Council Request Update

November 2, 2017

Council Request: 17-176
Requested by: Councilmember Barrentine
Request: Request for the policies and procedures relating to residual disposal at the Allen Filtration Plant
Assigned to: Utilities
Response: Please see the response provided by Director of Utilities Tom Brennan

To: Mayor Jefferson and City Council Members

Through: Eric Keck, City Manager

From: Tom Brennan, Director of Utilities

Date: October 26, 2017

Subject: Council Request 17-176
The policies and procedures relating to residual disposal at Allen Filtration Plant

City Council requested the policies and procedures relating to residual disposal at the Allen Filtration Plant. The Allen Water Filtration Plant complies with Colorado Department of Public Health and Environment guidance documents that are attached.

Interim Policy and Guidance Pending Rulemaking for Control and Disposition of Technologically-Enhanced Naturally Occurring Radioactive Materials in Colorado

Rev. 2.1
Final Draft for Comment

February 2007

Colorado Department of Public Health and Environment

Hazardous Materials and Waste Management Division
Water Quality Control Division

Executive Summary

The purpose of this *Interim Policy and Guidance Pending Rulemaking for Control and Disposition of Technologically-Enhanced Naturally Occurring Radioactive Materials in Colorado* is to provide disposal policy, general guidance and suggested criteria for the control and release of technologically enhanced naturally occurring radioactive material (TENORM). Radioactivity is naturally present in rocks, soils, surface water and groundwater at trace concentrations. The radioactivity in TENORM is due to a few predominant radionuclides associated with two radioactive decay series, namely uranium-238 and thorium-232 and their respective decay products, and potassium-40. The interim policy describes a tiered, graded approach acceptable to the Colorado Department of Public Health and Environment (the Department) for disposal or reuse of TENORM, primarily from the treatment of drinking water, but may also be applied to other diffuse sources on a case-by-case basis. The guidance provides an overview of the issue and suggested approaches to controlling potential doses from TENORM. In a few isolated instances, a radioactive materials license may be required for control or disposal of TENORM.

Most industrial waste streams that contain small amounts of radioactivity are not classified as radioactive waste. Disposal of most commercial low-level radioactive waste (LLRW) is prohibited in Colorado. One Colorado facility is licensed to accept a subset of low-level radioactive waste (LLRW) that is limited only to TENORM. In Colorado, TENORM may be considered solid waste, depending on the dose and risk of the particular waste. In most instances, bulk TENORM will be able to be managed as a solid waste, whereas more concentrated forms may require licensure and management as radioactive material. Therefore, the final disposition of wastes containing TENORM are made using a risk-informed approach that depends on the amount of radioactivity in the waste, the associated risks to the public, workers, and the environment, along with other stakeholder (social) inputs using reasonable and prudent precautions. Since disposal of solid waste is largely regulated at the local level, suggested criteria for permitting authorities is presented. Detailed discussions of the regulations follow in later sections.

The Department has authority under numerous Colorado statutes and regulations that are relevant to control and disposition of TENORM, on which the interim Policy and Guidance are largely based. The statutes and regulations include: the *Colorado Solid Waste Act* [30 CRS 20, Pt.1], the *Radiation Control Act*, [25 CRS 11], *Hazardous Waste Commission Regulations* [6CCR 1007-3], *Basic Standards for Groundwater* [5CCR1002-41] and the *Basic Standards and Methodologies for Protection of Surface Water* [5CCR 1002-31], and the *Primary Drinking Water Regulations* [5 CCR 1003-1], the *Colorado Rules and Regulations Pertaining to Radiation Control* [6CCR 1007-1], the *Colorado Hazardous Waste Regulations* (for the underground injection control program), and the *Regulations Pertaining to Solid Waste Disposal Sites and Facilities* [6CCR 1007-2]. The Colorado programs for drinking water and solid waste generally mirror those of the EPA. For the Radiation program, Colorado is an Agreement state, and its radiation program is modeled after, but may go beyond the scope of, the U.S. Nuclear Regulatory Commission program, which does not regulate NORM or TENORM. About a dozen states have specific regulations for TENORM, the others regulate it under their rules and regulations of radioactive materials.

The regulation of radioactive material is the responsibility of the Radiation Control Program (RCP) of the Hazardous Materials and Waste Management Division (HMWMD) of the Department. The authority to regulate TENORM is found in the general provisions *Radiation Control Act* [CRS-25-11-101], and the *Colorado Rules and Regulations Pertaining to Radiation Control* [6 CCR-1007]. Colorado has adopted dose-based limits of exposure to workers and the public derived from federal regulations. Workers at most facilities are considered members of the public, not radiation workers. Federal guidance provides an upper dose limit to members of the public from all industries and facilities, and provides for a site-specific approach to be taken. The As Low As Reasonably Achievable (ALARA) concept is also applied to reduce the potential dose as far below the limit as is feasible, economic, social and logistical concerns taken into account. In addition to risk, other stakeholder concerns were taken into account when deriving the policy and guidance.

The guidance also recommends a preventive approach such as engineered safety systems or operational procedures, to safely manage potential exposures to TENORM. The control of occupational exposures associated with TENORM is addressed by the guidance. Very few workers are likely to be exposed to the extent that they would be required to become trained radiation workers. Common industrial hygiene practices employed at the subject facilities, perhaps with some additional training, usually provide adequate protection from radioactivity.

It is anticipated that rulemaking will be pursued in the near future to codify the policy and accepted practices in the guidance. Since the issue of TENORM spans multiple industries and jurisdictions, it is not possible for a one-size-fits-all approach. Therefore, in addition to the suggested approach taken in this document, other approaches may be submitted to the Department for review.

The Department primarily developed this policy and guidance to help utilities and disposal contractors develop best practices for protection to workers, the general public and the environment from radioactivity concentrated as a result of radionuclide removal from drinking water, and is based on existing practices of the Department. It is designed to be a companion document to the Environmental Protection Agency (EPA) "*A Regulators' Guide to the Management of Radioactive Residuals from Drinking Water Technologies*" (EPA 2005). It may be expanded to other industrial sectors (i.e., oil and gas, uranium overburden) as needs arise and resources become available.

The policy and guidance do not apply to common activities, such as tilling or plowing for agricultural purposes and preparation and grading of sites for construction. It is concerned with practices and operations that might concentrate and relocate radioactivity or make radioactivity more accessible such that members of the public potentially may receive doses that would warrant the application of appropriate protective measures and corrective actions.

The last documented review of CPDHE policy regarding the handling and disposition of TENORM, and specifically water treatment residues, was conducted in 1988. Since that time, numerous changes in national and state regulations and policies have occurred on how residuals are handled and disposed. A number of federal and state statutes, regulations and guidance documents are the basis for the criteria in the disposal policy and recommended practices in this guidance. Work on the revised policy began in 2003. A stakeholder process was used in 2005 to develop input for the first draft, which was issued in January, 2006. Comments were received on the first draft through June 2006, leading to a major rewrite, which yielded this document, which is also consistent with existing policy and approach. Concurrent with the comment and rewriting period, the Rocky Mountain Low-Level Radioactive Waste Board took up the issue of diffuse TENORM and made modifications to its rules, which are reflected in this draft. Also, the Nuclear Regulatory Commission has issued guidance to provide enforcement discretion for utilities that possess uranium in source material concentrations (USNRC 2006). Under current regulations, utilities that possess uranium in source material concentrations are required to obtain a specific radioactive materials license.

The primary method of distribution of the document will be through electronic files. Therefore, acronyms and references for both the Policy and the Guidance are consolidated into the same listings, and hyperlinked.

References

6 CCR 1007-2. *Regulations Pertaining To Solid Waste Disposal Sites and Facilities.* 6 CCR 1007-2. Colorado Department of Public Health and Environment, Denver, CO. April

6 CCR 1007. *Colorado Rules and Regulations Pertaining to Radiation Control* [6 CCR-1007] Colorado Department of Public Health and Environment, Denver, CO.

6 CCR 1003-7. *Regulations Pertaining To The Beneficial Use Of Water Treatment Sludge And Fees Applicable To The Beneficial Use Of Sludges.* [5 CCR 1003-7] Colorado Department of Public Health and Environment, Denver, CO. October.

5 CCR 1003-2. *Water and Wastewater Facility Operators Certification Requirements.* Regulation #100. Water Quality Control Commission. Colorado Department of Public Health and Environment, Denver, CO. .

5 CCR 1002-41. *The Basic Standards for Groundwater*. Regulation #41. Water Quality Control Commission. Colorado Department of Public Health and Environment, Denver, CO. March

5 CCR 1002-31. *Basic Standards and Methodologies for Protection of Surface Water* [5CCR 1002-31] August.

5 CCR 1003-1. *Colorado Primary Drinking Water Regulations* [5 CCR 1003-1] Colorado Department of Public Health and Environment, Denver, CO. March

6 CCR 1007-3. *Hazardous Waste Commission Regulations* [6CCR 1007-3] Colorado Department of Public Health and Environment, Denver, CO. August

25 CRS 11. *Radiation Control Act* [25 CRS 11-101]

25 CRS 15. *Colorado Hazardous Waste Act* [25 CRS 151

30 CRS 20. *Colorado Solid Waste Disposal and Facilities Act* [30 CRS 20, Pt.1]

33 USC. 1251 *Federal Water Pollution Control Act*. (33 U.S.C. 1251 et seq.) P.L. 107–303, November 27, 2002.

40 USC 121 *Atomic Energy Act* [40 USC 121] as amended.

42 USC 15801 *Energy Policy Act of 2005*. Public Law 109-58

42 USC. 9601-9675. *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* (CERCLA). 1980

42 USC. 6901-6992k. Resource Conservation and Recovery Act (RCRA)

EPA 2005. *A Regulators' Guide to the Management of Radioactive Residuals from Drinking Water Treatment Technologies*. EPA 816-R-05-04. U.S. Environmental Protection Agency, Washington, DC. July.

USNRC 2006. *Guidance For Receiving Enforcement Discretion When Concentrating Uranium At Community Water Systems*. RIS 2006-20. U.S. Nuclear Regulatory Commission, Washington, DC.

