged. Some information about the different regulatory agencies and their activities that is germane to the types of materials that may enter wastewater and affect POTW operations include the following.

The primary division of the regulatory framework is based on the origin of radioactive material. In general, man-made radioactive materials are regulated differently than NORM and TENORM. Radioactive materials consisting of source, byproduct, and special nuclear material are subject to the provisions of the Atomic Energy Act (AEA). Radioactive materials used in the commercial and private sector are subject to the rules of the NRC. When these types of radioactive materials are used in the defense sector in weapons development operations, they are under the control of the DOE. However, DOE also regulates TENORM and accelerator produced radioactive material under AEA authority at DOE facilities.

The AEA allows the NRC to establish formal agreements with States, granting the States with authority to develop and oversee the implementation of specific regulations regarding use and possession of source, byproduct and special nuclear materials generated or used at these facilities. The 33 States with such an agreement (i.e., Agreement States) are required to maintain a radiation protection program that is adequate to protect public health and safety and is compatible with that of the NRC.

The lead Federal agency in the regulation of NORM and TENORM is EPA. The DOE also regulates TENORM at DOE facilities. In addition, some State and local authorities regulate various aspects of the NORM and TENORM materials discussed above. Other radioactive materials are generally regulated by the States.

Under the Clean Water Act as amended, EPA establishes regulations addressing what industries may discharge to POTWs, as well as regulations concerning the POTWs effluent and sewage sludge. TENORM in wastewater effluents, sewage sludge and ash from a POTW could be regulated by EPA. EPA currently regulates the use and disposal of sewage sludge produced by POTWs under 40 CFR Parts 257 and 503, which at this time do not address radioactive material. EPA also has authorities under the Safe Drinking Water Act (SDWA) to set standards for radionuclides in drinking water under the Clean Air Act (CAA) to limit radionuclide releases to the air; under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) to regulate the limits for both man-made radioactive materials and TENORM releases from contaminated facilities to a sanitary sewer; and under the Resource Conservation and Recovery Act (RCRA) to regulate the non-AEA hazardous waste residuals.

Under the AEA and the Reorganization Plan 3 of 1970, EPA also has authority to establish generally applicable environmental standards for the protection of the general environment from radioactive materials. In addition, the AEA directs EPA to promulgate the Federal Guidance on radiation exposure to workers and the public. Also, under the Radon Gas and Indoor Air Quality Research Act (1986) and Indoor Radon Abatement Act (1988), EPA has authority to develop national programs, technical policies, and guidance for controlling radon and indoor air pollution exposure.

OSHA administers programs under the Occupational Safety and Health Act of 1970. Under this law, OSHA has issued regulations for protecting workplace safety and health, including exposure to hazardous or toxic materials, and radiation. Although these standards may not apply to all municipal wastewater treatment plant workers, these workers may be covered by their State OSHA program.

State Agencies

In addition to the role of State agencies as NRC Agreement States, States have been active regarding the issue of potential radioactive contamination at POTWs. While many States (both Agreement and non-Agreement States) regulate radioactive material, only some have promulgated regulations regarding TENORM, in a manner similar to the regulations regarding man-made radioactive materials. For example, some States have established licensing and inspection requirements for users of TENORM. Other States require users of TENORM to register with the State, rather than being issued a license. To date, 13 States have approved regulations for TENORM, and several States have either TENORM-related guidance or regulations for TENORM generated in specific industries, this primarily includes the oil and gas industries and the mining industry. Other States regulate TENORM to varying degrees through their radiation control regulations without specific TENORM regulations (see Appendix E).

State radiation control programs are good sources of information about radiation protection available to POTW operators. State radiation control programs are composed of individuals who have studied radiation and have experience with that particular State’s radiation problems. In some instances, the State health agency or occupational safety office may have developed or adopted specific radiation protection standards or guidance that could apply to municipal or other wastewater treatment plants.

Local Authorities

The nature of the arrangement between a POTW and its customers will depend upon Federal, State, and local law as well as any applicable requirements in implementing their EPA-approved pretreatment program (40 CFR Part 403). In some cases, there are local permits issued to POTW users that would govern the circumstances of discharges to the POTWs. In other cases, the arrangements are purely contractual and the relationship between the POTW and its users (including whether users must notify the POTW before the discharging of radioactive material) would be a contract condition.

POTWs may not have the same authority concerning radioactive material as they do for any other material in plant influents. This is because the U.S. Supreme Court has held that for certain activities covered by the AEA, Federal authority preempts other regulatory authorities whose purpose is radiation protection. If the purpose is something other than protection of public health against radiation safety hazards, State and local authorities might be able to impose additional limits on radioactive effluent discharges.

Because preemption case law employs several subtly different tests that can be only meaningfully applied to concrete facts, development of general guidance on the issue is difficult. It is hard to predict whether unusual cost to the POTW caused by radioactive effluent discharges would be a sufficient reason to impose more restrictive discharge limits than those permitted under Federal law because there are no Federal cases in which (1) the specific facts corresponded to the scenarios faced by local POTW authorities and (2) the court decision addressed the preemption issue.

ES.5 WHAT CAN A POTW DO TO DETERMINE IF THERE IS RADIOACTIVE CONTAMINATION? WHO CAN HELP?

The POTW operator should determine whether radioactive material is entering the sewage treatment plant and is accumulating in the sewage sludge or ash, before conducting extensive sampling or making major changes in sewage sludge or ash management practices. There are a number of steps that can be taken by the POTW operator to identify possible sources (man-made and naturally-occurring) of radioactive material that may contribute certain radionuclides to the system. For many POTWs, the levels of radioactive materials accumulating in the sewage sludge or ash are inconsequential. For some POTWs, the levels may be high enough that some action to reduce potential exposures is prudent.

Information on possible sources of radioactive materials in the POTW service area should be sought. State and local agencies (e.g., regulatory agencies, geological surveys) should be contacted for information on natural background levels of radionuclides in soils and ground water. Either the NRC or State radiation control agency should be contacted for information licensees who manage radioactive materials and who may be permitted to discharge wastewater to the POTW. The State or local drinking water regulatory agency can provide information on drinking water systems that may be permitted to discharge residuals to the sewer system. These agencies also can assist in identifying specific types of radioactive materials that the POTW may want to include in a sampling and analysis plan, if a sampling program is to be conducted.

The POTW operator is advised to review the recommended criteria, once information is obtained on potential sources of radioactive material, to determine if further action is warranted.

1. If the POTW is located in an area with elevated levels of uranium and radium in the soils and ground water, or if drinking water treatment plants cause elevated levels of radioactive materials to be discharged to the sanitary sewer system, it is possible that radon gas may be elevated in certain poorly-ventilated indoor areas of the POTW where sewage sludge or ash is managed. To determine whether there is any elevated exposure to workers in these areas, testing of the indoor air for radon may be appropriate.
2. If there are industrial users of TENORM that are permitted to discharge waste to the sanitary sewer system, it may be appropriate to monitor for radon in poorly-ventilated areas. It also may be appropriate to periodically analyze sewage sludge or ash samples for specific radionuclides associated with these particular industries.
3. If there are many licensees in the service area that manage other than sealed sources of radioactive material, or if the combined contribution to system-wide wastewater flow from licensed entities is greater than a small percent of the POTWs total flow, there may be a need for a periodic sewage sludge or ash sampling program, which would include measurement of specific radionuclides associated with these licensees. The POTW operator also may want to periodically review licensee discharge records, obtainable from the industrial sources or from the Federal or State regulatory agency, for the type and quantity of radioactive materials that have been discharged to the sanitary sewer system.
4. If there are elevated levels of NORM, or if there are drinking water treatment plants that discharge residuals to the sewer, or there are industries that manage TENORM that discharge to the sewer, or if there are many industries licensed to manage man-made radioactive materials that discharge more than a small percent of the POTWs total flow to their sanitary sewer system, it may be appropriate to routinely sample the sewage sludge or ash and to monitor indoor radon levels.

If, in the judgment of the POTW operator, there are sources present that could contribute elevated levels of radioactive materials to the system, and an indoor air or sewage sludge or ash sampling program is contemplated, the POTW should seek the assistance of a radiation protection specialist, such as a certified health physicist, in developing a sampling and analysis plan. A list of certified health physicists is available by State and city on the American Academy of Health Physics (AAHP) Web site (http://www.hps1.org/aahp/members/members.htm). Consultants are marked with an asterisk.

Sampling of sewage sludge or ash, or monitoring for radon inside the POTW, should be conducted to confirm the presence or absence of specific radionuclides, based upon the results of investigations of possible sources. The sampling plan should lay out a phased approach. Initially, relatively inexpensive screening analyses should be performed to determine whether further radionuclide-specific analyses are needed. Gross alpha and gross beta activity analysis and gamma spectrometry can provide an indication of whether specific radionuclides associated with previously identified sources are present in the sewage sludge or ash. (See Chapter 5 for more detailed information on the analyses to perform.) The POTW operator can use this information to determine whether any further sampling is needed or whether an unacceptable exposure condition may exist that could be addressed by changes in management practices. Data on specific radionuclide levels can be evaluated by using the screening tables provided in Chapter 6 of this report. These screening tables allow a rough estimation of possible dose. However, as previously stated, it is very important to contact a radiation protection specialist for assistance in evaluating the results of preliminary sampling and analysis and the screening calculations before conducting a more extensive sampling or monitoring program, or before changing existing management practices.

ES.6 HOW CAN A POTW OPERATOR INTERPRET LEVELS OF RADIOACTIVITY DETECTED IN THE PLANT?

In general, there is no need for further action when estimated doses, using screening calculations, are below the ISCORS-recommended consultation level of 10 mrem/year. If doses are estimated to be 10 mrem/year or greater, the POTW operator is advised to consult with its State regulatory agency to determine if additional analyses should be conducted or if any response actions need to be considered. The 10 mrem/year value should not be considered a radiation exposure limit. The value also does not include estimated or measured radon levels at the POTW. The POTW can follow the phased approach described below to assess the significance of levels of radioactive materials detected in the sewage sludge or ash.

The interpretation of detected radioactivity levels in a POTWs sewage sludge or ash can be conducted by a series of steps based upon the use of tables generated from the ISCORS survey results and dose modeling effort for various scenarios included in the full dose modeling report. First, the POTW operator should compare the concentrations of radioactive material in the sewage sludge or ash with the concentrations provided in the screening tables of Chapter 6. These screening tables are based on an effective dose equivalent of 1 mrem per year, which is the negligible individual dose determined by the National Council of Radiation Protection and Measurements (NCRP 1993), and also is one-tenth of the ISCORS recommended consultation level described above. As such, any measured concentrations of radioactive material that are less than the respective values in the screening tables represent negligible potential exposures. ISCORS recommends that no further action regarding radioactive materials in sewage sludge or ash at a POTW is needed.

If any concentrations in the sewage sludge or ash exceed these values, then the estimated dose can be calculated using the procedures provided in Chapter 6. The concentration of each radionuclide that exceeds the screening concentration in the sewage sludge or ash sample is multiplied by the dose-to-source ratio for that radionuclide. Conservatism is built into these values by the use of the 95^{th}-percentile dose-to-source ratios. The result (in mrem/year) for each radionuclide is then summed to get an estimated total dose. When the calculated dose from all radionuclides exceeds 10 mrem/year, ISCORS recommends that POTW operators consult with their State radiation protection regulatory agency. This value is merely used as a guideline for consultation. It does not indicate a problem or suggest the need for any mitigation actions.

Calculations also are provided in Chapter 6 to estimate radon concentrations in indoor air based on the Ra-226 and Th-228 concentrations in the sewage sludge or ash. If these calculations exceed the EPA recommended indoor radon action level of 4 pCi/L, then radon tests should be performed. If test results exceed 4 pCi/L, then action should be taken to mitigate. These steps are outlined in Figure ES.1.

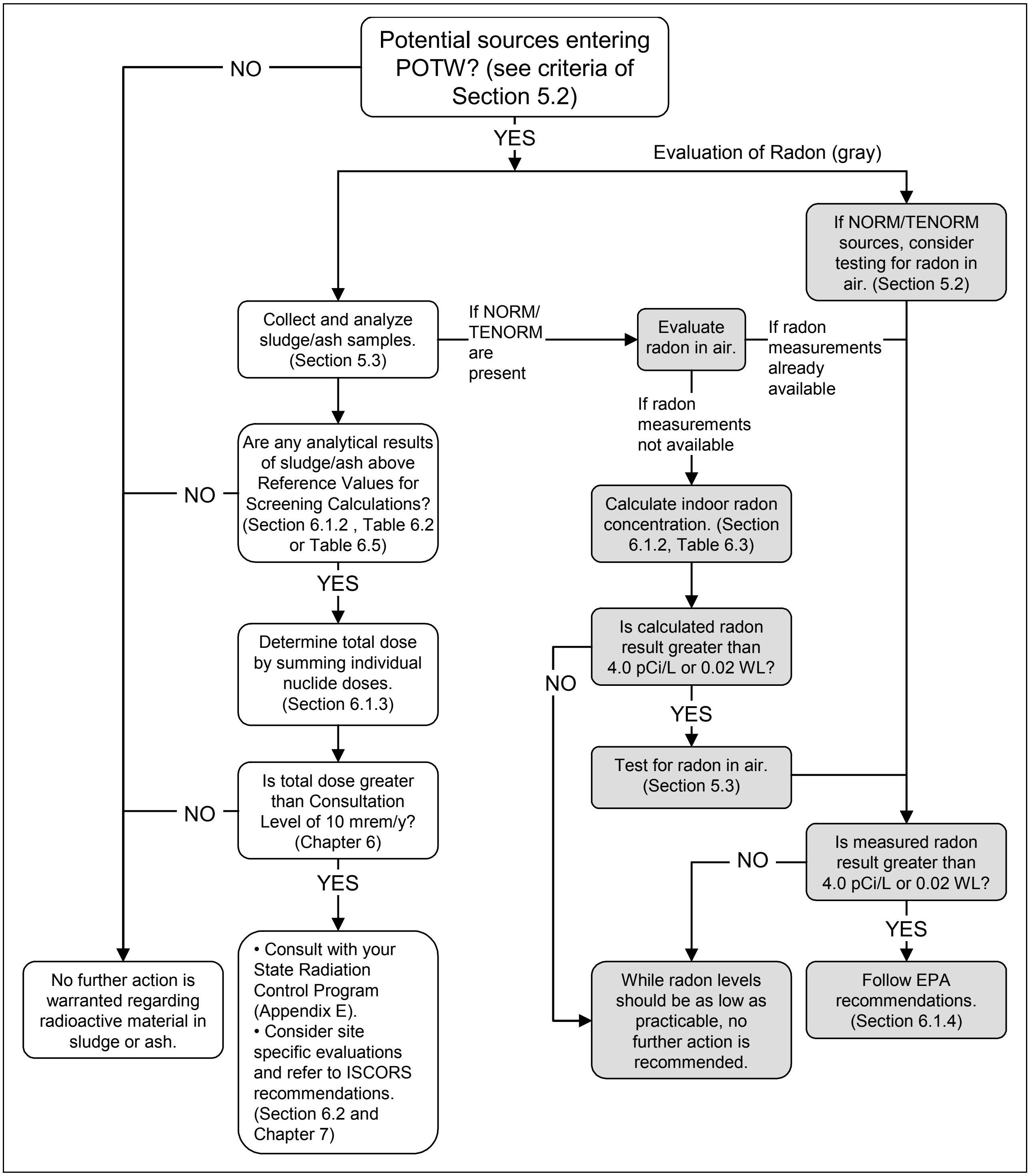

Figure ES.1 Flowchart for ISCORS Recommendations on Radioactive Materials in Sewage Sludge and Ash (See noted sections for details on recommendations.)

Depending on the results of the screening calculation and on current sewage sludge or ash management practices, consultation with the State agency may result in (1) no further action is needed; (2) additional measurements or analyses may be needed; (3) the appropriate State regulatory agency provides direction on applicable State-level requirements; (4) a professional radiation protection specialist or a health physicist is contacted for assistance in designing a monitoring program or evaluating existing management practices; or (5) another agency should be contacted for further guidance (EPA for NORM and TENORM sources and NRC for source, special nuclear, and by-product material only).

When screening calculations suggest that potential dose to workers or the public may be above the acceptable radiation dose level agreed upon in consultation with the relevant State, the POTW operator may want to conduct a more thorough evaluation of the levels detected in the sludge, ash, or indoor air, based on site-specific conditions. Such an evaluation may require additional sampling or monitoring, use of site-specific parameters as input to the modeling scenarios presented in the ISCORS Dose Modeling Report (ISCORS 2003b), creation of more directly applicable modeling scenarios than those used in the ISCORS Dose Modeling Report (ISCORS 2003b), or actual physical surveys of potentially affected areas of the POTW or other sludge management locations. The State radiation control program should be apprised of the results to determine appropriate standards for comparison.

Although the screening tables in Chapter 6 list 35 radionuclides, based on the ISCORS survey results and the Dose Assessment Report's conservative scenarios, there were only 6 radionuclides of primary concern. The 6 radionuclides are Radium-226 and Radium-228, which are NORM or TENORM; Thorium-228, Thorium-230, and Lead-210, which are either NORM/TENORM or source material; and Iodine-131, which is byproduct material used in medical applications.

The following factors may be important to consider when a POTW operator or contractor that uses or disposes of sewage sludge or ash is deciding whether to perform measurements at the use or disposal sites:

- Indications that radioactive materials have been discharged to the sanitary sewer system and have entered the POTW,
- Contract arrangements between the POTW and the dischargers,
- Adequate and available records on past sewage sludge or ash applications,
- The frequency and amount of sewage sludge or ash applications to each site, and
- Results of the screening calculations.

If results of the screening calculations are above the State's acceptable radiation dose level, but survey results are negative, the POTW operator may consider taking soil samples at the land application site for analysis of radioactive materials, after consultation with appropriate Federal or State authorities.

ES.7 WHAT CAN BE DONE TO REDUCE RADIATION DOSES AND RADON LEVELS?

If the results of the analysis of sewage sludge or ash samples or monitoring for indoor radon indicate that some response by the POTW operator is needed, there are a number of actions aimed at reducing radiation doses and radon levels that could be considered. Consultation with Federal or State radiation regulatory authorities and health specialists should be made prior to taking actions to reduce exposures. They can assist the POTW operator in identifying possible sources of the radionuclides, assist in establishing an appropriate course of action, and take enforcement actions against dischargers if needed to correct the problem. These regulatory agencies may also assist the POTW operator in communicating with the public.

The regulatory agency may determine that the levels are not sufficiently elevated to cause concern for worker or public health and safety. In that case, no additional action by the POTW would be needed to protect workers. However, the POTW operator should convey the regulator s findings to the POTW workers so that they know there is no cause for concern. A letter or other documentation from the regulator would be useful in communicating with workers that the levels do not pose a concern.

POTWs, in consultation with the regulatory agencies, should determine what can be done to control sources of radionuclides entering the POTW. Each situation will be unique and the appropriate actions will vary from no additional action to regulatory enforcement. The approach taken will be affected by the answers to several questions that the POTW and the regulator may explore.

1. Where did the radionuclides come from?
2. How did the radionuclides get to the POTW?
3. How often are radionuclides expected to reach the POTW?
4. Who is responsible for controlling the sources of the radionuclides?
5. Are the appropriate controls in place to minimize releases of radionuclides to the POTW?

The POTW operator can work with the regulator to decide on appropriate actions to prevent reoccurrences. Examples of these actions include the following:

- Consult directly with likely industrial dischargers who may be routinely discharging radioactive material to the sewer system, to explore the possibility of voluntary reductions in such discharges.
- Encourage dischargers to use spill prevention measures to reduce the potential for accidental releases.
- Impose appropriate additional local controls on the discharger, such as local discharge limits and regular reporting of discharges.
- Require notification of planned or accidental discharges, or request notification from the source facility when future releases occur. If the POTW lacks the authority to require

notification, consult with the Local Emergency Planning Committee (LEPC) and State Emergency Response Committee (SERC).

- Request that regulators take enforcement action against dischargers who violate license conditions and contribute to the elevated levels.
- Provide regulators with information on interferences in operating practices created by the dischargers.
- Correct infiltration and inflow problems that transport naturally-occurring radionuclides to the POTWs sanitary sewer system.

If the release was a one-time accident and future releases are unlikely, action to prevent reoccurrence may not be needed.

Where levels of radioactivity are elevated, the most important concern for the POTW operator should be the protection of the workers and the public. If consultations with the regulatory agency indicate that there may be a concern regarding exposure to the POTW workers, the POTW operator may need to limit the amount of time workers spend near units with elevated levels of radioactivity, increase the distance between workers and the radiation source(s), increase the shielding between the source(s) and the workers, and increase ventilation rates in areas where radium and radon are present.

Many of the measures that protect workers from radiation hazards are the same as those used at POTWs to protect against pathogens. State health or occupational safety agencies, or OSHA safety and health regulations and guidance for radiation exposures may be available or applicable. Personal hygiene practices such as washing hands before eating, drinking, or smoking prevents ingestion of radionuclides as well as pathogens. Similarly, the use of personal protection equipment (PPE—for the eyes, face, head, and extremities) such as protective clothing, respiratory devices, and protective shields and barriers should be provided, if elevated levels of radiation warrant, in dusty sewage sludge and ash handling areas to reduce the potential for health risks from inhaling dust and any radionuclides associated with the dust, although such measures would not protect against radon. Restrictions to limit personnel entry, or employee time spent in areas with elevated radiation levels could also be recommended if the radiation evaluations of the facility warrant.

Levels of radon gas in indoor air where average concentrations of Rn-222 exceed 4 pCi/liter, or total radon levels (Rn-220 and Rn-222 combined) exceed 0.02 Working Levels[2] may indicate that best management practices are warranted.

If elevated levels of radioactivity have been identified, the POTW employees should be informed. The POTWs employees should also be provided with factual information on the risks

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[2] A measure of radon in air; 1 Working Level is equal to the total energy emitted by alpha particles from short lived radon decay products in equilibrium with radon gas in air at a concentration of 100 pCi/L (3.7 kBq per m^3).

associated with the level of radiation exposure. Regulatory agencies or health physicists may have literature available to assist in communicating with POTW personnel.

In evaluating levels of radioactive materials in sewage sludge or ash that is managed through any type of land application process, it is possible that potential future sources of exposure may be indicated through various dose-modeling scenarios. This situation may occur if the land application site is eventually converted to another type of land use, particularly one with minimal restrictions, such as residential development. Where such future exposures may be a concern, the POTW operator may want to re-evaluate existing management practices to avoid creating an unacceptable future exposure scenario, limit applications to reduce radionuclide buildup at the site, or establish procedures whereby appropriate measures to control potential radon exposure, such as standard practices for ventilating basements of buildings placed in these areas, are utilized in such residential developments. This may be a particular problem for monofills—land fills with trenches that are used for disposal of sewage sludge and ash only; while not evaluated for radiation doses in the ISCORS dose assessment study, such a site with elevated radiation levels might require further land use restrictions.

In rare instances, sewage sludge and ash management may cause contamination of equipment at the POTW or at disposal or land application sites. If such situations occur, the POTW operator may be responsible for removing the contamination. Consultation with the regulatory agencies should be pursued to determine any requirements that may apply. Cleanup of contaminated sites can be a costly endeavor for the POTW. Depending upon the applicable Federal or State laws, some dischargers may be liable for portions of the cleanup costs if their discharges caused the contamination. Legal counsel should be consulted as to whether any dischargers may be liable for portions of the cost associated with the contamination of a particular site.

1 INTRODUCTION

Authorities that operate Publicly Owned Treatment Works (POTWs) have many considerations to address in the monitoring and daily operation of the treatment plants. One of these considerations is the potential for radioactive materials to become concentrated in the treatment plant. Radioactive materials are typically not a major concern at POTWs; however, they are a component of the waste stream that is not well understood by POTW operators.

There are more than 16,000 POTWs in the United States. Along with nearly 35 billion gallons per day of treated effluent, these POTWs generate approximately 7 million to 8 million metric tons (dry weight) of sewage sludge every year. The Nuclear Regulatory Commission (NRC) estimates that of the more than 22,000 regulated users of Atomic Energy Act (AEA) radioactive materials, about 9000 users have a potential to release radioactive materials to the sewer. Naturally occurring radioactive materials may also enter the sewer systems. (See Box 1.1.) In some situations, these radioactive materials may enter the wastewater treatment systems and become concentrated in sewage sludge and ash. At the present time, there are no specific Federal regulations that limit the levels of radioactive material in sewage sludge and ash.

In the United States, there have been no identified cases in which radioactive materials in sewage systems have been a threat to the health and safety of POTW workers or the public. However, there have been a small number of facilities where elevated levels of man-made radioactive materials have been detected. (See Box 1.2 and Table 1.1.) Based upon this past experience, there was a concern that radioactive material could concentrate in sewage sludge and ash and could pose a threat to the health and safety of workers or the public.

The Sewage Sludge Subcommittee (Subcommittee) of the Interagency Steering Committee on Radiation Standards (ISCORS), comprised of representatives from several Federal agencies (see Section 4.4 for more information about ISCORS), was created to assist NRC and the U.S. Environmental Protection Agency (EPA) in addressing this concern. The Subcommittee conducted a survey of radioactive material in sewage sludge and ash, performed dose modeling of the survey results, and developed this report for POTW operators. (See http://www.iscors.org/library.htm.) The survey, which included samples from POTWs with the greatest potential for elevated levels of radiation, was undertaken by the Subcommittee to provide an estimate of radioactive materials that may be found in municipal sewage sludge and ash. The survey results indicated that the majority of samples with elevated radioactivity were attributable to naturally-occurring radioactive materials rather than man-made sources. The dose modeling conducted by the Subcommittee suggests that the greatest potential for concern involves potential exposures of certain POTW workers and occupants of buildings constructed on long-term land application sites.

This report, based upon the information produced by the ISCORS survey and dose modeling efforts, has three major purposes: (1) to alert POTW operators to the possibility of radioactive materials concentrating in sewage sludge and incinerator ash; (2) to inform POTW operators how to determine if, indeed, there are elevated levels of radioactivity in their sewage sludge and ash; and (3) to assist POTW operators in deciding how to reduce potential radiation exposure from sewage sludge and ash. A final draft of this report and the associated dose modeling report were published for public comment November 26, 2003 (68 FR 66503). Changes have been made to address comments received.

Box 1.1 Recent Example of Radioactive Material Concentrating in Sewage Sludge

There are certain geographical areas of the United States where relatively high radium concentrations occur in ground water. Many public drinking water supplies depend upon ground water as their source of water, and some of these supplies have radium levels that exceed the drinking water standard for radioactive material. In treating these water supplies to remove the radium, a waste stream containing the removed radium may be created. If this waste stream is discharged to the sanitary sewer, the radium can be reconcentrated in the sewage sludge produced by the POTW. In some cases, farmers and the general public use treated sewage sludge with elevated levels of radium as an organic soil conditioner or fertilizer. Several States have been aware of such situations and are in the process of evaluating the radium levels in these materials.

Box 1.2 Elevated Levels of Radioactive Material

The term “elevated levels of radioactive material”, as used throughout this report, refers to measured or detected levels of radioactive material that should, in the opinion of ISCORS, alert the POTW that some appropriate actions may be warranted. The various appropriate actions, which are described in this report, are suggested as best or prudent management practices that could be taken to ensure that worker safety, public health and environmental protection have not been compromised. The presence of such “elevated levels” in a particular sewage sludge or ash sample does not imply that a dangerous or hazardous condition exists, but rather that the POTW may want to consider taking some appropriate action.

Since the “elevated levels” term has not been quantified, the use of this term does not imply some quantified incremental exceedance of an existing benchmark or standard. Determining whether there is concern for worker safety or general public health at a measured level of radioactivity in a particular sludge sample is dependent on a number of factors, and should be considered on a case-by-case basis. Efforts by the ISCORS Sewage Sludge Subcommittee to conduct a survey and to perform dose modeling of radioactive material concentrations in various types of sewage sludge and ash products may provide perspective on the levels of radioactive materials that may be detected in sewage sludge or ash samples and on the appropriate level of concern for worker safety and general public health.

1.1 REPORTED INCIDENCES OF RADIOACTIVE CONTAMINATION

In its 1994 report, *Nuclear Regulation: Action Needed to Control Radioactive Contamination at Sewage Treatment Plants*, the Government Accountability Office (GAO)[3] described nine cases

[3] In 2004, Congress changed the name of the US General Accounting Office to the US Government Accountability Office.

where contamination was found in sewage sludge or ash or the wastewater collection system, some of which have resulted in considerable cleanup expense to the POTW authority or specific industrial dischargers of the wastewater (see Table 1.1).

Table 1.1 Sewage Treatment Plants Where Elevated Levels of Radioactive Material Were Found

Location	Year Found	Radionuclides	Actions Taken
Tonawanda, New York	1983	Americium-241	State spent over $2 million cleaning up treatment plant. No final decision has been made regarding radioactive material found in the landfill.
Grand Island, New York	1984	Americium-241 Hydrogen-3 Polonium-210	No plant cleanup was warranted.
Oak Ridge, Tennessee	1984	Cobalt-60 Cesium-134 Cesium-137 Manganese-54	Soil around sewer line cleaned up, and some special sludge disposal occurred.
Royersford, Pennsylvania	1985	Manganese-54 Cobalt-58 Cobalt-60 Strontium-89 Zinc-65 & others	No plant cleanup was warranted.
Erwin, Tennessee	1986	Americium-241 Plutonium-239 Thorium-232 Uranium	Sludge digester cleaned up.
Washington, DC	1986	Carbon-14 Hydrogen-3 Phosphorous-32&33 Sodium-22 Sulfur-35 & others	No plant cleanup was warranted.
Portland, Oregon	1989	Thorium-232	Sewage lines cleaned up and pretreatment system added.
Ann Arbor, Michigan	1991	Cobalt-60 Manganese-54 Silver-108m, 110m Zinc-65	No plant cleanup was warranted.
Cleveland, Ohio	1991	Cobalt-60	Treatment plant cleanup and related activities have cost over $1 million.

Source: GAO, 1994

There have also been a few additional cases identified that are still under evaluation. These cases include Kiski Valley, Pennsylvania and Youngstown, Ohio.

The U.S. Nuclear Regulatory Commission (NRC) conducted a limited survey in the mid-1980s to determine if radioactive material discharged to sewage systems was concentrated in sludge. This took place at the facilities of 15 radioactive material users (licensees) and associated sewage treatment plants. The sampling revealed no reconcentration problems (GAO 1994).

In 1986, the EPA published a literature review titled *Radioactivity of Municipal Sludge* (EPA 1986). The literature search and follow-up telephone survey identified nine references containing data on radioactivity concentrations in sewage sludges. These references included the results of one-time surveys and ongoing monitoring programs by local authorities and State agencies, results for individual facilities and facilities from as many as 10 cities, and reports of incidents of sludge contamination reported by NRC. The data obtained varied widely with respect to the purpose of data collection, type of material sampled, number of samples, and radionuclides analyzed. The available data identified four radionuclides as most frequently reported: iodine-131, radium-226, americium-241, and cesium-137.

The NRC and EPA efforts to characterize radioactive materials in sewage sludge and ash in a recent survey are discussed in Section 1.3 and Chapter 4.

1.2 SELECTED EXAMPLES OF CONTAMINATION

Despite efforts to identify POTWs with radioactive contamination through surveys, most of the cases involving elevated levels of radioactive materials at POTWs have been discovered through measurements obtained for other purposes. As shown in Table 1.1, at least five of these instances warranted some mitigative action. Brief discussions of three of these cases illustrate the need for the POTW authority to be aware of the possibilities of radioactive contamination and the potential consequences.

Oak Ridge, Tennessee, Sanitary Sewage Treatment Facility

In March of 1984, staff from the Oak Ridge weapons complex was performing a survey to identify if any material contaminated with mercury or uranium from the complex had been used as fill in the surrounding community. Elevated radiation readings were detected along Emory Valley Road. Soil samples revealed contamination from radioactive cesium-137 (Cs-137) and cobalt-60 (Co-60). During this time, the Quadrex Corporation notified the Tennessee Division of Radiological Health that contaminated sediment was detected in Quadrex's drain sump. The Quadrex facility was involved in the decontamination of large pieces of radioactively contaminated equipment, such as duct work and piping. The process produced large volumes of water with low levels of contamination. Subsequent examination of the sewage collection system confirmed the soil and sediment contaminations were related and that the Quadrex plant was probably responsible for the releases. Cracks in the sewer line apparently resulted in the radioactive material contaminating the soil.

Further examination showed that contamination had also occurred at the Oak Ridge Waste Treatment Plant (ORWTP). Surveys at the ORWTP showed contamination of sewage sludge in a digester storage tank, as well as sludge placed on drying beds in November 1983.

Quadrex agreed to assist in decontaminating the exposed contaminated sludge and to assist the city in conducting measurements when portions of the old sewer line were to be excavated. The contaminated sludge was subsequently disposed in a sanitary landfill.

In the late 1980s, it was discovered that, in addition, routine, licensed discharges of several different radionuclides (e.g., Co-60, Cs-137, and uranium) from multiple facilities resulted in reconcentration of radioactive materials in sewage sludges. This occurred even though the discharge levels were reportedly only small fractions of regulatory limits. (Since then, NRC's regulatory discharge limits have been changed, which has reduced the concentrations of radioactive materials in sewage sludge.) These routine discharges to the sewer led to the expenditure of considerable resources over the past ten years.

The most significant concern related to radioactive material discharges faced by the Oak Ridge POTW managers was the possibility that radionuclides, even at low levels, may have inhibited their ability to continue land applying the sludge. The practice of land application of the Oak Ridge sludge was frequently called into question. In response, Oak Ridge developed a site-specific, risk-based methodology for establishing radionuclide limits for its sewage sludge (see Appendix F).

Portland, Oregon, Contaminated Wastewater Collection Lines

Thorium-232 was detected in wastewater collection lines in Portland, Oregon, in 1989. While contamination did not reach the treatment facility, the collection lines were contaminated and sewer workers took special precautions. The generator of the wastewater containing the Th-232 was identified, remediated the contamination, and installed a pretreatment system to reduce discharges.

The Cleveland, Ohio, Southerly Sewage Treatment Plant

The Northeast Ohio Regional Sewer District (NEORSD) operates the Southerly plant. It is an activated sludge facility that produced 103,000 wet tons of filter cake and incinerated 97,000 tons of the filter cake in 1992. During an aerial survey conducted in April 1991 of licensees in the area, NRC inspectors noted elevated readings of radiation at the sewage treatment plant. Subsequent ground level measurements indicated radioactive cobalt-60 was present, primarily in areas where ash had accumulated in fill areas and storage lagoons. Additional surveys were conducted in September 1991 and March 1992 to determine the extent of the contamination. These measurements of ash deposits indicated no new contamination had occurred since 1991. The highest direct radiation readings were found when a probe was lowered into animal burrows made in the residue deposits. This suggested that the concentration of material was higher below the surface. From the records of the areas where the ash was placed, it appeared that the contamination occurred in the late 1970s, and perhaps in the early 1980s.

In 1992, NEORSD developed a remediation plan to remove ash from three storage lagoons that were filled to near capacity. Remediation was completed in 1993, resulting in 174,000 cubic yards of contaminated ash stabilized on site in two areas that are fenced (total of about 25 acres) and capped with six inches of dirt. Radiation measurement devices were placed at the periphery of the area and seven monitoring wells were installed. Some contamination still exists in other areas of the site and the NEORSD is currently working with the Ohio Department of Health to assess its extent and degree. In 1994, NEORSD terminated sewer service to the wastewater generator.

As of November 2002, the remediation costs incurred by NEORSD included about $1,800,000 for the onsite remediation and related activities and $120,000 to erect the fence around the fill and holding pond areas. The NRC spent about $370,000 on radiation exposure assessment, soil sampling and analyses, and other surveys. The POTW authority engaged in a series of legal actions to recover the costs from the waste generator; about $1,200,000 was recovered. To date, the generator has failed to meet the NEORSD criteria for restoration of sewer service.

Livermore, California, Water Reclamation Plant

In the mid-1960s, small quantities of Pu-239/Am-241 were released to the Livermore, CA municipal sewer system by the Lawrence Livermore National Laboratory (LLNL). These releases, which did not exceed regulatory release limits in effect at that time, resulted in elevated levels of alpha-emitting radionuclides in the sewage sludge. Dried sludge from the Livermore Water Reclamation Plant (LWRP) was used for various purposes in the Livermore community, particularly in the 1970s construction of a municipal park. Additionally, dried sludge had been released to various homeowners for residential gardening and horticulture.

Concerns over the potential health implications of Pu-239 contaminated sludge were raised in 1993 as a result of background soil samples collected in the municipal park by the Environmental Protection Agency (EPA) that exceeded the expected background and global fallout levels for Pu-239/240. Numerous studies (see MacQueen et. al., 2002) conducted by LLNL, EPA, and the Agency for Toxic Substances and Disease Registry (ATSDR) have concluded that the elevated levels of Pu-239 in the municipal park were attributable to use of LWRP sludges, but that potential doses to exposed individuals were well below any level of concern. ATSDR has recently performed additional dose modeling analyses based on data collected at the time of the releases, and on more recent soil sampling, and has concluded that "...the historic distribution of Pu-contaminated sludge is determined to be no apparent public health hazard. ATSDR does not recommend any additional soil sampling, since it considers that available data, while containing uncertainties ...provide an adequate basis for these public health conclusions." (See the ATSDR website for information on the draft report released for public comment "Plutonium 239 in Sewage Sludge Used as a Soil or a Soil Amendment in the Livermore Community" — http://www.atsdr.cdc.gov.)

Blue Plains, Washington, DC, Advanced Wastewater Treatment Facility

In April of 2000, contractors were excavating and demolishing abandoned ferric chloride and ferrous chloride (pickle liquor) piping as part of a construction project at the Blue Plains facility. The fiberglass reinforced pipe was placed in a dumpster and sent to a waste transfer station where it was rejected due to above background levels of radiation detected by the scale house radiation monitors at the facility.

A Certified Health Physicist (CHP) investigated the construction debris in the dumpster and discovered that the inside surface of the pipe contained a thin layer of pipe scale that was radioactive. The scale was collected and sent to a laboratory for analysis. The sample results revealed that the scale contained several naturally occurring radionuclides with radium-226 being the most predominant. The scale found in the pipe can be classified as a technologically enhanced naturally occurring radioactive material (TENORM). Although the activity concentrations and external radiation levels were relatively low the demolished piping could not be disposed of as regular construction debris so it was properly packaged and shipped to a radioactive disposal facility for processing and burial.

Following the discovery of the pipe scale, a controlled approach had to be taken to demolish and dispose of the remaining ferric chloride and ferrous chloride pipes that were to be removed as part of an upcoming chemical delivery system upgrade project. The contractor that removed the piping developed and submitted a detailed plan describing the safety precautions and work procedures to be used in the removal and disposal of the pipe.

The safety precautions and work procedures that were followed during this project were similar to the ones followed during an asbestos abatement project. Prior to disassembling the contaminated piping it was drained, flushed, and pressure washed to remove the scale. The workers that removed the piping received training with regards to the hazards of TENORM and wore disposable protective clothing, respirators, gloves, and disposable boots while conducting the work. Ambient air monitoring was performed throughout the project with the purpose of ensuring that the concentration of suspended radioactive particulates remained low. In addition, the workers wore personal dosimeters to measure external radiation exposure over time.

All the contaminated piping, identified as part of this project, was successfully removed in 2001 and 2002.

1.3 CONGRESSIONAL INTEREST

A joint House and Senate hearing was held in June 1994[4] to officially release and address questions raised in a GAO report, *Actions Needed to Control Radioactive Contamination of Sewage Treatment Plants* (GAO 1994). The hearing and GAO report were stimulated by concerns associated with the elevated levels of radioactive materials in sewage sludge incinerator ash at the NEORSD's Southerly plant described in Section 1.2. Testimony presented by both NRC and EPA during the hearing noted that there was no indication of a widespread problem in this area and that the NEORSD incident appeared to be an isolated incident. However, at the hearing NRC and EPA committed to jointly develop guidance for POTWs and to collect more data on the concentration of radioactive materials in samples of sewage sludge and ash from POTWs across the country.

Since the hearing and GAO report, the NRC and EPA, with the assistance of other Federal agencies participating on the ISCORS Subcommittee, have been addressing questions regarding radioactive materials in sewage sludge and ash from POTWs. The Subcommittee, formed by ISCORS in 1996, developed an initial draft of this ISCORS report for POTWs, which was issued in May 1997 for public comment. A revised draft of this guidance was issued for comment in June 2000. The Subcommittee has also conducted a comprehensive survey of radioactive materials in sewage sludge and ash from 313 POTWs nationwide. The survey focused on POTWs in regions where the potential for elevated levels of radioactive materials in wastewaters may exist. The results of this survey are available in a survey report (ISCORS 2003) and are summarized in Chapter 3 of this report.

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[4] Radioactive Contamination at Sewage Treatment Plants, Joint Hearing before the Committee on Governmental Affairs, U.S. Senate and the Subcommittee on Environment, Energy, and Natural Resources of the Committee on Government Operations, House of Representatives, One Hundred Third Congress, Second Session, June 21, 1994. S. Hrg. 103-1034.

2 PURPOSE

One purpose of this report is to inform POTW operators of the possibility for radioactive materials to concentrate in sewage sludge and incinerator ash. A second purpose is to help POTW operators determine what to do about the radioactive materials present in their sewage sludge or ash. This guidance is not intended to serve as a comprehensive reference regarding radioactivity. However, it provides information on important issues related to the control of radioactive materials that may enter POTWs.

This report poses the following questions; answers to these questions are found in various sections of this report, as cited below:

Is There Radioactive Material in My Treatment Plant?

One of the first things a POTW operator needs to realize is that there is radioactive material in the soil that the building foundation rests on, in the indoor air of the facility, and in the wastewater that the system treats. Chapter 3 discusses why there is radioactive material in sewage sludge and when the presence of these materials may be of concern. Chapter 5 discusses how to determine if there are elevated levels of radioactivity and who can help if there are elevated levels.

Who Are the Other Players in My Specific Case?

The Federal and State regulatory authority over radioactive materials, sewage sludge, and industries that may discharge into sewage systems is complex. Further information on regulatory authorities is available in Chapter 4.

What Should the POTW Authority Consider Doing to Determine if There Is a Problem With Elevated Levels of Radioactive Materials?

There are several steps to consider in evaluating whether a POTW may have a problem regarding radioactivity. Chapter 5 describes what a POTW can do to determine if there are elevated levels of radioactive materials at their facility, and who can help. Appendix A is a primer on radioactivity and radioactive materials. The information provided in Appendix A should be helpful in understanding the nomenclature and some of the basics about the health risks of radioactivity.

What Can the POTW Authority Do if Elevated Levels Are Found?

There are a number of options that a POTW operator may want to consider if elevated levels of radioactive materials are found. Chapter 7 presents the options, as well as their legal and technical aspects.

3 WHY IS THERE RADIOACTIVE MATERIAL IN SEWAGE SLUDGE AND ASH? WHAT IS THE CONCERN?

Radioactive materials are an ever-present component of the natural environment and are also concentrated or produced through some human activities. Generally, the presence of radioactive materials is a concern only when concentrations become sufficiently elevated above background levels to potentially pose a health risk or in cases where the ability of a POTW to use or dispose of the sewage sludge or ash is inhibited. There have not been many known occurrences of such elevated concentrations since the 1980s. There have been no identified cases in which radioactive materials in sewage systems have been a threat to the health and safety of POTW workers or the public. This section explores sources of radioactive materials that may reach a POTW and why they may become a concern to POTW personnel and the public.

3.1 TYPES OF SOURCES

There are three general sources of radionuclides in the environment: natural sources, natural sources concentrated or enhanced by human activity, and man-made sources. Radioactive material from all of these types of sources has the potential to enter sewage systems.

Box 3.1 Sources of Radioactivity

Natural Sources: Geologic formations, water, and soils that contain small amounts of radioactive elements, typically known as naturally-occurring radioactive materials (NORM).

Technologically Enhanced Naturally-Occurring Radioactive Materials (TENORM): Naturally-occurring radioactive material whose radionuclide concentrations or potential for human exposure have been increased by any human activities.

Man-made Sources: Radioactive materials generated by human activities such as accelerator material; nuclear byproduct material, source material, or special nuclear material; and fallout from nuclear weapons testing.

3.1.1 Natural Sources

Natural sources of radiation include geologic formations and soils that contain uranium, radium, radon, and other nuclides that are radioactive. Water originating in or moving through the formations and soil may transport the radioactive materials either dissolved in the water itself or attached to dissolved and suspended solids in the water. Radon is also released to the atmosphere from soil and water. Radon can enter any building through ground contact openings in a concrete slab or foundation wall. Underground connections to manholes, piping conduits, and utility tunnels usually provide additional pathways for radon entry in industrial facilities similar to POTWs.

The amount of naturally-occurring radioactive materials in the ground varies widely. Some areas with elevated levels of naturally-occurring radioactive materials include locations such as those underlain by phosphate ore and uranium ore deposits. The lowest levels are generally found in sandy soils of the Atlantic and Gulf Coasts. Figure 3.1 shows average indoor screening-level radon concentrations by county in the United States. These average concentrations may roughly correspond to the general levels of uranium and radium in soils in the area. The map in Figure 3.1 provides general indication of the distribution of radon in homes across the United States, but it is not, however, a valid tool for predicting the radon concentration in any particular building. The general advice from EPA since 1989 has been that all homes, schools, and Federal workplaces be tested for radon (EPA 1994, EPA 2002, EPA 2004, and Fisher 2003). EPA recommends by this publication that testing should be considered in certain cases by POTWs as well.

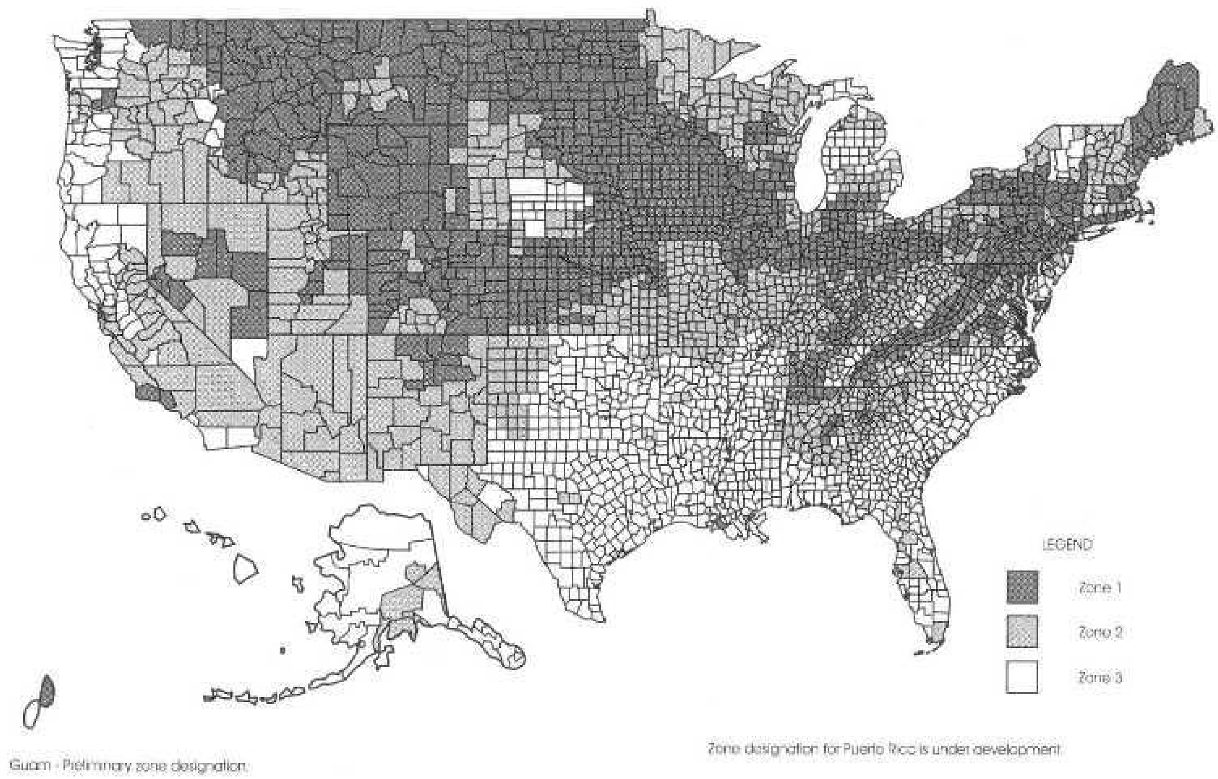

Figure 3.1 Average Indoor-Air, Screening-Level Concentrations of Radon in the United States (from EPA 1993a). Zone 1 counties have a predicted average indoor screening level greater than 4 pCi/L. Zone 2 counties have a predicted average between 2 pCi/L and 4 pCi/L. Zone 3 counties have a predicted average less than 2 pCi/L.

Although Figure 3.1 and Figures 3.3 and 3.4 in Section 3.3.3 may be generally useful for determining if a POTW is in a high NORM area, elevated NORM may be present in the ground water as a result of other factors related to local geologic and land use conditions. For example, southern New Jersey has elevated radium in ground water, even though the information contained in Figures 3.1, 3.3, and 3.4 indicate otherwise. In 1983–89, the U.S. Geological Survey (Kozinski 1995) conducted a study of the effects of geology, geochemistry, and land use on the distribution of naturally occurring radionuclides in ground water in the aquifer system in the Coastal Plain of New Jersey. They concluded that concentrations of radium-226 and radium-228 tended to be higher in water samples from wells in areas where the Bridgeton Formation (predominantly gravel) and agricultural land use are present within a 500 meter radius of the well head. Irrigation of agricultural land commonly is necessary because of the low moisture capacity of the well-drained soils developed on the Bridgeton Formation. Irrigation tends to increase the leaching of nutrients (such as calcium, magnesium, and nitrate) from the soil. Because soils developed on the Bridgeton Formation are well-drained and naturally low in nutrients, these soils require the application of large amounts of fertilizer and lime for optimal crop production.

Leaching of uranium and radium from the minerals of the Bridgeton Formation is suspected to be a source of the radium in the ground water. The correlation of radium concentration with the concentrations of chemical constituents added to soil in agricultural areas indicates that leaching of radium may be enhanced by the chemical processes in ground water that are associated with the addition of agricultural chemicals to the geochemical system. These effects are especially severe when combined with the naturally acidic ground water chemistry of southern New Jersey because acidic water tends to dissolve radium more easily in the first place (Szabo 1998).

While national maps of soil uranium and radon show the areas with the most radioactive elements present, they do not necessarily show where some radionuclides can be most readily dissolved. Radium especially is more soluble in naturally acidic areas such as southern New Jersey even though the amounts of radioactive elements in soil may not be as high as in some other parts of the State. To determine whether there is any indication of naturally-occurring radioactive material that may enter the wastewater system, the POTW operator should contact the State Radiation Control Program (see Appendix E) or the State Drinking Water Program for information specific to the area served by the POTW.

3.1.2 Technologically Enhanced Naturally-Occurring Radioactive Materials

Levels of naturally-occurring radioactive materials can be enhanced by human activity and by technologies associated with extraction processes. These materials, when enhanced by human activity, are known as Technologically-Enhanced Naturally Occurring Radioactive Materials (TENORM). Examples of TENORM include articles made from or coated with naturally-occurring radioactive materials and wastes from mineral and petroleum production, burning coal, geothermal energy production, quarry operations, and the processing of large volumes of water containing dissolved radon gas.

TENORM may be introduced to the sewage system from ground and surface water, plants and food, as well as from potential discharges from industries (e.g., water treatment plants, mining and petroleum industries, fertilizers, electronics, ceramics, foundries and paper/pulp mills). EPA is in the process of studying this potential radiation hazard. Additional information on TENORM may be found in NAS (1999), Eisenbud and Gesell (1997), and at http://www.epa.gov/radiation/tenorm.

3.1.3 Man-Made Sources

Radioactive materials are also generated by human activities. Man-made sources include radioactive material produced for and as a result of the operation of nuclear reactors (i.e., source material, special nuclear material, and byproduct material) and from nuclear accidents (e.g., the Chernobyl incident). Other man-made sources are produced from the operation of accelerators and from global fallout from testing of nuclear weapons.

NRC and Agreement States have licensed about 22,000 facilities to use radioactive materials and about 9000 of these have the potential to release radioactivity to sewers. Licensees include utilities, nuclear fuel fabricators, universities, medical institutions, radioactive source manufacturers, and industrial users of radioactive materials. Laboratories and universities use man-made radioactive materials (e.g., carbon-14) in research, including in genetic research, the study of human and animal organ systems, and in the development of new drugs. Radioactive materials are also found in consumer products such as smoke detectors, luminous watches, and tobacco products (NCRP, 1987b). Radioactive materials are prescribed to medical patients for the diagnosis and treatment of illnesses (Murray and Ell, 1998 and the website of the Society of Nuclear Medicine at http://www.snm.org).

Nuclear power plants and nuclear fuel cycle facilities are not considered significant sources of radioactive materials in POTWs because almost all of these facilities maintain their own sewage treatment systems that are not directly connected to the POTWs. Some fuel cycle facilities treat their wastewater onsite then discharge the treated effluent to the municipal sewer system according to a permit issued by the local POTW. In these cases, they may also have commitments in their licenses to sample the POTW sewage sludge for radionuclides. Any sewage sludge shipped offsite is monitored to ensure that only low levels of radioactive material are present. (See NRC Information Notice 88-22 – "Disposal of Sludge from Onsite Sewage Treatment Facilities of Nuclear Power Plants.") Thus, potential quantities of radioactive materials released by nuclear power plants and fuel cycle facilities into sewage treatment systems are generally quite small compared to some other types of licensees. Contaminated clothing from these facilities is sometimes sent to a licensed nuclear laundry offsite that may discharge wastewater to a POTW. Other waste from the facilities containing radioactive materials is collected, treated, and packaged for disposal in licensed low-level radioactive waste disposal facilities.

3.2 HOW RADIOACTIVE MATERIALS REACH POTWS

Radioactive materials reach POTWs primarily via wastewater discharges. Chemicals and other materials (e.g., lime, fly ash, waste pickle liquor, or wood ash) used by the POTWs may also contain radioactive materials. In addition, infiltration and inflow into sanitary sewers may contain radioactive materials. Table 3.1 summarizes the sources and pathways by which radioactive materials may reach POTWs.

Table 3.1 Sources and Potential Pathways for Radioactive Materials to Reach POTWs

Discharges to POTWs	Treatment Process	Infiltration and Inflow
• Drinking water and drinking water residuals that contain NORM • Sewage with radioactive materials from food and from medical procedures • Wastewater from NRC or Agreement State licensees handling radioactive materials in unsealed form • Wastewater from industries handling or processing materials containing NORM • Exempt or unlicensed radioactive materials	• Process chemicals with radioactive materials (e.g., lime, fly ash, waste pickle liquor, or wood ash) • Wood chips, sawdust, or other bulking agents used in composting sewage sludge • Any process that agitates or aerates water liberates radon gas.	• Infiltrating ground water containing NORM, including radon gas. • Surface waters runoff containing NORM or fallout, via combined sewers

The local drinking water supply may contain NORM found in the soil or geologic media from which the water is removed. The local drinking water treatment facility may remove some of the radioactive materials from the raw water by aeration, ion exchange, precipitation, coagulation, or filtering of dissolved or suspended solids. The resulting residuals are sometimes disposed of by discharge to the wastewater collection system. Any radioactive materials remaining in the finished water supply (i.e., radon) would eventually be transported to the POTW along with wastewater. Even if the water is not treated, the NORM in the raw water is transported to the POTW either directly through sewage lines or by the collection of septage from individual septic tanks.

As discussed previously in Section 3.1.2, a large number of industries utilize mineral ores and materials that may contain naturally occurring radionuclides. These materials may be present in the mineral molecular structure, as a contaminant coating mineral grains, or as radioactive minerals included in the raw material for an industrial practice. These radionuclides become concentrated in solid or liquid form. In some instances, industries that use large amounts of water for manufacturing processes can accumulate naturally occurring radionuclides in their liquid wastes or sludges. Not all industrial facilities have pre-treatment prior to discharging to the sanitary sewer system, so it is possible that solid particulate matter or liquid wastes containing TENORM may enter the POTW facilities. It is also possible that local sources of ground or surface water in the service area may contribute to higher levels of NORM in the facility; this may be especially true if local water treatment plants discharge their residuals to the sewer. The POTW operator should use their list of industrial dischargers to the system, noting the type of products that are manufactured, and compare that list with the types of industries known or suspected to utilize or generate NORM and TENORM wastes in Section 3.1.2. This can then be used, along with guidance from State and EPA radiation program officials, to evaluate the potential sources of contamination entering the system.

In many cases, naturally occurring radioactive elements may be mobilized, or leached, from mineral waste or ore used in industrial processes to form TENORM. Uranium is particularly soluble in acidic waters, but it can also be mobilized in basic solutions. While radium is generally not soluble except in the presence of certain ionic solutions (e.g., barium), it can be suspended in water. Process operations first leach and then concentrate the radioactive materials in the product and waste streams. Industrial facilities that utilize large quantities of water may also inadvertently concentrate the naturally occurring radionuclides present in all water sources. Radioactive mineral scales may accumulate in piping or filters at processing and manufacturing plants, or radionuclides may accumulate in process wastewater, sewage sludge or ash. Manufacturing facilities that utilize certain minerals to make finished products may accumulate radioactive wastes in liquid or solid forms. Knowledge about radionuclides associated with certain minerals and metals used in a variety of industries and small businesses is limited in those industries. It is possible that companies without pre-treatment facilities may inadvertently discharge these radionuclides to the sewer system. Regulation of industries or companies that create or utilize NORM or TENORM will vary by State.

As a hypothetical example, a small business making ceramic products uses ground zircon flour to make the glaze for its finished product. Excess flour, containing uranium and radium as a decay product, accumulates as a dust in a finishing room of the company, the company washes its fired ceramics before packing them for shipment, the wastewater and dusts are discharged to the sewer without any pre-treatment. Knowledge about radionuclides associated with certain minerals and metals used in a variety of industries and small businesses is limited.

The following are known to have TENORM contamination potential:

- Water treatment facilities (radium scale and sludge contamination in wastes and filters)
- Paper and pulp facilities (radium scale and sludge contamination)
- Ceramics manufacturing (zircon, uranium in wastes and molds)
- Paint and pigment manufacturing (thorium, uranium, radium in wastes from titanium ores)
- Metal foundry facilities (zircon contamination in molds for metal parts/machinery, thorium in welding rods)
- Optical glass (thorium incorporated in glass)
- Fertilizer plants (uranium, thorium, radium, radioactive potassium associated with fertilizer production, concentrations in wastes, filters, products, metal piping scales)
- Aircraft manufacture (depleted uranium counterweights; in older facilities, radium dials, nickel-thorium alloys used in engine manufacture)
- Munitions and armament manufacture (depleted uranium in ammunition and armor)

- Scrap metal recycling (TENORM–contaminated piping and metal)
- Zirconium manufacturing
- Oil and gas production, refining and storage (TENORM (radium)-contaminated scale or sludge in piping, tanks, separators)
- Electricity generation, cement and concrete product manufacture (coal ash containing uranium, thorium and radium particularly in fly ash component)
- Geothermal energy production (TENORM (radium)-contaminated scale or sludge in piping, tanks, separators)

The following list of minerals are known to either be radioactive, or are known to have the potential for radioactive contamination by inclusion of radionuclides in their molecular structure, or association with other radioactive minerals in their original ore body. A list of industries that use these minerals is included for information purposes (USGS 1973). The inclusion of an industry in this listing does not necessarily mean that radioactivity may be present at any or all such sites.

Copper	Used in manufacturing copper wire, nails, and copper sheeting, brass, bronze, electrical and electronic equipment, war munitions, and chemical reagents.
Fluorospar (Fluorite)	Used as a flux in manufacturing steel, enamelware, opalescent glass, hydrofluoric acid; refining of antimony and lead; and manufacturing vases, paper weights, and dishes.
Gypsum	Used as a flux in glass and porcelain manufacturing, retarder in cement, filler in fertilizers. Alabaster is used for statues, vases, lamps, and pedestals.
Molybdenum	Used in manufacturing steel and iron castings and high speed tools.
Niobium	Used in manufacturing stainless steel, high temperature alloys, jet engines, and gas turbines.
Phosphate (Phosphorous)	Used in fertilizer manufacturing, as phosphoric acid for industrial and food manufacturing uses, water softeners, and in manufacturing glass and ceramics.
Potassium (Phosphorous)	Used in manufacturing glass, optical glass, incandescent light bulbs, black and gun powders, dyeing and tanning, and as (cyanide) solvent in gold extraction and photography.
Precious Metals (gold, silver)	Used for coinage and jewelry, in manufacturing scientific and electronic instruments, photography, gold plating, lettering, and dentistry.

Rare Earths (yttrium, lanthanum, monazite, bastanite)	Used as thorium in manufacturing electrodes, optical glass, refractory manufacture, and in the textile industry.
Tin	Used in manufacturing tin plate or sheet tin, as solder, bronze, tin amalgam, gun metal, type metal, speculum metal, pewter, and a polishing powder.
Titanium (Leucoxene, ilmenite, rutile)	Used as a steel additive; for metal for airplanes and ships, welding rod coatings; in carbide cutting tools, white pigment for paint manufacture, lacquer enamels and rayon, glass, and highly opaque, light weight paper.
Tungsten	Used in manufacturing X-ray tubes, filaments in incandescent lights, and automobile engines.
Vanadium	Used in manufacturing special steels and bronzes, high speed tools, ceramics, inks, and for silk dyeing.
Zircon	Used in strengthening steel, brass, and copper; widely used in ceramics as a glaze, as coating for ceramic and metal molds, refractory bricks, polishing powder, pyrotechnics, and sandblasting powder. Used in manufacturing aircraft engines and parts, cutting tools, nuclear reactors, surgical tools, electric arc lamps, and in the tanning and manufacturing of textiles.

Other potential sources of radioactive materials include facilities with NRC and Agreement State licenses. All licensees are authorized by the regulations (see Section 4.1 for details about the regulations) to discharge radioactive materials to the sewers, but are not required to report such discharges. Although NRC licensees are not required to report such discharges, they are required to keep records that are subject to inspection. However, it is estimated that only 20% of NRC and Agreement State licensees actually discharge to the sewer system. The main reason most licensees do not discharge radioactive material to the sewers is that they possess only sealed sources, which are extremely unlikely to be released into sewers. Other licensees may have unsealed sources, but not in liquid form, and hence there is no radioactivity released to wastewater.

Many licensees which use radioactive materials in liquid form do not need to discharge to the sewers because (1) the materials used are very short-lived and can decay in short-term storage and then be discharged as non-radioactive, or (2) the material may contain wastes that cannot be disposed of into sanitary sewers, if the material is non-dispersible or due to the presence of other non-radioactive pollutants. These pollutants may be prohibited from discharge into sewers by regulations issued under the Clean Water Act or the Resource Conservation and Recovery Act, rather than by NRC's regulations.

Radioactive material is handled in "unsealed" forms in the nuclear fuel fabrication industry, in the production of radiopharmaceutical medicines, and in research. Limits in quantities and concentrations that the NRC and Agreement States allow to be discharged to the sanitary sewer are based on a fraction of the dose limit that can be received by an individual member of the public (see Section 4.1 for the dose limits).

Table 3.2 lists types of NRC licensees that could dispose radioactive materials into the sewer system and radionuclides previously found in POTW sewage or those that could be present. It should be noted that a broad scope licensee is usually authorized to possess and use any radionuclide with an atomic number from 1 to 83. This means that many more radionuclides than those listed in Table 3.2 could be disposed into the sanitary sewer. The half lives and types of radiation emitted by these radionuclides are listed in Appendix A, Table A.1.

Licenses may be issued for specific applications, such as for industrial radiography, irradiators, well logging or specific medical uses. In such cases, the application, the physical and chemical states and the radioactivity of the materials are well defined. In other cases, the application is not as well defined, such as medicine and research. The physical and chemical form and activity will depend on the nature of the medical treatment, diagnosis or research being conducted. To accommodate undefined or changing applications, broad scope licenses are issued (e.g., to large medical institutions, universities, and research facilities).

Two other domestic sources of radioactive materials in sewage are medical procedures and food. Radioactive materials (e.g., iodine-131, technetium-99m, strontium-89, and thallium-201) used in the diagnosis and treatment of medical conditions are also discharged to the POTW when excreted. For POTWs that serve large medical institutions, a major portion of the radioactive discharges to the sewer comes from patients. POTWs serving large medical centers and universities in which extensive research is conducted may receive discharges from both the research activities and from patients. A complicating factor is that some patients reside far away from the medical centers. Wastes from these patients will probably be discharged to the POTW serving the patients' residences. Refer to Table 3.2 for radionuclides commonly used in the medical facilities.

Radioactive material can also enter a POTW in chemicals and other materials used in wastewater treatment and sludge processing. In addition, infiltrating ground water may contain radioactive materials from natural sources that were either dissolved or attached to suspended solids as the water flows through soils and geologic formations. Similarly, surface water and sediment in runoff containing NORM or fallout may enter the POTW via combined sewers. The amount of radioactive materials entering POTWs by infiltration and inflow will vary depending upon the degree of infiltration and inflow, and the amount of natural sources and fallout in the service area.

Table 3.2 Types of NRC and Agreement State Licensees and Typical Radionuclides

<table>
<tr><th>Academic
(broad scope)</th><th>Medical
(broad scope, nuclear pharmacies)</th><th>Manufacturing and Distribution
(broad scope, nuclear laundries, decontamination services)</th></tr>
<tr><td>Carbon-14
Cobalt-60
Cesium-137
Hydrogen-3
Iodine-125/131
Iron-59
Manganese-54
Phosphorus-32
Phosphorus-33
Sulphur-35</td><td>Carbon-14
Chromium-51
Cobalt-57
Gallium-67
Indium-111
Iodine-125/131
Iron-59
Phosphorus-32/33
Strontium-89/90
Sulphur-35
Technetium-99m
Thallium-201</td><td rowspan="3">Americium-241
Antimony-125
Cobalt-60
Cesium-134/137
Hydrogen-3
Iodine-125/131
Manganese-54
Niobium-95
Phosphorus-32
Plutonium-238/239/240
Polonium-210
Strontium-89/90
Sulphur-35
Uranium-233/234/235/238
Zirconium-95</td></tr>
<tr><th>Research and Development
(broad scope)</th><th>Others
(e.g., ore processing mills, uranium enrichment plants)</th></tr>
<tr><td>Carbon-14
Cesium-134
Hydrogen-3
Iodine-125/131
Phosphorus-32
Sulphur-35</td><td>Plutonium-238/239/240
Radium-226
Thorium-228/232
Uranium-233/234/235/238</td></tr>
</table>

3.3 WHY RADIOACTIVE MATERIALS MAY BE OF CONCERN AT A POTW

As with any other building, POTWs may have elevated levels of radon gas in the indoor air, due to pressure driven infiltration of soil gas. Commercial facilities that operate HVAC equipment or process air flows that depressurize the indoors relative to the ground (or outdoors) will increase this type of infiltration. Additionally, POTWs may have pipe tunnels and conduits that usually provide opportunities for easy radon transport into the facility. Finally, any process that agitates or aerates large quantities of water containing even small concentrations of radon may result in large indoor air concentrations.

Although it is unlikely that radionuclide levels in sewage sludge and ash at most POTWs across the country pose a concern for treatment plant workers or the general public, it is possible that radioactive material from natural and man-made sources could become concentrated in sewage sludge and ash at some POTWs. This could cause interferences with POTW operations, including cost effective use or disposal of sewage sludge and ash. However, there are low amounts of radioactive materials that are legally authorized, under Federal and State laws and regulations, to be disposed into the sanitary sewer system. This section addresses POTW operations that have potential to cause concerns due to exposure to radiation. (For more information regarding radioactivity, see Appendix A.)

3.3.1 Reconcentration of Radioactive Materials at POTWs

The purpose of wastewater treatment facilities is to reduce or remove pollutants from wastewater in order to ensure adequate water quality before the treated effluent is reused or discharged to surface waters. The removal of radionuclide contaminants by various wastewater treatment processes and the usual association of these contaminants with solids can cause the concentration of the contaminants to increase, or reconcentrate, in sewage sludge and ash. Radioactive materials disposed of into the sanitary sewer in dilute form may become reconcentrated in the sludge solids during different stages of wastewater treatment and sludge processing, in a manner similar to some heavy metals.

Reconcentration may occur during physical, biological, or chemical processes. Sludge treatment and processing may result in increasing the concentration of the radioactive contaminant by decreasing the concentration of other components. Final concentration will depend on the characteristics of the processes used at the treatment facility, the efficiencies of those processes, as well as the chemical form of the radionuclides and their half-lives.

Radioactive materials found in sewage are partitioned between the liquid and solid phases of the influent. During treatment, the concentrations of radionuclides change as the solids are removed and the treatment processes remove radionuclides from the wastewater. Because radionuclide concentrations in wastewater influents are very dilute, there is generally no concern unless the radionuclide concentrations are increased, or reconcentrated, during the treatment process.

A study performed for NRC (Ainsworth et. al., 1994) reported that reconcentration of suspended radionuclides is very possible in primary treatment. NRC methods of determining solubility (NRC Information Notice 94-07 “Solubility Criteria for Liquid Effluent Releases to Sanitary Sewage under the Revised 10 CFR Part 20”) allow some suspended material to be discharged to the sewer system and, therefore, do not guarantee that reconcentration will not occur. This study also indicated that dissolved radionuclides (those not associated with the suspended solids) are unlikely to be reconcentrated during primary treatment. Reconcentration is possible during secondary treatment, but neither the mechanism(s) or unit process(es) involved is (are) understood in a quantitative manner.

Reconcentration can also occur during sludge treatment (Ainsworth et al., 1994). It can potentially result from the physical, chemical, and biological removal of radionuclides from the sewage and sewage sludge produced during wastewater treatment. Physical processes that increase the solids content of the sludge without loss of radioactive materials may lead to reconcentration. Sludge handling techniques that may contribute to reconcentration include digestion, dewatering, and incineration. Incineration may be the most significant process, because the total mass of the sludge is greatly reduced by water removal and combustion of organic material.

Although there is a potential for a reconcentration of radioactive materials in the sewage sludge or ash at POTWs, there have only been limited surveys of radionuclide levels in sewage sludge or sludge products. A recent study by the Association of Metropolitan Sewerage Agencies (AMSA) revealed the presence of both man-made radioactive material and NORM at low levels in sewage sludges and sludge products (NBP 1999). AMSA coordinated an extensive sampling effort as part of their national survey conducted in 1995. While this was a voluntary survey and was not structured to ensure a statistically representative result, samples from 55 POTWs in 17 States do provide a significant database. The ISCORS survey (ISCORS 2003) estimated potential doses from seven typical sludge management scenarios, based on the results of analyses of sewage sludge and ash products from 313 POTWs. The results of both surveys are generally consistent. Table 3.3 summarizes results from the AMSA study and the ISCORS survey. Table 3.4 provides typical ranges of radioactive material concentrations found in U.S. soils and common items such as fertilizers and building materials. Appendix L provides an analysis of the major contributors to the doses estimated in the ISCORS survey, for the selected sludge management scenarios where radiation exposure could potentially be a concern. Section 3.4 summarizes the results of the ISCORS survey and ISCORS Dose Assessment (ISCORS 2003b).

3.3.2 Radiation Exposure Due to POTW Operations

Based on what is known about the potential for reconcentration at POTWs, possible sources of radiation exposure would be at sludge processing or handling areas at the POTW and at off-site locations where the sewage sludge or ash is disposed or used. People most likely to be exposed to elevated levels of radioactive materials would be sewage sludge or ash handling personnel at the POTW or members of the public residing on former land application sites, where sludge had been applied for many years. Three primary ways for these people to be exposed to radiation associated with POTW operations are inhalation, ingestion, and direct exposure (see Figure 3.2).