Table of Contents

Acronyms, Abbreviations And Symbols

µ	Micro
^{40}K	Potassium-40
^{228}Ac	Actinium-228
^{224}Ra	Radium-224
^{226}Ra	Radium-226
^{228}Ra	Radium-228
^{232}Th	Thorium-232
^{NAT}Th	Natural thorium
^{234}U	Uranium-234
^{238}U	Uranium-238
^{NAT}U	Natural uranium
ALARA	As Low As Reasonably Achievable
BAT	Best Available Technologies
Bq	Becquerel
CD	Certificate of Designation
CDPHE	Colorado Department of Public Health and Environment
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CESQG	Conditionally Exempt Small Quantity Generators
CDPS	Colorado Discharge Permit System
CPDWR	Colorado *Primary Drinking Water Regulations*
CRCPD	Conference of Radiation Control Program Directors
CRR	Colorado *Rules And Regulations Pertaining to Radiation Control*
CWA	Clean Water Act
CWS	Community Water System
Department	The Colorado Department of Public Health and Environment
D&O	Design and Operations
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
g	Gram
HMWMD	Hazardous Materials and Waste Management Division
IX	Ion Exchange
K	Potassium
L	Liter
LLMW	Low-Level Mixed Waste
LLRW	Low-Level Radioactive Waste
m	Milli
MCL	Maximum Contaminant Level
MCLG	Maximum Contaminant Level Goal
MGD	Million Gallons Per Day
MSWLF	Municipal Solid Waste Landfill
^{nat}U	Naturally Occurring Uranium
NCRP	National Council on Radiation Protection and Measurements
NORM	Naturally Occurring Radioactive Material

NPDES	National Pollution Discharge Elimination System
NRC	U.S. Nuclear Regulatory Commission
O & M	Operations and Maintenance
pCi	Picocurie
POTW	Publicly Owned Treatment Works
POU	Point of Use
PWS	Public Water Systems
RAA	Running Annual Average
Radiation Regulations	Colorado *Rules and Regulations Pertaining to Radiation Control*
RCA	Radiation Control Act
RCP	Radiation Control Program
RCRA	Resource Conservation And Recovery Act
Rem	Radiation Equivalent Man
RMP	Residual Management Plan
RO	Reverse Osmosis
RR	Radionuclides Rule
SDWA	Safe Drinking Water Act
SDWIS	Safe Drinking Water Information System
SPARRC	Software Program to Ascertain Residuals Radionuclide Concentrations
SSCT	Small System Compliance Technologies
Sv	Sievert
TENORM	Technologically Enhanced Naturally Occurring Radioactive Materials
TCLP	Toxicity Characteristic Leaching Procedure
WQCD	Water Quality Control Division
y	Year

Interim Disposal Policy for TENORM

1 Introduction

1.1 Purpose

The purpose of this Interim Policy and Guidance Pending Rulemaking is to provide disposal policy, general guidance and suggested criteria for the control and release of technologically enhanced naturally occurring radioactive material (TENORM), primarily uranium and thorium. Radioactivity is naturally present in rocks, soils, surface water and groundwater at trace concentrations. The radioactivity in TENORM is due to a few predominant radionuclides associated with two radioactive decay series, namely uranium-238 (^{238}U) and thorium-232 (^{232}Th) and their respective decay products, and potassium-40. The interim policy describes an approach, consistent with current practice, acceptable to the Colorado Department of Public Health & Environment (the Department) for disposal of TENORM, primarily from the treatment of drinking water, but may also be applied to other sources (waste streams) on a case-by-case basis. The guidance provides an overview of the issue and suggested approaches to controlling potential doses from TENORM. In a few isolated instances, a radioactive materials license may be required for control or disposal of TENORM.

Disposal of liquid and solid residuals may come with logistical, political, and economic challenges. In some cases, there are no easy answers for safe, economical disposition. Disposal of most commercial low-level radioactive waste (LLRW) is prohibited in Colorado. One Colorado facility is licensed to accept a subset of low-level radioactive waste (LLRW) that is limited only to TENORM. Many wastes that contain small amounts of radioactivity are not classified as radioactive waste. In Colorado, TENORM may be considered solid waste, depending on the dose and risk of the particular waste. In most instances, bulk TENORM will be able to be managed as a solid waste, whereas more concentrated forms may require licensure and management as radioactive material. Therefore, the final disposition of wastes containing TENORM are made using a risk-informed approach that depends on the amount of radioactivity in the waste, the associated risks to the public, workers, and the environment, along with other stakeholder (social) inputs using reasonable and prudent precautions. Since disposal of solid waste is largely regulated at the local level, suggested criteria for permitting authorities is presented. Detailed discussions of the regulations follow in later sections.

1.2 Scope

The Department has authority under numerous Colorado statutes and regulations that are relevant to control and disposition of TENORM, on which the interim Policy and Guidance are largely based. The statutes and regulations include the

- *Colorado Solid Waste Act* [30 CRS 20, Pt.1],
- *Radiation Control Act*, [25 CRS 11],
- *Hazardous Waste Commission Regulations* [6 CCR 1007-3],
- *Basic Standards for Groundwater* [5 CCR 1002-41],

- *Basic Standards and Methodologies for Protection of Surface Water* [5 CCR 1002-31],
- *Primary Drinking Water Regulations* [5 CCR 1003-1],
- *Colorado Rules and Regulations Pertaining to Radiation Control* [6CCR 1007-1],
- *Colorado Hazardous Waste Regulations* (for the underground injection control program), and the
- *Regulations Pertaining to Solid Waste Disposal Sites and Facilities* [6CCR 1007-2].

The Colorado programs for drinking water and solid waste generally mirror those of the U.S. Environmental Protection Agency (EPA). Drinking water is regulated by the Water Quality Control Division (WQCD), and solid waste is regulated by the Hazardous Materials and Waste Management Division (HMWMD) of the Department. For the Radiation Control Program, Colorado is an Agreement state, and its radiation program is modeled after, but may go beyond the scope and requirements of, the U.S. Nuclear Regulatory Commission (NRC) program, which does not regulate diffuse NORM or TENORM.

The regulation of radioactive material is the responsibility of the Radiation Control Program (RCP), within the HMWMD. The authority to regulate TENORM is found in the general provisions of the *Radiation Control Act* [CRS-25-11-101], and the *Colorado Rules and Regulations Pertaining to Radiation Control* [6 CCR-1007]. Colorado has adopted dose-based limits of exposure to workers and the public derived from federal regulations. Workers at most facilities are considered members of the public, not radiation workers. Federal guidance provides an upper dose limit to members of the public from all industries and facilities, and provides for a site-specific approach to be taken. The As Low As Reasonably Achievable (ALARA) concept is also applied to reduce the potential dose as far below the limit as is feasible, economic, social and logistical concerns taken into account. In addition to risk, other stakeholder concerns were taken into account when deriving the policy and guidance.

The Department primarily developed this policy and guidance to help utilities and disposal contractors develop best practices for protection to workers, the general public and the environment from radioactivity concentrated as a result of radionuclide removal from drinking water. It may be expanded to other industrial sectors (i.e., oil and gas, uranium overburden) as needs arise and resources become available. It is designed to be a companion document to the Environmental Protection Agency (EPA) "*A Regulators' Guide to the Management of Radioactive Residuals from Drinking Water Technologies*" (EPA 2005).

The guidance also recommends a preventive approach such as engineered safety systems or operational procedures, to safely manage potential exposures to TENORM. The control of occupational exposures associated with TENORM is addressed by the guidance. Very few workers are likely to be exposed to the extent that they would be required to become trained radiation workers. Common industrial hygiene practices employed at the subject facilities, perhaps with some additional training, usually provide adequate protection from radioactivity.

It is anticipated that rulemaking will be pursued in the coming years to codify the policy and accepted practices in the guidance. Since the issue of TENORM spans multiple industries and jurisdictions, it is not possible for a one-size-fits-all approach. Therefore, in addition to the suggested approach taken in this document, other approaches may be submitted to the Department for review.

The policy and guidance do not apply to common activities, such as tilling or plowing for agricultural purposes and preparation and grading of sites for construction. It is concerned with practices and operations that might concentrate and relocate radioactivity or make radioactivity more accessible such that members of the public potentially may receive doses that would warrant the application of appropriate protective measures and corrective actions.

The last documented review of CPDHE policy regarding the handling and disposition of TENORM, and specifically, water treatment residues was conducted in 1988. Since that time, numerous changes in national and state regulations and policies have occurred on how residuals are handled and disposed. A number of federal and state statutes, regulations and guidance documents are the basis for the criteria in the disposal policy and recommended practices in this guidance. Work on the revised policy began in 2003.

2 Definitions

The following definitions are provided for the purpose of facilitating the interpretation and implementation of the policy and guidance. Definitions that are in Colorado statute or regulation are followed by the citation.

“Administrative Release” means the act of removing items or material from administrative controls with no further radiological restrictions on their use or disposition. This definition is used to differentiate it from “clearance” or “unrestricted release,” which relates to the release of material or items that are under the jurisdiction of a regulatory authority or regulatory controls for licensed radioactive materials.

“ALARA” means As Low As is Reasonably Achievable. In radiation protection philosophy, ALARA means making every reasonable effort to maintain exposures to radiation as far below dose limits as is practical, consistent with the purpose of the practice, taking into account the state of technology, the economics of improvements in relation to the technology, the economics of improvements in relation to benefits to public health and safety, and other societal and socioeconomic considerations.

"Background radiation" means radiation from: (1) extraterrestrial sources; (2) naturally occurring radioactive material (which has not been technologically enhanced), including radon, except as a decay product of source or special nuclear material; and (3) global fallout as it exists in the environment from the testing of nuclear explosive devices or from past nuclear accidents such as Chernobyl that are not under the control of the licensee or registrant. "Background radiation" does not include sources of radiation from radioactive materials regulated by the Department.

“Biosolids” means the accumulated residual product resulting from a domestic wastewater treatment works. Biosolids does not include grit or screenings from a wastewater treatment works, commercial or industrial sludges (regardless of whether the sludges are combined with domestic sewage), sludge generated during treatment of drinking water or domestic or industrial septage.

"Byproduct material" means:
(1) 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; and
(2) The tailings or wastes produced by the extraction or concentration of uranium or thorium from ore processed primarily for its source material content, including discrete surface wastes resulting from uranium or thorium solution extraction processes. Underground ore bodies depleted by these solution extraction operations do not constitute "byproduct material" within this definition.

"Certificate of Designation" means a document issued by the governing body having jurisdiction to a person authorizing the use of land for a solid waste disposal site and facility pursuant to the [Solid Waste] Act. The "certificate of designation", which incorporates all information as may be required by the Department and the governing body having jurisdiction, is then issued by the governing body having jurisdiction if the Department has determined that the minimum standards are met.

“Composting” means the biological process of degrading organic materials that is facilitated and controlled through intentional and active manipulation of piles and windrows. These manipulations may include but are not limited to, grinding, mixing of feedstocks and bulking materials, addition of liquids, turning of piles or mechanical manipulation.

"Compost facility" means a site where compost is produced.

“Compost Feedstock” or “Feedstock” means any decomposable organic material used in the production of compost or chipped and ground material including, but not limited to, green wastes, animal material, manure, biosolids and solid waste.

“Community water system” means a public water system that serves at least 15 service connections used by year-round residents or that regularly serves at least 25 year-round residents.