Inhalation of alpha- or beta-emitting radioactive materials is a concern because radioactive material taken into the body results in radiation doses to internal organs and tissues (e.g., lining of the lungs). POTW workers could inhale radioactively contaminated dust during ash or sludge handling operations. The drier the material, the more likely it could be resuspended into the air when it is handled. POTW workers can also inhale radon and its progeny in both wet and dry conditions. Measures taken by POTW workers to avoid inhalation of biological pathogens and chemically toxic materials in sewage sludge and ash dust may effectively reduce the possible exposure to radioactive materials. Members of the public could also inhale contaminated dust blown from disposal or land application sites or dust from handling sewage sludge products made available for public use.

Ingestion of alpha- or beta-emitting radioactive materials is a concern for the same reason as inhalation. It may occur when food crops are grown on areas where sewage sludge or ash has been applied to the land as fertilizer or soil conditioner. (See Wisconsin DNR for more information on plant uptake from sludge-amended soils.) Ingestion could also occur when the materials migrate into the ground water or surface waters used as drinking water sources. POTW workers could ingest radioactive materials if they fail to observe good sanitary practices, such as washing their hands before eating after handling sewage sludge or ash. (The ISCORS survey did not measure uptake in food crops grown on sludge amended soils. It also did not measure direct gamma exposure to POTW workers. These potential pathways were considered, however, in the ISCORS dose modeling project.)

Table 3.3 Summary of Concentrations of Radioactivity in Sewage Sludge and Ash from AMSA Survey and ISCORS Survey (pCi/g)

Radio-nuclide	AMSA[1]			ISCORS Survey[1]		Radio-nuclide	AMSA[1]			ISCORS Survey[1]	
	min	median	max	min	max		min	median	max	min	max
gross alpha	nd	7.4	80.1	nd	178	Tl-202				nd	1.53
gross beta	nd	15.0	61.5		140	Tl-208	nd	0.16	2.08	nd	13.5
H-3*				nd	8	Pb-210				nd	13
Be-7	nd	1.54	50.03	nd	30	Bi-212	nd	0.47	11.48	nd	15.7
C-14*				nd	3	Bi-214	0.12	0.66	39.1	nd	16
Na-22	nd	nd	0.031			Pb-212	0.08	0.48	7.3	nd	15
K-40	nd	4.5	60.8	nd	26	Pb-214	0.14	0.71	46.48	nd	17
Cr-51				nd	35	Rn-219				nd	0.4
Mn-54	nd	nd	0.06			Ra-223				nd	0.8
Co-57	nd	nd	0.09	nd	0.26	Ra-224				nd	12
Fe-59				nd	0.4	Ra-226	nd	1.74	118.12	nd	47
Co-60	nd	nd	0.05	nd	5.1	Ra-228				nd	38
Zn-65	nd	nd	nd	nd	0.06	Ac-227	nd	nd	3.86		
Sr-89				nd	300	Ac-228	nd	1.30	51.08		
Sr-90				nd	9.4	Th-227				nd	1.1
Ru-106	nd	nd	0.23			Th-228				nd	14
Ag-108m	nd	nd	1.08			Th-230				nd	2.6
In-111				nd	3.6	Th-232				nd	1.7
Cd-109	nd	nd	6.28			Th-234				nd	80
I-125				nd	40	Pa-231	nd	nd	1.34		
I-131	nd	2.6	174.6	nd	840	Pa-234m				nd	77
Cs-134	nd	nd	0.08	nd	0.04	U-234					91
Cs-137	nd	nd	0.37	nd	3.6	U-235	nd	nd	0.93	nd	3.4
La-138				nd	0.07	U-238					74
Ce-141				nd	0.016	Np-237	nd	nd	1.97		
Eu-152	nd	nd	0.1			Pu-238				nd	0.19
Sm-153				nd	27	Pu-239				nd	0.17
Eu-154	nd	nd	0.13	nd	21	Am-241	nd	nd	0.58	nd	2.5
Eu-155	nd	nd	2.82			Am-243	nd	nd	1.27		
Gd-153	nd	nd	2.24			Cm-243	nd	nd	1.41		
Tl-201				nd	241						

Sources:

AMSA data, for 55 POTWs, from NBP (1999); ISCORS Data from ISCORS (2003)

1 nd, not detected

* pCi/g, wet weight

Table 3.4 Survey Concentration Ranges and Typical U.S. Background Concentrations of Radionuclides in Soil, Fertilizer, and Common Building Materials (All values are in pCi/g-dry weight)

Radio-nuclide	Soil[1]	Phosphate Fertilizer[3]	Building Materials[3]	Sludge Concentrations[3]	Ash Concentrations[3]
Bi-212	0.1–3.5	0.1–4.6	0.1–3.7	0.1–13	0.3–16
Bi-214	0.1–3.8	4.0–140	2.5–5.0[4]	0.04–16	0.62–16
Cs-137	0.1–0.2[5]	NDA[6]	NDA	0–3.6	0–0.37
K-40*	2.7-19	32–160[7]	0.8–30	0.3–26	7.4–22
Pa-234m*	0.1–3.8	4.0–140	0.2–5.0[4]	0–27	1–77
Pb-212*	0.1–3.5	0.1–4.6	0.1–3.7	0–15	0.36–15
Pb-214*	0.1–3.8	4.0–140	0.2–5.0	0.06–17	0.61–16
Ra-223*	<0.1–0.2	0.2–6.6	0.1–0.2[4]	0.06–0.09	0.1–0.8
Ra-224*	0.1–3.5	0.1–4.6	0.1–3.72	0.2–12	0.4–4.9
Ra-226*	0.1–3.8	0.1–24	0.1–3.5	0–47	0–22
Ra-228*	0.1–3.5	0.1–4.6	0.1–3.7[1]	0.14–38	0.65–30
Th-227*	<0.1–0.2	0.2–6.6	0.1–0.2	0–0.5	0.02–1.1
Th-228*	0.1–3.5	0.1–4.6	0.1–3.7	0.07–9	0.4–14
Th-230*	0.1–3.8	4.0–140	0.2–5.0	0.09–1.7	0.3–2.6
Th-232*	0.1–3.5	0.1–4.6	0.1–3.7[1]	0.02–1.6	0.22–1.7
Th-234*	0.1–3.8	4.0–140	0.2–5.0	0–23	1–80
Tl-208*	0.1–3.5	0.1–4.6	0.1–3.7	0.02–4.8	0.11–14
U-234*	0.1–3.8	4.0–140	0.2–5.0	0.18–44	1.2–91
U-235*[8]	<0.1–0.2	0.2–6.6	0.1–0.2	0–3.1	0.03–3.4
U-238*	0.1–3.8	4.0–140	0.2–5.0[4]	0.18–26	0.8–74

Notes:

The curie (Ci), or fractions of a curie (e.g. picocurie), is the unit for expressing a quantity of radioactivity. The unit normally used to describe the concentrations of radioactivity in the environment is picocuries per gram (pCi/g).

1 Tykva, R. and J. Sabol. "Low-Level Environmental Radioactivity–Sources and Evaluation." Technomic Publishing Company, Inc.,: Lancaster, Pennsylvania. 1995. This reference is the source of data for concentrations of radionuclides in soil and building materials except for the concentrations of U-238, U-235, and Cs-137 that came from references 9 and 6, respectively. The concentrations of the daughters or decay products of U-238, such as Th-234, Ra-226, etc., those of U-235, such as Th-227 and Ra-223, and those of Th-232 are set equal to those of their respective parent radionuclides by assuming that the daughters are in secular radioactive equilibrium with the parent radionuclides.

2 Source for data on fertilizers: National Council on Radiation Protection and Measurements (NCRP). NCRP Report No. 95, "Radiation Exposure of the U.S. Population from Consumer Products and Miscellaneous Sources." pp. 24-32. 1987. This is the source of data for the concentrations of radionuclides in phosphate fertilizers (not typical blended fertilizers) except for the concentration of K-40 in phosphate fertilizers) which came from the reference in note 8. The concentrations of typical blended commercial fertilizers would be 10% to 50% of these values.

3 A value zero as the lower boundary of the range occurs when a very low concentration is rounded to reflect the same number of decimal places as the two sigma laboratory uncertainty. Non-detected values are not included in this range.

4 Eisenbud, M. and T. Gesell. "Environmental Radioactivity." Fourth Edition, Academic Press: New York, New York. 1997.

5 Cs-137 concentration range in soil obtained from Figure 4-4, p. 94 of NCRP Report No. 50, "Environmental Radiation Measurements." 1976.

6 NDA, no data available.

7 Source for data on K-40 in fertilizer: S. Cohen and Associates. "Final Draft NORM Waste Characterization." EPA Contract No. 68D20155, WA No.5-09, pp. B-3-1 to B-3-24. 1997.

8 Values for U-235 in soil, fertilizer and building materials were based on the concentrations of U-238 in the same materials and the natural ratio of U-235 to U-238.

* Naturally-occurring radionuclide: All concentrations are expressed in pCi/g dry, unless noted; 1 pCi = 0.037 Bq.

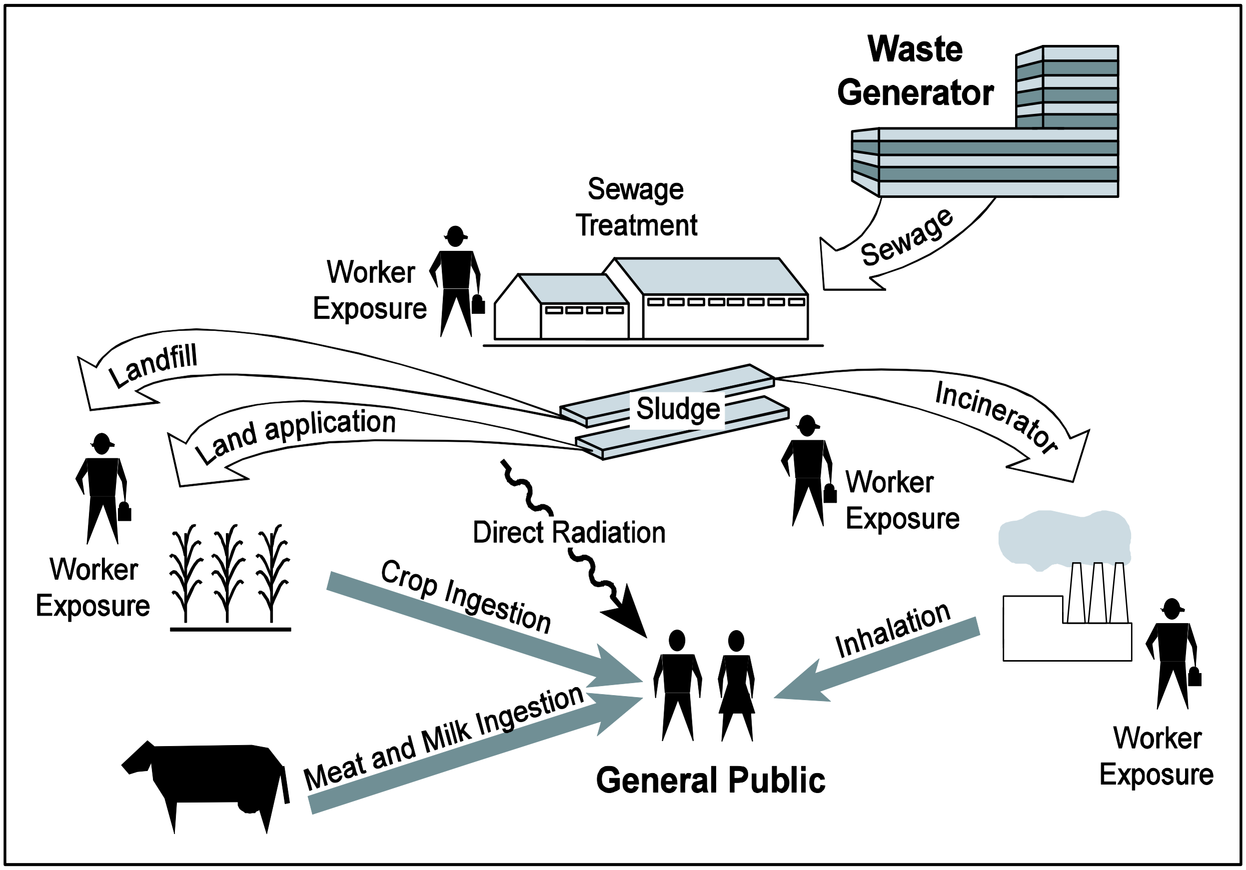

Figure 3.2 Primary Pathways for Radiation Exposure due to POTW Operations

Measures taken to limit the potential ingestion of heavy metals at land application sites would help to reduce possible exposure to radioactive materials. Similarly, measures taken by POTW workers to avoid ingestion of pathogen-containing materials would serve to prevent ingestion of radioactive materials.

Radioactive materials that emit gamma radiation are of concern because the gamma rays pose an external radiation exposure hazard. Because gamma rays can pass through common construction materials, the distance between the radioactive material and the person is a factor in the amount of exposure the person receives.

POTW workers most likely to receive direct exposure are workers that handle sewage sludge and ash, or work in areas of elevated indoor radon. Farmers and other members of the public who use sewage sludge products or ash as fertilizer or soil conditioners could receive direct exposure to gamma radiation if these materials are present. The exposure would be from the ground or from concentrations of biosolids in piles, or from contact radiation from dust particles on clothes or skin.

3.3.3 What Are the Average Radiation Doses from All Sources? How Do Doses from Sewage Sludge and Ash Compare?

Almost everything, including people, contains some radioactive material. Naturally occurring radioactive materials are found in the earth, in the materials used to build our homes, and in the food and water we ingest. Even the air we breathe contains some radioactive gases and particles. People are exposed to radiation on a daily basis from both natural and man-made origins.

Human exposure to radiation sources is derived primarily from background natural radiation; however, a person's occupation, geographic location, time spent outdoors, need for diagnostic medical treatments and testing, time spent traveling in airplanes, and other activities can determine the relative contributions of natural, man-made, and global fallout sources. On the average, 80 percent of human exposure to radiation comes from natural sources: radon gas, the human body, outer space, rocks, and soil. The remaining twenty percent comes from man-made radiation sources, primarily X-rays. Diagnostic medical and dental X-rays, radiation treatment and other applications of nuclear medicine contribute approximately 10 percent to 15 percent of the average annual human dose. Certain consumer products (television sets and other electrical appliances, smoke detectors, building materials and tobacco products) and to a lesser extent, airport and other types of inspection equipment, contribute approximately three to five percent of the average radiation dose.

It is estimated that less than one percent of the average annual dose to humans from background radiation is a result of global fallout. Global fallout results from nuclear accidents (e.g., Chernobyl) and from nuclear weapons testing during the 1940s to 1960s. Although above-ground testing ceased in the United States in 1963, radiation remaining in the atmosphere continues to account for a residual level of background human exposure.

The average radiation dose to an individual in the United States is about 360 mrem/yr. (The term "dose" and other background information on radioactivity are described in Appendix A.) Typical values for annual exposure to radiation within the United States are summarized in Table 3.5.

Terrestrial radiation comes from radioactive material that is naturally occurring in the environment. Radon occurs in the environment and is listed separately in Table 3.5 because of radon's significant contribution to radiation exposure (see also Figure 3.1). Most of the radon dose comes from indoor exposure in homes, schools, and workplaces. The reader is referred back to the map in Figure 1.1 for average indoor air concentrations of radon in the US, and also http://www.epa.gov/radon for more information. Cosmic radiation comes from outer space and some of it penetrates through the atmosphere covering the earth. The amount of cosmic radiation will vary depending on the altitude and latitude where one lives. Internal radiation comes primarily from ingested natural radioactive substances, such as potassium-40.

As demonstrated by the ranges shown in Table 3.5, radiation exposure can vary greatly, as the various factors that contribute to total exposure are not constant from location to location, and an individual's lifestyle and daily activities vary this amount. For example, the atmosphere serves as a shield against cosmic radiation; therefore, dose increases with altitude. The dose at an altitude of one mile at Denver (60 mrem/yr) is about double that at sea level (30 mrem/yr). Also, a flight on a commercial airliner increases an individual's dose from cosmic gamma rays about 1 mrem for each cross-country flight.

Table 3.5 Average Annual Exposure to Radiation

Source of Radiation	Average. Exposure (mrem/yr)	Typical Range of Variability (mrem/yr)
Natural Sources		
Terrestrial	30	10 –80
Radon	200	30–820
Cosmic	30	30–80
Internal	40	20–100
Man-Made Sources		
Medical	50	
Consumer products	10	
Other (Nuclear fuel cycle and occupational)	1	
Total	360	90–1080
Sources: NCRP 1987a, for average exposure values; Huffert et al. 1994, and Fisher 2003 for ranges of variability.		

Dose rates from terrestrial sources vary from about 10 mrem/yr to 80 mrem/yr across the United States. The major sources in the ground are potassium, thorium, uranium, and uranium progeny. The higher doses are associated with uranium deposits in the Colorado Plateau (Figure 3.3), granitic deposits in New England, and phosphate deposits in Florida (Figure 3.4). The lowest rates are the sandy soils of the Atlantic and Gulf coastal plains. Annual doses for individuals living in brick homes may increase up to 10 mrem/yr due to naturally-occurring thorium, uranium, and radium found in clays often used to make bricks.

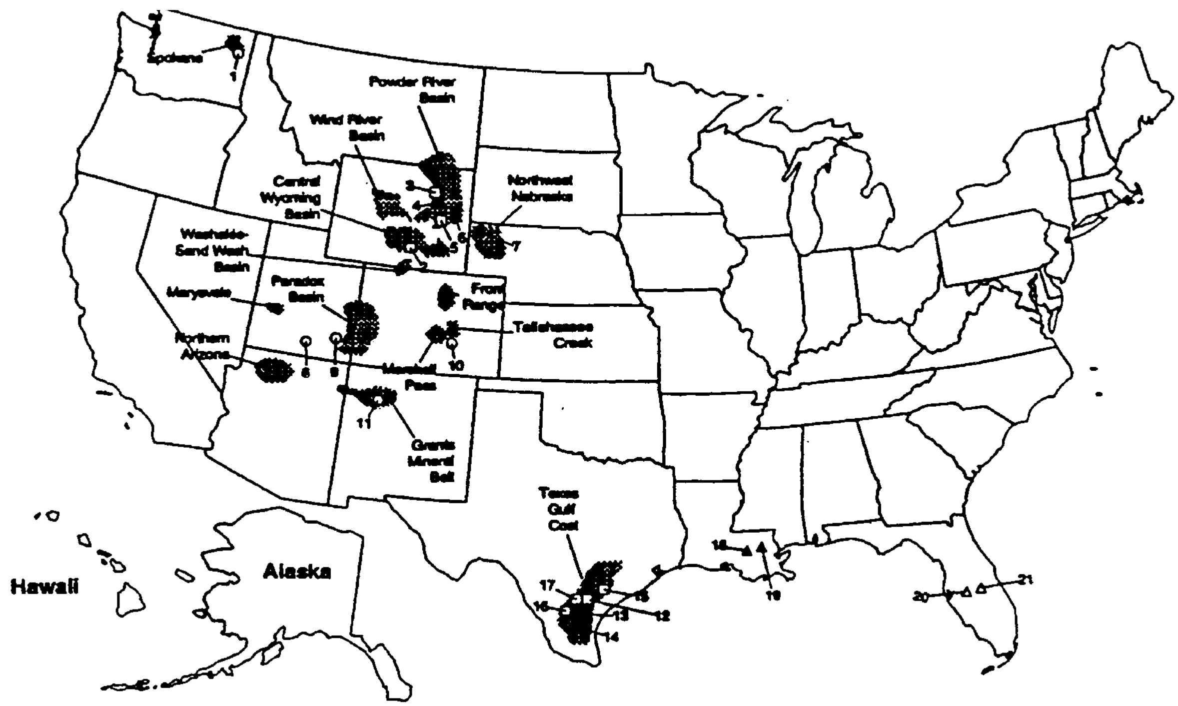

Figure 3.3 Uranium Deposits in the United States. Reference DOE (1977)

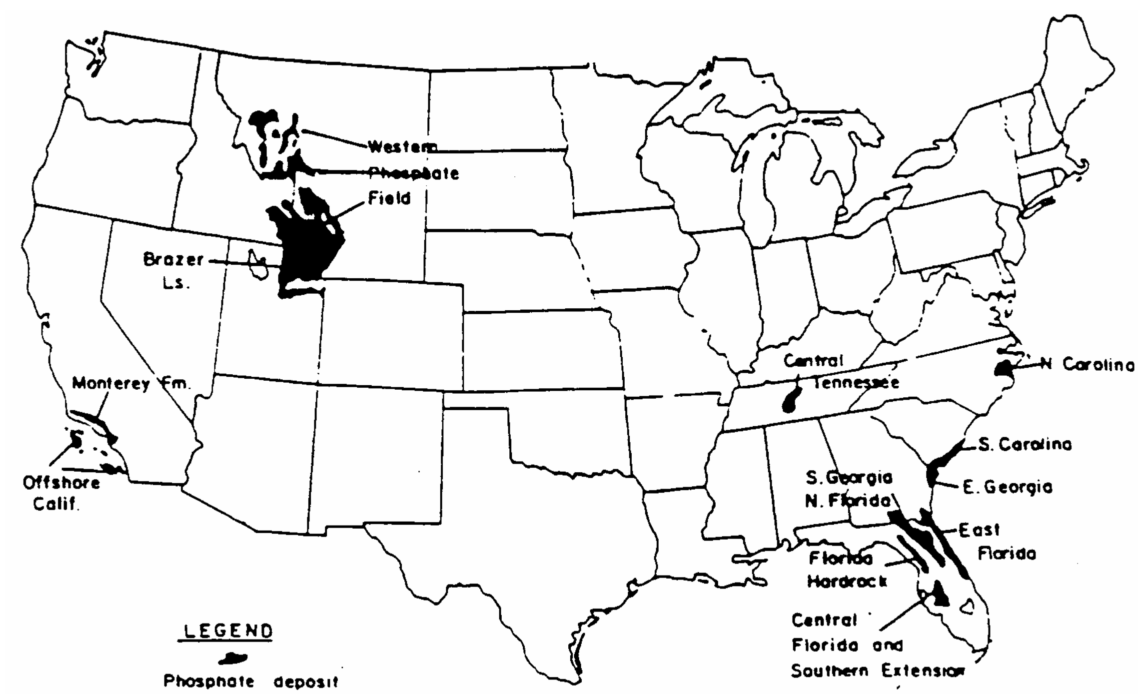

Figure 3.4 Major Phosphate Deposits in the United States with Significant Uranium Content

The principal naturally-occurring radionuclides in food are potassium-40 (a common example is bananas) and radium-226 (e.g., in brazil nuts). Radium in water, particularly ground water, varies across the United States. According to a U.S. Geological Survey/Environmental Protection Agency report (USGS 1998), "Radium is present in higher concentrations in some States, such as the north-central States, including southern Minnesota, Wisconsin, northern Illinois, Iowa and Missouri, and southeastern States from Georgia to New Jersey."

Radiation doses at POTWs are generally insignificant compared to background radiation under most conditions. However, under conditions at POTWs where elevated levels of radionuclides have been detected, there is the possibility that doses to POTW workers and to the general public could be of concern. Previous studies attempting to quantify these doses, however, have failed to measure actual exposures that would indicate a potential health risk. For example, the NRC conducted a study to estimate maximum radiation exposures to POTW workers and others who could be affected by low levels of man-made radioactivity in wastewater (Kennedy et al. 1992). The estimates of these hypothetical exposures to workers range from zero to a dose roughly equal to natural background levels. The study, which did not consider NORM/TENORM, used scenarios, assumptions, and parameter values generally selected in a manner to produce prudently conservative estimates of individual radiation doses. However, the quantities of radionuclides released into the sewer systems were assumed to be the maximum allowed under NRC regulations. Thus, the calculations were not intended to be based on realistic or prudently conservative conditions at POTWs, but based on maximized releases to sewer systems.

3.4 SUMMARY OF RESULTS OF ISCORS SURVEY

Radioactive materials are a natural part of the environment and a byproduct of human activity. Naturally-occurring and man-made radioactive materials may enter POTWs by water infiltration or inflow, domestic discharges, and permitted or accidental discharges. There are numerous factors to consider when determining the sources of radioactive material and whether radionuclides are present in sewage sludge or ash at levels that are of any concern to worker safety or public health.

The ISCORS Survey (ISCORS 2003) results provide an estimate of the range of concentrations of radionuclides that may be present in sewage sludge and ash. The ISCORS Dose Assessment project (ISCORS 2003b) provides a means for estimating potential doses associated with these levels of radionuclides under various sludge management scenarios. Table 3.6 combines the dose modeling results with the Survey measurements, and makes it clear that while some scenarios and radionuclides give rise to very low doses, there are other radionuclide-scenario combinations that may be a significant increment over background.

Based on results of the ISCORS Survey and Dose Assessment, the tables in Appendix L show the radionuclides that may be most likely to be of concern in terms of potential doses to members of the public and to POTW workers. From the ISCORS Dose Assessment, the scenarios most likely to be of concern are the Onsite Resident and the POTW Worker Loading scenarios. The Appendix L tables show the radionuclide, the 95th percentile concentration and the maximum concentration measured in the ISCORS survey, the percent of samples in which the radionuclide was detected, probable source of the radionuclide, and the most significant scenario, based on the 95th percentile concentration.

The radionuclides listed in these tables are only those thought most significant based on the ISCORS Survey results and the ISCORS Dose Assessment methodology. The analysis included in Appendix L may be useful as an indication for individual POTWs of which radionuclides should be considered initially. However, concentrations and exposure scenarios at an individual POTW will be different from those of the ISCORS Survey and Dose Assessment. Thus, POTW operators should not eliminate from further consideration any radionuclide that might be identified within its service area, as a result of surveying licensees or identifying industries or natural sources of radionuclides (see Chapter 5). Also, a site-specific evaluation may be required (see Chapter 6). In particular, there are specific radionuclides listed in the Appendix L tables that have resulted in contamination at certain POTWs (see Chapter 1), such as Co-60, Am-241, U-234, and U-238.

The basic conclusions of the ISCORS Survey and Dose Assessment project are as follows:

- None of the non-POTW scenarios shows a significant current widespread threat to public health. For instance, the scenarios with the largest potential critical groups—the Nearby Town and the Incinerator Neighbor—show relatively small estimated doses, as does the Landfill Neighbor. The landfill neighbor scenario assumes that institutional and engineering controls (deed restrictions and cap) remain intact past the required 30-year monitoring period. There is a possibility, however, that site restrictions would not be followed. If an intruder were to build a house on either a surface impoundment or municipal solid waste landfill where sewage sludge or ash was buried, doses could be significantly higher. This scenario was not considered plausible by ISCORS, so it was not modeled.
- If agricultural land application is carried out for a long time into the future, then the potential exists for future radiation exposure primarily due to radon, if the land application site is converted to residential use. This is illustrated in the 50 and 100 year application sub-scenarios of the Onsite Resident. Some non-radon doses could be above certain dose criteria (see Table 3.6) even at 20 years of application. However, the levels of radioactive materials detected in sewage sludge and ash in the ISCORS survey and as calculated in the dose assessment indicate that, for most POTWs, radiation exposure to the general public through the use of sludge as a soil amendment for growing food crops is very low and consequently, is not likely to be a concern.
- In specific cases of very high concentrations of radioactive materials (e.g., levels above 95%), there is the potential for localized radiation exposure.
- Within the POTW, little exposure is expected for sampling and transport. Only when workers are in the same room with large quantities of sludge (e.g., for storage or loading) is there the potential for significant exposure, predominantly due to radon. In this case, the degree of exposure is likely to depend highly on the configuration of the POTW in terms of room sizes, ventilation, and so forth, as well as the duration of exposure of the worker.
- While ISCORS believes that the seven scenarios in Table 3.6 represent the most likely exposures from sewage sludge, there are numerous other scenarios that may be plausible considering site specific conditions, such as a future farm field worker or a landfill intruder (discussed above), and which may warrant investigation. In such cases, POTW operators are encouraged to seek advice from health physics consultants for site specific modeling.

The highest doses computed for the Onsite Resident and the POTW Worker are notable; but several important factors account for these elevated values, suggesting that typical exposures would not necessarily approach such levels:

- The exposure scenarios are somewhat conservative; in addition, the doses mentioned above are upper-end percentile values.
- The doses for the Onsite Resident for 50- or 100-years of annual application would be significant, but very few farms in the country, so far, have used sewage sludge for even 20 years.
- The highest doses are generally attributable to the indoor radon pathway. For the Onsite Resident, the 95-percentile sample doses tend to be a factor of 6.5 higher than the corresponding median (50^{th}-percentile) sample doses, regardless of the number of years of application, simply because of the difference in the concentration of radium in the sludge (13 pCi/g versus 2 pCi/g). Both for the Onsite Resident and the POTW Worker, exposures can be decreased significantly through the use of readily available radon testing and mitigation technologies.

Processes at POTWs can reconcentrate radioactive materials in sewage sludge and ash. People working with or near the sludge at the POTW, those working at disposal sites, and users of sludge products could be exposed to any radionuclides that reach the POTW. Exposure could occur from inhalation of dust, ingestion of contaminated food, or direct exposure. Guidance on determining whether these or other potential exposures could occur, and whether these exposures should be a concern at a POTW, as well as suggestions on appropriate response actions, is provided in Chapters 5–7 of this report.

Table 3.6 Calculated Total Peak Dose from Survey Samples: Summary Results With and Without Indoor Radon Contribution (mrem/year)

Scenario	Subscenario	Median sample (mrem/year)		95% sample (mrem/year)		Dominant Radionuclide(s) [pathways]
		TEDE	TEDE w/o Rn	TEDE	TEDE w/o Rn	
S1–Onsite Resident	1 yr of sludge application	0.5	0.2	3	1	Ra-226 [indoor radon][1]
	5 years application	2.5	1	14	4.9	Ra-226 [indoor radon] [1]
	20 years application	9.2	3.4	55	16	Ra-226 [indoor radon] [1]
	50 years application	22	7.2	130	37	Ra-226 [indoor radon] [1]
	100 years application	42	13	260	69	Ra-226 [indoor radon] [1]
S2–Recreational User	N/A	0.04	–	0.22	–	Ra-226 [external]
S3–Nearby Town	1 yr of sludge application	6.4e-04	–	3.2e-03	–	Ra-226 [outdoor radon]
	5 years application	2.8e-03	–	0.014	–	Ra-226 [outdoor radon]
	20 years application	8.5e-03	–	0.045	–	Ra-226 [outdoor radon]
	50 years application [2]	0.017	–	0.094	–	Ra-226 [outdoor radon]
	100 years application [2]	0.029	–	0.17	–	Ra-226 [outdoor radon]
S4–Landfill	MSW — Sludge	4.6e-03	1.6e-03	0.027	0.01	Ra-226 [indoor radon] [1]
	MSW — Ash	0.014	3.1e-03	0.041	0.014	Ra-226 [indoor radon] [1]
	Impoundment	0.21	0.062	1.2	0.36	Ra-226 [indoor radon] [1]
S5–Incinerator	N/A	1.2	–	7.7	–	multiple [multiple]
S6–Sludge Application Worker	1 yr of sludge application	0.032	–	0.15	–	Ra-226 [external]
	5 years application	0.16	–	0.77	–	Ra-226 [external]
	20 years application	0.57	–	3	–	Ra-226 [external]
	50 years application	1.3	–	7.4	–	Ra-226 [external]
	100 years application	2.3	–	15	–	Ra-226 [external]
S7–POTW Workers	Sampling (mrem/sample)	9.6e-08	–	4.9e-07	–	Ra-226 [external]
	Transport (mrem/hr)	4.6e-05	1.1e-05	1.9e-04	5.6e-05	Th-228 [indoor radon, external] [1]
	Loading	3.8–17 [3]	2.7	17–70 [3]	13	Ra-226, Th-228 [indoor radon] [1]

Notes:

All values rounded to two significant figures. 95% DSRs are used in all total peak dose calculations. The symbol "–" denotes that indoor radon was not separately calculated. N/A denotes Not Applicable. MSW denotes Municipal Solid Waste.

1 The dominant radionuclide applies to doses that include radon. However, radon is typically controlled by concentration level (e.g., pCi/L or WL) and not by dose. The recommendations in Chapter 6 of this report use EPA's radon guidelines (4 pCi/L or 0.02 WL) as a metric for actions relating to indoor radon.

2 There are very few land application sites in the country that are known to have applied sewage sludge annually for more than 20 years; the 50- and 100-year computations are included for the information of POTW operators in their consideration of future sludge management practices.

3 Range represent results from the nine combinations of air exchange rate and room height (see Section 1.2).

4 WHAT ARE THE RELEVANT REGULATORY AGENCIES? WHAT ARE THEY DOING?

The regulatory framework for radioactive materials in wastewater is somewhat complex. There are many levels of authority and types of requirements. Federal Guidance on radiation exposure to workers and the public is prepared under the authority of the EPA as issued by the President. Regulations are issued and enforced by various agencies at different levels of government, depending upon the type of radioactive material and the agreements arranged. Information provided in this section includes only those aspects most germane to the types of materials that may enter wastewater and therefore affect POTW operations.

The primary division of the regulatory framework is based on the origin of radioactive material. In general, man-made radioactive materials are regulated differently than NORM and TENORM.

Radioactive materials consisting of source, byproduct, and special nuclear material (see Appendix G for definitions of these materials) are subject to the provisions of the Atomic Energy Act (AEA). Radioactive materials used in the commercial and private sector are subject to the rules of the NRC. When these materials are in the defense sector in weapons development operations, they are under the control of the Department of Energy (DOE). However, DOE also regulates TENORM and accelerator produced radioactive material under AEA authority. This guidance focuses on the NRC regulations, rather than the DOE requirements, primarily because DOE's requirements are generally consistent with NRC's, and only apply to DOE's nuclear facilities.

The AEA allows the NRC to establish formal agreements with States, granting the States with authority to develop and oversee the implementation of specific regulations regarding use and possession of source, byproduct and special nuclear materials generated or used at these facilities. States with such an agreement, i.e., Agreement States, are required to maintain a radiation protection program that is adequate to protect public health and safety and is compatible with that of the NRC. A current map showing Agreement States is provided in Appendix B. Information on the relevant agencies that are designated under the AEA with the authority to develop and oversee regulations for commercial use of radioactive materials is listed in Appendix E.

The lead Federal agency in the regulation of NORM and TENORM is EPA. The DOE also regulates NARM at DOE facilities. In addition, some State and local authorities also regulate various aspects of the materials discussed above. Other radioactive materials are generally regulated by the States. The Department of Labor=s Occupational Safety and Health Administration (OSHA) regulates workplace safety and health, including exposure to hazardous or toxic materials, and radiation. More detailed information on the role and regulations of the NRC, Agreement States, EPA, State agencies, and local authorities, as well as ISCORS, is provided in the following sections.

4.1 U.S. NUCLEAR REGULATORY COMMISSION (NRC) AND AGREEMENT STATES

NRC and Agreement States regulate the possession, use, and disposal of certain radioactive materials, and also develop and implement guidance and requirements governing licensed activities, inspection and enforcement activities to ensure compliance with the requirements. The primary radiation protection regulations for AEA materials regulated by the NRC are contained in the Code of Federal Regulations (CFR), Title 10, Part 20. Section 20.1301 of these regulations contains the dose limit for members of the public, which is 100 mrem/year from operations of an NRC-licensed facility. Subpart E of Part 20 provides radiological criteria for termination of NRC licenses, including, in Section 20.1402, a dose criterion of 25 mrem/year for termination of a license for unrestricted use. Section 20.2003 describes the limits on sewer disposal for radioactive materials. This regulation sets limits on the concentration of radioactive material that may be discharged to the sewer in one month and the total annual quantity of discharge. In 1991, the NRC revised the regulatory provisions that limit releases to the sewer, due to the discovery of problems with metallic radioactive materials disposed of as finely dispersed materials. The NRC regulations now require that all radioactive materials disposed to the sewer be readily soluble (or be readily dispersible biological material) in water. The Agreement States have adopted compatible regulations.

With some specified exceptions, any activity involving source, byproduct, and special nuclear material must be conducted under a license issued by the NRC or an Agreement State. The exempt activities are described in NRC's 10 CFR Part 30, Part 40, and other Parts. For example, exemptions from specific licensing include some consumer products, such as smoke detectors and luminous watches. While medical facilities and hospitals may be required to obtain a license, individuals undergoing medical procedures with radioactive materials are not subject to these regulations.

Licenses are issued to licensees only after NRC or the Agreement State is satisfied that the licensee has the qualified staff, equipment, procedures, instrumentation, training programs, and management oversight deemed necessary to operate the proposed program in a safe manner and within the restrictions specified in the license. Both NRC and Agreement States monitor their licensees by means of periodic inspections. The frequency of inspections depends on the type of license issued to the licensee and is based on risk. The frequency will vary from annual inspections for complex licensees, such as hospitals with a broad license, radiopharmaceutical companies, and other large users of byproduct materials, to inspections once every 3-5 years for small or simple licensees who may use only one small radioactive source in a routine and well-established application. The license may be suspended or revoked if NRC or the Agreement State finds that the licensee's operation does not meet requirements of the regulations, conditions of the license, and operating procedures. Additional information about NRC and Agreement State licensing and enforcement is provided in Appendix I.

4.2 U.S. DEPARTMENT OF ENERGY (DOE)

Under the Atomic Energy Act, the Department of Energy Organization Act (DOA), and other related Federal statutes, DOE has been assigned broad responsibility for protection of the public, the environment, and real or personal property from radiological hazards associated with its research, development, weapons production, and other activities. Operators of DOE facilities are responsible for compliance with regulations and internal directives that contain specific requirements for managing radioactive materials. For a summary of these directives, consult "The Long-term Control of Property: Overview of Requirements in Orders DOE 450.1 and 5400.5", which can be obtained from DOE's Office of Environment, Safety and Health website (http//:tis.eh.doe.gov/oepa/) under the section entitled "Policy and Guidance–Radiation Protection." DOE also implements radiation worker protection requirements at its facilities, under 10 CFR Part 835.

DOE internal directives restrict the release of radioactive material to the environment by setting an annual general public dose limit based on all pathways of potential exposure. Controls are in place at each DOE nuclear facility to ensure that releases of radioactivity from all sources are monitored so that general public exposures are well below the general public dose limit. Any release of liquid waste that contains radionuclides that meets the protective levels established in DOE internal directives is considered a "Federally permitted release," and as such, is subject to treatment by a process selected through the Best Available Treatment procedure, and is also subject to the As Low As Reasonably Achievable standard. Although Federally permitted releases to sewage systems are not subject to prior notice or approval by the POTW operator, DOE internal directives do require that radioactivity levels be controlled so that a local POTW's wastewater treatment and sludge management processes are not disrupted.

4.3 U.S. ENVIRONMENTAL PROTECTION AGENCY (EPA)

EPA has limited authority to regulate radioactive materials. Under the Atomic Energy Act of 1954 as amended (AEA) and the Reorganization Plan No.3 of 1970, EPA has authority to establish generally applicable environmental standards for the protection of the general environment from radioactive material regulated under the AEA. 42 U.S.C. § 2201(b); Reorganization Plan No.3 of 1970, § 2(a)(6). (Under the Reorganization Plan, "standards" mean limits on radiation exposure or levels, or concentrations or quantities of radioactive material, in the general environment outside the boundaries of locations under the control of persons possessing or using radioactive material.) In addition, the AEA directs EPA to advise the President and Federal agencies in the formulation of radiation standards. 40 U.S.C. § 2021(h). The Atomic Energy Act and the Reorganization Plan do not provide implementation and enforcement authority for EPA. Rather implementation and enforcement of EPA's generally applicable standards are the responsibility of other Federal agencies.

4.3.1 Role in Regulating Facilities That May Discharge to POTWs

The Clean Water Act (CWA) prohibits the addition of any pollutant to navigable waters from a point source except in compliance with provisions of the CWA. In addition, the CWA requires EPA to establish pretreatment standards for certain pollutants that are introduced into POTWs.

EPA must establish pretreatment standards for pollutants that are not susceptible to treatment by the POTWs—the pollutant "passes through" the POTW—or these pollutants interfere with POTW operations (33 U.S.C. 1317(b)). Pretreatment standards are implemented through local POTW programs that are required conditions of POTW discharge permits (Sections 402(a)(3) and (b)(8)). Indirect users of POTWs (for example, facilities that introduce pollutants into POTWs through sewers or by hauling waste to POTWs) must comply with pretreatment standards.

EPA has established two types of national pretreatment standards under section 307(b). First, EPA has promulgated general and specific prohibitions on the introduction of pollutants into a POTW that apply to each user regardless of the applicability of other national standards. These standards prohibit the introduction of any pollutant that will cause pass through and interference and, among other things, the introduction of pollutants that will obstruct POTW flow or pollutants that will cause acute worker health or safety problems. Second, EPA has established "categorical" pretreatment standards. Categorical standards specify quantities or concentrations of pollutants that may be introduced by industrial users in specific industrial categories (40 CFR 403.5 and 403.6).

While the Clean Water Act (CWA) 33 U.S.C. 1251, et seq., defines "pollutant" to include radioactive material (see 33 U.S.C. § 1362(6)), it is the EPA's longstanding position that EPA has no authority under the CWA to regulate radioactive materials regulated under the AEA. The AEA regulates radioactive source material such as uranium and thorium or ores containing them, special nuclear material such as plutonium or enriched uranium, or byproduct radioactive material such as the tailings or wastes produced by the extraction of uranium or thorium (42 U.S.C. § 2014(e),(z), and (aa)).

Box 4.1 EPA Authority

As discussed above, EPA has no authority to regulate radioactive "source material, special nuclear material, and byproduct material" in sewage sludge. However, EPA has authority under the CWA to regulate radioactive materials that are not source, special nuclear, or byproduct material regulated under the AEA (e.g., TENORM).

EPA also regulates the discharges of waste material from contaminated facilities cleaned up under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). If such facilities discharge to a sanitary sewer, EPA has the authority to regulate the limits for both man-made radioactive materials and TENORM. EPA may also grant authority to a State to serve as the regulator of CERCLA cleanups.

EPA regulates the management of hazardous industrial waste, pursuant to the Resource Conservation and Recovery Act (RCRA). EPA and NRC are currently exploring the conditions under which RCRA hazardous waste disposal facilities could more routinely accept low-activity radioactive materials.

EPA also establishes radiation-related standards in other areas that may indirectly affect the consideration of both man-made radioactive materials and TENORM at a POTW. For example, under the Clean Air Act (CAA) EPA may limit radionuclide releases to the air from facilities (e.g., elemental phosphorous plants). These facilities may generate waste products containing radioactive materials that could enter the sanitary sewer system.

Another radiation-related standard that may indirectly affect POTWs includes EPA's standards for radionuclides in drinking water under the Safe Drinking Water Act (SDWA). These regulations, encompassing both man-made radioactive materials and TENORM, have caused many municipalities to incorporate water treatment that removes radioactive materials from the influent water before releasing it to the service connections. It has been noted in several instances that municipal water treatment facilities discharged residues with elevated radioactive material content from this process to the sanitary sewer systems. EPA is currently developing new guidance that addresses disposal of drinking water treatment residuals and filters. The guidance will provide responses to frequently asked questions, information on water treatment technologies and associated wastes, applicable waste disposal options, a review of existing Federal and State laws and regulations governing those wastes, a review of occupational radiation health and safety practices, and a list of licensed disposal facilities.

4.3.2 Role in Regulating Radon and Indoor Air

Radon and indoor air quality information and guidance are provided by the U.S. EPA's Office of Radiation and Indoor Air (ORIA). ORIA develops national programs, technical policies, and guidances for controlling radon and indoor air pollution exposure. Its concerns for indoor air include exposures to smoke, molds, mildew, and indoor radon. Under the Radon Gas and Indoor Air Quality Research Act (1986) and Indoor Radon Abatement Act (1988), as well as authorities of the Clean Air Act, EPA has developed guidance rather than regulations for control of radon in buildings and schools. (See Table 6.1.)

Since the mid-1980s, the United States has made significant progress in reducing the risk from exposure to radon. This progress is the result of a long-term effort between EPA, citizens, non-profit organizations, State and local governments, the business community, and other Federal agencies working together. More adult Americans are knowledgeable about radon than at any time since the mid-1980s, when radon became a National health concern. Since the mid-1980s, about 18 million homes have been tested for radon and about 700,000 of them have been mitigated. Approximately 1.8 million new homes have been built with radon-resistant features since 1990.

4.3.3 Role in Regulating POTWs

EPA regulates POTWs in several ways. As discussed above, the CWA prohibits the discharge of any pollutant to navigable waters except in compliance with its requirements. A POTW that wishes to discharge pollutants into the waters of the United States may achieve such compliance by obtaining a National Pollutant Discharge Elimination System (NPDES) permit from EPA. Permits are issued to dischargers (including both industries and POTWs), specifying the discharge conditions and monitoring requirements to ensure certain conditions are met. NPDES permits prescribe the terms under which parties may discharge pollutants. Under the CWA, EPA may authorize States to administer their own permit program under State law so long as the program meets certain requirements prescribed by the Act. EPA suspends issuance of its own NPDES permits if EPA approves the State program.

As explained above, EPA also implements a CWA National Pretreatment Program. Under this program, facilities discharging a significant amount of wastewater to the POTW must limit their discharges of specific pollutants to the sanitary sewers. By limiting the discharge of these pollutants, the sewage treatment plants receiving the discharges are better able to meet their NPDES permit conditions, to protect the treatment plant workers from these pollutants and to keep pollutants in the sewage sludge produced by these plants below specified limits.

EPA also regulates the use and disposal of sewage sludge produced by POTWs. The relevant regulations are found in 40 CFR Parts 257 and 503, but at this time, do not address radioactive material in sewage sludge which EPA may have authority to regulate (i.e., the non-AEA radioactive components). Under the Resource Conservation and Recovery Act (RCRA), EPA cannot directly regulate as hazardous waste radioactive material that is subject to the AEA in sewage sludge. However, EPA could regulate the non-AEA hazardous waste components of the sludge under RCRA.

When sewage sludge is incinerated, some radioactive material may be emitted. EPA has no direct authority under the Clean Air Act (CAA) to regulate the concentration of radioactive materials in sewage sludge/ash at POTWs. However, radionuclides were expressly included in the initial list of hazardous air pollutants in Part 112(b) of the CAA, and EPA has authority to establish National Emission Standards for Hazardous Air Pollutants (NESHAPs) under Part 112 of the CAA for facilities that emit radionuclides to the ambient air. Although EPA does not regulate the concentration of radionuclides in sewage sludge/ash directly under the CAA, the measures required to control emissions of hazardous air pollutants from POTWs may indirectly affect the concentration of radionuclides in sewage sludge.

Under the CWA, EPA determines the pollutants for which it will establish sewage sludge use and disposal standards (i.e., 40 CFR Part 503) based on current information about the potential for adverse consequences to human health and the environment. Part 405(d) of the CWA requires EPA, based on available information, to establish numerical pollutant limits for pollutants present in sewage sludge in concentrations that may adversely affect public health and the environment. These standards must be adequate to protect public health and the environment from reasonably anticipated adverse effects. This authority, in combination with the Agency's authority under AEA to establish generally applicable environmental standards for the protection of the general environment from radioactive material and to establish NESHAPs for hazardous air pollutants (including radionuclides) under part 112 of the CAA for facilities which emit radionuclides to the ambient air, would appear to provide adequate authority to establish numerical limits for any radionuclides in sewage sludge/ash for most end use and disposal practices if deemed necessary to protect public health and the environment.

While the definition of "pollutant" in the NPDES Regulations (40 CFR 122.2) specifically exempts radioactive materials that are regulated under the AEA as amended (42 U.S.C. 2011 et seq.), the Pretreatment Regulations (40 CFR Part 403) prohibit "interference," which includes a discharge which "inhibits or disrupts the POTW, its treatment processes or operations, or its sludge processes, use or disposal" [40 CFR 403.3(i)]. Significant industrial users discharging to

POTWs are regulated through control mechanisms (typically permits) with specific components issued by the POTWs (or States) under Pretreatment Programs that are approved by EPA.

4.4 OCCUPATIONAL SAFETY AND HEALTH ADMINISTRATION (OSHA)

The Occupational Safety and Health Administration (OSHA) developed occupational radiation standards (see 29 CFR 1910.1096 [??]) that might apply whenever an operator becomes aware of the presence of radiation at the facility. Although these standards may not apply to municipal wastewater treatment plant workers, these workers may be covered by their State's OSHA program, requiring that all controls, monitoring, recordkeeping, and training outlined in the OSHA standards be met.

Additional OSHA standards that may be applicable to wastewater systems include:

- Requirements that personal protection equipment (or PPE, for the eyes, face, head, and extremities) such as protective clothing , respiratory devices, and protective shields and barriers be provided, used, and maintained whenever processes or radiological hazards capable of causing injury through absorption, inhalation, or physical contact necessitate such equipment. There are numerous other requirements related to the possession and use of PPE, including training for employees who would use the equipment. For more information, see 29 CFR 1910.132-136.
- Requirements for practices and procedures to protect employees in general industry from the hazards of entry into permit-required confined spaces. For more information, see 29 CFR 1910.146.

4.5 INTERAGENCY STEERING COMMITTEE ON RADIATION STANDARDS (ISCORS)

NRC and EPA formed the Interagency Steering Committee on Radiation Standards (ISCORS) in 1995 to resolve and coordinate regulatory issues associated with radiation standards. The objectives of the committee include the following: (1) facilitate a consensus on acceptable levels of radiation risk to the public and workers, (2) promote consistent risk assessment and risk management approaches by setting and implementing standards for occupational and public protection from ionizing radiation, (3) promote completeness and coherence of Federal standards for radiation protection, and (4) identify interagency issues and coordinate their resolution. In addition to NRC and EPA, ISCORS membership also includes senior managers from the Department of Defense, the Department of Energy, the Department of Labor's Occupational Safety and Health Administration, the Department of Transportation, the Department of Homeland Security, and the Department of Health and Human Services. Representatives of the Office of Management and Budget, Office of Science and Technology Policy, and the States are observers at meetings.

ISCORS formed a Subcommittee to conduct the ISCORS sewage survey and to develop this POTW report. Most of the information previously available on reconcentration of radionuclides in sewage sludge and ash was due to unusual circumstances that triggered discovery of incidents in the course of other POTW operations. The Subcommittee has evaluated the occurrence of radioactive materials in sewage sludge and ash, including the sampling of sewage sludge and ash from POTWs across the country (ISCORS, 2003) and has conducted modeling to evaluate the dose associated with radioactive material in sewage sludge and ash (ISCORS, 2003b). These activities were conducted to evaluate the need for future regulatory actions by individual agencies. Some of the regulatory actions that could have been considered include the following:

- NRC regulations that would further limit the sanitary sewer discharge of man-made radioactive materials.
- EPA regulations that would further limit the discharge of NORM/TENORM through NPDES permits.
- EPA regulations that would include requirements for radioactive materials in sewage sludge/ash use and disposal practices.

Chapters 5 and 6 of this report provide recommendations to POTW operators, based on the ISCORS analyses, on prudent steps that may be taken to determine if there is any concern for radiation levels present in the sewage sludge or ash.

4.6 STATE AGENCIES

In addition to the role of State agencies as NRC Agreement States, States have been active regarding the issue of potential radioactive contamination at POTWs. Many States (both Agreement and non-Agreement States) regulate radioactive material, and have promulgated regulations regarding TENORM, in a manner similar to the regulations regarding man-made radioactive materials. For example, some States have established licensing and inspection requirements for users of TENORM. Other States require users of TENORM to register with the State, rather than being issued a license. To date, 13 States have approved regulations for TENORM, and several States have TENORM-related guidance, or regulations for TENORM generated in specific industries; this primarily includes the oil and gas industries and the mining industry. Other States regulate TENORM to varying degrees through their radiation control regulations without specific TENORM regulations (see Appendix E). State radiation control programs may also address the following areas:

- X-ray machines;
- Licensing of radiological technologies;
- Accelerator-produced radioactive materials;
- Source, by-product, or small amounts of special nuclear materials (if Agreement State);
- Radon awareness;
- Certification programs for radon tester or mitigators;
- Non-ionizing sources of radiation, such as radio frequency sources, lasers, and others;
- Drinking water standards for radium, radon, and others;

- Cleanup of radioactively contaminated sites;
- Monitoring around nuclear power plants;
- Emergency response to nuclear power plants and radioactive materials incidents;
- Regulation and guidance for occupational radiation health and safety protection;
- Low-level radioactive waste siting; and
- Laboratory services.

As an example, the State of New Jersey has issued, or is in the process of issuing discharge permits for water purveyors who are treating the groundwater for radium. The two that are currently in operation are ion exchange units that discharge backwash and regeneration water to POTWs. This discharge contains high concentrations of radium. Because of the size of the ion exchange units, they accumulate greater than the licensing exempt quantity for radium. Therefore, they were issued radioactive material licenses through the radiation protection program. Discharge limits for licensees were applicable and were specified in the significant industrial user permit and in the radioactive material license. Because of the uncertainty regarding radionuclides in sewage sludge, only temporary discharge permits were issued. Requirements are in place for monitoring the discharge periodically and the State has been monitoring the sludge of the receiving POTWs.

Recently there have been proposals in New Jersey for treating either the backwash/regeneration water or the drinking water with a radium selective complexor that captures the radium and holds it in the resin until it is disposed of at a low-level radioactive waste disposal facility. Estimates are that the units could operate up to three years before change out of the resin. A radioactive materials license would be required, but there would be no discharge of radium to the POTW. This method has proved to be cost effective when considering the monitoring requirements on the backwash/regeneration discharge (at least once monthly).

Other examples of State involvement in addressing radioactive contamination at POTWs include the case studies presented in Chapter 1 (i.e., Tennessee and Oregon). State radiation control programs are good contacts for the POTW operator for information about radiation control. State radiation control programs are composed of individuals who have studied radiation and have experience with that particular State's problems.

4.7 LOCAL AUTHORITIES

The role and authority of local jurisdictions, especially POTW authorities, is one of the more complex of the relationships related to POTWs and radioactive material. As noted above, significant industrial users discharging to POTWs are regulated through control mechanisms (typically permits) with specific components issued by the POTWs (or States) under Pretreatment Programs that are approved by EPA. The nature of the arrangement between the POTW and its customers will depend upon Federal, State, and local law as well as any applicable requirements in EPA's pretreatment program (40 CFR Part 403). In some cases, there are local permits issued to POTW users that would govern the circumstances of discharges to the POTWs. In other cases, the arrangements are purely contractual and the relationship between the POTW and its users (including whether users must notify the POTW before discharging radioactive material) would be a contract condition.

Through effective pretreatment and source control programs, POTWs have had considerable success in reducing problems associated with industrial sources of contaminants that interfere with the performance of treatment facilities or sewage sludge quality (EPA, 1991). As a recent example, between 2000 and 2001, the City of Los Angeles Department of Public Works realized a 30% reduction of sanitary sewer overflows after requiring existing restaurants to conduct best management practices (BMPs) in existing restaurants to control the levels of fats, oils and grease (FOG) discharged and the installation of pretreatment technology (grease interceptors) in both existing and newly built restaurants. Existing restaurants that failed to implement the BMPs were also required to install the grease interceptors. The City also instituted a pipe-cleaning program to identify and clean problem areas, and increased its inspections of food service establishments to reinforce the need for complying with the BMPs and technology requirements (City of Los Angeles Press Release, April 10, 2002).

However, POTWs may not have the same authority concerning radioactive material as they do for any other material in influents to the POTW. This is because the U.S. Supreme Court has held that for certain activities covered by the AEA, Federal authority preempts other regulatory authorities whose purpose is radiation protection. See *Pacific Gas & Electric Co. v. State Energy Conservation Commission*, 461 U.S. 190, 209–212 (1983).

In order to determine the true purpose of a regulation, courts will examine the legislative text, history, and the effect of the regulation. See *Perez v. Campbell*, 402 U.S. 637, 651-52 (1971). If the purpose of a State or local government regulation is the protection of workers and the public from the health and safety hazards of materials covered by the AEA, then the action is preempted. See *United States v. Kentucky Natural Resources & Environmental Protection Cabinet*, 252 F.3d 816, 823–824 (6th Cir. 2001); 10 CFR 8.4. If the purpose is something other than protection against radiation safety hazards, State and local authorities might be able to impose limits on radioactive effluent discharges. However, the Court in *English v. General Electric*, 496 U.S. 72, 84-85 (1990) held that State laws which have a direct and substantial effect on the decisions made by nuclear facility operators regarding radiological safety levels may be preempted regardless of their purpose.

Because preemption case law employs several subtly different tests that can only be meaningfully applied to concrete facts, development of general guidance on the issue is difficult. For example, see *Kerr McGee Chemical Corp. v. City of West Chicago*, 914 F.2d 820, 825-827 (7th Cir. 1990) (outlining preemption principles applied by various courts in AEA cases). It is hard to predict whether unusual cost to the POTW caused by radioactive effluent discharges would be a sufficient reason to impose discharge limits greater than those permitted under Federal law because there are no Federal cases in which: (1) the specific facts corresponded to the scenarios faced by local POTW authorities and (2) the court decision addressed the preemption issue.

Local POTW authorities should also be aware of two relatively recent court cases which have addressed issues of local authority on radiation matters, but which do not provide definitive answers. In Cleveland, Ohio, a discharger of radioactive materials was unable to obtain a restraining order to prevent local authorities from terminating sewer service based on the radioactive materials in its wastewater. The POTW's actions were supported by restraining orders from both Federal and State courts, but a settlement of the overall case precluded either Federal and State court from reaching a final opinion. Therefore, there remains some uncertainty in this case.

In Santa Fe, New Mexico, a discharger has obtained a summary judgment in Federal Court, which prevented local authorities from regulating environmental matters generally, including radioactive discharges. However, this decision was based on interpretation of New Mexico statutes. The Court held that while State law authorizes local governments to construct and operate sewage treatment plants, the regulation of environmental matters generally has not been delegated to local authorities and may only be exercised at the State level. *Interstate Nuclear Services Corp. v. City of Santa Fe*, 179 F. Supp.2d 1253,1259 (D.N.M. 2000).

5 WHAT CAN A POTW OPERATOR DO TO DETERMINE IF THERE IS RADIOACTIVE CONTAMINATION? WHO CAN HELP?

Although POTWs may not be the primary regulatory authority, there are several sequential steps, listed below, that a POTW may consider if they have concerns regarding radioactivity. It is also likely that the cost for each succeeding step will be more than the cost of the preceding step. The steps include the following:

- Determine what radioactive materials may be discharged into or otherwise enter the wastewater collection and treatment system.
- Determine if monitoring or sampling for radioactive material and radon at the POTW should be performed.
- Determine how a POTW operator can sample and analyze sewage sludge and ash for radioactive material, test and monitor for radon.
- Estimate potential doses from radioactive material in sewage sludge and ash through screening calculations, and compare with existing standards or guidance.
- Conduct a site-specific evaluation that may involve additional surveys or sampling of the POTW, POTW personnel, and/or use or disposal sites.

The first three steps are discussed in Sections 5.1 through 5.3 below. The last two steps are discussed in Sections 6.1 and 6.2.

In taking the steps described in Chapter 5 or 6, the POTW authority may want to consider employing a consultant when evaluating the potential for a radioactive contamination problem. Part of the POTW's consideration will depend upon available resources and experience of the authority's own personnel, as well as the initial findings regarding the number and complexity of the sources of radioactive material in the service area. Assistance and advice are available to the POTW authority from the appropriate State Radiation Control Program, the Conference of Radiation Control Program Directors, the NRC Regional Office, and the EPA Regional Radiation Program. Information regarding these programs and offices, including contact information, is provided in Appendices B, C, D, and E.

5.1 DETERMINE WHAT RADIOACTIVE MATERIALS MAY BE DISCHARGED INTO OR OTHERWISE ENTER THE WASTEWATER COLLECTION AND TREATMENT SYSTEM

The POTW operator should identify the source(s) of radioactive materials that enter the wastewater system. As described in Chapter 3, the sources of potential contamination may be from naturally occurring and/or man-made materials. The ISCORS survey indicated that the most common sources are likely to be naturally occurring and medical radionuclides (ISCORS 2003). Appendix L contains an analysis of the results of the ISCORS survey, which may provide valuable perspective on which types of radioactive material are possible sources in any POTW.

To determine if information is available regarding the potential presence of NORM and TENORM in the service area, the POTW operator should contact the State Radiation Control Agency (see Appendix E). EPA regional radiation program managers (see Appendix D) may also be able to assist in this question.

To determine potential sources of man-made radioactive materials, the POTW operator should identify facilities in the service area that are licensed to use radioactive materials. A list of licensees, obtained from the appropriate regulatory agency, should be used to determine likely sources. If the POTW is in an Agreement State, the State can provide a list of the licensees and the material(s) they are licensed to use. If the POTW is not in an Agreement State, the POTW can check with the NRC (e.g., the NRC Regional Office) to identify the licensees that are located in their service area. If the POTW services any Federal government facilities, it will also be necessary to contact the NRC Regional Office, even in an Agreement State. These facilities cannot be licensed by the State and are always under NRC purview. For example, Army, Navy, and Air Force facilities are licensed by the NRC.[5] In all States, the POTW should contact the State radiation control program office for information regarding non-AEA man-made radioactive materials (i.e., accelerator produced material, NARM). If there is a DOE facility in the service area, the POTW should contact the DOE facility directly to determine if there may be a potential for the discharge of radioactive materials to the sanitary sewer.

Information on what radioactive material is authorized for use is as important as identifying the user. For instance, if a wastewater discharger only uses a “sealed source”, it is unlikely the facility would discharge radioactive material in the sewer system. In the case of licensed materials, this information can be requested from the licensee or from the NRC or Agreement State; for NORM and TENORM, the facility would need to be contacted directly. After the likely sources of radioactive materials have been identified, the facility should be contacted to determine if any continuous or accidental releases may have occurred.

5.2 DETERMINE IF MONITORING OR SAMPLING FOR RADIOACTIVE MATERIAL AT THE POTW SHOULD BE PERFORMED

In Section 5.1 above, a number of suggested steps were provided for a POTW to follow in learning what available information may exist on radioactive materials entering into or being discharged into the sanitary sewer system. Following are some criteria that may be useful in determining if it is appropriate to sample test the POTW facility for radon, or to sample the sewage sludge or ash for radionuclide content:

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[5] Additional information for Navy and Air Force facilities may be obtained from the corresponding Service Coordinating Committee. The Navy Committee can be contacted directly at 703/602-2582 and the Air Force Committee can be contacted directly at 210/536-3331.

The POTW facility is located in an area with elevated levels of uranium and radium occurrence in soils, bedrock or ground water (see Figure 3.1, Figure 3.3, or Figure 3.4). Naturally occurring radioactive materials may enter the POTW with wastewater discharges, air or water infiltration, or stormwater runoff into the collection system. Most importantly, check with your State Drinking Water or Radiation Control Program to determine if NORM is present in the ground water.

There are drinking water treatment plants that may discharge residuals into the sewer system from treatment of source water to comply with EPA drinking water MCLs for radium and uranium, or for alpha and beta emitting radionuclides. The current standards are: combined radium-226/228, 5 pCi/L; total uranium, 30 μg/L; a combined standard of 4 mrem/yr for beta emitters; and a gross alpha standard of 15 pCi/L, not including radon and uranium (see 40 CFR Part 141).

There are industrial facilities in the POTW service area for the following industries which discharge significant quantities of untreated process wastewater into the sewer system: ceramics, electronics, minerals or metal fabrication (any one of aluminum, copper, gold, silver, phosphate, potassium, vanadium, zinc, zirconium, tin, rare earths, molybdenum, titanium, depleted uranium, radium), paper and pulp, metal foundry and engine manufacture, munitions and armament manufacturing; luminous watch and clock manufacture, cement or concrete, optics, electric lighting, gypsum board manufacture, welding, paint and pigment, or fertilizer manufacture. What percentage of total discharge to the system is provided by these facilities? All of these industries have been associated with the use of TENORM materials or production of TENORM wastes.

There are NRC or Agreement State licensees or DOE or DoD facilities in the service area that discharge to the sewer system in the following categories: medical, medical laboratory, research and development, college or university, nuclear laundries, decommissioning facilities for byproduct material facilities, UF_6 production plants, hot cell operations, uranium enrichment plants, or uranium fuel fabrication plants. There are State licensed accelerators that may discharge to the sewer system. There are facilities which discharge landfill leachate or Superfund site discharges in the service area. It is important to know how many such licensees and other sources there are and how much they discharge to the system annually. What percentage of total discharges of radioactive material to the system is provided by these facilities?

While there have been few studies conducted to evaluate the volumes and movement of radionuclides throughout the sewage system and their accumulation and occurrence in sewage sludge or ash, a POTW can make some qualitative judgments about whether monitoring or surveying is prudent based on an informed analysis of dischargers to the system.

- If there are no occurrences of any of the possible sources listed above in the system, the likelihood of finding contamination by radioactive materials in the sewage sludge and ash is low, but is still remotely possible. Sampling or monitoring would not likely be warranted.
- If either criterion 1 or 2 applies, the possibility does exist that NORM or TENORM could be elevated, and the sewage sludge or ash and indoor radon may merit sampling. If there are

poorly ventilated indoor areas of the POTW where sewage sludge or ash materials are stored, or where radon gas can infiltrate, there may be a concern for accumulation of radon and exposure to workers. Therefore, testing of the air for radon may be appropriate.

- If industries listed in criterion 3 are present in the service area, the possibility exists that NORM or TENORM could occur in the sewage sludge and ash, and warrant radionuclide sampling of the POTW sludge and ash, and monitoring of the air in poorly ventilated indoor areas of the POTW for radon.
- If criterion 4 applies, (i.e., there are either multiple licensees in the service area, or the licensees and other sources contribute a significant fraction—more than a few percent—of the wastewater in the sewer system), it may be appropriate to periodically sample and test the sewage sludge and ash for the presence of radionuclides, particularly those that are man-made. Since the volume of wastewater discharged from a licensee may or may not be indicative of the amount of radionuclides discharged during the year, it may also be appropriate to review licensee discharge records as a better indicator of the type and quantity of radioactive materials that enter the system.
- If any of criteria 1, 2, or 3 applies and criterion 4 also applies, the likelihood exists for the occurrence of NORM, TENORM, and man-made radionuclides in the sewage sludge or ash, and it may be appropriate to sample the sewage sludge or ash, or to monitor indoor air for radon. (It should be noted that there may be other sources causing the accumulation of radon gas in the POTW, other than the sewage sludge and ash.)

Further information on identifying and dealing with new industrial sources, radioactive contaminants, and individual facilities is provided in a guidance document developed by the National Biosolids Partnership (NBP 1999).

The results of the ISCORS survey and associated dose modeling (see Section 4.4) may be helpful to POTWs when deciding whether they should sample.

5.3 HOW CAN A POTW OPERATOR SAMPLE AND ANALYZE SEWAGE SLUDGE AND ASH OR MONITOR FOR RADON?

If it is found that sampling of sewage sludge and ash should be conducted (either because of detected contamination or undetected radioactive materials are believed to be present), a carefully planned program should be executed. An initial gamma scan and gross alpha and gross beta determination may be useful as an inexpensive screening tool for further analysis. A gamma spectrometer is used to estimate gamma-emitting radionuclide concentrations. Gamma spectrometry can discriminate among various radionuclides on the basis of characteristic gamma and X-ray energies to provide a nuclide-specific measurement. Gross alpha or gross beta activity analyses are used to screen samples to determine the need for nuclide-specific analyses. Further assessments may require analyses for specific radioactive materials. It should be noted that the ISCORS survey consisted of a single sample taken at each of the participating POTWs. If a POTW operator determines that sludge sampling is warranted, based on the criteria in Section 5.2, it may be prudent to obtain analyses on more than one sample, to reduce the likelihood of unrepresentative results.

If the POTW operator determines that either NORM/TENORM or other AEA radioactive material could be present in the sewage sludge or ash, various analyses could be considered to confirm the presence or absence of these materials. Where NORM/TENORM is suspected, a gross alpha and beta screen can be performed. If gross alpha and/or gross beta results are 5 pCi/g or greater, radiochemical analyses should be performed for radium-226 and radium-228. Gamma spectroscopy should also be performed to determine the presence of other nuclides, including the daughter nuclides of radium-226 and radium-228. It should be noted that the gamma spectroscopy results for radium-226 will differ from the radiochemical results. The radiochemical results are more accurate for radium-226 and radium-228 and should be used to determine dose as explained in Chapter 6. If AEA material is suspected, gamma spectroscopy should be performed to identify the presence of specific gamma-emitting radionuclides. All analyses should be performed on a dry weight basis. In addition, in order to account for isotopes that do not have significant gamma contributions, samples should be held for 21 days or more to allow ingrowth of the short-lived gamma-emitting progeny. Because thorium is likely not in equilibrium with its progeny because of differences in solubility between the different elements, alpha spectroscopy is more appropriate if a discharge is suspected.

Most States have radon offices and their personnel may be able to provide some assistance as to previous measurements in the county where POTWs are located, means and methods for conducting radon surveys at the POTW or at land application sites, and lists of licensed or certified radon contractors who could conduct surveys. Private radon proficiency programs can also provide lists of certified radon professionals working in the area. Information on these professionals can be found at: http://www.epa.gov/radon/iaq/proficiency.html.

The quickest way to test for radon is with short-term tests. Short-term tests take place at a site for 2 days–90 days, depending on the device or devices utilized. Some detectors that could be used include “charcoal canisters,” “alpha track,” “electret ion chamber,” “continuous monitors,” and “charcoal liquid scintillation detectors.” Because radon levels tend to vary from day to day and season to season, a short-term test is less likely than a long-term test to yield the year-round average radon level. If results are needed quickly, however, an initial short-term test followed by a second short-term test can be used to decide whether levels of radon at the POTW require remediation. Long-term tests remain at a site for more than 90 days. “Alpha track” and “electret” detectors are commonly used for this type of testing. A long-term test provides a reading that is more likely to yield the year-round average radon level than a short-term test.

The EPA guidance, *POTW Sludge Sampling and Analysis Guidance Document* (1989), provides information on conducting sampling and analysis of sludge.[6] Additional information on collecting sewage sludge and ash samples can be found in the Quality Assurance Program Plan used in the ISCORS Survey (ISCORS 2003). Information on how to collect samples, what containers to put them in, how to preserve them, and other sampling steps, should be worked out in consultation with the selected analysis vendor. Also, some analyses require specific time

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6 The EPA guidance document can be obtained from the Education Resource Information Center (ERIC number W134) by calling (800) 276-0462 or the National Technical Information Center (NTIS number PB93-227957) at (800) 553-NTIS.

periods for counting radionuclide decay emissions or collecting radon or other decay products. These time periods may vary with the radionuclides being tested and can take several days or weeks to complete.

A radiochemical laboratory should be selected before sampling so that the laboratory may be consulted on the analytical methodology and sampling protocol. A list is maintained by the Conference of Radiation Control Program Directors (CRCPD) of laboratories that provide radiological analysis of diverse materials, have quality assurance and quality control programs, and will perform work for government and private firms. Appendix J lists those laboratories from the December 2002 CRCPD list that have indicated they perform analyses of sludge samples, and provides some direction on evaluating radiochemical laboratories. Individual States may have specific requirements for laboratory certification.

Box 5.1 Typical Analysis Costs

Costs for analysis will depend on the type of analyses that are requested. The more detailed or complicated the analysis, the more expensive and time demanding the analysis becomes. Gamma spectroscopy analysis for one sample could cost a few hundred dollars, gross alpha/beta analysis may cost a few hundred dollars and costs for radiochemical analysis for alpha and beta emitters may range from several hundred to over one thousand dollars, depending on the radionuclides analyzed. For evaluations of radon, simple short-term measurements of radon in air can be relatively inexpensive and easy to collect.