"Industrial wastes" means all solid wastes, including mill tailings and mining wastes, resulting from the manufacture of products or goods by mechanical or chemical processes that are not a hazardous waste regulated under 6CCR 1007-3, the Colorado Hazardous Waste Regulations. Such waste may include, but is not limited to, waste resulting from the following manufacturing processes: electric power generation; fertilizer/agricultural chemicals; food and related products/by-products; inorganic chemicals; iron and steel manufacturing; leather and leather products; nonferrous metals manufacturing/foundries; organic chemicals; plastics and resins manufacturing; pulp and paper industry; rubber and miscellaneous plastic products; stone, glass, clay, and concrete products; textile manufacturing; transportation equipment and water treatment. This term does not include oil and gas wastes regulated by the Colorado Oil and Gas Conservation Commission.

"Licensed material" means radioactive material received, possessed, used, transferred, or disposed of under a general or specific license issued by the Department.

"Monofill" means a landfill or section of landfill at which only one type of waste is accepted for disposal.

"Natural radioactivity" means radioactivity of naturally occurring nuclides.

"Natural thorium" means thorium with the naturally occurring distribution of thorium isotopes (essentially 100 weight per cent thorium-232).

"Natural uranium" means uranium containing a mixture of the uranium isotopes 234, 235 and 238 (approximately 0.7 weight percent uranium-235 and the remainder by weight essentially uranium-238) that is neither enriched nor depleted in the isotope uranium 235.

"Naturally occurring radioactive material" [NORM] means any nuclide that is radioactive in its natural physical state and is not manufactured. "Naturally occurring radioactive material" does not include source material, special nuclear material, or by-products of fossil fuel combustion, including but not limited to bottom ash, fly ash and flue-gas emission by-products. 25-11-101 (2.7)

"Occupational dose" means the dose received by an individual in the course of employment in which the individual's assigned duties involve exposure to radiation or to radioactive material from licensed and unlicensed sources of radiation whether or not the sources of radiation are in the possession of the licensee, registrant or other person. Occupational dose does not include doses received (1) from background radiation, (2) from any medical administration the individual has received, (3) from exposure to individuals administered radioactive material and released in accordance with Section 7.26 of these regulations, (4) from voluntary participation in medical research programs, or (5) as a member of the public.

“Practice” means an activity that can result in radiation exposures and doses to workers or members of the public from TENORM, including any associated sources of radiation used in the normal course of a process, usage, beneficiation, manufacturing, storage, distribution, recycling, or disposal. Practice excludes events that can be classified as emergencies or incidents.

“Process knowledge” describes a collection of facts, information, and data characterizing or describing past or current processes or practices. When invoked, process knowledge shall be documented, as is appropriate, with supporting technical information, including plans, procedures, specifications, assumptions, algorithms, definitions, expert testimony, etc. As a substitute, professional judgment shall only be used in situations where information or data are not reasonably available by collection, survey, literature search, or experimentation.

“Products” means something made, manufactured, refined, beneficiated, or processed as raw or finished material and feedstock for use by other industries or in consumer or industrial products. Products include items, materials, devices and equipment.

"Public dose" means the dose received by a member of the public from exposure to radiation or radioactive material released by a licensee, or to any other source of radiation under the control of a licensee. Public dose does not include occupational dose, or doses received from background radiation, from any medical administration the individual has received, from exposure to individuals administered radioactive material and released in accordance with Section 7.26 of these regulations, or from voluntary participation in medical research programs. Part 1.

“Public water system” (PWS) means a system for the provision to the public of water for human consumption through pipes or other constructed conveyances, if such system has at least fifteen service connections or regularly serves an average of at least twenty-five individuals daily at least 60 days out of the year. Such term includes:
(i) Any collection, treatment, storage, and distribution facilities under control of the operator of such system and used primarily in connection with such system.
(ii) Any collection or pretreatment storage facilities not under such control, which are used primarily in connection with such system.
Such term does not include any "special irrigation district." A public water system is either a "community water system" or a "non-community water system."

“Radiation” means alpha particles, beta particles, gamma rays, x-rays, and other particles capable of causing ionizations. This definition does not include nonionizing radiation, such as micro- and radio-waves, and infra-red and ultraviolet radiation.

"Radioactive material" means any material, solid, liquid, or gas, which emits ionizing radiation spontaneously. 25-11-101 (3)

"Reasonably maximally exposed individual" means a representative of a population who is exposed to TENORM at the maximum TENORM concentration measured in environmental media found at a site along with reasonable maximum case exposure assumptions. The exposure is determined by using maximum values for one or more of the most sensitive parameters effecting exposure, based on cautious but reasonable assumptions, while leaving the others at their mean value. (CRCPD Part N)

“Recycling or Reuse” means any process by which material, products, feedstock are used or reused as is for any purpose; contaminated scrap metals which may be recycled for their metallic properties; and equipment salvaged and returned intact for use in their originally intended purpose (form and function).

"Residual radioactivity" means radioactivity in structures, materials, soils, groundwater, and other media at a site resulting from activities under the licensee’s control. This includes radioactivity from all licensed and unlicensed sources used by the licensee, but excludes background radiation. It also includes radioactive materials remaining at the site as a result of routine or accidental releases of radioactive material at the site and previous burials at the site, even if those burials were made in accordance with the provisions of Part 4 of the radiation regulations. (CRCPD Part N)

"Risk-Based" An approach to regulatory decision-making in which a safety decision is solely based on the numerical results of a risk assessment. This places heavier reliance on risk assessment results than may currently be practicable. Note that the Commission [NRC] does not endorse an approach that is "risk-based;" however, this does not invalidate the use of calculations to demonstrate compliance with certain criteria, such as dose limits. (SECY-98-144)

"Risk-informed" An approach to regulatory decision-making that represents a philosophy whereby risk insights are considered together with other factors to establish requirements that better focus licensee and regulatory attention on design and operational issues commensurate with their importance to health and safety. A "risk-informed" approach enhances the traditional approach by: (a) allowing explicit consideration of a broader set of potential challenges to safety, (b) providing a logical means for prioritizing these challenges based on risk significance, operating experience, and/or engineering judgment, (c) facilitating consideration of a broader set of resources to defend against these challenges, (d) explicitly identifying and quantifying sources of uncertainty in the analysis, and (e) leading to better decision-making by providing a means to test the sensitivity of the results to key assumptions. Where appropriate, a risk-informed regulatory approach can also be used to reduce unnecessary conservatism in deterministic approaches, or can be used to identify areas with insufficient conservatism and provide the bases for additional requirements or regulatory actions. (SECY-98-144)

“Should” The term “should” is used to identify elements or actions that are considered guidance, but are not mandatory. If the guidance is not followed, technical equivalency in the outcome should be demonstrated when using alternate methods.

"Sludge" means any solid or semi-solid waste generated by municipal, commercial, or industrial wastewater treatment plant, water supply treatment plant, or air pollution control facility, which has been treated to obtain pathogen destruction, odor control, or putrescibility control.

"Solid waste" means any garbage, refuse, sludge from a waste treatment plant, water supply treatment plant, air pollution control facility, or other discarded material, including solid, liquid, semisolid or contained gaseous material resulting from industrial operations, commercial operations or community activities. "Solid waste" does not include any solid or dissolved materials in domestic sewage, or agricultural wastes, or solid or dissolved materials in irrigation return flows, or industrial discharges which are point sources subject to permits under the provisions of the "Colorado Water Quality Control Act", Title 25, Article 8, C.R.S or materials handled at facilities licensed pursuant to the provisions on "Radiation Control Act" in Title 25, Article 11, C.R.S. “Solid waste” does not include: (a) materials handled at facilities licensed pursuant to the provisions on radiation control in Article 11 of Title 25, C.R.S.; or (b) excluded scrap metal that is being recycled; or (c) shredded circuit boards that are being recycled.

"Source material" means material, in any physical or chemical form, including ores, that contain by weight one-twentieth of 1 percent (0.05 percent) or more of uranium, thorium or any combination thereof. Source material does not include special nuclear material.

"Source of radiation" means any radioactive material or any device or equipment emitting or capable of producing, radiation.

“Surface Contamination” means the presence of radioactive contamination on or near the surface of an item or material. If the radioactivity is present in inaccessible areas or on internal surfaces and at depths well beyond the surface, the contamination shall be considered as volumetric contamination. Surface contamination is expressed in terms of radioactivity levels per unit area, including Bq/cm^{2}$_{2}$, Bq/100 cm^{2}, or dpm/100 cm^{2}.

"Survey" means an evaluation of the radiological conditions and potential hazards incident to the production, use, transfer, release, disposal, or presence of sources of radiation. When appropriate, such evaluation includes, but is not limited to, tests, physical examinations and measurements of levels of radiation or concentrations of radioactive material present.

"Technologically enhanced naturally occurring radioactive material" or "TENORM" means naturally occurring radioactive material whose radionuclide concentrations are increased by or as a result of past or present human practices. "TENORM" does not include:

(a) Background radiation or the natural radioactivity of rocks or soils;
(b) "Byproduct material" or "source material," as defined by Colorado statute or rule; or
(c)Enriched or depleted uranium as defined by Colorado or federal statute or rule. 25-11-201 (1)(b)(4).

"Total effective dose equivalent" (TEDE) means the sum of the deep dose equivalent for external exposures and the committed effective dose equivalent for internal exposures.

“Use-Protected Designation” are waters that the Commission has determined do not warrant the special protection provided by the outstanding waters designation or the antidegradation review process.

“Volume Contamination” means the presence of radioactive contamination residing in or throughout the volume or matrix of an item or material. Volume contamination is usually expressed in terms of radioactivity levels per unit mass, including Bq/g, Bq/kg, Bq/cm^{3}, or dpm/cm^{3}.

"Waste impoundment, or impoundment,” means a facility or part of a facility that is a natural topographic depression, excavation, pit, pond, lagoon, trench or diked area. An impoundment, which may be lined with earthen material or synthetic material, is designed for storage, treatment or final disposal of solid waste. Examples of impoundments are holding, storage, settling and aeration pits, ponds and lagoons.

"Water treatment plant sludge disposal" means the final disposal of the accumulated solids from the processing of raw water in a treatment plant of a municipality or industry.

3 Disposal Policy for TENORM

3.1 General Provisions

3.1.1 NORM/TENORM may be classified as wastewater, solid waste or radioactive material depending on the physical, chemical, radiological characteristics and hazard of the material, as well as regulatory definitions.

3.1.2 Control and disposition of diffuse NORM/TENORM are addressed through WQCD discharge permits, Solid waste Design and Operations Plans, radioactive materials licenses, exemptions, or a combination of the above. Disposition is dependent on the origin and radionuclide concentration of materials, and the Department and local permitting authority approval.

3.1.3 Not withstanding this policy and guidance, the Department retains its full authority over these materials under Colorado statutes and regulations.

3.1.4 Any facility wishing to receive a variance from the limits set forth in this policy may submit documentation to the Department demonstrating that acceptance of specified material will not jeopardize public health or the environment or create worker safety, liability or long term management concerns. The requirements of § 4.34 of the Radiation Regulations and pertinent sections of Section 1.5 of the Solid Waste Regulations apply. The Department shall make the final determination whether or not the variance will meet compatibility, regulatory limits and design criteria.

3.1.5 Control and release of discrete NORM (e.g., sealed sources and radium needles) must follow the established Radiation Regulations and the implementing regulations of the Energy Policy Act of 2005 (insert citation).

3.1.6 Facilities generating solid diffuse NORM/TENORM shall representatively analyze their materials for gross alpha, and should representatively analyze their materials for natural uranium. Material with a median gross alpha concentration greater than 40 pCi/g or uranium values greater than 30 pCi/g above background shall consult with the Division prior to disposition and provide an isotopic characterization of the materials for ^{226}Ra, ^{228}Ra and ^{nat}U. The requirement to consult with the Radiation Control Program is found in Section 12 of the Solid Waste Regulations.

3.1.7 Disposal facilities receiving TENORM are generally precluded from receiving radioactive materials "unless so designated." [The Solid Waste Act [C.R.S 30-20-110.(c)] Therefore, the local permitting authorities are to be consulted prior to disposition of TENORM in landfills. Suggested permitting criteria that the permitting authorities may want to consider are presented in this policy and guidance.[1]

[1] The Solid Waste Act [C.R.S 30-20-110.(c)] states: "No radioactive materials or materials contaminated by radioactive substances shall be disposed of in sites or facilities not specifically designated for that purpose."

3.1.8 Records of transfer or disposal of TENORM shall be maintained as required by § 4.48 of the Radiation Regulations.

3.1.9 The Department will base its decisions relative to disposition of diffuse NORM/TENORM on a risk-informed basis, which includes an evaluation of risk to workers, the public, and the environment. Disposition decisions should also incorporate social and economic factors that are consistent with other government sectors (i.e., local permitting authorities) using reasonable and prudent precautions.

3.1.10 Facilities that have been remediated and released for any use with no further radiological restrictions shall be ALARA and meet an annual dose limit of 25 mrem (0.25 mSv), above background, from all appropriate pathways associated with the presence of residual sources of radioactivity (except radon and its short-lived decay products) from land, consistent with the requirements of § 4 of the Radiation Regulations.

3.1.11 Remediation (interventions, clean ups) that result in doses to workers involved in intervention activities above limits for members of the public will be subject to regulatory controls under the Radiation Regulations.

3.1.12 Doses are to be determined using best estimates evaluated over the expected duration of the radiological hazards for radionuclides characterized by slow migration rates in ground water (about 1,000 years). Doses should be determined using risk assessment methods recognized by the Department or standard setting organizations, or by environmental measurements or results of site characterization studies, when feasible, using process knowledge.

3.1.13 If institutional controls are used to meet the dose criteria when releasing a site or facility (other than an already approved facility), a risk assessment analysis should be performed to determine whether there is reasonable assurance that such controls will remain effective over the expected duration of the radiological hazards. The application of institutional controls should consider cost-benefits and societal impacts to receptors and the environment. However, cost alone shall not be the only factor used in defining and implementing institutional controls.

3.1.14 If institutional controls are used to meet dose criteria, the documentation of such controls shall be permanently recorded such that knowledge of the controls is maintained for reference by future site owners and/or occupants, workers and the public. Institutional controls include environmental covenants, deed covenants, constraints on the extraction of natural resources, and zoning laws, among others, that restrict the use of the site to applications intended to minimize radiation

---

The designation comes from the local permitting authority in the form of the Certificate of Designation, and CDPHE approved Disposal and Operations Plans that are required for each facility. Since many items contain trace amounts of radioactivity, the Department uses discretion when interpreting this regulation. The local permitting authority is eitherthe County or the municipality. The ultimate disposition of residuals is a dual process. State and local approval is required to be consistent with the regulation.

exposures to members of the public. Institutional controls should require that the owner/operator or an independent third party carry out periodic monitoring and maintenance of the site and facilities to restrict the movement of radioactivity into the accessible environment.

3.2 Criteria

Table 3-1 presents a summary of the disposal tier criteria.

Table 3-1. Summary of disposal tiers and surface activity release limits

Volumetric disposal			
	Combined $^{226/228}Ra$ (pCi/g above background)	^{NAT}U (pCi/g above background)	^{NAT}Th (pCi/g above background)
Exempt [2] (includes any MSWLF)	< 3	< 30	< 3

---

[2] 1) For natural uranium, the isotopic distribution is given as 48.9% for 238U, 48.9% for 234U, and 2.2% for 235U, by activity.
2) When two or more radionuclides are present from dissimilar decay series (e.g., 210Po and 228Th), the sum-of-the-fractions shall be used in determining if the release limit is met. It is defined as:

$$\sum_{i=1}^{n} C_i \div CL_i \leq 1$$

where Ci is the concentration of radionuclide, i, on or in a material of interest; CLi is the criteria limit for radionuclide, i, on or in material of interest; and n is the total number of radionuclides present in the mixture determined using appropriate radio-analytical procedures or process knowledge.
3) The sum-of-the-fractions method need not be applied when radionuclides present are part of a decay series and its decay products are in secular equilibrium based on process knowledge or radiochemical analysis. If sufficient time has elapsed since the parent and decay products were separated, secular equilibrium may be assumed taking into account their radioactive half-lives.
4) For radionuclides that are known or assumed to be present in the mixture, but are not detectable by conventional or portable survey equipment used to measure the presence of those that are reliably detectable, the sum-of-the-fractions expression may be modified as follows to account for the radioactivity associated with undetectable radionuclides:

$$\sum_{i=1}^{n} \frac{C_i}{CL_i} \div D_{f,i} \leq 1$$

where: Df,i is the detectable fraction of radionuclide, i, in the mixture, and by definition Df,i . 0, and the other terms are as previously defined. The detectable fraction represents the actual fraction of radionuclides that are measured by the chosen survey method. The presence and fraction of detectable radionuclides, for the given type of radiation survey instrumentation being used, shall be determined by appropriate radio-analytical procedures or process knowledge.
For materials containing single or mixtures of radionuclides that are not detectable (i.e., Df,i = 0) by the chosen survey instrumentation or method, the above modification does not apply and their presence and concentrations shall be determined using appropriate laboratory radio-analytical procedures. More specific guidance on implementation can be found in MARSSIM [Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM), EPA 402-R-97-016, Rev. 1]. MARSSIM, Section 4.3.2 and Appendix I.11, presents the methodology in considering the presence of multiple radionuclides and use of surrogate ratios for radionuclides that are not detectable, nor readily measurable.
5) For implementation purposes, additional guidance may be obtained from the following documents:
Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) (NUREG-1575); Multi-Agency Radiological Laboratory Analytical Protocols Manual (MARLAP) (EPA 402-B-04-001A); Minimum Detectable

	Combined $^{226/228}Ra$ (pCi/g above background)	^{NAT}U (pCi/g above background)	^{NAT}Th (pCi/g above background)
Approved MSWLF or Compost feed	< 10	< 100	< 10
Industrial Landfill	< 50	< 300	< 50
RCRA C Hazardous Waste Landfill	< 400	0.05% by weight	0.05% by weight
Surface activity release limits (from ANSI N13.12) (ANSI 1999)[8]			
Radionuclide groups	Surface activity release limits		
Group 1: Radium and thorium, and associated decay products: ^{210}Po, ^{210}Pb, ^{226}Ra, ^{228}Ra, ^{228}Th, ^{230}Th, and ^{232}Th.	600 dpm/100 cm^2 or 0.1 Bq/cm^2		
Group 2: Natural-U: ^{238}U, ^{235}U, and ^{234}U.	6,000 dpm/100 cm^2 or 1.0 Bq/cm^2		
Group 3[3]: ^{40}K	3,600 dpm/100 cm^2 or 0.6 Bq/cm^2		

Concentrations with Typical Radiation Survey Instruments for Various Contaminants and Field Conditions (NUREG-1507); A Nonparametric Statistical Methodology for the Design and Analysis of Final Status Decommissioning Surveys (NUREG-1505, Rev.1); and recognized dose assessment codes: Development of Probabilistic RESRAD 6.22 and RESRADBUILD 3.22, and NUREG/CR-6697; Residual Radioactive Contamination from Decommissioning – User's Manual DandD, Ver. 2.1 (NUREG/CR-5512, Vol. 2); and MicroShield® (Ver. 6.0).

[3] For ^{40}K, the volume release level is based on its specific activity of 834 pCi/g and rounded off to 800 pCi/g, assuming an elemental abundance of 0.0118%. The surface release level for ^{40}K was derived using the NRC's "DandD" code and bench-marking the result to N13.12-1999. Levels assume an annual dose (TEDE) of less than or equal to 1.0 mrem, see ANSI/HPS N13.12-1999.

3.2.1 Diffuse material containing TENORM at concentrations not exceeding the administrative release levels of combined ^{226}Ra or ^{228}Ra of less than (<) 3 pCi/g above background, natural uranium < 30 pCi/g above background, and natural thorium < 3 pCi/g above background is exempted from radiological control by this policy. This material is still a solid waste and may be disposed of or composted at an approved solid waste facility, or it may also be beneficially used in accordance with 5 CCR 1003-7 and/or Item 3.2.9 below[4].

3.2.2 For purposes of this guidance, background values for ^{226}Ra of 1.4 pCi/g, ^{228}Ra of 1.3 pCi/g, 1.3 pCi/g of ^{NAT}Th, and 2.4 pCi/g for ^{NAT}U (Myrick 1983) may be assumed. Site-specific background values may be determined and applied with Department approval.

3.2.3 Diffuse concentrations of NORM/TENORM may be disposed of in a Resource Conservation and Recovery Act (RCRA) Subtitle D municipal solid waste landfill or a compost facility with Department approval, consistent with local land use authority, if the maximum of combined ^{226}Ra or ^{228}Ra is < 10 pCi/g above background, natural uranium is < 100 pCi/g above background, and natural thorium is < 10 pCi/g above background, providing appropriate worker training and process controls are in approved disposal and operation plans (included in WQCD discharge permits, Solid Waste D&O Plans or radioactive materials licenses).

3.2.4 Diffuse concentrations of NORM/TENORM may be disposed of in a RCRA Subtitle D industrial landfill or comparably controlled monofill with Department approval, consistent with local land use authority, if the maximum of combined ^{226}Ra or ^{228}Ra is < 50 pCi/g above background, ^{nat}U is < 300 pCi/g above background and ^{nat}Th is < 50 pCi/g above background.