A POTW operator who elects to conduct a laboratory radionuclide analysis of a facility's sewage sludge and ash can use the information to determine whether any further sampling is needed, or whether an unacceptable exposure condition may exist that could be addressed by changes in management practices. Data on specific radionuclide levels can be evaluated by using the screening calculations provided in Chapter 6. These screening calculations allow a rough estimation of possible radiation dose. However, it is very important to contact a radiation protection specialist for assistance in evaluating the results of preliminary sampling and analysis and the screening calculations before conducting a more extensive sampling or monitoring program, or before changing existing management practices.

If there is any concern by the POTW operator regarding potential radiological contamination of buildings or facilities where sewage sludge or ash is land applied or disposed in a landfill, there may be a need to conduct an appropriate radiological survey, as discussed in Section 6.2.

6 HOW CAN A POTW OPERATOR INTERPRET LEVELS OF RADIOACTIVITY DETECTED IN THE PLANT?

Once data is collected on levels of radioactive materials in the sewage sludge or ash, in the indoor air of the POTW, or in soils or other areas where sludge had been previously managed, it is necessary to evaluate the quantitative results to determine whether they are at a level of concern, and whether any follow-up action is needed to assure protection of workers and the general public. This evaluation can be performed in various ways, depending on the type of sampling or monitoring data obtained and the levels of specific radionuclides. The following sections provide instruction on performing simple screening calculations, based on the dose modeling results reported by ISCORS. Performing these calculations provides important perspective on the need for any further actions, including routine monitoring or changes to current sludge management practices.

Conservatively calculated reference unit dose concentrations for specific radionuclides are provided in Table 6.2 for assessing potential exposure to workers at the POTW, and in Table 6.5 for assessing potential exposures at a land application site. In addition to assessing potential radiation dose, the values in these tables can be used to determine whether any further actions are warranted. Based on the ISCORS analysis of typical sludge management practices (ISCORS 2003b), if the concentration of individual radionuclides in sewage sludge or ash is less than or equal to the concentrations in these tables, there is reasonable confidence that potential doses are insignificant (i.e., below 1 mrem/year). However, it must be noted that the values in these tables were developed for the purpose of providing a screening tool, and should not be used to evaluate actual exposures or to estimate actual doses without additional site-specific analyses. The recommended screening process is contained in Sections 6.1.2 and 6.1.3. The screening table concentrations are based on an effective dose equivalent of 1 mrem/year per source or practice, which is the Negligible Individual Dose determined by the National Council on Radiation Protection and Measurements (NCRP 1993) and is consistent with the consensus standard from the American National Standards Institute/Health Physics Society (ANSI N13.12-1999) for control of solid materials.

ISCORS believes that if the annual dose from all radionuclides detected in a sewage sludge or ash sample, estimated through procedures provided in this Chapter, is 10 mrem or less, no further steps are warranted. Where the estimated annual dose from all radionuclides exceeds 10 mrem, ISCORS recommends that the POTW operator consult with the State radiation protection regulatory agency (see Appendix E). This conservative estimated dose (i.e., 10 mrem/year) should not be considered a radiation exposure limit. Instead, it is provided solely as a recommendation for when the POTW operator should seek further consultation. It is not to be interpreted as a requirement for taking other actions. The 10 mrem/year criterion is not a limit, does not include radon, and is not intended to suggest that higher dose levels are unacceptable. In general, ISCORS believes that the screening process described in this section will identify and address any potential radiological exposures associated with sewage sludge or ash management practices, and will provide a guideline for determining whether further actions are needed to ensure public and worker health and safety.

The basis for the values used in the screening tables presented in this chapter is the ISCORS Dose Modeling Assessment (ISCORS 2003b). Conservatism is built into these values by use of the 95th percentile dose-to-source ratios. Therefore, estimates of annual doses based on these Screening tables are more likely to overestimate actual exposures than to underestimate them. Nevertheless, because it is possible that the dose could be greater, ISCORS recommends that a POTW operator should consult with the appropriate State authorities if estimated annual doses exceed 10 mrem.

6.1 ESTIMATE POTENTIAL DOSES FROM RADIOACTIVE MATERIAL IN SEWAGE SLUDGE AND ASH THROUGH SCREENING CALCULATIONS

This section describes how to estimate potential doses from radioactive material in sewage sludge and ash, where some preliminary sampling data are available, using several simple screening calculations. These calculations are based on the exposure scenarios described in the ISCORS Dose Modeling Report (ISCORS, 2003b), and were used in developing the dose estimates in Chapter 3 (Table 3.6). The screening calculations are divided into two parts: estimates of radiation exposure (primarily to workers in the POTW) from POTW operations (Section 6.1.1) and estimates of radiation exposure (primarily to the public) from the use or disposal of sewage sludge or ash outside the POTW (Section 6.1.2). In each case, doses are calculated for all significant radionuclides detected in the sludge, excluding the radon pathway. Radon concentrations are calculated separately. Examples of these screening calculations are provided in Appendix K.

The estimated doses derived from use of these screening calculations are considered to be very conservative. Doses at a specific POTW should be evaluated by using realistic, site-specific values and parameters.

6.1.1 Compare Estimated Doses to Existing Standards

Standards and guidance for radiation protection of the public, of workers, and of the environment, developed by regulatory agencies and national and international organizations, are listed in Table 6.1 as background information. These standards, however, are generally not directly applicable to situations involving sewage sludge or ash management. The relevance of any of these standards and guidance depends on a number of factors, including the laws and regulations that directly apply to the POTW. Determining which standards or guidance should be used to compare to doses from screening calculations requires consultation with appropriate State or Federal regulatory agencies (see Appendices C, D, and E). The specific authority of each regulatory agency is discussed in Chapter 4.

Table 6.1 What are the Existing Standards for Protection of Human Health from Exposure to Hazards Such as Ionizing Radiation and Radioactivity?

Standard or Guideline (Year)	Type	Limit
Indoor Air Radon in Homes and Schools (*A Citizen's Guide to Radon* (2004 and 2002), and *Radon Measurements in Schools*–Revised Edition (2002))	EPA guidance	4 pCi/L or 0.02 Working Levels
Radiation Protection Guidance to Federal Agencies for Occupational Exposure (1987) [1]	Final guidance	As low as reasonably achievable (ALARA) and not to exceed 5 rem in any year by an adult radiation worker. Also includes guidance to not exceed 0.5 rem to an unborn worker's child or not exceed one-tenth of the adult value for individuals under eighteen years old
Occupational Radiation Protection (1987) (Workers not covered by other regulations) [1]	Regulation (29 CFR 910.1096)	5 rem/yr whole body dose
Occupational Radiation Protection (1993) (DOE workers) [1]	Regulation (10 CFR Part 835)	5 rem/yr total effective dose equivalent
Occupational Dose Limits for Adults (1991) (Applies to NRC and Agreement State Licencees) [1]	Regulation (10 CFR Part 20.1201)	5 rem/yr total effective dose equivalent
Drinking Water Maximum Contaminant Levels (MCLs) (1976 and 2000)	Regulation (40 CFR 141)	Gross Alpha – 15 pCi/L Beta/photon emitters – 4 mrem/yr Radium (226 & 228) – 5 pCi/L Tritium – 20,000 pCi/L Strontium-90 – 8 pCi/L Uranium – 30 µg/liter
Nuclear Regulatory Commission Public exposure limit, from single licensed operation (1991)	Regulation (10 CFR 20.1301)	100 mrem/year
Radiation Protection of the Public and the Environment (1990)	DOE Order (DOE 5400.5)	100 mrem/year total effective dose equivalent
Radioactive Waste Management (1993)	DOE Order (DOE 435.1)	25 mrem/year – All pathways, except air 10 mrem/year – Air pathway
NRC Radiological Criteria for License Termination (Decommissioning) for Unrestricted Use (1997)	Regulation (10 CFR 20.1402)	25 mrem/year and ALARA
State Decommissioning Criteria	Various regulations or guidance	Background – 100 mrem/year
National Emission Standards for Hazardous Air Pollutants; Radionuclides	Regulation (40 CFR 61 Subparts H and I)	10 mrem/year

1 Occupational Exposure refers to radiation workers. Radiation workers are personnel that have been trained in radiation protection practices and are monitored for exposure to radiation. POTW workers are not radiation workers and these standards do not apply to them.

6.1.2 Estimating POTW Worker Radiation Dose

The steps for estimating radiation dose for POTW workers, considering the case where POTW workers are exposed to a large quantity of sewage sludge in a confined area, such as in a storage or loading room are provided below. If radon monitoring has not been performed, but data are available on levels of Ra-226 and Th-228 in the sewage sludge or ash, then use Step 3 of Screening Calculation A (Box 6.1, also see Appendix K) can be used to provide conservative estimates of radon concentrations. *These conservative estimated doses were developed for screening purposes only. Estimates of potential doses for specific POTWs would require modeling of individual site-specific characteristics.*

Box 6.1 Screening Calculation A: POTW Workers

Purpose: To estimate doses and radon concentrations for POTW Workers in a loading or storage room.

Calculation Procedure:

1. Select Radionuclides for which the sludge sample concentration is greater than the "POTW Screening Concentration" in column 3 of Table 6.2.
2. Multiply the sample concentrations for the selected radionuclides by the dose-to-source ratios (DSRs) in column 2 of Table 6.2, and add them together to get the total dose from non-radon pathways.
3. In cases where radon measurements have not been taken, the sample concentrations for Ra-226 and Th-228 can be multiplied by the radon conversion factors in Table 6.3 to obtain the radon concentrations in Working levels or pCi/liter. The values in Table 6.3 should be used if no specific information is available regarding the air exchange rate and room height for the loading or storage room. If specific information on air exchange rate and room height is available, the values from Table 6.4 may be used. The calculated concentrations can then be compared with EPA guidelines described in Section 6.1.4.

Notes:

- The sample concentration of Th-227 is a surrogate for Ac-227.
- Screening calculation assumes a worker spends most of his/her time in a room that contains a large quantity of sludge, either for storage or for loading.
- Screening calculation for radon makes conservative assumptions about room size, ventilation, etc. An alternative calculation, presented in Appendix K, can be used to make adjustments for site-specific room characteristics.
- If radon concentrations (above 4.0 pCi/L or 0.02 WL) are calculated, consult Section 6.1.4 for EPA recommendations on radon monitoring.

Table 6.2 Reference Values for Screening Calculation for Non-Radon Pathways for Screening Calculation A

Radionuclide	POTW Loading DSR (mrem/y per pCi/g)	POTW Screening Concentration(pCi/g)
Ac-227	4.05E-01	2.5
Am-241	2.35E-02	43
Be-7	1.23E-02	82
C-14	5.60E-07	1.8E+06
Ce-141	1.25E-02	80
Co-57	1.92E-02	52.
Co-60	7.00E-01	1.4
Cr-51	7.40E-03	140
Cs-134	4.07E-01	2.5
Cs-137	1.46E-01	6.8
Eu-154	3.32E-01	3.0
Fe-59	3.31E-01	3.0
H-3	1.33E-03	750
I-125	6.00E-04	1700
I-131	9.20E-02	11
In-111	8.05E-02	12
K-40	4.53E-02	22.
La-138	3.46E-01	2.9
Np-237	2.89E-02	35
Pa-231	8.05E-02	12
Pb-210	1.33E-03	750
Po-210	4.35E-04	2300
Pu-238	1.80E-02	56
Pu-239	2.38E-02	42
Ra-226	4.84E-01	2.1
Ra-228	2.59E-01	3.9
Sm-153	5.80E-03	170
Sr-89	3.95E-04	2500
Sr-90	1.05E-03	960
Th-228	4.55E-01	2.2
Th-230	1.68E-02	60
Th-232	8.35E-02	12
Tl-201	1.01E-02	99
Tl-202	1.05E-01	9.5
U-233	7.55E-03	130
U-234	6.15E-03	160
U-235	3.68E-02	27
U-238	1.13E-02	88
Zn-65	1.60E-01	6.2

Table 6.3 Indoor Radon Working Levels and pCi/Liter Concentration per Unit Sludge Concentration for Screening Calculation A

Radionuclide (Daughter)	POTW Loading	
	WL	pCi/L
Ra-226 (Rn-222)	5.0E-04	3.2E-01
Th-228 (Rn-220)	2.0E-02	1.1E+01
NOTE: Default values to be used if information is not available on the room height and air exchange rate.		

Table 6.4 Indoor Radon Working levels and pCi/Liter Concentration per Unit (pCi/g) Sludge Concentration for Screening Calculation A

Air exchange rate (per hour)	Room height (m)	Ra-226		Th-228	
		WL	pCi/L	WL	pCi/L
1.5	2	5.0E-4	0.32	2.0E-2	11
	4	2.5E-4	0.15	1.0E-2	4.7
	6	1.7E-4	0.097	6.8E-3	2.9
3	2	1.6E-4	0.14	1.0E-2	9.0
	4	8.2E-5	0.069	5.0E-3	4.1
	6	5.5E-5	0.045	3.3E-3	2.6
5	2	6.9E-5	0.082	5.9E-3	8.0
	4	3.5E-5	0.041	2.9E-3	3.8
	6	2.3E-5	0.026	1.9E-3	2.5
NOTE: This table may be used when information is available to describe the air exchange rate and the room height for the loading or storage room. The combination of air exchange rate and room height should be matched as well as can be. If the match is not exact, match to values of air exchange and room height that are smaller than the actual values.					

6.1.3 Estimating Radiation Dose Due to Use or Disposal of Sewage Sludge and Ash

The calculations for radiation dose from use or disposal of sewage sludge and ash are presented in a two-tiered format. Screening Calculation B (Box 6.1, also see Appendix K) is an upper-bound estimate. If Screening Calculation B is not appropriate, then Screening Calculation C (Box 6.3, also see Appendix K), which provides a scenario-specific evaluation, should be used. *These conservative estimated doses were developed for screening purposes only. Estimates of potential doses for specific POTWs would require modeling of individual site-specific characteristics.*

Box 6.2 Screening Calculation B: Non-POTW Upper-Bound

Purpose: To obtain an upper bound on the reasonably likely radiation doses that may be experienced by individuals outside the POTW.

Calculation Procedure:

1. Select the radionuclides for which the sludge sample concentration is greater than the "Screening concentration" in column 3 of Table 6.5.
2. Multiply the sample concentrations for the selected radionuclides by the DSRs in column 2 of Table 6.5, and add them together to get the total dose from non-radon pathways.
3. Divide the Ra-226 sample concentration in pCi/g by 57 to obtain the pCi/liter indoor Rn-222 concentration, or by 8,300 to obtain the indoor Working Levels.

Notes:

- The sample concentration of Th-227 is a surrogate for Ac-227.
- If radon concentrations above 4 pCi/L or 0.02 WL are calculated, consult Section 6.1.4 for EPA recommendations on radon monitoring.
- Screening calculation assumes that land application occurs for a maximum of 20 years. If additional years of land application are anticipated, use Screening Calculation C (Box 6.3).
- If doses from ash are to be evaluated, then Screening Calculation C (Box 6.3) should be used.

Table 6.5 Reference Values for Screening Calculations B and C

Radionuclide	Max DSR (land application 20 yr) (mrem/y per pCi/g)	Screening Concentration (pCi/g)
Ac-227	1.18E+01	0.08
Am-241	7.99E-01	1.25
Be-7	4.04E-05	2.48E+04
C-14	4.84E-01	2.07
Ce-141	2.60E-05	3.85E+04
Co-57	6.60E-04	1.51E+03
Co-60	2.59E-01	3.86
Cr-51	1.27E-05	7.87E+04
Cs-134	6.52E-02	15.3
Cs-137	2.08E-01	4.81
Eu-154	1.80E-01	5.56
Fe-59	8.81E-04	1.14E+03
H-3	1.55E-04	6.46E+03
I-125	6.99E-02	14.3
I-131	1.31E-02	76.3
In-111	2.73E-05	3.66E+04
K-40	2.84E-02	35.2
La-138	6.57E-02	15.2
Pb-210	2.93E-01	3.41
Pu-238	7.04E-01	1.42
Pu-239	7.74E-01	1.29
Ra-226 *	9.82E-01	1.02
Ra-228	4.12E-01	2.43
Sm-153	1.78E-06	5.62E+05
Sr-89	4.70E-05	2.13E+04
Sr-90	3.59E-01	2.79
Th-228	5.23E-01	1.91
Th-230	1.25E+00	0.80
Th-232	2.97E+00	0.34
Tl-201	3.28E-06	3.05E+05
Tl-202	8.03E-05	1.25E+04
U-234	2.37E-01	4.22
U-235	2.22E-01	4.50
U-238	2.12E-01	4.72
Zn-65	1.13E-02	88.3

* Ra-226 DSR excludes the radon pathway.

Box 6.3 Screening Calculation C: Non-POTW Scenarios

Purpose: To estimate radiation doses under different exposure scenarios outside the POTW.

Calculation Procedure:

1. Select the radionuclides for which the sludge sample concentration is greater than the "Screening Concentration" in column 3 of Table 6.5.
2. Select the exposure scenarios that are to be evaluated. The scenarios, organized by sludge management practices, are:

    Agricultural Application B

    Note: consideration should be given to both the number of *past* applications as well as potential *future* applications.

        Onsite Resident (Table 6.6)

        Nearby Town (Table 6.6)

        Sludge Application Worker (Table 6.7)

    Land Application for Reclamation

        Recreational User (Table 6.8)

    Landfill

        Municipal Solid Waste Landfill Neighbor (Table 6.8)

        Impoundment Neighbor (Table 6.8)

    Incineration

        Incinerator Neighbor (Table 6.8)

3. For each scenario selected, multiply the sample concentrations for the selected radionuclides by the DSRs from the appropriate table, and add them together to get the total dose from non-radon pathways.
4. If appropriate, multiply the sample concentrations by the radon conversion factors in Table 6.9 or 6.10 to obtain the radon concentrations in working levels (WL) or pCi/liter, respectively.

Notes:

Step 1 is optional. The alternative is to select *all* the radionuclides for which there are both sample measurements and calculated DSRs.

The sample concentration of Th-227 is a surrogate for Ac-227.

Table 6.6 Agricultural Application Non-Radon DSR (mrem/y per pCi/g) Values for Screening Calculation C

Radio-nuclide	Onsite Resident (years of application)					Nearby Town (years of application)				
	1	5	20	50	100	1	5	20	50	100
Ac-227	1.03E-02	4.80E-02	1.53E-01	2.53E-01	3.02E-01	5.94E-05	2.78E-04	8.84E-04	1.49E-03	1.78E-03
Am-241	1.43E-03	7.09E-03	2.79E-02	6.72E-02	1.27E-01	4.22E-06	2.10E-05	8.25E-05	1.99E-04	3.75E-04
Be-7	1.40E-06	1.41E-06	1.41E-06	1.41E-06	1.41E-06	6.43E-12	8.73E-12	8.73E-12	8.73E-12	8.73E-12
C-14	2.42E-02	1.21E-01	4.84E-01	1.21E+00	2.41E+00	5.22E-07	5.22E-07	5.22E-07	5.22E-07	5.22E-07
Ce-141	4.91E-08	4.91E-08	4.91E-08	4.91E-08	4.91E-08	7.12E-11	7.19E-11	7.19E-11	7.19E-11	7.19E-11
Co-57	4.03E-04	6.54E-04	6.60E-04	6.60E-04	6.60E-04	2.98E-10	8.18E-10	8.45E-10	8.45E-10	8.45E-10
Co-60	3.54E-02	1.37E-01	2.59E-01	2.77E-01	2.77E-01	1.36E-08	6.68E-08	2.08E-07	2.62E-07	2.64E-07
Cr-51	5.58E-09	5.58E-09	5.58E-09	5.58E-09	5.58E-09	1.80E-11	1.86E-11	1.86E-11	1.86E-11	1.86E-11
Cs-134	1.88E-02	5.31E-02	6.52E-02	6.52E-02	6.52E-02	2.84E-08	1.04E-07	1.49E-07	1.49E-07	1.49E-07
Cs-137	1.31E-02	6.25E-02	2.08E-01	3.74E-01	4.77E-01	4.28E-08	2.14E-07	8.46E-07	1.99E-06	3.27E-06
Eu-154	1.74E-02	7.44E-02	1.80E-01	2.20E-01	2.26E-01	7.50E-09	3.72E-08	1.35E-07	2.27E-07	2.46E-07
Fe-59	1.16E-05	1.16E-05	1.16E-05	1.16E-05	1.16E-05	7.44E-10	7.97E-10	7.97E-10	7.97E-10	7.97E-10
H-3	1.20E-05	5.41E-05	1.55E-04	1.69E-04	1.69E-04	5.32E-07	5.32E-07	5.32E-07	5.32E-07	5.32E-07
I-125	7.06E-06	7.13E-06	7.13E-06	7.13E-06	7.13E-06	1.55E-08	1.62E-08	1.62E-08	1.62E-08	1.62E-08
I-131	4.81E-18	4.81E-18	4.81E-18	4.81E-18	4.81E-18	2.12E-08	2.13E-08	2.13E-08	2.13E-08	2.13E-08
In-111	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.54E-11	4.55E-11	4.55E-11	4.55E-11	4.55E-11
K-40	1.88E-03	6.38E-03	9.51E-03	9.65E-03	9.65E-03	4.94E-10	2.40E-09	7.32E-09	9.30E-09	9.41E-09
La-138	1.41E-02	4.61E-02	6.57E-02	6.64E-02	6.64E-02	2.69E-08	1.06E-07	2.21E-07	2.45E-07	2.46E-07
Pb-210	1.91E-02	9.23E-02	2.98E-01	5.06E-01	6.09E-01	4.04E-07	1.95E-06	6.41E-06	1.11E-05	1.37E-05
Pu-238	1.22E-03	5.98E-03	2.24E-02	4.91E-02	8.01E-02	3.62E-06	1.78E-05	6.65E-05	1.46E-04	2.39E-04
Pu-239	1.35E-03	6.72E-03	2.66E-02	6.53E-02	1.26E-01	3.95E-06	1.97E-05	7.80E-05	1.91E-04	3.71E-04
Ra-226	4.91E-02	2.46E-01	9.82E-01	2.45E+00	4.83E+00	1.19E-04	5.94E-04	2.36E-03	5.85E-03	1.15E-02
Ra-228	3.55E-02	1.71E-01	4.12E-01	4.62E-01	4.62E-01	1.96E-04	9.44E-04	2.46E-03	2.80E-03	2.81E-03
Sm-153	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.39E-11	7.39E-11	7.39E-11	7.39E-11	7.39E-11
Sr-89	2.64E-06	2.66E-06	2.66E-06	2.66E-06	2.66E-06	5.70E-10	5.87E-10	5.87E-10	5.87E-10	5.87E-10
Sr-90	3.04E-02	1.35E-01	3.59E-01	4.81E-01	5.04E-01	5.76E-08	2.87E-07	1.10E-06	2.16E-06	2.64E-06
Th-228	1.49E-02	4.11E-02	4.90E-02	4.90E-02	4.90E-02	3.41E-04	9.40E-04	1.12E-03	1.12E-03	1.12E-03
Th-230	6.25E-02	3.13E-01	1.26E+00	3.16E+00	6.44E+00	4.30E-05	2.15E-04	8.56E-04	2.12E-03	4.19E-03
Th-232	5.28E-02	2.64E-01	1.06E+00	2.63E+00	5.25E+00	3.51E-04	1.75E-03	7.02E-03	1.75E-02	3.49E-02
Tl-201	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.49E-11	4.49E-11	4.49E-11	4.49E-11	4.49E-11
Tl-202	3.45E-13	3.45E-13	3.45E-13	3.45E-13	3.45E-13	2.19E-10	2.22E-10	2.22E-10	2.22E-10	2.22E-10
U-234	1.01E-03	4.96E-03	1.85E-02	4.03E-02	6.55E-02	1.15E-06	5.64E-06	2.10E-05	4.58E-05	7.42E-05
U-235	2.50E-03	1.23E-02	4.58E-02	9.99E-02	1.62E-01	1.19E-06	5.84E-06	2.19E-05	4.83E-05	8.05E-05
U-238	9.90E-04	4.86E-03	1.81E-02	3.94E-02	6.35E-02	1.04E-06	5.10E-06	1.90E-05	4.14E-05	6.69E-05
Zn-65	7.33E-03	1.13E-02	1.13E-02	1.13E-02	1.13E-02	5.64E-09	1.37E-08	1.40E-08	1.40E-08	1.40E-08

Table 6.7 Sludge Application Worker Non-Radon DSR Values (mrem/y per pCi/g) for Screening Calculation C

Radionuclide	Sludge Application Worker (years of application)				
	1	5	20	50	100
Ac-227	7.62E-03	3.57E-02	1.13E-01	1.89E-01	2.24E-01
Am-241	4.42E-04	2.20E-03	8.64E-03	2.08E-02	3.92E-02
Be-7	4.00E-05	4.04E-05	4.04E-05	4.04E-05	4.04E-05
C-14	1.71E-07	1.71E-07	1.71E-07	1.71E-07	1.71E-07
Ce-141	2.60E-05	2.60E-05	2.60E-05	2.60E-05	2.60E-05
Co-57	2.05E-04	3.34E-04	3.36E-04	3.36E-04	3.36E-04
Co-60	9.87E-03	3.83E-02	7.22E-02	7.72E-02	7.72E-02
Cr-51	1.27E-05	1.27E-05	1.27E-05	1.27E-05	1.27E-05
Cs-134	5.35E-03	1.52E-02	1.86E-02	1.86E-02	1.86E-02
Cs-137	2.25E-03	1.07E-02	3.56E-02	6.39E-02	8.15E-02
Eu-154	4.73E-03	2.03E-02	4.90E-02	6.02E-02	6.13E-02
Fe-59	8.81E-04	8.81E-04	8.81E-04	8.81E-04	8.81E-04
H-3	3.36E-07	3.36E-07	3.36E-07	3.36E-07	3.36E-07
I-125	2.05E-07	2.07E-07	2.07E-07	2.07E-07	2.07E-07
I-131	4.90E-05	4.90E-05	4.90E-05	4.90E-05	4.90E-05
In-111	2.73E-05	2.73E-05	2.73E-05	2.73E-05	2.73E-05
K-40	6.51E-04	2.21E-03	3.29E-03	3.34E-03	3.34E-03
La-138	5.08E-03	1.67E-02	2.37E-02	2.39E-02	2.39E-02
Pb-210	2.34E-05	1.23E-04	4.04E-04	6.88E-04	8.30E-04
Pu-238	3.75E-04	1.84E-03	6.88E-03	1.51E-02	2.46E-02
Pu-239	4.16E-04	2.08E-03	8.22E-03	2.01E-02	3.90E-02
Ra-226	7.41E-03	3.70E-02	1.47E-01	3.64E-01	7.14E-01
Ra-228	6.74E-03	4.21E-02	1.12E-01	1.27E-01	1.27E-01
Sm-153	1.78E-06	1.78E-06	1.78E-06	1.78E-06	1.78E-06
Sr-89	1.15E-06	1.16E-06	1.16E-06	1.16E-06	1.16E-06
Sr-90	1.67E-05	7.40E-05	1.97E-04	2.64E-04	2.76E-04
Th-228	6.23E-03	1.71E-02	2.05E-02	2.05E-02	2.05E-02
Th-230	2.63E-03	1.39E-02	6.75E-02	2.26E-01	6.40E-01
Th-232	1.25E-02	1.76E-01	2.04E+00	7.26E+00	1.61E+01
Tl-201	3.28E-06	3.28E-06	3.28E-06	3.28E-06	3.28E-06
Tl-202	8.03E-05	8.03E-05	8.03E-05	8.03E-05	8.03E-05
U-234	1.23E-04	6.03E-04	2.24E-03	4.89E-03	7.91E-03
U-235	6.08E-04	2.98E-03	1.11E-02	2.42E-02	3.92E-02
U-238	1.94E-04	9.51E-04	3.54E-03	7.70E-03	1.24E-02
Zn-65	1.52E-03	2.34E-03	2.36E-03	2.36E-03	2.36E-03

Table 6.8 Land Reclamation, Landfill, and Incinerator Scenario DSR Values (mrem/y per pCi/g) for Screening Calculation C

Radionuclide	Recreational User	MSW Landfill	Landfill Impoundment	Incinerator Neighbor
Ac-227	2.35E-03	4.77E-11	2.48E-09	1.18E+01
Am-241	1.82E-04	3.72E-05	1.90E-03	7.99E-01
Be-7	4.58E-05	0.00E+00	0.00E+00	1.09E-06
C-14	9.76E-02	4.81E-05	6.02E-03	3.99E-07
Ce-141	3.33E-05	0.00E+00	0.00E+00	3.02E-06
Co-57	2.76E-04	0.00E+00	0.00E+00	1.02E-04
Co-60	1.10E-02	2.95E-30	1.68E-28	7.97E-03
Cr-51	1.49E-05	0.00E+00	0.00E+00	8.78E-07
Cs-134	6.41E-03	0.00E+00	0.00E+00	6.69E-03
Cs-137	2.86E-03	2.76E-10	1.39E-08	1.43E-02
Eu-154	5.36E-03	2.70E-22	1.42E-20	4.34E-03
Fe-59	9.67E-04	0.00E+00	0.00E+00	3.54E-04
H-3	4.51E-06	3.01E-07	1.66E-05	3.17E-06
I-125	3.33E-05	0.00E+00	0.00E+00	6.99E-02
I-131	6.23E-05	0.00E+00	0.00E+00	1.31E-02
In-111	3.30E-05	0.00E+00	0.00E+00	2.42E-07
K-40	7.17E-04	9.19E-06	4.26E-04	4.81E-04
La-138	5.60E-03	7.72E-04	4.45E-02	1.06E-02
Pb-210	8.28E-04	2.54E-10	1.52E-08	4.74E-02
Pu-238	1.29E-04	5.10E-07	2.52E-06	7.04E-01
Pu-239	1.45E-04	5.58E-05	2.37E-03	7.74E-01
Ra-226	8.72E-03	1.95E-03	8.88E-02	8.80E-02
Ra-228	7.37E-03	5.93E-27	3.24E-25	2.53E-02
Sm-153	2.77E-06	0.00E+00	0.00E+00	2.03E-07
Sr-89	1.51E-05	0.00E+00	0.00E+00	4.70E-05
Sr-90	1.45E-03	3.06E-11	1.58E-09	3.86E-02
Th-228	6.51E-03	0.00E+00	0.00E+00	5.23E-01
Th-230	3.05E-03	8.95E-04	4.32E-02	5.85E-01
Th-232	1.24E-02	7.93E-03	4.06E-01	2.97E+00
Tl-201	5.01E-06	0.00E+00	0.00E+00	2.31E-07
Tl-202	9.54E-05	0.00E+00	0.00E+00	4.74E-06
U-234	1.34E-03	7.32E-06	3.41E-04	2.37E-01
U-235	2.15E-03	8.23E-06	3.36E-04	2.22E-01
U-238	1.23E-03	3.71E-06	1.38E-04	2.12E-01
Zn-65	2.35E-03	0.00E+00	0.00E+00	2.28E-03

Table 6.9 Indoor Radon Working Level Concentration per Unit Sludge Concentration for Screening Calculation C (WL per pCi/g)

Radionuclide	Onsite Resident (Years of Application)					MSW Landfill	Landfill Impoundment
	1	5	20	50	100		
Ra-226	6.01E-06	3.00E-05	1.20E-04	2.99E-04	5.91E-04	1.48E-07	7.57E-06
Th-228	3.36E-07	9.27E-07	1.11E-06	1.11E-06	1.11E-06	–	–
Th-230	–	–	–	–	–	6.25E-08	3.32E-06
Th-232	–	–	–	–	–	6.47E-07	3.33E-05
U-234	–	–	–	–	–	3.15E-10	1.68E-08

Table 6.10 Indoor Radon Concentrations per Unit Sludge Concentration for Screening Calculation C (pCi/L per pCi/g)

Radionuclide (Daughter)	Onsite Resident (Years of Application)					MSW Landfill	Landfill Impoundment
	1	5	20	50	100		
Ra-226 (Rn-222)	8.72E-04	4.36E-03	1.74E-02	4.34E-02	8.57E-02	1.93E-05	9.85E-04
Th-228 (Rn-220)	1.45E-05	4.00E-05	4.77E-05	4.77E-05	4.77E-05	–	–
Th-230 (Rn-222)	–	–	–	–	–	8.14E-06	4.32E-04
Th-232 (Rn-220)	–	–	–	–	–	3.64E-06	1.87E-04
U-234 (Rn-222)	–	–	–	–	–	4.11E-08	2.19E-06

6.1.4 Interpretation of Measured Radon in Air

EPA has recommended that when homes or schools are tested for the presence of radon gas, action be taken to reduce radon concentration levels if test results average 4 pCi/liter (or 0.02 working levels (WL)) or greater (EPA, 1994, EPA 2002, and EPA 2004). EPA recommends, by this present publication, that the same action level used for homes and schools should be utilized for POTWs. While exposure to radon in homes or schools is evaluated differently than occupational exposure, many nations and the ICRP (1993) also recommend that intervention levels for exposure to radon in homes be utilized in workplaces (National Research Council 1999). Methods used for radon detection were discussed previously in Section 5.3.

As discussed in Chapter 5, the operators of certain POTWs may want to determine whether there are radon levels in air in enclosed areas in the plant that present elevated exposure to workers, due to the applicability of various criteria identified in Section 5.2 (e.g., location of the POTW in an area with high levels of naturally-occurring radioactive material). To assess the potential for excessive levels of radon exposure, the POTW operator should follow EPA recommendations for testing and evaluating radon levels in homes and schools. These recommendations may be summarized as follows:

Step 1: Take an initial short-term test.
If initial levels are at 4 pCi/liter or higher, perform Step 2.

Step 2: Take a short-term follow-up test where initial test results were 4 pCi/liter or higher.
Take a long-term test in these locations for a better understanding of the annual average indoor radon level.

Step 3: Appropriate Follow-up Action.
Take action to reduce levels if the average of the initial and short-term follow-up testing is 4 pCi/liter or greater, or the result of the long-term test is 4 pCi/liter or greater. Chapter 7 contains recommendations for appropriate actions to reduce levels of radon in the plant.

6.2 RECOMMENDATIONS ON EVALUATING ESTIMATED DOSES DERIVED FROM SCREENING CALCULATIONS

Where preliminary radionuclide sampling or monitoring data has been obtained, the POTW operator should use the information contained in this guidance to determine what, if any, additional steps or actions are warranted. Potential doses should be estimated from the screening calculations described in the previous section. These screening calculations are based on the overall results of the ISCORS survey and dose modeling, and as a result, produce generally conservative estimates of actual doses. Therefore, it is recommended that no further action by the POTW operator is warranted where estimated doses are below 10 mrem/year. At estimated doses above 10 mrem/year, the POTW operator should consult with the appropriate State radiation protection regulatory agency (see Appendix E), and request guidance on whether any next steps are necessary. The 10 mrem/year criterion is not a limit, does not include radon, and is not intended to suggest that higher dose levels are unacceptable.

Consultation with the State agency may result in one of several recommendations, such as the following, depending on the results of the screening calculation and on current sewage sludge or ash management practices:

- No additional steps need be taken.
- Additional sewage sludge or ash samples are needed.
- Additional indoor radon monitoring is needed.
- A site-specific evaluation or a monitoring program is needed (see Section 6.3).
- Another agency should be contacted for further guidance.[7]
- A professional radiation protection specialist or a health physicist should be contacted for assistance in designing a monitoring program or evaluating existing management practices.
- Possible changes in management practices that would reduce exposures should be evaluated.

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[7] The EPA may be consulted on NORM and TENORM sources, concentrations, or dose estimates. If the estimated annual dose is 25 mrem or more, based on concentrations of Source and By-Product material only, the NRC should be consulted.

6.3 CONDUCT A SITE-SPECIFIC EVALUATION THAT MAY INVOLVE ADDITIONAL SURVEYS OR SAMPLING OF THE POTW, POTW PERSONNEL, AND/OR USE OR DISPOSAL SITES.