3.2.5 Diffuse concentrations of NORM/TENORM may be disposed of in a RCRA Subtitle C landfill with Department approval, consistent with local land use authority, if the maximum of combined ^{226}Ra or ^{228}Ra is < 400 pCi/g above background and ^{nat}U and ^{nat}Th at levels less than source material concentrations. The total activity of the material must be below 2,000 pCi/g. Source material contains uranium, thorium or combined concentrations greater than 0.05% by weight.

[4] The radium, thorium, and uranium values come from a recent risk-based ANSI (1999) standard that considered appropriate release levels for materials and equipment that in addition to surface activity limits also have volumetric release limits. The 1983 Uranium Mill Tailings Remedial Action legislation specified a level of 5 pCi/gm radium-226 in surface soils above background averaged over a 100 m^2 area as an exemption level, which has been used in Colorado. The 5 pCi/gm was specified as a health-based level for uranium mill tailings at that time, when the public dose limit was 500 mrem/y. Newer dose-based methods of calculating dose would indicate values near background to stay within the 100 mrem/y allowable public dose level, and the corresponding 25 mrem/y source constraint. Examples are NCRP 129, and the draft NRC screening limits. The background values come from a study of background across Colorado (Myrick 1983). Please note that EPA cites a risk range of 10^{-4} to 10^{-6} or sites contaminated with radium and uranium and that release from control of a site with 25 mrem may exceed this value.

3.2.6 Diffuse concentrations of NORM/TENORM containing combined ^{226}Ra or ^{228}Ra greater than 400 pCi/g above background, or natural uranium or natural thorium at levels greater than source material concentrations, must be disposed of in a facility licensed to receive source material, Type 2 byproduct material or low-level radioactive waste. Source material contains uranium, thorium, or combined concentrations greater than 0.05% by weight. Possession of NORM/TENORM with uranium, thorium, or combined concentrations greater than 0.05% by weight requires specific licensing and disposal at licensed facilities[5].

3.2.7 Material and equipment with surface TENORM contamination shall meet the release limits specified in ANSI N13.12 (ANSI 1999) prior to free release from the facility, which are reproduced here in Table 3-1

3.2.8 Items known to contain activity levels in excess of the surface release levels of Table 3-1 shall not be intentionally coated, plated, or covered as a means to reduce actual or apparent surface activity levels.

3.2.9 Decontamination of equipment should only be performed by parties specifically licensed to provide such services. Process knowledge may be used to satisfy this requirement if the facility has no elevated TENORM in residuals or elevated NORM in its source water.

3.2.10 All land disposal of NORM/TENORM should meet the radon standard found at Part 18, Appendix A, criterion 6(1) of the Radiation Regulations (20 pCi/m^3/s^{-1}). Review criteria for categories of land disposal facilities are contained in the Section 4 of the companion guidance document.

3.2.11 In addition to meeting the criteria established above, beneficial reuse of diffuse NORM/TENORM shall meet the requirements of the WQCD Drinking Water Sludge Regulation [1003-7], and the Biosolids Regulation 64, where applicable. Direct land application of residuals > 40 pCi/g gross alpha, but less than 10 pCi/g (370 becquerel per kilogram) $^{226}Ra/^{228}Ra$ combined in the sludge before application to land may be considered by the Department and the local permitting

[5] From the definitions in Part 1 of the Regulations: "Source material" means material, in any physical or chemical form, including ores, that contains by weight one-twentieth of 1 percent (0.05 percent) or more of uranium, thorium or any combination thereof. 0.05 % by weight means 500 micrograms of uranium and or thorium per gram of material. Expressed in terms of activity for single isotopes (each having a different mass):

500 micrograms of U-nat = 339 pCi
500 micrograms of U-238 = 170 pCi
500 micrograms of Th-232 = 55 pCi

Since the definition of source material includes combinations of uranium and thorium we use a sum of ratios to determine if a material is source material. Type 2 byproduct material is uranium and thorium tailings. As such, this allows for disposal of TENORM at a uranium mill. It must be noted that DOE will not allow direct disposal of radium-bearing residuals in uranium mill tailings impoundments because it can cause a challenge to the radon cap. Uranium-bearing TENORM may be used as an alternate feed at a uranium mill.

authority on a case-by-case basis. *[The related assessment was based on a total of 3 applications of 5,000 kg of material per acre for each application.*] Review criteria for beneficial reuse facilities are contained in Section 4 of the companion guidance. (Part N)

3.2.12 Liquids containing NORM/TENORM discharged to the land shall meet the Maximum Contaminant Levels and standards for protection of groundwater in the *Basic Standards for Groundwater*.

3.2.13 Facilities that generate TENORM in concentrations greater than a combined 50 pCi/g $^{226/228}$Ra, or source material concentrations for natural uranium or thorium (in excess of the exemptions in § 3.5.1 of the Radiation Regulations) shall apply for a specific radioactive materials license, or demonstrate that existing operational and environmental permits and programs provide equivalent protection to the environment, workers and other members of the public.

4 Dose criteria for unlicensed TENORM.

4.1 The total effective dose equivalent to individual members of the public from all pathways and sources (except radon and its *short lived* progeny)[6] and practices associated with site and facility operations, including effluent discharges into the environment shall not exceed 0.1 rem, or 100 mrem (1 milliSievert) in a year, exclusive of the dose contributions from background radiation, from any medical administration an individual has received, from exposure to individuals administered radioactive material and released in accordance with § 7.26 of the Radiation Regulations, from voluntary participation in medical research programs, and from the dose contribution from the disposal of radioactive material into sanitary sewerage in accordance with § 4.35 of the Radiation Regulations.

4.2 Workers exposed to NORM/TENORM in unlicensed facilities are considered incidentally exposed workers who are members of the public. Workplaces generating NORM/TENORM in unlicensed facilities should ensure that the reasonably maximally exposed individual incidentally exposed to NORM/TENORM does not exceed a radiation dose constraint of 25 mrem/y above background (excluding radon) in order to keep the person below 100 mrem/y from all sources[7].

4.3 The dose in any unrestricted area from external sources, exclusive of the dose contributions from patients administered radioactive material and released in

[6] Dose limits for internal and external exposures exclude doses from radon gases (^{219}Rn, ^{220}Rn, ^{222}Rn) and its short-lived decay products. Exposures and doses to long-lived radon products are to be included in the dose limit.

[7] EPA uses a risk range of 10^{-4} to 10^{-6}, which may not be met if workers receive 25 mrem/y. However, Colorado regulations are primary, and the dose constraint in regulation is 25 mrem/y, which the Department believes is protective.

accordance with § 7.26 of the Radiation Regulations, does not exceed 0.002 rem, or 2 mrem (0.02 milliSievert) in any one hour.[8]

4.4 Workplaces generating NORM/TENORM that yield doses greater than 25 mrem/y above background (excluding radon) to the reasonably maximally exposed individual shall be required to possess a specific radioactive materials license, and are required to follow the pertinent sections of § 1, 3, 4, 10, 12 and 17 of the Radiation Regulations.

4.5 Radon.

Exposure to outdoor and indoor radon is not specifically regulated under Colorado or federal regulation, therefore the following are recommendations:

4.5.1 Outdoor radon. Radon (^{222}Rn) and its short-lived decay products released to outdoor environments shall be controlled to a radon exhalation rate or release rate corresponding to[9]:
(i) an annual average concentration of less than or equal to 0.50 pCi/L (20 Bq/m^3), above background, at downwind locations of property or site boundaries, or
(ii) an equivalent radon gas limit based on working level (WL) concentration for its short-lived decay products using relevant guidelines from the U.S. Environmental Protection Agency.

4.5.1.1 Conformance may be demonstrated by atmospheric dispersion modeling and downwind sectors concentration averaging, or environmental measurements when feasible

4.5.2 Indoor radon.

The presence of indoor radon (222Rn) and its short-lived decay products in buildings and structures shall be limited in areas that are occupied or occupiable to[10]:

---

[8] RH 4.14.1.2

[9] When two or more radon isotopes are present in the mixture, the sum-of-the-fractions method shall be used in determining conformance with the annual average concentration limit. Other radon isotopes may include ^{219}Rn and ^{220}Rn. Where ^{219}Rn or ^{220}Rn are the gases of concern, an alternate radon concentration limit shall be calculated based on a radon gas or WL concentration, dose limit, or risks comparable to that of ^{222}Rn using U.S. Environmental Protection Agency guidelines.

[10] When two or more radon isotopes are present in the mixture, the sum-of-the-fractions method shall be used in determining conformance with the annual average concentration limit. Where 219Rn or 220Rn are the gases of concern, an alternate radon concentration limit shall be calculated based on a radon gas or WL concentration, dose limit, or risks comparable to that of 222Rn using U.S. Environmental Protection Agency guidelines.
c. The derivation of an alternate radon gas limit or WL concentration shall take into consideration specific building characteristics, such as ventilation rates, equilibrium of decay products, and occupancy times.
d. In the context of the standard, "occupied" or "occupiable" means casual or routine occupancy of areas within a structure where radon may exist at elevated levels. For residential structures, indoor areas may include basements, rooms built directly on the ground, and rooms or areas with exposed soils, rocks, and

(i) an annual average concentration of less than 4 pCi/L (150 Bq/m^3),
(ii) an equivalent radon gas limit based on working level (WL) concentration for short-lived decay products using relevant guidelines from the U.S. Environmental Protection Agency, or
(iii) a radon gas or WL concentration for short-lived decay products established for workers under a standard of care defined by the Occupational Safety and Health Administration (OSHA) or Mine Safety and Health Administration (MSHA).

4.5.2.1 In mitigating ambient radon gas or short-lived decay products concentrations, mitigation techniques and building design features should be applied using U.S. Environmental Protection Agency guidelines addressing mitigation practices and building construction standards.

4.5.2.2 The conduct of radon gas or radon decay products measurements or installation of radon mitigation systems shall be performed by qualified organizations or individuals listed in state agencies' (or the U.S. Environmental Protection Agency's) radon measurement proficiency programs.

---

materials containing TENORM. For commercial structures, indoor areas may include offices, work shops, warehouses, etc., and areas with exposed soils, rocks, and materials containing TENORM. Such situations should require further evaluations in planning and implementing specific monitoring methods or when considering mitigative measures.

e. Conformance with this criterion should be demonstrated by using long-term monitoring methods for radon gas or decay products using radon measurement proficiency programs approved by a State agency with legislative authority or the U.S. Environmental Protection Agency. Long-term refers to measurement periods that adequately represent the seasonal and yearly variability in indoor radon levels.

5 Limitations

The Department may, upon application or upon its own initiative, grant such limitations, exemptions or exceptions[11] from the requirements of this policy as it determines will not result in undue hazard to public health and safety or property.[12]

The Department will not apply this policy and guidance to the following and are given for the purpose of further defining the scope of the policy and guidance and facilitating its interpretation and implementation:.

5.1 Persons who receive, possess, use, process, transfer, distribute, or dispose of TENORM are exempt from the recomendations of this policy and guidance with respect to any combination of natural thorium, or ^{226}Ra and ^{228}Ra if the materials contain, or are contaminated at, concentrations less than 3 pCi/g (~0.1 Bq/gm), or natural uranium at 30 pCi/g (1.0 Bq/g) above natural background. The progeny of the exempt TENORM ^{226}Ra and ^{228}Ra are also exempt. Manufacture of consumer or retail products at concentrations greater than 3 pCi/g is subject to further controls.

5.2 Naturally occurring radioactive material (NORM) as any of the primordial radionuclides or radioactivity present in soils, rocks, and materials involving practices and human activities that are generally regarded as common practice are also exempt. Among others, such practices include materials used in scientific research, engineering studies and applications, farming, tilling, plowing, site grading, grave digging, trenching, or similar types of excavation or earth work. This exclusion does not apply to materials or practices making radioactivity more accessible to humans or the environment; thereby, resulting in material that should be considered TENORM. Among others, such practices include homebuilding using materials obtained from mining and mineral extraction spoils, overburden, and wastes; or building homes on sites containing extraction spoils, overburden, and wastes from mineral mining or oil and gas extraction.

5.3 Materials, products, and practices for which an exemption from regulatory requirements has been provided by a regulatory agency with legislative authority, and materials and equipment that have been decontaminated to release criteria defined by a regulatory agency with legislative authority. Uranium and thorium covered by exemptions from USNRC or state regulations are still considered to be subject to regulations under the Atomic Energy Act (40 USC 121), and, thus, are not NORM nor TENORM.

5.4 Source, byproduct, or special nuclear material, as defined by the Atomic Energy Act of 1954 (40 USC 121) amended.

[11] References the definitions found in IAEA 2004.
[12] Colorado *Rules and Regulations Pertaining to Radiation Control*, § 1.5.1.

5.5 Distribution and consumption of foodstuffs known to contain NORM when cultivated under normal agricultural practices, including the use of man-made fertilizers, and processed such that naturally occurring radionuclide concentrations and isotopic ratios have not been increased or altered through human intervention. This exclusion does not apply to foodstuffs grown in TENORM whether as a product, waste, or mixed with soils (e.g., beneficial reuse of sludges).

5.6 Potassium (K), potassium compounds, and products containing potassium, provided that naturally occurring potassium isotopic ratios are maintained, i.e., the potassium has not been isotopically enriched in ^{40}K.

5.7 The possession, storage, and distribution of fuels, such as coal and coal byproducts (e.g., gas), natural gas and natural gas byproducts, and crude oil and crude oil products. This exclusion addresses itself only to fuel products before combustion and does not include production waste and residues contained in processing systems, storage tanks, and distribution pipelines that may contain TENORM. Wastes and residues generated during and after combustion may be excluded if it is demonstrated that such wastes and residues have TENORM at levels resulting in exposures and doses that are in conformance with this policy and guidance.

5.8 Possession, custom blending, distribution, and use of fertilizer feedstock and products for agricultural applications, and animal feed products, including phosphate and potash fertilizers.

5.9 Sites and facilities previously contaminated with TENORM that have been remediated under the provisions of the U.S. Environmental Protection Agency regulations and directives or appropriate state requirements. This provision includes all related restrictions defining the types and amounts of material allowed to remain at the site, surficial extent of the site or facility, and assignment of specific institutional controls.

5.10 Future disposals shall meet the requirements of the Department.

5.11 Use of mineral admixture in concrete, as defined and authorized by the U.S. Environmental Protection Agency (Office of Solid Waste and Emergency Response) regulations and directives or equivalent state requirements.

5.12 Other persons who possess or use TENORM shall be exempt when the Department makes a determination, upon its own initiative or upon request for such determination.

5.13 [Persons who receive water treatment plant liquid or sludge, apply such material to farmland by spreading, or cultivate such material into farmland as a soil amendment in accordance with a permit from the local permitting authority are hereby exempt from this Policy if the gross alpha is < 40 pCi/g (WQCD Division Drinking water Sludge Regulation [1003-7], and the Biosolids Regulation 64,).

6 Regulatory Basis for Disposal Policy and Dose Criteria

6.1 Radiation Control Act

The EPA has federal jurisdiction over TENORM, but has chosen to not promulgate specific regulations yet for these wastes. Colorado has authority over all forms of radioactivity, including NORM and TENORM. Colorado exercises discretion on regulating materials that do not pose a health or environmental risk. The authority is found in the *Radiation Control Act* (RCA) (CRS 25-11-101 et seq), which states: "The department shall develop and conduct programs for evaluation and control of hazards associated with the use of any and all radioactive materials and other sources of ionizing radiation, including criteria for disposal of radioactive wastes and materials to be considered in approving facilities and sites pursuant to part 2 of this article." The RCA is divided into three parts. TENORM is addressed in Part 1. Yet, the definition of TENORM is actually found in a subsection of Part 2, which mostly addresses disposal of LLRW and regulation of direct disposal at uranium mills.[13] Despite the location of the definition, TENORM is regulated under Part 1 of the RCA.

The regulatory scheme is not discrete, but is rather distributed throughout the RCA and the implementing regulations. The RCA requires that the Department issue licenses pertaining to radioactive materials[14], and all radioactive material be disposed of in a licensed facility. However, the implementing regulations provide for relief from the regulations when public health can be protected using other methods. Disposal in a properly sited, constructed, and permitted solid waste or hazardous waste facility can provide the same level of protection (NCRP 2004). Disposal of TENORM in permitted landfills under approved certificates of designation is allowed under the RCA[15]

> § 25-11-107(1) states "No person shall acquire, own, possess, or use any radioactive material occurring naturally or produced artificially without having been granted a license therefore from the department; nor shall he transfer to

[13] It should be noted that Part 2 of the Act exempts uranium mills from certain licensing requirements for the disposal of drinking water residuals. Colorado does have one uranium mill, however it is not clear if they are interested in receiving these residuals, or if they will be licensed to receive off-site wastes in the future. Note that DOE will not allow direct disposal of radium-bearing drinking water treatment residuals in uranium mill tailings impoundments due to potential challenges to the radon cap. Uranium-bearing residuals are candidates for alternate feed at uranium mills.

[14] 25-11-103 (2) Pursuant to rules and regulations adopted as provided in section 25-11-104, CDPHE shall issue licenses pertaining to radioactive materials, prescribe and collect fees for such licenses, and require registration of other sources of ionizing radiation. No other agency or branch of this state shall have such power or authority.

[15] Nothing in this part 2 shall be deemed to apply to the treatment, storage, management, processing, or disposal of solid waste, which may include naturally occurring radioactive material as defined in section 25-11-101 (2.7), and TENORM as defined in subsection (4) of this section, either pursuant to a certificate of designation issued under article 20 of title 30, C.R.S., or at a solid waste disposal site and facility considered approved or otherwise deemed to satisfy the requirement for a certificate of designation pursuant to article 20 of title 30, C.R.S., or section 25-15-204 (6).

> another or dispose of such material without first having been granted approval of the department therefore." Again, material needs to be licensed (general or specific), but also transfer for disposal must be granted by the Department.
>
> § 25-11-107 (2) No person shall knowingly use, manufacture, produce, transport, transfer, receive, send, acquire, own, or possess any source of ionizing radiation unless such person is licensed by or registered with the department. Again, the literal interpretation of this section is that the residuals are sources of ionizing radiation, and therefore are captured by the Act.

A previous effort to promulgate specific regulations for disposal of NORM in the early 1990s resulted in a conflict between the proponents of the bill and certain industries. The result of that conflict was that the rulemaking died, and a provision was inserted into the RCA that remains:

> §25-11-104 (1)(b): "The state board of health may adopt regulations concerning the disposal of naturally occurring radioactive materials at any time after the promulgation by the federal Environmental Protection Agency or its successor of rules for the disposal of naturally occurring radioactive materials."

The Department interprets this to mean NORM disposal should be treated from a regulatory standpoint as any other residual radioactivity. Fortunately, the RCA also allows TENORM to be considered solid waste (Department discretion is made using a risk-informed basis including reasonable and prudent precautions).

Therefore, TENORM is regulated under the RCA, and could require a general license (unless the Department determines a specific license is required). Exemptions can be granted that would allow the disposal in permitted facilities as solid waste or as licensed material in a licensed site. Licensed material has been disposed of in permitted facilities, with Department approval.

Licenses come in two types, general and specific. A general license is automatically bestowed; no application is required, by virtue of possession of the material; although recent changes to the general license rules may require registration with the Department. Some residuals will require specific radioactive materials licenses in order to control the material and transfer it for disposal to other licensees. Specific licenses come with more requirements. Licensing is discussed in more detail in the Section 6 of the companion guidance.

6.1 Colorado Rules and Regulations Pertaining to Radiation Control

In addition to the RCAct, there are implementing regulations to be considered. The *Colorado Rules and Regulations Pertaining to Radiation Control* § 1, 3, 4,10 and 17 are of interest. The rules and regulations (the Radiation Regulations) address licensing, protection of the public and workers from radiation, disposal, worker education, and transportation requirements.

6.1.1 Part 1, General Provisions

Of particular importance is an exemption found in § 1.5 Exemptions:

> §1.5.1 General Provision. "The Department may, upon application or upon its own initiative, grant such exemptions or exceptions from the requirements of these regulations as it determines are authorized by law and will not result in undue hazard to public health and safety or property."

This provision provides the Department with the discretion to manage TENORM, if alternative approaches are protective of public health and the environment. Conversely, the Department has the authority to impose requirements to protect health.

> § 1.9 Additional Requirements. "The Department may, by rule, regulation, or order, impose upon any licensee or registrant such requirements in addition to those established in these regulations, as it deems appropriate or necessary to minimize danger to public health and safety or property."

6.1.2 Part 3, Licensing

§ 3 of the rules and regulations address licensing requirements. As noted previously, licenses can be general or specific, depending on the practice or source being considered. There are also exemptions from licensing that apply to TENORM.

As with the other sections, there are exemptions, the primary one that is germane here is that source material is exempt from specific licensing if it is less than 0.05% by weight:

> § 3.2.1. Any person is exempt from this part to the extent that such person receives, possesses, uses, owns or transfers source material in any chemical mixture, compound, solution, or alloy in which the source material is by weight less than 1/20 of 1 percent (0.05 percent) of the mixture, compound, solution or alloy.