If screening calculations suggest that potential doses to workers (within the POTW or those who handle sewage sludge or ash outside of the POTW) may be above the acceptable radiation dose level (as determined after consultation with the State agency), the POTW operator may want to conduct a more thorough evaluation of the levels detected in the sludge, ash, or indoor air, based on site-specific conditions. This evaluation may involve additional sampling or monitoring, use of modeling scenarios developed for the ISCORS dose modeling project and substitution of actual site-specific input data, creation of more directly applicable modeling scenarios than those used in the ISCORS dose modeling project, or actual physical surveys of potentially affected areas of the POTW or other sludge management locations. Results of the surveys of sludge management locations should be reported to the State radiation control program to determine the appropriate standards for comparison.

6.3.1 Evaluate Any Potential External Radiation Exposure of Collection System Workers or POTW Personnel

There may be a potential for external radiation exposure (i.e., from outside the body, rather than from ingestion or inhalation) to collection system workers and POTW personnel if elevated levels of gamma-emitting radionuclides are discharged into the wastewater system (more information regarding the various types of radionuclides is provided in Appendix A). If there is the potential for such discharges, the POTW should consider such an evaluation. This evaluation may be conducted using two methods: (1) use a radiation survey meter to identify any points at which such contamination exists, and (2) use an integrating radiation measuring device to determine if any exposures could occur over time. It is advisable to hire a health physics consultant to assist in the selection of appropriate survey methods and instruments.

In planning and conducting a radiological survey at a POTW, the following guidelines should be considered:

- Direct measurement can be conducted with an instrument using a sodium iodide detector tube or a very sensitive Geiger Muller detection device. The instrument should be able to detect gamma radiation in the micro-roentgen per hour range.
- In taking measurements along the collection system, it is best to focus on system junctions and bends that are immediately downstream from the wastewater generator of concern. These are points that allow the accumulation of radioactive material. Prior to taking collection system measurements, it is important to create a baseline of the background radiation levels; a background measurement should be taken in the general vicinity of the system before taking measurements in the collection system itself. If possible, these background measurements should be taken upstream of the discharger over grassy areas. Table 3.4 provides typical ranges of radioactive material concentrations found in U.S. soils and common items such as fertilizers and building materials, as well as the range of radioactive material concentrations detected during the pilot survey of sludges and ash from

nine POTWs. This table is taken from Appendix B of the pilot survey report (NRC and EPA 1999) and the ISCORS Survey Report (ISCORS 2002).

- If there is reason to believe that collection system workers may be exposed to elevated levels, then appropriate monitoring of the collection system may be necessary. Monitoring down manholes in the collection system may result in highly variable measurements. These variations may be a few times the background levels and may result from the construction materials used in the manhole. Marked variations may be observed between concrete and brick, or even among different concrete or brick materials. These variations are largely due to the natural radioactive materials in the construction materials. If elevated values are found, further investigation may be warranted. Consultation with the radiation regulatory authority is recommended. More detailed information on this issue may be found in the National Biosolids Partnership guidance (NBP 1999).
- At the POTW, direct radiation measurements should be taken at locations where solid materials accumulate, including grit chambers and points of sludge collection. If incineration of sludge is performed, the residual ash should also be measured. Background measurements should be made away from the sludge collection point. Some variability in measurements can be expected. These measurements are necessary to compare levels in sewage sludge and ash samples.
- To identify changes over time, POTW operators may also want to employ an integrating measurement device that accumulates radiation exposure over time. It is also possible to periodically conduct follow-up surveys using direct radiation measurements; however, integrating measurement devices are more effective for time analyses.
- Although there are expensive self-recording types of devices available, it may be more cost effective to use some thermoluminescent dosimeters (TLD). These devices are crystal structures that store the energy imparted by incident radiation so that it can be subsequently measured to evaluate the exposure received. The selection of the particular TLD to use should be made after consultation with the vendor, including a discussion of the particular use intended.
- The locations selected for placing the TLDs should be determined carefully, in a manner similar to the location selection process for the direct radiation measurements. Several of the TLDs should be placed in an area removed from sludge processing (e.g., an office desk, cabinet) to serve as a background measurement. The TLD devices used for system measurements can be hung down manholes or over areas where sludge is collected, or over conveyer belts where sludge is transported. The TLDs should be left in place for a period of a few weeks to a month and then returned to the vendor for evaluation.

A source of useful information on such surveys is a Federal consensus document, *Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM)*. This manual may provide useful information on planning and conducting a survey involving potential contamination of surface soils and building surfaces. This manual, prepared specifically for site surveys involving radiological contaminants, contains useful information on sampling procedures, field measurement methods and instrumentation, quality assurance and quality control procedures and interpretation of results. This information was developed as a consensus approach by four Federal agencies (EPA, DOE, NRC, and DOD) to determine whether dose or risk-based release criteria for buildings and soils have been met. In the context of a POTW survey for radiological contaminants, the methods and procedures contained in this manual should be generally applicable. The MARSSIM document and related informational tools can be obtained from the EPA's Office of Radiation website (http://www.epa.gov/radiation/marssim/).

As previously noted, the POTW operator should consult a qualified health physicist for assistance in designing a sampling and analysis program.

6.3.2 Evaluate Any Potential External Radiation Exposure of Sludge Management Workers or the General Public

In addition to evaluating the potential for exposures to POTW workers from exposure to radioactive materials where sewage sludge and ash is managed within the plant, the POTW operator may also need to evaluate potential exposures to other workers who handle or manage sewage sludge and ash outside of the plant or to members of the public. If a thorough survey of sludge accumulation points at the POTW indicates that potential exposures are below levels of concern, there is a reduced probability that radionuclide levels in soils at land application sites will be elevated. Also, if the screening calculations performed in Section 6.1 are below the 10 mrem/year consultation level, then there is a reduced probability that radionuclide levels in soils at a disposal or land application site will be elevated. However, materials placed in these sites in the past may have resulted in a buildup of radioactive material that would not have been detected otherwise.

A survey of land application sites where sludge has been disposed is a prudent step if there is reason to believe that elevated levels of radioactive materials may have been discharged to the system. Measurement of radiation levels in these areas can be made with the same instrument used for the collection and treatment systems. Background levels should be measured in areas without sewage sludge or ash for comparison purposes. Some variation in background levels should be expected due to local soil conditions. If levels significantly above background are found, it is suggested that the appropriate radiation control authority be consulted.

In cases where the POTW operator or a contractor uses or disposes of sewage sludge or ash, the following factors may be considered to decide whether to perform measurements at the use or disposal sites:

- Indications that radioactive materials had been discharged to the treatment system and had entered the POTW.
- The liability arrangements between the POTW and the contractor.
- The adequacy of available records on past sewage sludge/ash applications.
- The frequency and amount of sewage sludge/ash applications to each site.
- The results of the screening calculations of Section 6.1.

If the results of the screening calculations are above the 10 mrem/year consultation level, but the gamma survey results are negative, the POTW operator should consider taking soil samples at the land application site, after consultation with appropriate Federal and State authorities.

6.3.3 How to Evaluate Any Potential Radiation Exposure within the POTW

Following the steps described above, any significant occurrence of radioactive materials at a collection system or within the POTW should have been detected. If there is a determination of potential significant exposure from the direct radiation measurements, a determination of the source of the radioactive material should be made. Such a determination would also be necessary to identify the possibility of ingestion or inhalation of radioactive material during wastewater collection and treatment, or sewage sludge and ash use or disposal practices. In these cases, it may be necessary to take physical samples of the sewage sludge, ash, or other residual material and have this material analyzed at a laboratory with the capability for such an assessment. Other cases where sampling and analysis may be required are circumstances where the source of the radioactive material is not detectable by the methods previously described. These would be instances where the radiation emitted was only alpha or weak beta radiation. Such radioactive materials include some man-made elements that are heavier than uranium, and more common radioactive materials, such as hydrogen-3 (tritium) and carbon-14.

7 WHAT CAN BE DONE TO REDUCE RADIATION DOSES AND RADON LEVELS?

As discussed in Section 6.2, POTW operators should determine the appropriate course of action to reduce radiation doses and radon levels through consultation with radiation regulatory authorities and health specialists, if estimated doses exceed 10 mrem/year. Actions may include reducing levels of radioactivity at the source or reducing exposure to sludge. In rare cases, corrective actions may be needed for contaminated equipment or disposal sites.

7.1 CONTACT REGULATORY AGENCIES FOR ASSISTANCE

If estimated radiation doses or radon concentrations are above recommended levels (i.e., 10 mrem/year for non-radon exposures or 4.0 pCi/liter for radon), the POTW operator should consult with State radiation regulatory agencies (see Appendix E). Based on the initial contact with the State, the POTW operator may also need to contact the NRC regional office or the EPA regional office Radiation Program Manager (see Appendices C and D, respectively). These regulatory agencies are valuable sources of information on radiation and radiation protection and may assist the POTW operator in addressing the situation and in communicating with the public. They can also help identify possible sources of the radionuclides, assist in establishing an appropriate course of action, and take enforcement actions if needed to correct the situation.

The regulatory agency may determine that the levels are not sufficiently elevated to cause concern for worker or public health and safety. In that case, no additional action by the POTW would be needed to protect workers. However, the POTW operator should convey the regulator's findings to the POTW workers so that they know there is no cause for concern. A letter or other documentation from the regulator would be useful in communicating with workers that the levels do not pose a concern.

7.2 CONTROLLING SOURCES OF RADIONUCLIDES ENTERING THE POTW

POTW operators, in consultation with the regulatory agencies, should determine what can be done to control sources of radionuclides entering the POTW. Each situation will be unique and the appropriate actions will vary from no additional action to regulatory enforcement. The approach taken will be affected by the answers to several questions that the POTW operator and the regulator may explore.

1. Where did the radionuclides come from? Consultation with the regulatory agency could identify whether the radionuclides are naturally-occurring, TENORM, or man-made. (See Section 3.1 for a description of these types of sources.) For man-made sources, the presence of specific radionuclides could help regulators determine if a licensee is the source.
2. How did the radionuclides get to the POTW? As discussed in Section 3.2, radionuclides may reach the sewers and POTW in several ways. For example, radionuclides may enter the POTW via discharges, POTW treatment processes, or infiltration and inflow. To determine

the location of discharges that may cause contamination, the POTW operator may need to take samples from the sewers leading from the sources. The necessity of sampling should be discussed with the NRC or State contact prior to initiation. Based on this information, the POTW operator should be able to determine the source(s) of any radioactive materials that may enter the POTW.

3. How often are radionuclides expected to reach the POTW? Knowing the timing of releases enables POTW operators to plan for their arrival. For example, some users of radioactive materials are allowed to continuously or intermittently release small amounts of radionuclides to the sewer system. Accidental discharges may only occur once or infrequently. Naturally occurring radionuclides may reach the POTW continuously or periodically following precipitation events that increase infiltration and inflow.
4. Who is responsible for controlling the sources of the radionuclides? Regulatory agencies are responsible for setting license conditions and limits to protect human health. Licensees are responsible for operating or handling their materials in accordance with regulations and their license conditions. Landowners may be responsible for controlling erosion that carries natural sources into the sewer system through inflow. POTW operators are responsible for maintaining an effective infiltration and inflow program, which could reduce the potential for natural sources to reach the POTW.
5. Are the appropriate controls in place to minimize releases of radionuclides to the POTW? The POTW operator may want to evaluate the effectiveness of the controls used by the discharger to minimize releases of radionuclides. The POTW operator may need to consult with the regulatory agency to review the regulations and license conditions imposed on a discharger, or their implementation by the discharger. The POTW operator should review infiltration and inflow controls if that is the source.

The POTW operator can work with the regulator to decide on appropriate actions to prevent reoccurrences. The following include examples of these actions:

- Consult directly with likely industrial dischargers who may be routinely discharging radioactive material to the sewer system, to explore the possibility of voluntary reductions in such discharges.
- Encourage use of spill prevention measures to reduce the potential for accidental releases.
- Impose appropriate additional local controls on the discharger, such as local discharge limits and regular reporting of discharges.
- Require notification of planned or accidental discharges, or request that notification from the source facilities when future releases occur. Notification would enable the POTW to monitor the condition at the POTW and take measures to protect workers if necessary. POTW operators may lack the authority to require notification, but could request it as a voluntary measure by the user and consult with the Local Emergency Planning Committee (LEPC) and State Emergency Response Committee (SERC).
- Request that regulators take enforcement action against dischargers who violate license conditions and contribute to the elevated levels.

- Provide regulators with information on interferences in operating practices created by the dischargers. This information may be useful for the regulator in deciding whether to modify the release limits.
- Correct infiltration and inflow problems that transport naturally-occurring radionuclides to the POTW especially pressure driven radon gas.

If the release was a one-time accident and future releases are unlikely, action to prevent reoccurrence may not be needed.

7.3 REDUCING EXPOSURE TO RADIOACTIVITY FROM SLUDGE

When there are elevated levels of radioactivity, the most important concern for the POTW should be the protection of the workers and the public.

7.3.1 Reducing Exposure at the POTW

If consultations with the regulatory agency indicate there may be a concern regarding exposure to the POTW workers, the POTW may need to obtain the services of a qualified consultant, such as a health physicist, to evaluate the radiation levels at the plant and disposal sites. The consultant can recommend appropriate protective measures that are commensurate with the radiation hazards to keep exposure levels as low as reasonably achievable. These measures may include: increasing the distance between workers and the radiation source(s); increasing the shielding between the source(s) and the workers; increasing ventilation rates in areas where radium and radon may be present; provide appropriate equipment and health and safety training to potentially affected workers; and limiting the amount of time workers spend near units with elevated levels of radioactive materials.

As mentioned earlier, OSHA occupational radiation standards (see 29 CFR 1910.1096) might apply whenever an operator becomes aware of the presence of radiation at the facility. Although these standards may not apply to municipal wastewater treatment plant workers, workers could be covered by their State OSHA program, requiring that all controls, monitoring, recordkeeping, and training outlined in the OSHA standards be met.

Many of the measures that protect workers from radiation hazards are the same as those used at POTWs to protect against pathogens. State health or occupational safety agencies, or OSHA safety and health regulations and guidances for radiation exposures may be available or applicable. Personal hygiene practices such as washing hands before eating, drinking, or smoking prevents ingestion of radionuclides as well as pathogens. Similarly, the use of personal protection equipment (or PPE, for the eyes, face, head, and extremities) such as protective clothing , respiratory devices, and protective shields and barriers should be provided, if elevated levels of radiation warrant, in dusty sewage sludge and ash handling areas to reduce the potential for health risks from inhaling dust and any radionuclides associated with the dust, although such measures would not protect against radon. Restrictions to limit personnel entry, or employee time spent in areas with elevated radiation levels could also be recommended if the radiation evaluations of the facility warrant. Additional safety measures are provided in Appendix A.

Elevated levels of radon gas in indoor air, where average concentrations of Ra-222 exceed 4 pCi/liter, or total radon levels (Ra-220 and Ra-222 combined) exceed 0.02 WL, may indicate that best management practices are warranted. There are a number of actions that the POTW operator may want to consider:

1. Evaluate the possibility of increasing ventilation and air exchange.
2. It may be feasible to decrease worker time spent in confined areas where sludge is managed.
3. It may be prudent to continue monitoring indoor locations for radon where sewage sludge and ash are processed or stored.
4. The POTW operator should take into account the possibility of radon entering the building from sources other than sewage sludge or ash.

POTW operators are encouraged to consult with regulatory agency personnel or a health physics consultant for assistance in interpreting measured radon levels in the POTW.

The POTW operator may need to consult with the regulatory agency and other experts such as those certified by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers about possible ways of increasing ventilation and air exhaust for the affected location(s). States with radon certification programs may be contacted to obtain information on certified radon mitigation contractors.

If elevated levels of radioactivity have been identified, the POTW employees should be informed. The POTW employees should also be provided with factual information on the risks associated with the level of radiation exposure. Regulatory agencies or health physicists may have literature available to assist in communicating with POTW personnel, particularly if occupational radiation safety rules have been adopted by State agencies that may be applicable to municipal facilities.

7.3.2 Reducing Exposure Outside the POTW

In evaluating levels of radioactive materials in sewage sludge or ash that is managed through any type of land application process, it is possible that potential future sources of exposure may be indicated through various dose modeling scenarios. This situation may occur, for example, if the land application site is eventually converted to another type of land use, particularly one with minimal restrictions, such as residential development. Where such future exposures may be a concern, the POTW operator may want to re-evaluate existing management practices to avoid creating an unacceptable exposure scenario. Rather than continuing to apply sewage sludge or ash on an on-going basis to a dedicated land application site, the POTW operator may want to consider the following:

- Reduce the number of years of application to the same site;
- Reduce the frequency of applications to the same site;
- Increase holding times at the POTW before land application, which would allow for decay of radionuclides with relatively short half-lives;

- Divert sludge management from land application to landfill disposal or land reclamation;
- Consider other alternative sludge use or disposal practices, where land use restrictions may be more feasible and effective.

Monofills, which are landfills with trenches that are used for disposal of sewage sludge and ash only, were not specifically evaluated for radiation doses in the ISCORS dose assessment study. ISCORS believes that such a site, if it had received sewage sludge or ash for burial with elevated radiation levels, should be surveyed for radiation levels before consideration for future land transfer or sale for other uses, such as residential construction. Restrictions on transfer or future land use, and or site remediation might be required if radiation levels have been elevated.

7.4 CORRECTIVE ACTIONS FOR CONTAMINATED AREAS

In rare instances, sewage sludge and ash management may cause contamination of equipment or disposal or land application sites. If this situation occurs, the POTW operator may be responsible for removing the contamination. Consultation with the regulatory agencies (see Appendix D for contact information for EPA's Regional Offices) should be pursued to determine any requirements that may apply.

Cleanup of contaminated sites can be a costly endeavor for the POTW. Depending upon the applicable Federal and State laws, some dischargers may be liable for portions of the cleanup costs if their discharges caused the contamination. Legal counsel should be consulted as to whether any dischargers may be liable for portions of the cost.

8 COMMENTS OR QUESTIONS ON THIS REPORT

If you have any questions or comments regarding this report, please contact either NRC or EPA.

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APPENDIX A
FUNDAMENTALS OF RADIATION

What is Radiation?

Radiation is energy in the form of high speed particles and electromagnetic waves (photons) that are released from unstable atoms. Radiation with enough energy to separate molecules or remove electrons from atoms is known as ionizing radiation. Non-ionizing radiation does not have enough energy to remove electrons from their orbits. Radioactivity is the property that some unstable atoms exhibit in the process of undergoing spontaneous transformation, decay, or disintegration, which emits radiation. Materials that contain radioactive atoms are known as radioactive materials.

Radiation is in every part of our lives. It occurs naturally in the earth and can reach us through cosmic rays from outer space. Radiation may also occur naturally in the water we drink or the soils in our backyard. It even exists in food, building materials, and in our own human bodies. Radiation is used for scientific purposes, medical reasons, and power (e.g., the U.S. Navy uses radiation to power submarines through the water). People also come into contact with radiation through man-made sources such as X-rays, nuclear power plants, and smoke detectors.

The radiation of interest in this guidance is ionizing radiation. At excessive levels, the process of ionization can cause disease and injury to plants and animals. The three most common types of ionizing radiation are:

- Alpha radiation – positively charged particles that are emitted from naturally-occurring and man-made radioactive material. The alpha particle has the least ability to penetrate other materials. Most alpha particles can be stopped by a single sheet of paper or the top layer of skin. Consequently, the principal hazard from alpha emitters to humans occurs when the material is ingested or inhaled. The limited penetration of the alpha particle means that the energy of the particle is deposited within the tissue (e.g., lining of the lungs) nearest the radioactive material once inhaled or ingested. Examples of alpha emitters are radon, thorium, and uranium.
- Beta radiation – negatively charged particles (electrons) that are typically more penetrating but have less energy than alpha particles. Beta particles can penetrate human skin or sheets of paper, but can usually be stopped by thin layers of plastic, aluminum, or other materials. Carbon-14 and hydrogen-3 (or tritium) are two common beta emitters. Although they can penetrate human skin, beta particles are similar to alpha particles in that the predominant hazard to humans comes from ingesting or inhaling the radioactive materials that emit beta radiation. Other examples of beta emitters are phosphorus-32 and strontium-90. Some radioactive materials emit positively charged electrons, or positrons.
- Gamma (or X-ray) radiation – the most penetrating type of radiation. They can pass through the human body and common construction materials. Thick and dense layers of concrete, steel, or lead are used to stop gamma radiation from penetrating to areas where humans can be exposed. Gamma emitters can pose both external and internal radiation hazards to

humans. Technetium-99m is an example of a gamma emitter that is widely used in medical diagnosis. Other gamma emitters include thallium-201 and selenium-75.

Some radionuclides emit more than one type of radiation. For example, cesium-137 and iodine-131 are both gamma and beta emitters. Potassium-40, a common naturally-occurring radionuclide, is also a beta/gamma emitter. Radium-226 emits both alpha and gamma radiation.

How is Radiation Measured?

Whether it emits alpha or beta particles or gamma rays, the quantity of radioactive material is typically expressed in terms of its radioactivity or simply its activity and is measured in curies. One curie equals 37 billion atomic disintegrations per second. Activity is used to describe a material, just as one would discuss the length or weight of a material. For example, one would say "the activity of the uranium in the container is 2 curies." Generally, the higher the activity of the material, the greater the potential health hazard associated with that material if it is not properly controlled. At nuclear power reactors, the activity of radioactive material may be described in terms of hundreds to millions of curies, whereas the units typically used to describe activity in the environment and at POTWs are often microcuries (: Ci) or picocuries (pCi). A microcurie is one one-millionth (1/1,000,000) of a curie and a picocurie is one one-trillionth (1/1,000,000,000,000) of a curie.

The activity of a radionuclide decreases or decays at a constant rate. The time it takes the activity of a radioactive material to decrease by half is called the radioactive half-life. After one half-life, the remaining activity would be one-half (2) of the original activity. After two half-lives, the remaining activity would be one fourth (1/4), after three half-lives one eighth, and so on. For example, if a radionuclide has a half-life of 10 years, the amount of material remaining after 10 years would be 2 of that originally present. After 100 years (10 half-lives), the remaining activity would be 1/1024 of the amount that was originally present. Some radioactive materials have extremely short half-lives measured in terms of minutes or hours; for example, technetium-99m, used in medical procedures, has a half-life of 6 hours. Others have half-lives measured in terms of millions to billions of years; for example, naturally occurring thorium-232 has a half-life of 14 billion years, and natural uranium-238 has a half-life of 4.5 billion years. Half-lives for a number of radionuclides are shown in the following table.

Table A.1 Radionuclides Included in the ISCORS Dose Assessment (ISCORS 2003)

Radio-nuclide	Major Radiations	Half-life	Radio-nuclide	Major Radiations	Half-life
Ac-227[c]	alpha, beta, gamma	22 years	Po-210[b]	alpha	138 days
Ac-228[d]	beta, gamma	6 hours	Pu-238	alpha	88 years
Am-241	alpha, gamma	432 years	Pu-239	alpha	24×10^{3} years
Be-7[c]	gamma	53 days	Ra-223[d]	alpha, gamma	11 days
Bi-212[d]	alpha, beta, gamma	61 minutes	Ra-224[d]	alpha, gamma	4 days
Bi-214[d]	beta, gamma	20 minutes	Ra-226	alpha, gamma	1600 years
C-14	beta	5730 years	Ra-228	beta	6 years
Ce-141	beta, gamma	33 days	Rn-219[d]	alpha, gamma	4 seconds
Co-57	gamma	271 days	Sm-153[a]	beta, gamma	47 hours
Co-60	beta, gamma	5 years	Sr-89	beta	51 days
Cr-51[a]	gamma	28 days	Sr-90	beta	29 years
Cs-134	beta, gamma	2 years	Th-227[d]	alpha, gamma	19 days
Cs-137	beta, gamma	30 years	Th-228	alpha, gamma	2 years
Eu-154	beta, gamma	9 years	Th-229[b]	alpha, gamma	7,340 years
Fe-59	beta, gamma	45 days	Th-230	alpha	77×10^{3} years
H-3	beta	12 years	Th-232	alpha	14×10^{9} years
I-125	gamma	60 days	Th-234[d]	beta, gamma	24 days
I-131[a]	beta, gamma	8 days	Tl-201[a]	gamma	3 days
In-111[a]	gamma	3 days	Tl-202[a]	gamma	12 days
K-40	beta, gamma	1.3×10^{9} years	Tl-208[d]	beta, gamma	3 minutes
La-138[a]	beta, gamma	135×10^{9} years	U-233[b]	alpha	158.5×10^{3} years
Np-237[b]	alpha, gamma	2.14×10^{6} years	U-234	alpha	245×10^{3} years
Pa-231[b]	alpha, gamma	32.8×10^{3} years	U-235	alpha, gamma	700×10^{6} years
Pa-234m[d]	beta, gamma	1 minute	U-238	alpha	4.5×10^{9} years
Pb-210	beta, gamma	22 years	Xe-131m[b]	gamma	12 days
Pb-212[d]	beta, gamma	11 hours	Zn-65	beta, gamma	244 days
Pb-214[d]	beta, gamma	27 minutes			

Notes:

Information on daughters for standard RESRAD radionuclides is included in Table 3.1 of the RESRAD manual (Yu et al., 2000).

a This radionuclide is not included in standard RESRAD, and was added as input to the code specifically for this project.

b Although this nuclide was not identified in the previous survey (EPA 1999), it is included in the dose assessment because it is a principal nuclide and its parent nuclide is included in the analysis. Am-241 decays to Np-237, U-233, and Th-229; U-235 decays to Pa-231; Pb-210 decays to Po-210; and I-131 decays to Xe-131m.

c Although this nuclide was not identified in the previous survey (EPA 1999), it is included in the assessment because it is the parent nuclide and its daughter nuclides are included in the analysis. Ac-227 is the parent nuclide of Ra-223, Rn-219, and Th-227.

d Radiological dose for this radionuclide is included in the dose of its parent nuclide. The parent nuclides are Ra-228 for Ac-228; Th-228 for Bi-212, Pb-212, Ra-224, and Tl-208; Ra-226 for Bi-214 and Pb-214; U-238 for Pa-234m and Th-234; and Ac-227 for Ra-223, Rn-219, and Th-227.

Some radioactive materials decay to form other radioactive materials. These decay products, in turn, decay, eventually forming stable nuclides. Each material formed through decay has a unique set of radiological properties, such as half-life and energy given off through decay. In the case of the radioactive materials found at POTWs, the radioactive materials present may consist of one or more separate decay "chains" or "series." The naturally-occurring uranium, actinium, and thorium decay chains are illustrated in Figures A.1, A.2, and A.3.

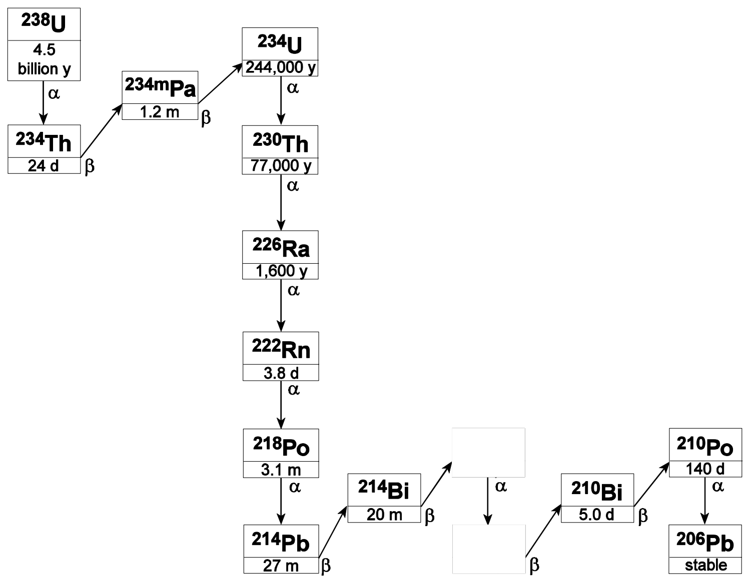

Figure A.1 Uranium (^{238}U) Decay Series

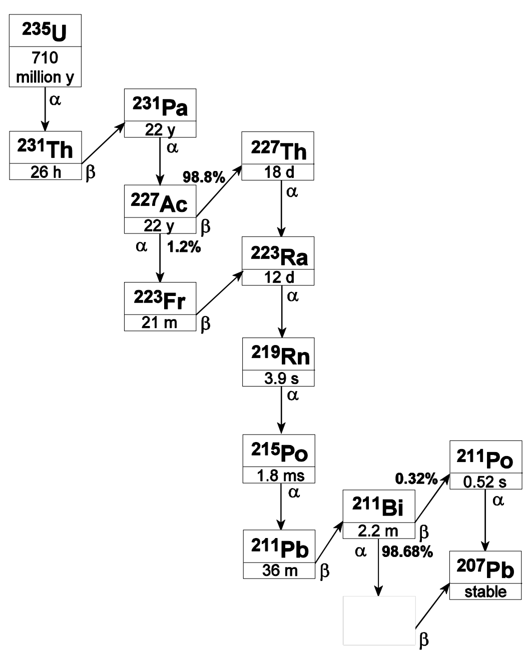

Figure A.2 Actinium (^{235}U) Decay Series

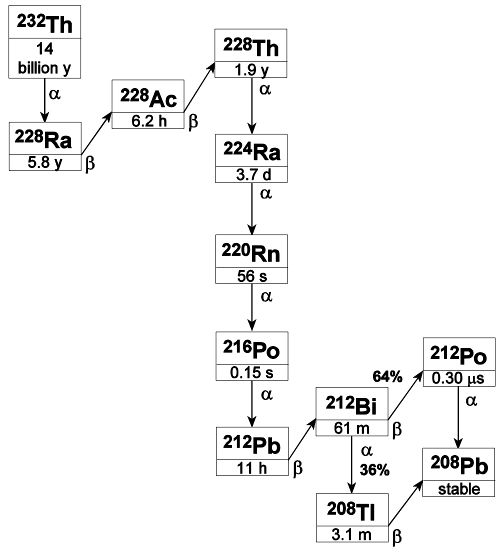

Figure A.3 Thorium (^{232}Th) Decay Series

Some of the radioactive materials in these chains emit gamma rays when they decay. The intensity of gamma radiation in air or exposure rate is measured in roentgens (R) or microroentgens (μR) per unit time, usually an hour, as in R/hr or μR/hr. In the environment, exposure rates are typically measured in terms of μR/hr. For example, in many parts of United States, the exposure rate from natural sources of radiation is between 5 and 15 μR/hr. This ambient level is referred to as the background exposure rate.

Many commercially available radiation detectors measure radiation fields in terms of μR/hr or counts per minute (cpm). Counts per minute refers to the number of radiation interaction events of ionizing particles or photons that are detected, or counted, in a minute by the detector. Only a fraction of those particles or photons that interact with the detector result in counts. The number of counts per minute can be related to exposure rate or radiation dose for a known radionuclide and established geometry for which the instrument has been calibrated.

Radiation dose is a measurement or estimate of the body's exposure to ionizing radiation. It is typically measured in units of rem. In the environment and at POTWs, doses are often measured in terms of millirem (mrem). A millirem is one one-thousandth (1/1,000) of a rem; a microrem (μrem) is one-millionth (1/1,000,000) of a rem. The dose rate is expressed in terms of dose per unit time, again usually an hour, as millirem/hr. For external radiation, exposure rates are often equated to dose rates using the conversion of 1 μR/hr = 1 μrem/hr. Doses from internal exposure to radioactive material that has been ingested or inhaled are more difficult to determine. Computer models that account for the distribution and excretion of the radioactive material within the body are used for estimating doses and dose rates from internal radioactive contamination.

What Are the Effects of Radiation Exposure?

Radiation may cause a range of effects when it interacts in, or passes through, living tissue. Human health effects begin at the cellular level. Some cells are unaffected by the radiation while others may be damaged but survive and reproduce normally. However, some damaged cells may survive in a modified form, which could potentially result in cancer. Some cells may die from the exposure to radiation.

Other health effects occur to organs and the whole body. Effects from low doses of radiation (tens of, rems) may include birth defects and genetic effects. High doses of radiation (hundreds of rems) over short periods of time may cause organ damage and, if high enough, death. Doses associated with exposures to natural background radiation or typical radioactive materials in POTWs are thousands of times lower than the high doses that cause significant biological damage.

At low doses, the principal concern associated with radiation exposure is the possible occurrence of cancer years after the exposure occurs. Other effects such as birth defects and genetic effects are not likely. For such low doses, the likelihood of producing cancer has not been directly established because it is not possible to distinguish cancers produced by such low levels of radiation from cancers that occur normally. The risk of developing cancer is usually expressed in terms of probability of an adverse health effect because a given dose of radiation does not produce a cancer in all cases.

What Can Be Done to Reduce Radiation Exposure Risks to Workers?

The following discussion applies only to systems where accumulation of radioactive material has been demonstrated by radiological health surveys.

POTW workers are most likely to be exposed to elevated levels of radioactive materials when coming into contact with sludge and process water; during maintenance of contaminated pumps or piping; or while moving or transporting sewage sludge and ash for disposal. Possible sources of radiation include pumps and piping where mineral scales accumulate; flocculation and sedimentation tanks where residual sludges accumulate; filters, pumping stations, and storage tanks where scales and sludges accumulate; and facilities where contaminated water accumulates. Facilities that are enclosed present the potential for enhanced radiation inhalation exposure, particularly from radon. Exposure to radiation can also occur at sewage sludge and ash processing or handling areas at the system and off-site locations such as landfills where residuals are shoveled, transported, or disposed of.

Table A.2 shows the three primary paths of radiation exposure at a system: inhalation, ingestion, and direct exposure.

Table A.2 Primary Pathways of Radiation Exposure at POTWs

Pathway	Concern
Inhalation	Inhalation of alpha- or beta-emitting radioactive materials is a concern because radioactive material taken into the body results in radiation doses to internal organs and tissues (e.g., lining of the lungs). Workers could inhale radioactively contaminated dust or water droplets while dealing with sewage sludge, wastewater, or ash. Cleaning methods for tanks, piping, or holding facilities such as air scour, or use of high pressure water sprays can increase suspension of radioactively contaminated water, dusts, and particulates in respirable air, thus increasing the potential hazard of inhalation or ingestion. Workers can inhale radon and its progeny in both wet and dry conditions. Simple dust masks may not provide adequate protection from exposures via this pathway, and workers should limit time spent at land disposal sites to reduce inhalation of contaminated dust.
Ingestion	Ingestion, or the swallowing of alpha, beta, or gamma-emitting radioactive materials, is a concern for the same reasons as inhalation exposure. Workers can ingest radioactive materials if they fail to observe good sanitary practices including washing their hands before eating; failing to cover their noses and mouths by wearing approved respiratory protection and swallowing contaminated dusts and water droplets; or eating and drinking in areas (including land disposal sites), where dusts or water droplets could settle on food or drink. Simple dust masks may not provide adequate protection from exposures via this pathway.
Direct Exposure	Radioactive materials that emit gamma radiation are of concern because the gamma rays pose an external radiation exposure hazard. Because gamma rays can pass through common construction materials and most protective clothing, the distance between the radioactive material and the person, as well as the time spent in proximity to the material are factors in the amount of exposure the person receives. As gamma radiation travels through air, exposure can occur near a source of radiation as well as through direct contact. Workers most likely to be directly exposed are those who handle or work in the vicinity of sludge tanks, piping, sewage sludge and ash piles, and contaminated water; work in areas of elevated indoor radon; or participate in the maintenance of the treatment system or the replacement and transportation of contaminated piping or pumps.

The Occupational Safety and Health Administration (OSHA) has developed occupational radiation standards (see 29CFR 1910.1096) that might apply whenever an operator becomes aware of the presence of radiation at the facility. Although these standards may not apply to municipal wastewater treatment plant workers, these workers may be covered by their State OSHA program, requiring that all controls, monitoring, record keeping, and training outlined in the OSHA standards be met.

Additional OSHA standards that may be applicable to wastewater systems include:

- Requirements that personal protection equipment (or PPE, for the eyes, face, be provided, used, and maintained whenever processes or radiological hazards capable of causing injury through absorption, inhalation, or physical contact necessitate such equipment. There are numerous other requirements related to the possession and use of PPE, including training for employees who would use the equipment. For more information, see 29 CFR 1910.132–136.
- Requirements for practices and procedures to protect employees in general industry from the hazards of entry into permit-required confined spaces. For more information, see 29 CFR 1910.146.