NOTE: The U.S. Nuclear Regulatory Commission is in the process of a rulemaking that would allow for general licensing of drinking water treatment residuals containing source material (USNRC 2006). Publication is expected sometime in 2007. Colorado may adopt a similar regulatory change in the future.

This means uranium that is less than about 350 pCi/g or natural thorium that is less than about 50 pCi/g does not require a license to possess or transfer. It is not a health-based exemption, and the Department evaluates each waste stream for protection of workers and public health and the environment.

There is also a table of exempt quantities and concentrations; however, there are no exemptions for radium or thorium[16]. The Radiation Control Program is evaluating whether it is feasible to derive exempt concentrations and quantities for radium and thorium; however, the risk associated with them is such that the exemptions would be expected to be for trivial amounts.

Section 6 of the companion guidance has additional detail on the basis and justification for the licensing approach used in this guidance.

6.1.3 Part 4. Standards for Protection Against Radiation

This part of the regulations addresses dose limits to members of the public and to occupationally exposed radiation workers. Most all workers who encounter TENORM are considered members of the public and are limited to the amount of dose they can receive. Part 4 has numerous provisions for licensed or registered sources of radiation. Some of these provisions are applicable to TENORM and are discussed below.

> § 4.5.2 "The licensee or registrant shall use, to the extent practical, procedures and engineering controls based upon sound radiation protection principles to achieve occupational doses and doses to members of the public that are as low as is reasonably achievable (ALARA)." This is a most important concept in radiation protection. Doses must be reduced as low as is practical below the regulatory limits.
>
> § 4.5.4 "To implement the ALARA requirements of 4.5.2 and notwithstanding the requirements in 4.14 of this part, a constraint on air emissions of radioactive material to the environment, excluding radon-222 and its decay products, shall be established by licensees, such that the individual member of the public likely to receive the highest dose will not be expected to receive a total effective dose equivalent in excess of 0.1 milliSievert (10 mrem) per year from these emissions. If a licensee subject to this requirement exceeds this dose constraint, the licensee shall report such event as provided in 4.53.2 and promptly take appropriate corrective action to ensure against recurrence." It is unlikely any facility would exceed this criterion, but it is included for completeness.
>
> § 4.14 lists the dose limits to members of the public.
> §4.14.1.1 "The total effective dose equivalent to individual members of the public from the licensed or registered operation does not exceed 1 milliSievert (0.1 rem, or 100 mrem) in a year, exclusive the dose contributions from background radiation, from any medical administration individual has received, from exposure to individuals administered radioactive material and released in accordance with

[16] Part 3, Schedules A and B.

RH 7.26, from voluntary participation in medical research programs, and from the dose contribution from the licensee's or registrant's disposal of radioactive material into sanitary sewerage in accordance with RH 4.35."

§4.14.1.2 "The dose in any unrestricted area from external sources, exclusive of the dose contributions from patients administered radioactive material and released in accordance with RH 7.26, does not exceed 0.02 milliSievert (0.002 rem, or 2 mrem) in any one hour."

Therefore, workers cannot receive more than 2 mrem in any one-hour from TENORM, and their total dose over a year cannot exceed 100 mrem. The Department further constrains the total dose to 25 mrem/y from any one source or practice, since members of the public may be exposed from more than one source during the course of the year[17].

§ 4.14.5 "The Department may impose additional restrictions on radiation levels in unrestricted areas and on the total quantity of radionuclides that a licensee or registrant may release in effluents in order to restrict the collective dose." It is under this provision that the Department invokes the dose constraint of 25 mrem/y from any one source.

Evaluation of disposal options is addressed in §4.34.

Part 4 also has requirements for disposal of radioactive material (§4.35), with respect to disposal into sewers and for the limits used in determining if material is radioactive with respect to NPDES permitting requirements. In addition, the discharge must be allowed and approved by the local sewerage agency.

Part 4 also has additional requirements for surveys (§4.15/4.17), posting (§4.28) and record keeping if material is licensed (§4.40).

Decommissioning of a site must meet the requirements of § 4.61, which require doses to the public to be less than 25 mrem/y[4]. Disposal facilities must show that they will meet this requirement post closure if they request a variance from the generic levels prescribed in this guidance.

6.1.4 Part 10. Notification to workers

This section has basic requirements for postings and notification to workers for licensed facilities. It also has a section on workers rights and training requirements for situations where the worker would be exposed to > 100 mrem/y.

[17] EPA utilizes a risk range of 10^{-4} to 10^{-6} for sites contaminated with radium and uranium and that release from control of a site with 25 mrem may exceed this value.

6.1.5 Part 17. Transportation

Colorado requirements for transportation of radioactive materials are the same as those of the US Department of Transportation (DOT) regulations. It must be noted that the DOT transportation regulations were rewritten, effective October 2004. Colorado is in the process of updating its regulations to be consistent with DOT. Under the new regulations, most NORM materials receive a relaxation from the standards such that most drinking water sludges are exempt from regulation, but media and filters may not. There may be instances where TENORM is considered radioactive for purposes of transportation, it is recommended that a certified hazardous materials shipper be contacted to review and determine the status of the material prior to arranging for transport. All disposal of TENORM that involves transporting the material must be compliant with DOT requirements. Further discussion can be found in Section 3.3.

6.2 Solid Waste Regulations

Comprehensive treatment of the requirements found in the Solid Waste Regulations is beyond the scope of this document. As follows, we have attempted to highlight those sections of the regulations that are most germane to the disposal policy:

> §2.1.2(C) "All sites and facilities, requiring a certificate of designation, shall have a waste characterization and disposal plan approved by the Department and in use for such site and facility. The plan shall outline waste screening methodologies, appropriate waste handling procedures, and waste exclusion procedures which shall be implemented at each facility." There are numerous provisions of this requirement. The more heterogeneous the facility's waste stream, the more rigorous the facility's waste screening methodologies will need to be in order to have an appropriate statistical power and confidence in waste characterization.

The design and operational requirements for landfills are found in Sections 2 and 3, for monofills in Sections 2, 3 and 12, and for surface impoundments in Section 9. As of this writing, Section 9 is undergoing revision. This Section will impact surface impoundments at drinking water treatment facilities.

6.2.1 Drinking Water Treatment Plant Sludge (Section 12)

Section 12 of the Solid Waste Regulations spells out the requirements for disposal of drinking water treatment plant sludge.

Disposal also includes the requirements of Sections 2 and 3 of the Solid Waste Regulations.

§12.1.4 Surface and groundwater monitoring may be required. Facilities that are out of compliance with current standards may be required to upgrade to meet surface and groundwater protection.

§12.2.1 has the 40 pCi/g gross alpha notification requirement for alum sludge for drinking water treatment plants.

§12.2.2 has design, operation and closure requirements for monofills. Subsequent sections have requirements for fencing, maps, and record keeping.

§12.3 has Sludge Acceptance criteria concerning pH and the presence of free liquids and other parameters. No other type of waste may be accepted by a monofill without approval by the Department, consistent with local land use authority.

6.2.2 Composting Facilities (Section 14)

Section 14 of the Solid Waste Regulations regulates composting facilities. Composting facilities that accept Type 3 feedstocks (which include sludges) are designated as Class I facilities. They are required to maintain a CD, a Design and Operation (D&O) Plan and financial assurance. There are also provisions for surface and groundwater protection, windblown and other operational parameters. Additional discussion is found in Section 4 of the companion guidance.

References

6 CCR 1007-2. *Regulations Pertaining To Solid Waste Disposal Sites and Facilities.* 6 CCR 1007-2. Colorado Department of Public Health and Environment, Denver, CO. April

6 CCR 1007. *Colorado Rules and Regulations Pertaining to Radiation Control* [6 CCR-1007] Colorado Department of Public Health and Environment, Denver, CO.

6 CCR 1003-7. *Regulations Pertaining To The Beneficial Use Of Water Treatment Sludge And Fees Applicable To The Beneficial Use Of Sludges.* [5 CCR 1003-7] Colorado Department of Public Health and Environment, Denver, CO. October.

5 CCR 1003-2. *Water and Wastewater Facility Operators Certification Requirements.* Regulation #100. Water Quality Control Commission. Colorado Department of Public Health and Environment, Denver, CO. .

5 CCR 1002-41. *The Basic Standards for Groundwater*. Regulation #41. Water Quality Control Commission. Colorado Department of Public Health and Environment, Denver, CO. March

5 CCR 1002-31. *Basic Standards and Methodologies for Protection of Surface Water* [5CCR 1002-31] August.

5 CCR 1003-1. *Colorado Primary Drinking Water Regulations* [5 CCR 1003-1] Colorado Department of Public Health and Environment, Denver, CO. March

6 CCR 1007-3. *Hazardous Waste Commission Regulations* [6CCR 1007-3] Colorado Department of Public Health and Environment, Denver, CO. August

25 CRS 11. *Radiation Control Act* [25 CRS 11-101]

25 CRS 15. *Colorado Hazardous Waste Act* [25 CRS 151

30 CRS 20. *Colorado Solid Waste Disposal and Facilities Act* [30 CRS 20, Pt.1]

33 USC. 1251 *Federal Water Pollution Control Act*. (33 U.S.C. 1251 et seq.) P.L. 107–303, November 27, 2002.

40 USC 121 *Atomic Energy Act* [40 USC 121] as amended.

42 USC 15801 *Energy Policy Act of 2005*. Public Law 109-58

ANSI 1999. *Surface and Volume Radioactivity Standards for Clearance*. ANSI/HPS N13.12-1999, American National Standards Institute/Health Physics Society. Health Physics Society, McLean, VA. August.

CDPHE 1993. *Biosolids Regulation*. Regulation No. 64. Water Quality Control Commission, Colorado Department of Public Health and Environment, Denver, CO. April

CRCPD 2004a. *Regulation And Licensing Of Technologically Enhanced Naturally Occurring Radioactive Material (Tenorm).* Part N. Conference of Radiation Control Program Directors, Frankfort, KY. April.

EPA 2006. *National Primary Drinking Water Regulations: Stage 2 Disinfectants and Disinfection Byproducts Rule.* Federal Register, FR: 71(2). U.S. Environmental Protection Agency, Washington, D.C. January 4.

EPA 2005. *A Regulators' Guide to the Management of Radioactive Residuals from Drinking Water Treatment Technologies*. EPA 816-R-05-04. U.S. Environmental Protection Agency, Washington, DC. July.

Myrick 1983. *Determination of Concentrations of Selected Radionuclides in Surface Soil in the U.S.*, Health Physics Vol. 45, 631-642

NCRP 2004. Approaches to Risk Management in Remediation of Radioactively Contaminated Sites. NCRP Report No.146. National Council on Radiation Protection and Measurements. Bethesda, MD. October 15.