In addition to the OSHA requirements, systems should be encouraged to follow the safety practices listed below. These measures can reduce workers= risk of exposure to radioactivity and radioactive particulates:

Safety Measures

✓ Use an OSHA-approved respirator to avoid inhalation of biological pathogens and chemically toxic materials in residuals. Simple dust masks may not provide adequate protection.

✓ Limit time spent at land disposal sites to reduce inhalation of contaminated dust.

✓ Ventilate all buildings, especially where waste with high concentrations of radionuclides are stored.

✓ Take standard OSHA measures to limit the potential ingestion of heavy metals and biological pathogens present in residual sludges, ashes, and at land disposal sites to help reduce possible ingestion exposure to radioactive materials.

✓ Use protective gloves and frequently wash hands (particularly before eating, smoking, and drinking) to reduce the potential for ingestion. Similarly, avoid eating, smoking, and drinking in the vicinity of facilities or land disposal sites where air suspension of contaminated particulates or water droplets could occur.

✓ Locate treatment units and waste storage areas as far away from common areas (e.g., offices) as possible.

✓ Shower after exposure to potentially radioactive materials and launder work clothing at the system if possible. If laundering equipment is not available, workers should keep and wash work clothing separately and avoid wearing contaminated clothing into the home. Work boots or shoes should be wiped and cleaned after potential contamination. They should stay at the system or not be worn into the home.

✓ Use gamma survey instruments or equivalent monitors at least once annually to monitor the system’s ambient radiation levels in areas where radionuclides are removed.

✓ Monitor levels of radiation to which staff are exposed. Systems should contact, or be referred to, State or other radiation experts for more information on how to monitor radiation levels.

Additional Safety Considerations

Radon is a natural decay product of radium and other radionuclides. Section 6.1.4 describes procedures for interpreting measured radon in air.

If the potential for elevated levels of radionuclides or radiation has been found at the POTW in accordance with the procedures discussed in this recommendations report, having operators who are trained in treating for radionuclides, and handling, disposing of, and transporting TENORM waste, is highly recommended. Assistance and advice are available from the appropriate State Radiation Control Program (see Appendix E), the EPA Regional Radiation Programs (see Appendix D), and the NRC Regional Offices (see Appendix C).

APPENDIX B
NRC AND EPA REGIONAL OFFICES BY STATE AND IDENTIFICATION OF NRC AGREEMENT STATES

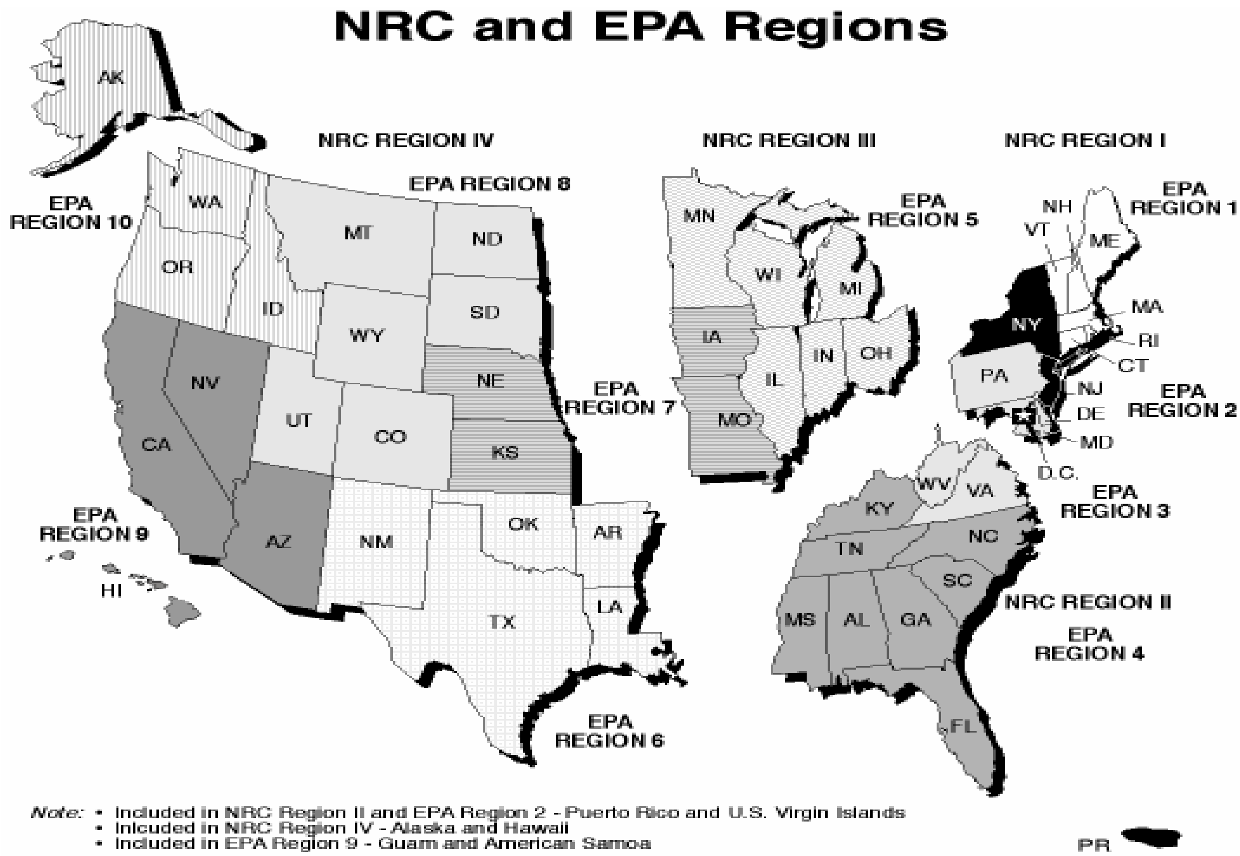

Figure B.1 Delineation of the NRC and EPA Regions.

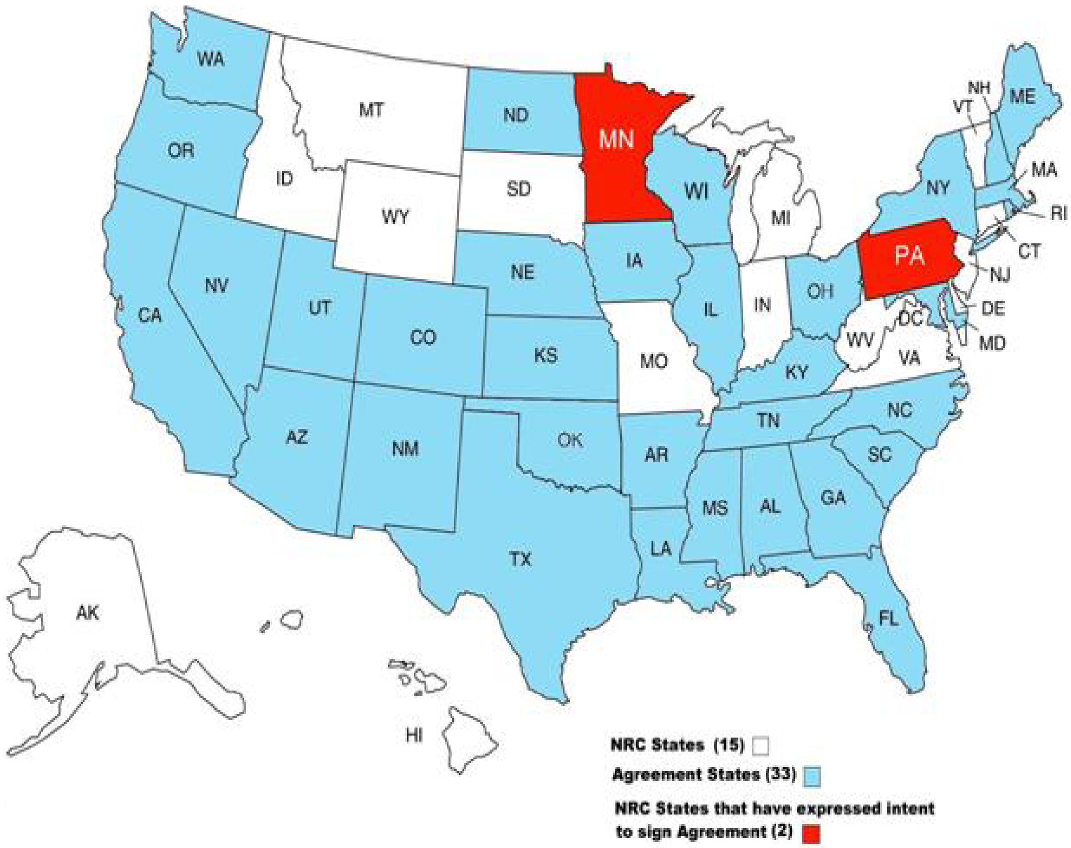

Figure B.2 Delineation of NRC Agreement States as of October 2004.

APPENDIX C
NRC REGIONAL OFFICES

Table C.1 NRC Regional Offices

Region and Address	Division of Nuclear Materials Safety	State Agreements Officer
Region I 475 Allendale Road King of Prussia, PA 19406-1415	(610) 337-5000	(610) 337-5042 (610) 337-5358
Region II Sam Nunn Atlanta Federal Center 61 Forsyth St, SW Suite 23T85 Atlanta, Ga 30303-8931	(404) 562-4400	See Region I
Region III 2443 Warrenville Road, Suite 210 Lisle, IL 60532-4352	(630) 829-9500	(630) 829-9661
Region IV Texas Health Resources Tower 611 Ryan Plaza, Suite 400 Arlington, TX 76011-4005	(817) 860-8100	(817) 860-8116 (817) 860-8143

For further information, consult the NRC website at URL:
http://www.nrc.gov/who-we-are/locations.html

APPENDIX D
EPA REGIONAL OFFICES

Table D.1 EPA Radiation Program Managers (As of 6/10/2004)

NAME/ADDRESS	PHONE NO.	FAX NO.
William White (acting) US EPA/Region 1 1 Congress Street Suite 1100 Boston, MA 02114-2023	(617) 918-1532	(617) 918-1333
Paul A. Giardina US EPA/Region 2 290 Broadway, 28th Floor New York, NY 10007-1866	(212) 637-4010	(212) 637-4942
Carol Febbo US EPA/Region 3 1650 Arch Street Philadelphia, PA 19103-2029	(215) 814-2076	(215) 814-2101
Todd Rinck US EPA/Region 4 61 Forsyth Street, SW Atlanta, GA 30303-3104	(404) 562-9062	(404) 562-9095
Jack Barnette US EPA/Region 5 (AE-17J) 77 West Jackson Boulevard Chicago, IL 60604	(312) 886-6175	(312) 886-0617
Monica Smith US EPA/Region 6 (6PD-T) 1445 Ross Avenue Dallas, Texas 75202-2733	(214) 665-6780	(214) 665-6762
Robert Dye US EPA/Region 7 (ARTD/RALI) 901 North 5th Street Kansas City, KS 66101	(913) 551-7605	(913) 551-7065
Richard Graham US EPA/Region 8 (8P-AR) 999 18th Street, Suite 500 Denver, CO 80202-2466	(303) 312-7080	(303) 312-6044

Table D.1 EPA Radiation Program Managers (As of 6/10/2004) (continued)

NAME/ADDRESS	PHONE NO.	FAX NO.
Michael S. Bandrowski US EPA/Region 9 (Air-6) 75 Hawthorne Street San Francisco, CA 94105	(415) 947-4194	(415) 744-1073
Jeff Kenknight US EPA/Region 10 1200 Sixth Avenue 10^{th} Floor Seattle, WA 98101	(206) 553-6641	(206) 553-0110

APPENDIX E
STATE AGENCIES FOR RADIATION CONTROL (AS OF OCTOBER 1, 2004)

For an up to date listing of the State radiation control contacts given below, see the Conference of Radiation Control Program Directors (CRCPD) Web site at URL: http://www.crcpd.org/ or Director of Agreement State and Non-Agreement State Directors and State Liaison Officers at the Office of State and Tribal Programs, USNRC, Web site: http://www.hsrd.ornl.gov/nrc/asframe.htm.

For a current listing of State Radon Contacts, see the CRCPD Web site at http://www.crcpd.org/radon.asp.

ALABAMA (Agreement State) Kirksey E. Whatley, Director State Department of Public Health Office of Radiation Control 201 Monroe Street, P.O. Box 303017 Montgomery, AL 36130-3017 Phone: 334/206-5391 Fax: 334/206-5387 kwhatley@adph.state.al.us http://www.adph.org/	**ALASKA** Clyde E. Pearce, Chief Section of Laboratories/State of Alaska/DH&SS Radiological Health Program 4500 Boniface Parkway Anchorage, AK 99507-1270 Phone: 907/334-2107 Fax: 907/334-2163 clyde_pearce@health.state.ak.us http://www.hss.state.ak.us/dph/labs/
ARIZONA (Agreement State) Aubrey V. Godwin, Director Arizona Radiation Regulatory Agency 4814 South 40th Street Phoenix, AZ 85040 Phone: 602/255-4845 ext. 222 Fax: 602/437-0705 agodwin@arra.state.az.us http://www.arra.state.az.us/	**ARKANSAS** (Agreement State) Jared Thompson, Program Leader Division of Radiation Control & Emergency Management Department of Health 4815 West Markham Street, Slot #30 Little Rock, AR 72205-3867 Phone: 501/661-2173 Fax: 501/661-5387 jwthompson@healthyarkansas.com

CALIFORNIA (Agreement State) Edgar D. Bailey, CHP, Chief Division of Food & Radiation Safety Radiological Health Branch California Department of Health Services P.O. Box 997414 Sacramento, CA 95899-7414 Phone: 916/440-7899 Fax: 916/440-7900 ebailey@dhs.ca.gov/rhb/ http://www.dhs.cahwnet.gov/rhb/index.htm	**COLORADO** (Agreement State) Steve Tarlton, P.E., Unit Leader Radiation Management Program Hazardous Materials and Waste Management Division Dept. of Public Health and Environment 4300 Cherry Creek Drive South Denver, CO 80230-1530 Phone: 303/692-3428 Fax: 303/759-5355 steve.tarlton@state.co.us http://www.cdphe.state.co.us/hm/rad/radiationservices.asp
CONNECTICUT Edward Wilds, Ph.D., Director Division of Radiation Department of Environmental Protection 79 Elm Street Hartford, CT 06106-5127 Phone: 860/424-3029 Fax: 860/424-4065 edward.wilds@po.state.ct.us	**DELAWARE** Frieda Fisher-Tyler, Administrator Office of Radiation Control Delaware Division of Public Health P.O. Box 637 Dover, DE 19903 Phone: 302/744-4944 Fax: 302/739-3839 frieda.fisher-tyler@state.de.us
DISTRICT OF COLUMBIA Harold Monroe, Bureau Chief Department of Health Bureau of Food, Drug, and Radiation Protection 51 N Street NE, Room 6025 Washington, DC 20002 Phone: 202/535-2188 Fax: 202/535-1359 hmonroe@dchealth.com	**FLORIDA** (Agreement State) William A. Passetti, Chief Bureau of Radiation Control Florida Department of Health 4052 Bald Cypress Way, Bin C21 Tallahassee, FL 32399-1741 Phone: 850/245-4266 Fax: 850/487-0435 bill_passetti@doh.state.fl.us http://www.doh.state.fl.us/environment/radiation
GEORGIA (Agreement State) Cynthia Sanders Radioactive Materials Program Department of Natural Resources 4244 International Parkway, Suite 114 Atlanta, GA 30354 Phone: 404/362-2675 Fax: 404/362-2653 csanders@dnr.state.ga.us http://www.dnr.state.ga.us/environ/aboutepd_files/rmprogram/default.htm	**HAWAII** Russell S. Takata, Program Manager Noise, Radiation, and Indoor Air Quality Branch Department of Health 591 Ala Moana Boulevard Honolulu, HI 96813-4921 Phone: 808/586-4700 Fax: 808/586-5838 rtakata@ehsdmail.health.state.hi.us

IDAHO Douglas Walker, Senior Health Physicist Development of Environmental Quality INEEL Oversight and Radiation Control Program 900 N. Skyline, Suite C Idaho Falls, ID 83402-1718 Phone: 208/528-2617 Fax: 208/528-2605 dwalker@deq.state.id.us	**ILLINOIS** (Agreement State) Gary N. Wright, Director Division of Nuclear Safety Illinois Emergency Management Agency 1035 Outer Park Drive, 5th Floor Springfield, IL 62704 Phone: 217/785-9868 Fax: 217/524-4724 wright@iema.state.il.us http://www.state.il.us/idns
INDIANA John H. Ruyack, Director Indoor and Radiologic Health Division State Department of Health 2 North Meridian Street, 5F Indianapolis, IN 46204-3003 Phone: 317/233-7146 Fax: 317/233-7154 jruyack@isdh.state.in.us http://www.in.gov/isdh/regsvcs/index.htm	**IOWA** (Agreement State) Donald A. Flater, Chief Iowa Department of Public Health Bureau of Radiological Health 401 S.W. 7th Street, Suite D Des Moines, IA 50309 Phone: 515/281-3478 Fax: 515/725-0318 dflater@idph.state.ia.us http://www.idph.state.ia.us/pa.rh.htm
KANSAS (Agreement State) Thomas A. Conley, CHP, RRPT, Chief, Radiation and Asbestos Control Section Bureau of Air and Radiation Department of Health and Environment 1000 SW Jackson Street, Suite 310 Topeka, KS 66612-1366 Phone: 785/296-1565 Fax: 785/296-0984 tconley@kdhe.state.ks.us http://www.kdh.state.ks.us/bar/	**KENTUCKY** (Agreement State) Robert L. Johnson, Manager Radiation Health and Toxic Agents Branch Cabinet for Health Services 275 East Main Street, Mail Stop HS-2E-D Frankfort, KY 40621-0001 Phone: 502/564-7818 Ext. 3697 Fax: 502/564-6533 robertL.johnson@mail.state.ky.us
LOUISIANA (Agreement State) Michael E, Henry, Senior Environmental Scientist Permits Division Office of Environmental Services 602 N. 5th, P.O. Box 4313 Baton Rouge, LA 70821-4313 Phone: 225/219-3366 Fax: 225/219-3154 ,ichael.henry@la.gov http://www.deq.state.la.us/	**MAINE** (Agreement State) Jay Hyland, PE, Program Manager Radiation Control Program Division of Health Engineering 11 State House Station Augusta, ME 04333 Phone: 207/287-5677 Fax: 207/287-3059 jay.hyland@maine.gov http://www.maine.gov/dhs/eng/rad/index.html

MARYLAND (Agreement State) Roland G. Fletcher, Environmental Program Manager III Radiological Health Program Air and Radiation Management Administration Maryland Department of Environment 1800 Washington Boulevard, Suite 750 Baltimore, MD 21230-1724 Phone: 410/537-3300 Fax: 410/537-3198 rflecther@mde.state.md.us	**MASSACHUSETTS** (Agreement State) Robert Walker, Director Radiation Control Program Department of Public Health 90 Washington St. Dorchester, MA 02121 Phone: 617/427-2944 Fax: 671/427-2925 bob.walker@state.ma.us http://www.mass.gov/dph/rcp/
MICHIGAN Liane Shekter Smith, Chief Hazardous Waste and Radiological Protection Section Waste and Hazardous Materials Division Michigan Department of Environmental Quality 525 W. Allegan Street P.O. Box 30241 Lansing, MI 48909-7741 Phone: 517/373-0530 Fax: 517/373-4797 shekterl@michigan.gov http://www.michigan.gov/deq/0,1607-7,7-135-3312-4120---,00.htm	**MINNESOTA** (Prospective Agreement State) Linda Bruemmer, Manager Section of Asbestos, Indoor Air, Lead, & Radiation Department of Environmental Health 121 E. Seventh Place, Suite 220 P.O. Box 64975 St. Paul, MN 55164-0975 Phone: 651/215-0945 Fax: 651/215-0975 linda.bruemmer@health.state.mn.us http://www.health.state.mn.us/
MISSISSIPPI (Agreement State) Robert W. Goff, Director Division of Radiological Health State Department of Health 3150 Lawson Street Jackson, MS 39215-1700 Phone: 601/987-6893 Fax: 601/987-6887 rgoff@msdh.state.ms.us http://www.health.ms.gov	**MISSOURI** Keith Henke, Planner Department of Health and Senior Services Section for Environmental Public Health 930 Wildwood Dr. P.O. Box 570 Jefferson City, MO 65102-0570 Phone: 573/751-6112 Fax: 573/526-6946 henkek@dhss.state.mo.us

MONTANA Juan Stevens, Coordinator Radiological Health Program Montana Department of Public Health & Human Services Licensure Bureau 2401 Colonial Drive P.O. Box 202953 Helena, MT 59620-2953 Phone: 406/444-1510 Fax: 406/444-3456 justevens@state.mt.us	**NEBRASKA** (Agreement State) Julia A. Schmitt, Program Manager X-Ray/Radioactive Materials/Emergency Response Regulation and Licensure Department of Health & Human Services 301 Centennial Mall South, P.O. Box 95007 Lincoln, NE 68509-5007 Phone: 402/471-0528 Fax: 402/471-0169 julia.schmitt@hhss.state.ne.us http://www.hhs.state.ne.us/rad/radindex.htm
NEVADA (Agreement State) Stanley R. Marshall, Supervisor Radiological Health Section Bureau of Health Protection Services Nevada State Health Division 1179 Fairview Drive, Suite 102 Carson City, NV 89701-5405 Phone: 775/687-5394, Ext. 276 Fax: 775/687-5751 smarshall@nvhd.state.nv.us http://www.hhs.state.ne.us/rad/radindex.htm	**NEW HAMPSHIRE** (Agreement State) Dennis O'Dowd, Acting Chief Radiological Health Section Bureau of Radiological Health Department of Health and Human Services 29 Hazen Drive Concord, NH 03301-6504 Phone: 603/271-4588 Fax: 603/225-2325 dodowd@dhhs.state.nh.us
NEW JERSEY Jill Lipoti, Ph.D., Assistant Director Radiation Protection Programs & Release Prevention Division of Environmental Safety, Health and Analytical Programs Department of Environmental Protection P.O. Box 415 Trenton, NJ 08625-0415 Phone: 609/984-5636 Fax: 609/633-2210 jill.lipoti@dep.state.nj.us http://www.state.nj.us/dep/rpp/index.htm	**NEW MEXICO** (Agreement State) William Floyd, Program Manager Radiation Protection Program Department of Environment 1190 St. Francis Drive, Room S2100 P.O. Box 26110 Santa Fe, NM 87505-4173 Phone: 505/476-3236 Fax: 505/476-3232 william_floyd@nmenv.state.nm.us http://www.nmenv.state.nm.us/nmrcb/home.html

NEW YORK (Agreement State) Adela Salame-Alfie, Ph.D., Director Bureau of Environmental Radiation Protection New York State Health Department 547 River Street Troy, NY 12180-2216 Phone: 518/402-7550 Fax: 518/402-7554 asa01@health.state.ny.us Clayton J. Bradt, CHP, Principal Radiophysicist, Radiological Health Unit Division of Safety and Health New York State Department of Labor NYS Office Campus, Building 12, Room169 Albany, NY 12240 Phone: 518/457-1202 Fax: 518/485-7406 usccjb@labor.state.ny.us John P. Spath, Program Manager Radioactive Waste Policy and Nuclear Coordination NYS Energy Research and Development Authority 17 Columbia Circle Albany, NY 12223-6399 Phone: 518/862-1090 Fax: 518/862-1091 jps@nyserda.org	Gene Miskin, Director Bureau of Radiological Health New York City Department of Health 2 Lafayette Street, 11th Floor New York, NY 10007 Phone: 212/676-1550 Fax: 212/676-1548 gmiskin@health.nyc.gov Barbara A. Youngblood, Chief Radiation Section Division of Solid & Hazardous Material NYS Depart. of Environmental Conservation 625 Broadway, 8th Floor Albany, NY 12233-7255 Phone: 518/402-8579 Fax: 518/402-8646 bayoungb@gw.dec.state.ny.us www.dec.state.ny.us/website/dshm/hazrad/rad.htm
NORTH CAROLINA (Agreement State) Beverly O. Hall, Chief Division of Radiation Protection Department of Environmental & Natural Resources 3825 Barrett Drive Raleigh, NC 27609-7221 Phone: 919/571-4141 Fax: 919/571-4148 beverly.hall@ncmail.net http://www.ncradiation.net	**NORTH DAKOTA** (Agreement State) Terry O'Clair, Director North Dakota Department of Health Division of Air Quality 1200 Missouri Avenue, Room 304 Bismark, ND 58506-5520 Phone: 701/328-5188 Fax: 701/328-5200 toclair@state.nd.us http://www.health.state.nd.us/AQ/

OHIO (Agreement State) Robert Owen, Chief Bureau of Radiation Protection Ohio Department of Health P.O. Box 118 Columbus, OH 43216-0118 Phone: 614/644-7860 Fax: 614/466-0381 rowen@gw.odh.state.oh.us	**OKLAHOMA** (Agreement State) Mike Broderick, Environmental Program Administrator Radiation Management Section Department of Environmental Quality P.O. Box 1677 Oklahoma City, OK 73101-1677 Phone: 405/702-5155 Fax: 401/702-5101 mike.broderick@deqmail.state.ok.us
OREGON (Agreement State) Terry D. Lindsey, Program Director Radiation Protection Services Oregon Health Services Department of Human Services 800 NE Oregon Street, Suite 260 Portland, OR 97232-2162 Phone: 503/731-4014, Ext. 660 Fax: 503/731-4081 terry.d.lindsey@state.or.us http://www.dhs.state.or.us/publichealth/rps/index.cfm	**PENNSYLVANIA** (Prospective Agreement State) David J. Allard, CHP, Director Bureau of Radiation Protection Department of Environmental Protection Rachel Carson State Office Building P.O. Box 8469 Harrisburg, PA 17105-8469 Phone: 717/787-2480 Fax: 717/783-8965 djallard@state.pa.us http://www.dep.state.pa.us/dep/deputate/airwaste/rp/rp.htm
RHODE ISLAND (Agreement State) Marie Stoeckel, Chief Division of Occupational & Radiological Health Department of Health 3 Capitol Hill, Room 206 Providence, RI 02908-5097 Phone: 401/222-7755 Fax: 401/222-2456 maries@doh.state.ri.us	**SOUTH CAROLINA** (Agreement State) T. Pearce O'Kelley, Chief Bureau of Radiological Health Department of Health & Environmental Control 2600 Bull Street Columbia, SC 29201 Phone: 803/545-4403 Fax: 803/545-4412 okelletp@dhec.sc.gov http://www.scdhec.net/ Henry Porter, Assistant Director Division of Waste Management Bureau of Land and Waste Management Department of Health and Environmental Control 2600 Bull Street Columbia, SC 29201 Phone: 803/896-4245 Fax: 803/896-4242 porterhj@dhec.state.sc.us

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APPENDIX F
EXAMPLES OF POTWS THAT HAVE RADIONUCLIDE MATERIALS PROGRAMS

Albuquerque, New Mexico

The City of Albuquerque has drafted a Radioactive Discharge Monitoring Program (RDMP). This will be a voluntary program of monitoring and reporting. The Albuquerque POTW has found they have the responsibility to be aware of all discharges to the sewer system that could impact operations at the treatment plant or impact the health and safety of employees and the public. The POTW will implement a program of discharger registration that requires dischargers to (1) periodically report their radionuclide discharges, (2) allow the POTW to perform surveillance monitoring, and (3) commit to voluntarily limit their discharges to levels that are as low as reasonably achievable (ALARA). These registrations will be issued and monitoring of the discharges will be permitted in accordance with a city sewer use and wastewater control ordinance. The agreement could be in the form of an amendment to an existing sewer discharge permit.

The Albuquerque POTW obtained a list of licensed radioactive materials users in the municipal service area from the appropriate regulatory authority (New Mexico is an Agreement State). Each of the licensees was evaluated to determine whether or not they discharge or have the potential to discharge radioactive materials to the sewer. This included an initial walk-through to familiarize the RDMP staff with the nature of the operation and potential opportunities for waste minimization.

The POTW will negotiate discharge limits with the dischargers so that the aggregate regulated discharges from all licensed facilities is ALARA and produces no greater than 1 in 10,000 excess risk of fatal cancer to the hypothetical most exposed individual. The POTW will work with potential dischargers to prevent accidental releases of radioactive materials.

The Albuquerque POTW retains a certified Health Physicist to interpret the reports from the dischargers and from monitoring the dischargers and the treatment facility. The health physicist uses radiation exposure models to ensure the radiation dose to the critical group is ALARA.

The dischargers will be asked to provide annual reports regarding the discharges they have made or plan to make to the sewer. In addition, the RDMP staff collects samples from the facilities' sample locations on a regularly scheduled basis and/or unannounced. The samples are analyzed by the State. To date the radionuclides found in the sewage have been of medical origin. Gamma radiation detectors installed in the plant have indicated that no measurable radiation exposure is being received by plant workers.

Formal adoption of the RDMP plan awaits passage of a revised sewer use and wastewater control ordinance. It has been stalled for more than 2 years due to its "political sensitivity." Unless there is a demand by dischargers for the change to occur, the situation will remain "as is."

St. Louis, Missouri

The City of St. Louis has its own requirements to limit radioactive discharges from industrial users. The district is concerned that low-level radioactive materials being discharged to the sewer system by numerous small sources may be concentrated by the district's wastewater treatment processes and possibly pose a hazard for the employees and adversely affect the district's sludge disposal options.

The District Ordinance for sewer use contains a limit of 1 curie/yr for the aggregate discharge from all users in a watershed (except excreta from individuals undergoing medical treatment or diagnosis). This number is currently under review.

The district requested lists of licensees from the NRC and the State and wrote the licensees letters informing them of the limits for radionuclide dischargers. Licensees are required to write the sewer district requesting approval to discharge radioactive materials and indicating the isotopes and the amounts to be discharged annually. The district then approves the discharges. The district requires quarterly reports from the licensees to ensure compliance with the District Ordinance and State and Federal regulations. The licensee's discharge permit is then modified to incorporate the approval of discharges and the reporting requirements.

As alternatives to discharging to the sewer system, licensees are encouraged to consider shipping the waste to an approved low-level radioactive waste disposal site or storing the waste for at least ten half-lives to allow sufficient decay to background levels prior to disposal to the sewer.

Oak Ridge, Tennessee

In response to its sewage sludge contamination problems (see Section 1.2), Oak Ridge developed a site-specific, risk-based methodology for establishing radionuclide limits for its sewage sludge. The sewage sludge criteria were then used to determine allowable plant releases that provided a basis for setting facility specific discharge criteria through the city's existing pretreatment program. Additionally, the city included a "radioactive materials" section in its pretreatment questionnaire which is filled out by all industrial users. The city also established an inexpensive screening program designed to ensure that elevated levels of radionuclides from spills or illegal discharges, would not reach the land application site.

The city of Oak Ridge was strongly supported by Tennessee's State radiation control program. Also aiding in the success of the program was ORWTP's close working relationship with local industry. The city of Oak Ridge expended considerable effort in developing a program that controlled radionuclide discharges in a manner that minimized regulatory burdens on local industry and still provided adequate protection for the POTW.

APPENDIX G
GLOSSARY AND ACRONYMS

AEA. Atomic Energy Act

Agreement State. Any State with which the Nuclear Regulatory Commission, or Atomic Energy Commission, has entered into an effective agreement under section 274b of the Atomic Energy Act, as amended. Under the agreement, the Commission relinquishes certain regulatory authority to the State which the State assumes under its own authority-the use of reactor-produced isotopes, the source materials uranium and thorium, small (non-critical) quantities of special nuclear materials, uranium mill tailing, the disposal of low-level radioactive waste, and the evaluation of sealed sources and devices. Currently, there are 33 Agreement States.

Background Radiation. Radiation from cosmic sources, *naturally occurring radioactive material (NORM)*, 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 or from nuclear accidents like Chernobyl which contribute to *background radiation* and are not under the control of the cognizant organization. *Background radiation* does not include radiation from *source*, *byproduct*, or *special nuclear materials* regulated by the cognizant Federal or State agency.

Becquerel (Bq). The International System (SI) unit of activity equal to one nuclear transformation (disintegration) per second. 1 *(Bq)* = 2.7×10^{-11} *curies* (Ci) = 27.03 picocuries.

Byproduct Material. In general, any radioactive material (except *special nuclear material*) yielded in or made radioactive by exposure to the radiation incident to the process of producing or utilizing *special nuclear material*.

Contamination. The presence of *elevated levels of radiation* where you don't want it.

CPM. counts per minute

Curie. The traditional unit of radioactivity. One *curie* (Ci) is equal to 37 billion atomic disintegrations per second (3.7×10^{10} dps = 3.7×10^{10} Bq), which is approximately equal to the decay rate of one gram of ^{226}Ra. Fractions of a *curie*, e.g., picocurie (pCi) or 10^{-12}Ci and microcurie (µCi) or 10^{-6} Ci, are levels typically encountered in the environment.

***microcurie* (µCi)**. one one-millionth (1/1,000,000) of a curie

***picocurie* (pCi)**. one one-trillionth (1/1,000,000,000,000) of a curie

Elevated Levels of Radioactive Material. Levels of radioactive material in sewage sludge or ash that should alert a POTW that some appropriate action(s) may be warranted (see Chapter 6 of this report).

Exposure Rate. The amount of ionization produced per minute in air by X-rays or gamma rays. The unit of exposure rate is roentgens/hour (R/h); typical units are microroentgens per hour (μR/h), i.e., 10^{-6} R/h.

Gamma Radiation. Penetrating high-energy, short-wavelength electromagnetic radiation (similar to X-rays) emitted during *radioactive decay*. Gamma rays are very penetrating and require dense materials (such as lead or steel) for shielding.

HP. Health Physicist

ISCORS. The Interagency Steering Committee on Radiation Standards.

NARM. Naturally occurring or accelerator-produced radioactive material, such as radium, and not classified as *source material*.

Naturally Occurring Radionuclides. Radionuclides and their associated progeny produced during the formation of the earth or by interactions of terrestrial matter with cosmic rays.

NORM. Naturally-occurring radioactive materials.

Radioactivity (or activity). The mean number of nuclear transformations occurring in a given quantity of radioactive material per unit of time. The International System (SI) unit of radioactivity is the *becquerel (Bq)*. The customary unit is the *curie (Ci)*.

Radioactive Half Life. The time required for one-half of the atoms of a particular *radionuclide* present to disintegrate.

Radioactive Decay. The spontaneous transformation of an unstable atom into one or more different nuclides accompanied by either the emission of energy and/or particles from the nucleus, nuclear capture or ejection of orbital electrons, or fission. Unstable atoms decay into a more stable state, eventually reaching a form that does not decay further or has a very long *radioactive half-life*.

Radionuclide. An unstable nuclide that undergoes *radioactive decay*.

Reconcentration. The increase in the concentration of radioactive materials in sewage sludge or ash resulting from wastewater and sludge treatment within the POTW.

rem (radiation equivalent man). The conventional measurement unit of radiation dose for estimating the body's effects from exposure to ionizing radiation. The corresponding International System (SI) unit is the *sievert (Sv)*: 1 Sv = 100 rem.

millirem. one one-thousandth (1/1,000) of a rem.

microrem. one one-millionth (1/1,000,000) of a rem.

Roentgen (R). intensity of photon (gamma or X-ray) radiation.

microroentgen (μR). one one-millionth (1/1,000,000) of a roentgen.

Source Material. In general, uranium and/or thorium other than that classified as *special nuclear material.*

Special Nuclear Material. In general, plutonium, ^{233}U, and uranium enriched in ^{235}U; material capable of undergoing a fission reaction.

TENORM. Naturally occurring radioactive materials whose concentrations or exposures to humans and the environment are increased by or as a result of past or present human practices. TENORM does not include background radiation or the natural radioactivity of undisturbed rocks or soils. TENORM also does not include uranium or thorium in source material as defined in the AEA and NRC regulations.

APPENDIX H
SOURCES OF ADDITIONAL INFORMATION

ASTM E 181-82 (Reapproved 1991), “Standard General Methods for Detector Calibration and Analysis of Radionuclides.”American Society for Testing and Materials, Philadelphia, Pennsylvania 19103.

CRCPD Publication 03-1, “Directory of Personnel Responsible for Radiological Health Programs,” January 2003, Conference of Radiation Control Program Directors, Inc., Frankfort, Kentucky 40601, http://www.crcpd.org.

Miller, W.H., et al, 1996, “The Determination of Radioisotope Levels in Municipal Sewage Sludge,” Health Physics, v. 71, no. 3, p. 286.

Miller, M.L., Bowman, C.R., and M.G. Garcia, 1997, “Avoiding Potential Problems.”

NCRP Report No. 50, “Environmental Radiation Monitoring,” 1976, National Council on Radiation Protection and Measurements, Bethesda, Maryland.

NCRP Report No. 58, “A Handbook of Radioactivity Measurement Procedures,” 1985, National Council on Radiation Protection and Measurements, Bethesda, Maryland.

APPENDIX I
ADDITIONAL INFORMATION ON NRC AND AGREEMENT STATE LICENSING AND ENFORCEMENT

This appendix provides additional information about how NRC and Agreement States License users of radioactive materials, and how the agencies enforce the regulations.

Who Must Obtain a License and What Happens if this is not Done?

According to NRC's 10 CFR Part 30, Section 30.3:

> Except for persons exempt as provided in this part and Part 150 of this chapter, no person shall manufacture, produce, transfer, receive, acquire, own, possess, or use byproduct material except as authorized in a specific or general license issued pursuant to regulations in this chapter.

This means that, with a few specified exceptions, any activity involving byproduct material must be conducted under a license issued by the NRC or an Agreement State. The exempt activities are described in NRC's 10 CFR Part 30. Most exemptions from specific licensing are for consumer products, such as smoke detectors.

Persons who are required to obtain an NRC license but fail to do so would be in violation of Federal law and, when discovered, would be subject to the penalties appropriate for such violations. In any case, such persons would most likely be unable to obtain the byproduct materials they need, because suppliers of such materials generally require copies of the license authorizing possession and use of the materials before the materials are delivered to the user.

What Radioactive Materials are Exempt from Licensing?

Section 30.3 cited above mentions certain exemptions from the NRC licensing requirements. These exemptions include certain DOE activities and also users of articles containing byproduct materials in concentrations and quantities below specified levels. These articles include some instruments containing luminous dials, such as timepieces, balances, marine compasses, electron tubes, gas or smoke detectors, and some other products. It should be noted that the manufacturers and distributors of these exempt devices are subject to NRC licensing.

In addition to the above, some radioactive materials may be exempt from licensing because they fall below NRC-established concentration or quantity levels. These levels do not apply to materials that have already been licensed but have for some reason, such as decay, diminished to activities below these levels. The exemption applies only to the initial determination of whether or not a potential user or owner of byproduct material needs to be licensed or is exempt from such a requirement. Once licensed, byproduct material remains under the conditions of the license regardless of how small the activities become because of decay or any kind of partitioning of the original licensed quantity.

Why are Some Industrial and Medical Facilities not Licensed?

The NRC may not license some facilities that use radioactive materials if the material they use is not byproduct material. Examples of such facilities would be those that use accelerators or accelerator-produced radioactive materials. However, even though such facilities may not come under NRC's jurisdiction, and are therefore not licensed by the NRC, they are usually within the jurisdiction of a State and may be licensed by that State if their activity requires licensing. Exceptions to this may be certain Federal facilities and their prime contractors, such as DOE facilities which, although not licensed by NRC or the States, are regulated by internal DOE Orders.

What Monitoring/Oversight Do NRC and the Agreement States Provide for Licensees under Their Control?

Both NRC and Agreement States monitor their licensees by means of periodic inspections. The frequency of inspections depends on the type of license issued to the licensee, and will vary from annual inspections for the larger licensees, such as hospitals, radiopharmaceutical companies, and other large users of byproduct materials, to inspections once every 3-5 years for small licensees who may use only one small radioactive source in a routine and well-established application. The inspections are designed to review the licensee's operation to make sure that it is being conducted safely and in accordance with good practices and the conditions specified on the license. Inspection frequencies may be increased if the NRC or Agreement State believes that the licensee requires closer oversight to implement improvements in their program to raise its standards. In addition, the license may be suspended or revoked if NRC or the Agreement State finds that the licensee's operation does not meet minimum safety standards.

Some facilities may be under the jurisdiction of more than one entity, such as many medical facilities that are licensed by NRC for those parts of their operation that use byproduct materials, and by the State in which they operate for those parts that use accelerator-produced radioactive materials. Most States regulate naturally-occurring and accelerator-produced radioactive materials.

What Causes Discharges Outside of Regulations or License Conditions?

The probable causes of illegal discharges are poor licensee programs, lack of knowledge of the regulations, or deliberate violations. Discharges to the sanitary sewers by NRC or Agreement State licensees must comply with NRC or compatible Agreement State regulations governing this aspect of the licensee's operation. There are many mechanisms in place to provide reasonable assurance that licensees will comply with this regulatory requirement. Licenses are issued to licensees only after NRC or the Agreement State is satisfied that the licensee has the qualified staff, equipment, procedures, instrumentation, training programs, and management oversight deemed necessary to operate the proposed program in a safe manner and within the restrictions specified in the license. Any signs of program weaknesses or irregular activities identified during inspection are brought to the licensee's attention for corrective action, and if these are found to be sufficiently serious, the license may be suspended pending completion of corrective actions, or revoked, thereby ending the licensee's use of licensed materials.

All these measures cannot prevent illegal discharges to the sewers, but they help to minimize such a possibility, and they provide an opportunity to identify such illegal activities if they occurred.

What Enforcement Actions do NRC and Agreement States take when Licensees Discharge Outside Regulations or License Conditions?

The enforcement actions that could be taken in such cases depend on the specifics of the situation. If the discharge above the limits is found to have been a one-time, inadvertent error in an otherwise sound program, the licensee could be issued a violation and the licensee's management may be called to the NRC or State offices for a meeting with NRC or State management to discuss the incident and the corrective actions the licensee intends to take to prevent recurrence. The NRC or State may also issue a letter to the licensee summarizing the corrective actions to be taken and the completion schedule. Follow-up inspections might be used to confirm completion of the corrective actions and their adequacy. The NRC and some States could also impose monetary penalties.

If, on the other hand, the discharge above the limits is found to be the result of a generally poor program, additional and more escalated enforcement actions could be taken to change the licensee's program. Such changes may involve hiring more competent professionals or managers, retraining of personnel, rewriting operating procedures, and any other measures that may be needed to improve the quality of the program. The program is then monitored closely. In more serious cases, the license could be revoked. In situations where willfulness is found and the matter is under NRC jurisdiction, the matter could be referred to the Department of Justice for appropriate legal action. If the matter is under State jurisdiction, it could be referred to the State Attorney General.

APPENDIX J
RADIOLOGICAL ANALYSIS LABORATORIES

There are a number of radiological laboratories throughout the United States that provide analyses of sewage sludge samples for POTWs. The Conference of Radiation Control Program Directors (CRCPD) maintains a list of such laboratories. These laboratories provide radiological analysis of diverse materials, have quality assurance and quality control programs, and will perform work for both government and private firms. The list is available from the CRCPD by phone at 502/227-4543, and is posted to the CRCPD web page, at URL: http://www.CRCPD.org (go to the "Free Documents" tab, then to "Orphan Source Documents," and then to "Radioassay and TCLP Services"). The list is updated periodically by the CRCPD. The CRCPD does not guarantee that the list is comprehensive, nor is there any certification of the quality of services provided. Thus, the authors of this report provide reference to this list only as a convenience to POTWs in locating laboratories that they may wish to evaluate. The NRC, EPA, and the ISCORS Subcommittee do not certify, approve, or endorse these laboratories.

Following are suggested criteria that POTW operators can use to help evaluate radiological laboratories:

1. Does the laboratory possess the appropriate well-documented procedures, instrumentation, and trained personnel to perform the necessary analyses?
2. Is the laboratory experienced in performing the same or similar analyses?
3. Does the laboratory have satisfactory performance evaluation results from formal monitoring or accreditation programs? The laboratory should have a formal quality assurance (QA) program in place. The laboratory should be able to provide a summary of QA audits and proof of participation in inter-laboratory cross-check programs. Equipment calibrations should be performed using National Institute of Standards and Technology (NIST) traceable reference radionuclide standards whenever possible.
4. Is there an adequate capacity to perform all analyses within the desired time frame?
5. Does the laboratory provide an internal quality control review of all generated data that is independent of the data generators?
6. Are there adequate protocols for method performance documentation and sample security?

APPENDIX K
POTW RADON SITE-SPECIFIC SCREENING CALCULATION

Screening Calculation D: POTW Site-Specific Radon Concentration Estimates

Purpose: To estimate radon concentrations from Ra-226 and Th-228 for POTW Workers in a loading or storage room, given certain room characteristics.

Calculation Procedure:

Obtain the following site-specific parameters:

> Sludge concentrations of Ra-226 and Th-228.
>
> V_{room}, the volume of the room in cubic meters.
>
> h_{room}, the height of the room in meters.
>
> D_{sludge}, the bulk density of the sludge in grams per cubic centimeter.
>
> V_{sludge}, the volume of sludge in the room.
>
> A_{sludge}, the area which the sludge covers in the room.
>
> R_x, the room air exchange rate in exchanges per hour.

For the concentration of Rn-222 from Ra-226, use the following formulae:

Concentration in pCi/liter =

$$(\text{Sludge Concentration of Ra-226 in pCi/g}) \times 1.49 \text{ x } (0.008 + R_x)^{-1} D_{sludge} V_{sludge} / V_{room}$$

Concentration in WL =

$$(\text{Sludge Concentration of Ra-226 in pCi/g}) \times$$
$$0.00931 \text{ x } (0.008 + R_x)^{-1} \times (2.69\, h_{room}^{-0.13} + R_x)^{-1} D_{sludge} V_{sludge} / V_{room}$$

For the concentration of Rn-220 from Th-228, use the following formulae:

Concentration in pCi/liter =

$$(\text{Sludge Concentration of Th-228 in pCi/g}) \times 720 \text{ x } (45 + R_x)^{-1} D_{sludge} A_{sludge} / V_{room}$$

Concentration in WL =

$$(\text{Sludge Concentration of Th-228 in pCi/g}) \times$$
$$3.00 \text{ x } (45 + R_x)^{-1} \times (1.25\, h_{room}^{-0.77} + R_x)^{-1} D_{sludge} A_{sludge} / V_{room}$$

Compare concentrations (combined for WL, separate for pCi/liter) with the levels recommended in Chapter 6.

Note:

Increasing the room parameters V_{room} or R_x will lead to *lower* concentrations, as will *decreasing* D_{sludge}, V_{sludge}, or A_{sludge}. Similarly, *decreasing* the room parameters V_{room} or R_x will lead to *higher* concentrations, as will *increasing* D_{sludge}, V_{sludge}, or A_{sludge}.

EXAMPLE CALCULATIONS FOR ESTIMATING RADIATION EXPOSURE FROM RADIOANALYSIS OF SLUDGE SAMPLES

The following are example calculations based on the screening calculations described in Chapter 6. Although these examples are based on real sludge measurements, most have been chosen to illustrate atypical levels of radioactivity.

Example 1: POTW Radiation Exposure Estimates for a High NORM Sludge

Screening Calculation A:

In Sample 1, the levels of I-131 (6.2), Ra-226 (25), Ra-228 (38), and Th-228 (9) exceed the “POTW Screening Concentration” in column 3 of Table 6.2.

Using the DSRs in Table 6.2, the non-radon doses from I-131 (1.1), Ra-226 (24.3), Ra-228 (19.7), and Th-228 (8.2) add up to 53.3 mrem/year.

The estimated radon concentrations due to Ra-226 are 0.06 WL or 37 pCi/Liter of Rn-222. The radon concentrations due to Th-228 are 0.43 WL or 220 pCi/Liter of Rn-220. The total Working Levels is 0.49 WL.

These results may warrant additional investigation, such as through a professional health physicist or consultant. For the radon concentrations, radon monitoring could be performed, or additional estimates could be calculated using Screening Calculation D.

Screening Calculation D:

The concentration of Ra-226 is 25 pCi/g, and Th-228 is 9 pCi/g. The POTW room parameters are $V_{room} = 70{,}000\ m^3$, $h_{room} = 4\ m$, $D_{sludge} = 1.5\ g/cm^3$, $V_{sludge} = 15{,}000\ m^3$, $A_{sludge} = 7500\ m^2$, $R_x = 2$ per hour.

The concentration of Rn-222 from Ra-226 is

$$25 \times 1.49 / 2.008 \times 1.5 \times 15{,}000 / 70{,}000 = 6.0 \text{ pCi/liter}$$

$$25 \times 0.00931 / 2.008 / (2.25 + 2) \times 1.5 \times 15{,}000 / 70{,}000 = 0.009 \text{ WL}$$

The concentration of Rn-220 from Th-228 is

$$9 \times 720 / 47 \times 1.5 \times 7{,}500 / 70{,}000 = 22 \text{ pCi/liter}$$

$$9 \times 3.00 / 47 / (0.4 + 2) \times 1.5 \times 7{,}500 / 70{,}000 = 0.038 \text{ WL}$$

These concentrations may warrant additional investigation, such as through radon monitoring and/or a professional health physicist or consultant.

Example 2: POTW Radiation Exposure Estimates for a High Medical-Isotope Sludge

Screening Calculation A:

In Sample 2, the levels of I-131 (230 pCi/g), K-40 (13 pCi/g), Ra-226 (2 pCi/g), Ra-228 (5 pCi/g), and Th-228 (1.3 pCi/g) are above the "POTW Screening Concentration" in column 3 of Table 6.2.

Using the DSRs in Table 6.2, the non-radon doses from I-131 (44.2), K-40 (1.2), Ra-226 (1.9), Ra-228 (2.6), and Th-228 (1.2) add up to 51.1 mrem/year.

The estimated radon concentrations due to Ra-226 are 0.005 WL or 3.0 pCi/Liter of Rn-222. The radon concentrations due to Th-228 are 0.06 WL or 31.5 pCi/Liter of Rn-220. The total Working Levels is 0.07 WL.

These results may warrant additional investigation, such as through a professional health physicist or consultant. For the radon concentrations, radon monitoring could be performed, or additional estimates could be calculated using Screening Calculation D.

Screening Calculation D:

In Sample 2, the concentrations are Ra-226 (2 pCi/g) and Th-228 (1.3 pCi/g). The POTW room parameters are $V_{\text{room}} = 70{,}000\ \text{m}^3$, $h_{\text{room}} = 4$ m, $D_{\text{sludge}} = 1.5\ \text{g/cm}^3$, $V_{\text{sludge}} = 15{,}000\ \text{m}^3$, $A_{\text{sludge}} = 7500\ \text{m}^2$, and $R_x = 2$ per hour.

The concentration of Rn-222 from Ra-226 is

$$2 \times 1.49 / 2.008 \times 1.5 \times 15{,}000 / 70{,}000 = 0.5 \text{ pCi/liter}$$

$$2 \times 0.00931 / 2.008 / (2.25 + 2) \times 1.5 \times 15{,}000 / 70{,}000 = 0.0007 \text{ WL}$$

The concentration of Rn-220 from Th-228 is

$$1.3 \times 720 / 47 \times 1.5 \times 7{,}500 / 70{,}000 = 3.2 \text{ pCi/liter}$$

$$1.3 \times 3.00 / 47 / (0.4 + 2) \times 1.5 \times 7{,}500 / 70{,}000 = 0.006 \text{ WL}$$

These radon concentrations may not warrant additional investigation.

Example 3: Non-POTW Radiation Exposure Estimates for a High NORM Sludge

Screening Calculation B:

In Sample 1, the levels of Ra-226 (25 pCi/g), Ra-228 (38 pCi/g), Th-228 (9 pCi/g), and U-234 (4.3 pCi/g) are above the Screening Concentration. In addition, the level of Ac-227 inferred from Th-227 (0.5 pCi/g) is also above the Screening Concentration.

Using the DSRs in Table 6.5, the screening doses for Ac-227 (5.9 mrem/yr), Ra-226 (24.6), Ra-228 (15.6), Th-228 (4.7), and U-234 (1.0) added together give a total upper bound dose of 51.8 mrem/yr.

The inferred Rn-222 concentration from Ra-226 is 0.44 pCi/liter.

Additional calculations for non-POTW exposure are probably warranted.

Screening Calculation C:

The radionuclide samples are the same as above.

Screening calculation B indicated a need for a more detailed evaluation. The POTW is currently incinerating sludge, so the incinerator scenario will be evaluated. The POTW is considering changing to agricultural application, so will examine the Onsite Resident, Nearby Town, and Sludge Application Worker scenarios for 1, 5, and 20 years.

The results of calculations are:

- Incinerator Scenario: Doses from Ac-227 (5.9), Ra-226 (2.2), Ra-228 (1.0), Th-228 (4.7), and U-234 (1.0) sum to 14.8 mrem/yr.
- Onsite Resident
  - 1 year of application: Doses from Ac-227 (0.005), Ra-226 (1.23), Ra-228 (1.35), Th-228 (0.13), and U-234 (0.004) sum to 2.7 mrem/yr.
  - 5 years of application: Doses from Ac-227 (0.02), Ra-226 (6.1), Ra-228 (6.5), Th-228 (0.4), and U-234 (0.02) sum to 13 mrem/yr.
  - 20 year of application: Doses from Ac-227 (0.08), Ra-226 (24.6), Ra-228 (15.7), Th-228 (0.4), and U-234 (0.08) sum to 41 mrem/yr.
- Nearby Town
  - 1 year of application: Doses sum to 0.01 mrem/yr.
  - 5 years of application: Doses sum to 0.06 mrem/yr.
  - 20 years of application: Doses sum to 0.16 mrem/yr.

- Sludge Application Worker
  - 1 year of application: Doses sum to 0.5 mrem/yr.
  - 5 years of application: Doses sum to 2.7 mrem/yr.
  - 20 years of application: Doses sum to 8.2 mrem/yr.

Radon concentrations for the Onsite Resident on relevant for Ra-226 and Th-228:

- 1 year of application: Total 0.0002 Working Levels, including 0.02 pCi/liter Rn-222 and 2e-6 pCi/liter Rn-220.
- 5 years of application: Total 0.0008 Working Levels, including 0.1 pCi/liter Rn-222 and 5e-6 pCi/liter Rn-220.
- 20 years of application: Total 0.003 Working Levels, including 0.4 pCi/liter Rn-222 and 6e-6 pCi/liter Rn-220.

Example 4: Non-POTW Radiation Exposure Estimates for a Typical Sludge

Screening Calculation B:

For Sample 3, only the levels of Pb-210 (8 pCi/g) and Ra-226 (4 pCi/g) were above the Screening Concentration in column 3 of Table 6.5.

The screening doses for Pb-210 (2.3) and Ra-226 (3.9) added together give 6.2 mrem/year.

The inferred Rn-222 concentration from Ra-226 is 0.07 pCi/liter.

Additional calculations for non-POTW exposures are probably not needed unless more than 20 years of land application are anticipated.

APPENDIX L
ANALYSIS OF ISCORS SURVEY AND DOSE ASSESSMENT RESULTS

The ISCORS Survey (Survey), which measured 45 radionuclides, can provide perspective to the POTW operator in determining which radionuclides are more likely to persist in the environment, what potential dose they may contribute to a member of the general public or to a POTW worker, and which radionuclides may be included initially in any sludge monitoring program that the POTW operator may decide to conduct.

The ISCORS Sewage Sludge Subcommittee sent questionnaires to 631 POTWs with the greatest potential to receive elevated levels of man-made and natural radiation. Selection of these POTWs was based on criteria that the Subcommittee felt would identify sludges with elevated levels of radiation. The 631 POTWs selected are not, therefore, statistically representative of the more than 16,000 POTWs across the country. From this population, 313 POTWs voluntarily provided samples of sewage sludge and ash to be analyzed for radionuclide levels. Of the 45 radionuclides measured, the major contribution to estimated dose is from NORM/TENORM sources, and the critical pathway is inhalation of indoor radon from Ra-226 and Th-228. Highest potential doses are associated with two specific scenarios (POTW worker and Onsite Resident) of the seven scenarios that were evaluated in the ISCORS Dose Modeling Project, as shown in Table 3.6. Radon is responsible for most of the calculated doses, and gamma ray exposure from radium for much of the remainder. The other radionuclides detected in the survey account for relatively minor contributions to dose. The analysis presented here is designed to illustrate the thought processes that may be used to determine what specific radionuclides and possible sources should be analyzed first, if a POTW operator decides that sewage sludge or ash samples will be taken on a one-time, or a periodic basis.

Onsite Resident Scenario

Of the 45 radionuclides detected in the Survey, less than 10 percent have the potential to contribute significantly to the onsite resident dose, due to their relatively long half lives. Table L.1 provides a listing of 4 radionuclides that could possibly be significant, in decreasing rank order. This list of 4 radionuclides was developed by calculating the contribution to dose of each radionuclide, relative to the single radionuclide (Ra-226) that presents the greatest contribution to dose in the onsite resident scenario. The 50 mrem per year total dose comprises of 40 mrem per year from radon (0.23 pCi/L) and 10 mrem per year from non-radon sources. Each radionuclide in Table L.1 contributes greater than 1 mrem per year. An effective dose equivalent of 1 mrem per year per source or practice is recommended as the Negligible Individual Dose by the National Council on Radiation Protection and Measurements (e.g., NCRP No. 116.). Such a dose is also consistent with the standard—American National Standards Institute (ANSI)/Health Physics Society (HPS) N13.12-1999 for control of solid materials which is being evaluated along with other views by NRC in clearance rulemaking on controlling the disposition of solid materials (68 *Federal Register* 9595, February 28, 2003).

POTW Worker Loading Scenario

For the POTW Worker Loading scenario, a 1 mrem per year cutoff was used, as described above, to eliminate from further consideration those detected radionuclides that provide little or no contribution to dose. In this scenario, there are 4 radionuclides of potential concern, out of the 45 detected, with relative contributions shown in Table L.2. All of these radionuclides are included in the onsite resident scenario except for I-131 and Th-228. Consequently, the total number of radionuclides that may be of concern is reduced to about one-third, from 45 to 6.

These six radionuclides are recommended to be the ones that the POTWs should first focus their attention in terms of reducing dose to workers and onsite residents. The six radionuclides of primary concern are radium-226 and radium-228, which are NORM or TENORM; thorium-228, thorium-230, and lead-210, which are either NORM/TENORM or source material; and iodine-131, which is a byproduct material used in medical applications.

Further Explanation of Analysis

The following discussion should provide more detailed explanation of the analyses performed, which lead to the data contained in Tables L.1–L.5.

By concentration, the 45 radionuclides are divided into three groups as shown in Tables L.3, L.4, and L.5. They are ranked in decreasing order of concentration according to the upper bound of 95% of the samples, from the highest, I-131 (#1) at 51 pCi/g to the lowest, Rn-219 (#45), at no detect (ND). The maximum concentration in pCi/g, percent of samples detected, a probable source of the radionuclide, half-life, and relative contributions to dose are also listed.

As shown in Table 3.6, two scenarios are chosen from the 7 scenarios investigated because they represent the ones where the doses are the greatest. These scenarios are the Onsite Resident and a POTW Worker Loading Sewage Sludge. For each radionuclide, the Relative Contribution to the Dose of the Worker Loading at the 95% peak dose is computed alongside the Relative Contribution of an Onsite Resident at the 95% peak dose in a house built on land with sludge applied for 20 years as shown in Tables L.3, L.4, and L.5. Although doses are potentially significant, there are very few land application sites in the country that are known to have applied sewage sludge annually for even 20 years.

Table 3.6 shows that for the Onsite Resident Scenario, the dose is estimated to be 55 mrem per year. For the POTW Worker Loading Scenario, the 95% peak dose is estimated to be 24 mrem per year. For this estimate, the air exchange rate is 3 per hour, the room height is 4 meters, and the worker loads for 1000 hours per year. Ra-226 (#5 shaded) and Th-228 (#13 shaded) are the main contributing radionuclides by means of the radon pathway, as shown in Table L.3. For the POTW Worker Loader, to obtain the Relative Contribution to dose, the product of the concentration and Dose to Source Ratio for Th-228 is normalized at 1000, whereas for the Onsite Resident, for Ra-226, the Relative Contribution is normalized at 1000. The Relative Contributions for other radionuclides are computed from normalizing the product of the concentration and the Dose to Source Ratios and scaling factor given in Table 6.1 for the Onsite Resident and Table 6.14 for the POTW Biosolids Loading Working Scenario, as presented in the Dose Assessment Report, Summary of Dose-to-Source Ratios (ISCORS 2004).

The sum of the doses from the radionuclides in Tables L.1 and L.2 give doses of 55 mrem per year and 37 mrem per year compared to Table 3.6 (55 mrem per year and 24 mrem per year) because the 95% concentration for each radionuclide may reside in different samples. In Table 3.6, the total dose for each sample was calculated and then the 95% of those doses was taken. This method explicitly incorporates the correlations (or lack thereof) among the different radionuclides.

The radionuclides most likely to be detected are those having concentrations greater than 4 pCi/g, and present in a high percentage of the samples, are indicated in Table L.3. Radium-226 is a main contributor for the POTW Worker Loading and Onsite Resident Scenarios. Radium-226, which is a naturally-occurring element in soils located mainly in the Atlantic and Interior Plains, was measured in 93% of the samples from POTWs. The highest concentrations of Ra-226 occur in POTWs where the influent comes from ground water. Th-228 is another main contributor, but only for a Worker Loading. Th-228 is also naturally-occurring, and was detected in 100% of the samples. The highest concentrations of Tyh-228 occur in POTWs where the influent comes from ground water and has an average daily flow of less than 10 MGD. However, it is a relatively minor contributor to an Onsite Resident. The main reason is the relatively short half-life of 2 years for Th-228 compared to 1600 years for Ra-226 that permits Th-228 to decay to lower levels during the 20 years of sludge application. Additional details about relationships between POTW characteristics and radionuclide concentrations are provided in the ISCORS survey report (ISCORS 2003).

There are specific radionuclides of interest, such as Co-60 (#35 shaded), which is a product of activation and has a 5-year half-life. Co-60 is of great concern because it had been detected in certain POTWs (see Chapter 1) and has resulted in a great deal of expense to contain. However, Co-60 contributes only a small amount to Worker Loading dose or Onsite Resident dose as Table L.5 shows. Furthermore, Co-60 was detected in only 4% of the samples.

Another example is Am-241 (#37 shaded), with a half-life of 432 years, and which is a decay product of Pu-241. It is widely used in smoke detectors employed in homes and commercial buildings. Am-241 was detected in sludge products at various POTWs (see Table 1.1 of Chapter 1). Am-241 is now of minor concern for the Onsite Resident where it is about 0.1% relative to Ra-226 and was detected in only 3% of the samples.

Therefore, based on conservative assumptions, there are no cases where the 95th percentile dose exceeds the limit of total radiation exposure of 100 mrem per year to individual members of the general public from all controllable sources as recommended by international and national radiation protection advisory bodies (International Commission on Radiological Protection and National Council on Radiation Protection and Measurements). This conclusion suggests that doses from exposure to radionuclides in sewage sludge and ash are below the current limit of total radiation exposure, based on the ISCORS Survey and Dose Assessment. This observation is further qualified since samples from the 313 POTWs included in the Survey were received from 631 POTWS specifically selected as having the greatest potential to receive radionuclides from licensees or from naturally-occurring sources out of more than 16,000 POTWs across the country.

Table L.1 Radionuclides that May be of Concern for Onsite Resident

There are 4 radionuclides with a dose from 1.2 to 50 mrem/y. Their relative contributions to the dose range from 24 to 1000 at 95% concentration. Forty-one radionuclides have relative contributions less than 24.

Rank	Radionuclide	Dose (mrem/y)	Relative Contribution
1	Ra-226	50 *	1000
2	Ra-228	2.1	42
3	Th-230	1.3	25
4	Pb-210	1.2	24

* 40 mrem/y radon dose (0.23 pCi/L); 10 mrem/y non-radon dose.

Table L.2 Radionuclides that May be of Concern for Worker Loading

There are 4 radionuclides with doses ranging from about 1.3 mrem/y to 20 mrem/y. Their relative contribution to the dose ranges from 65 to 1000 at 95% concentration. Forty-one radionuclides have relative contributions less than 65. Note: Air exchange rate = 3 per hour, room height = 4 meters, and time exposed to sludge = 1000 hours per year.

Rank	Radionuclide	Dose (mrem/y)	Relative Contribution
1	Th-228	20 *	1000
2	Ra-226	11 †	550
3	I-131	4.7	240
4	Ra-228	1.3	65

* 14 mrem/y radon dose (17 pCi/L); 6 mrem/y non-radon dose.

† 9 mrem/y radon dose (0.9 pCi/L); 2 mrem/y non-radon dose.

Table L.3 Radionuclides Most Likely to be Detected, Greater than 4 pCi/g for the 95th Percentile Concentration and High Percent of Samples

They are ranked in decreasing order of concentration. The maximum concentration, percent of samples detected, probable source and half-life are also listed. Finally, the Relative Contribution to the dose of a Worker Loading at a POTW (air exchange rate = 3 per hour, room height = 4 meters, and time exposed to sludge = 1000 hours per year) at the 95% peak dose is listed next to the Relative Contribution of an Onsite Resident at the 95 % peak dose after 20 years of application.

Rank	Radio-nuclide	Concentration (pCi/g)		Percent Samples Detected	Probable source	Half-life	Relative contribution, 95%-ile	
		95%-tile	Max				Worker Loading	Onsite Resident (20 y)
1.	I-131	51	840	246/311= 84	Medical, Pacific mountain, and 50–100 MGD	8 d	240	<1
2.	TL.201	46	241	151/311= 49	Medical, Appalachian Highlands, 50–100 MGD	3 d	23	<1
3.	Sr-89	20	70	68/98= 70	Medical	51 d	<1	<1
4.	U-234	17	44	92/92=100	U-processing Intermontane Plateaus	$245x10^3$ y	5	6.2
5.	Ra-226	13	47	289/311= 93	NORM, Atlantic & Interior Plains, ground water	1600 y	550	1000
6.	U-238	12	26	92/92= 100	Appalachian Highlands, Intermontane Plateaus	$4.5x10^9$ y	6.8	4.4
7.	K-40	12	26	308/311= 99	NORM, all geographic regions	$1.3x10^9$ y	27	2.3
8.	Be-7	9	22	263/311= 85	NORM, Appalachian Highlands	53 d	5.5	<1
9.	Pa-234m	7	27	80/311= 86	U-238 decay	1 m	<1	<1
10.	Th-234	6.7	23	191/311= 29	U-238-decay, Intermontane Plateaus, Rocky Mt.	24 d	<1	<1
11.	Ra-228	5.1	38	271/311= 87	NORM, Interior Plains, ground water, < 10 MGD	6 y	65	42
12.	H-3	5	8	111/158= 70	Academic/Medical/Research	12 y	<1	<1
13.	Th-228	4.1	9	92/92= 100	NORM, Interior and Atlantic Plains, ground water, < 10 MGD	2 y	1000	4.4

Table L.4 Radionuclides Somewhat Likely to be Detected, 95th Percentile Concentration >ND and <4 pCi/g , and Percent Samples Generally Low

They are ranked in decreasing order of concentration. The maximum concentration, percent of samples detected, probable source and half-life are also listed. Finally, the Relative Contribution of a Worker Loading at a POTW (air exchange rate = 3 per hour, room height = 4 meters, and time exposed to sludge = 1000 hours per year) at the 95% peak dose is listed next to the Relative Contribution of an Onsite Resident at the 95 % peak dose after 20 years of application.

Rank	Radio-nuclide	Concentration (pCi/g)		Percent Samples Detected	Probable source (only key sources are identified)	Half-life	Relative contribution, 95%-ile	
		95%-ile	Max				Worker Loading	Onsite Resident (20 y)
14.	Pb-210	4	13	135/311= 43	Uranium, Pacific Mountains	22 y	<1	24
15.	Pb-214	2.6	17	253/311= 81		27 m	<1	<1
16.	Bi-214	2.3	16	238/311= 77		20 m	<1	<1
17.	Pb-212	1.9	15	303/311= 97		11 h	<1	<1
18.	Bi-212	1.3	13	101/311= 32		61 m	<1	<1
19.	Sr-90	1	9.4	64/98= 65	Academic	29 y	<1	7.2
20.	C-14	1	3	62/158= 39	Academic	5730 y	<1	9.6
21.	Th-230	1	1.7	92/92= 100	Uranium, Appalachian Highlands, Atlantic and Interior Plains	77 x 10^3 y	<1	25
22.	Tl-208	0.96	4.8	180/311= 58		3 m	<1	<1
23.	Ra-224	0.9	12	47/311= 15		4 d	<1	<1
24.	Tl-202	0.53	1.16	73/311= 23		12 d	<1	<1
25.	Th-232	0.6	1.6	92/92= 100	U mills, Appalachian Highlands	14 x 10^9 y	2.5	13
26.	U-235	0.45	3.1	112/311= 26		700 x 10^6y	<1	<1
27.	Cs-137	0.11	3.6	133/311= 43		30 y	<1	<1
28.	Th-227	0.1	0.5	49/207= 24		19 d	<1	<1
29.	Pu-238	0.07	0.19	75/92= 82		88 y	<1	<1
30.	In-111	0.04	3.6	19/311= 6		3 d	<1	<1
31.	Pu-239	0.04	0.12	68/92= 74		24 x 10^3 y	<1	<1

Table L.5 Radionuclides Least Likely to be Detected, No Detect (ND) for the 95th Percentile and 4 or Less Percent of Samples Detected, Ranked in Decreasing Order of Maximum Concentration

The maximum concentration, percent of samples detected, probable source and half-life are also listed. Finally, the Relative Contribution to the dose of a Worker Loading at a POTW (air exchange rate = 3 per hour, room height = 4 meters, and time exposed to sludge = 1000 hours per year)at the 95% peak dose is listed next to the Relative Contribution of an Onsite Resident at the 95 % peak dose after 20 years of application. The max is used as the concentration to give an extreme relative dose.

Rank	Radio-nuclide	Concentration (pCi/g)		Percent samples detected	Probable source (only key sources are identified)	Half-life	Relative contribution, 95%-ile	
		95%-ile	Max				Worker Loading	Onsite Resident (20 y)
32.	I-125	ND	40	11/311= 4		60 d	<1-max	<1-max
33.	Sm-153	ND	27	1/311= 0.3		47 h	<1-max	<1-max
34.	Eu-154	ND	21	1/311= 0.3	Medical	9 y	42-max	75-max
35.	Co-60	ND	5.1	13/311= 4	Academic/Industry	5 y	21-max	26-max
36.	Cr-51	ND	3.5	6/311= 2		28 d	<1-max	<1-max
37.	Am-241	ND	2.5	10/311= 3	Smoke detector	432 y	<1-max	1.4-max
38.	Fe-59	ND	0.4	1/311= 0.3	Industry	45 d	7.8-max	<1-max
39.	Co-57	ND	0.26	13/311= 4		271 d	<1-max	<1-max
40.	Ra-223	ND	0.09	2/311= 0.6		11 d	<1-max	<1-max
41.	La-138	ND	0.07	1/311= 0.3		135×10^9 y	<1-max	<1-max
42.	Zn-65	ND	0.06	1/311= 0.3		244 d	<1-max	<1-max
43.	Cs-134	ND	0.04	1/311= 0.3		2 y	<1-max	<1-max
44.	Ce-141	ND	0.016	1/311= 0.3		33 d	<1-max	<1-max
45.	Rn-219	ND	ND	0/311= 0		4 s	<1-max	<1-max

Source:

Table 4.1 Concentrations of Radionuclides in Sludge, ISCORS Survey Report (ISCORS 2003) Background Tables