USNRC 2006. *Guidance For Receiving Enforcement Discretion When Concentrating Uranium At Community Water Systems*. RIS 2006-20. U.S. Nuclear Regulatory Commission, Washington, DC.

Implementing Guidance

- Drinking Water Treatment Residuals
- Oil and Gas Exploration and Production Wastes (reserved)
- Uranium Overburden (reserved)

1

1 Drinking Water Treatment Guidance

1.1 Introduction

Radioactivity is naturally present in rocks, soils, surface water and groundwater at trace concentrations. Drinking water sources sometimes may contain naturally occurring radioactive elements in concentrations such that long-term exposure may pose an increase of probability of detrimental health-effects (e.g., cancer). Drinking water is treated to remove a variety of contaminants, including radionuclides. Treatment processes can cause chemical changes that may concentrate radionuclides, even if the purpose of the treatment was for a different contaminant. The most common radionuclides are uranium, radium, thorium, decay products (called progeny) and potassium. The uranium series contains most of the isotopes commonly found in drinking water, with the exception of ^{228}Ra, which is part of the thorium decay series. Appendix A shows the decay series. Not all isotopes are of concern, as most are not found in drinking water. Exposure to and disposal of radionuclides in drinking water treatment residues from community water supplies is receiving increased attention and concern. These waste residuals are categorized as Technologically Enhanced Naturally Occurring Radioactive Materials (TENORM).

The Colorado Department of Public Health and Environment (the Department) developed this guidance to help utilities and disposal contractors develop best practices for protection to workers, the general public and the environment from radioactivity concentrated as a result of radionuclide removal from drinking water. It is designed to be a companion document to the Environmental Protection Agency (EPA) "*A Regulators' Guide to the Management of Radioactive Residuals from Drinking Water Technologies*" (EPA 2005).

A wide range of concentration of radionuclides may be possible depending on water source and the type of treatment. Treatment options, residuals management and disposal options, effluent-sampling and analysis, radioactive materials licensing, basic radiation health and safety principles, and instrumentation and surveys are reviewed.

In large water treatment plants, alum (aluminum sulfate), ferric chloride or other chemicals are added to raw water, forming a sort of gel that gradually coagulates or flocculates, and finally settles to the bottom of the tank as solid waste. Radionuclides and other impurities precipitate along with the solids with relatively high efficiency.

Some type of sedimentation and filtration usually follows coagulation. A variety of filter media are available for use after coagulation and in combination with other processes, such as fluoridation and disinfection. Activated carbon, sand, diatomaceous earth, greensand and membrane filters are all used. These filters may be backwashed and/or regenerated a number of times, but must ultimately be replaced and disposed of.

Smaller systems most likely treat radionuclides and other contaminants with technologies, such as reverse osmosis (RO), ion exchange (IX) or softening, which are technologies that generate solid waste as resins and membranes. These are likely generated in small amounts

Drinking water treatment plant residuals are categorized as resins, membranes, filter media, sludges and liquids. Liquid residuals include brines, concentrates, backwash water, rinse water, and acid neutralization solutions. Similar to solid residuals, the concerns related to liquid residuals are when they are finally disposed of by offsite discharge, deep well injection or some other method.

Disposal of liquid and solid residuals may come with logistical, political, and economic challenges. In some cases, there are no easy answers for safe, economical disposition. Whereas many residuals containing TENORM can be safely disposed of as solid waste under the Resource Conservation and Recovery Act (RCRA), others may require specific licensing by the Hazardous Materials and Waste Management Division (HMWMD) for disposal at licensed radioactive waste facilities. This guidance is intended to make the process as simple and cost effective as possible.

There are two major components to safely handling TENORM at water treatment facilities:

- Worker and public safety while processing the water;
- Safe handling, storage and disposition of residuals.

The last documented review of CPDHE policy regarding the handling and disposition of water treatment residues was conducted in 1988. Since that time, numerous changes in national and state regulations and policies have occurred on how water treatment residues are handled and disposed. A number of federal and state statutes, regulations and guidance documents are the basis for the criteria and recommended practices in this guidance. Work on the revised policy began in 2003. A stakeholder process was used in 2005 to develop input for the first draft, which was issued in January 2006. Comments were received on the first draft through June 2006, leading to a major rewrite, which yielded this document. Concurrent with the comment and rewriting period, the Rocky Mountain Low-Level Radioactive Waste Board took up the issue of diffuse TENORM and made modifications to its rules, which are reflected in this draft. Also, the Nuclear Regulatory Commission (NRC) has issued guidance for utilities that possess uranium in source material concentrations (USNRC 2006). Under current regulations, utilities that possess uranium in source material concentrations are required to obtain a specific radioactive materials license.

Some sources of drinking water are protected under the Federal *Clean Water Act* (33 USC. 1251) others under the *Safe Drinking Water Act* (42 USC 201) (SDWA), sometimes to the same regulatory levels as the drinking water itself. Interest has been renewed with the publication of the *Radionuclides Rule* (RR) in the Federal Register (EPA 2000). The RR establishes Maximum Contaminant Levels (MCL) and Maximum Contaminant Level Goals (MCLG) for uranium, combined radium, gross alpha, and beta particle activity in drinking water (Table 1-1). The U.S. EPA originally created and promulgated the RR in 1976 as part of the SDWA. The RR was revised on January 20, 2000, to include an MCL value for uranium. The state of Colorado, as a primacy agency, has adopted the EPA Standards as part of the *Colorado Primary Drinking Water Regulations* (CPDWR), 5 CCR 1003-1. The Water Quality Control Division (WQCD) of the Department is responsible for executing and enforcing the CPDWR. The current requirements of the CPDWR mandate that all community public water systems meet the following MCL values calculated based on a running annual average at the entry point(s) of the distribution system:

Table 1-1. MCLs and MCLGs

Contaminant	MCL	MCLG
Combined Radium 226 + Radium 228	5 pCi/L	zero
Gross alpha particle activity (excluding radon and uranium)	15 pCi/L	zero
Beta particle and photon activity	4 mrem/yr	zero
Uranium	30 ug/L	zero

In addition to the RR, a *Rule for Radon in Drinking Water* (EPA 1999) has gone through the comment period, but implementing regulations have not been adopted as of publication of this document (CRCPD 2004). A *Final Rule for Filter Backwash Recycling* was promulgated (EPA 2001); the Arsenic Rule (EPA 2001a) also may concern drinking water treatment facilities. Other rules that may require additional treatment of water that could result in TENORM are the *Stage 1 Disinfectants and Disinfection Byproducts Rule* (EPA 1998) and *Stage 2 Disinfectants and Disinfection Byproducts Rule* (EPA 2006),

Approximately 50 utilities are currently treating water to remove radioactivity. It is not known how many others will have residuals with TENORM as a result of treatment for compliance with other rules.

Figure 1 shows counties in Colorado that currently have at least one PWS that is out of compliance with the RR as of the end of 2006. Figures 2 – 5 show breakdowns of the summary figure by MCL, and affected population.

Even systems that do not violate the MCL may have TENORM in their residuals as a consequence of treatment for other parameters, e.g., enhanced coagulation. The largest generators of TENORM in drinking water residuals are from alum treatment of water that is not in violation of the MCL. This is why all systems should test their residuals.

The regulation of radioactive material is the responsibility of the Radiation Control Program (RCP) of the HMWMD of the Department. The authority to regulate TENORM is found in the general provisions *Radiation Control Act* [CRS-25-11-101], and the *Colorado Rules and Regulations Pertaining to Radiation Control* [6 CCR-1007] (Radiation Regulations). Colorado has adopted dose-based limits of exposure to workers and the public derived from federal regulations. Workers at most facilities are considered members of the public, not radiation workers. Federal guidance provides an upper dose limit to members of the public from all industries and facilities, and provides for a site-specific approach to be taken. The As Low As Reasonably Achievable (ALARA) concept is also applied to reduce the potential dose as far below the limit as is feasible, economic, social and logistical concerns taken into account.

A recent risk assessment of sewage treatment residuals showed that wastewater treatment facilities pose relatively little risk from radiation. The assessment also showed that radiation levels found in other industries, such as drinking water treatment, could be substantially higher, and may warrant further investigation (ISCORS 2005). In Colorado, some water sources contain enough natural radioactivity to cause elevated TENORM concentrations when the waters are treated. Additional risk assessments provided by utilities and disposal facilities show that disposal of many of the bulk residuals may be able to be safely disposed in landfills as solid wastes, but that other residuals, such as spent resins and media, pose more of a risk, and should be managed for their radioactive content. Additional information on risk assessment and risk management are presented in Appendix B.

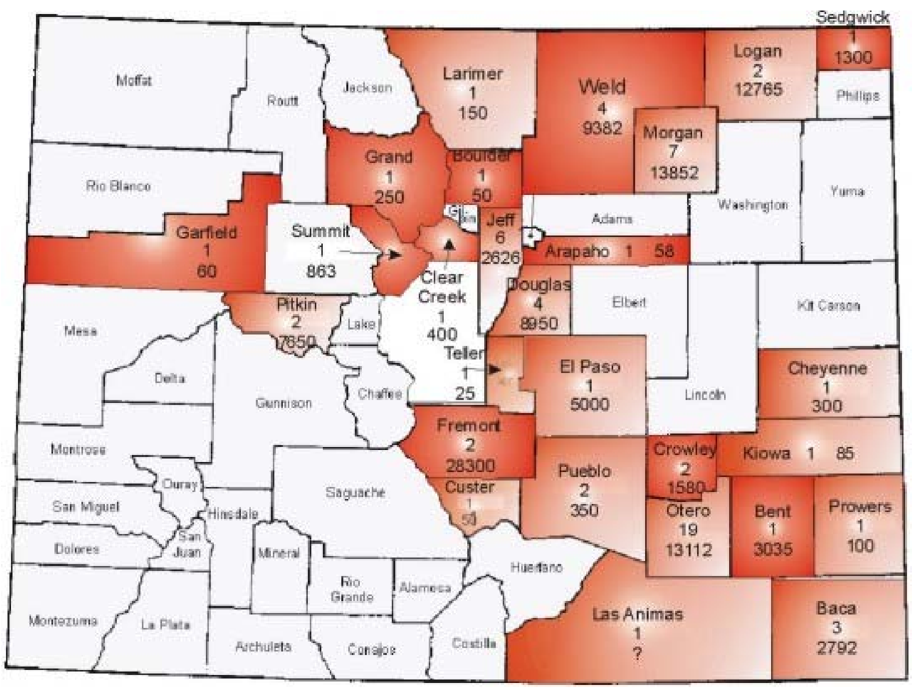


Figure 1. Counties with at least one PWS that exceeds drinking water MCLs and affected population as of the end of 2006.
Source: Colorado Department of Public Health and Environment, WQCD

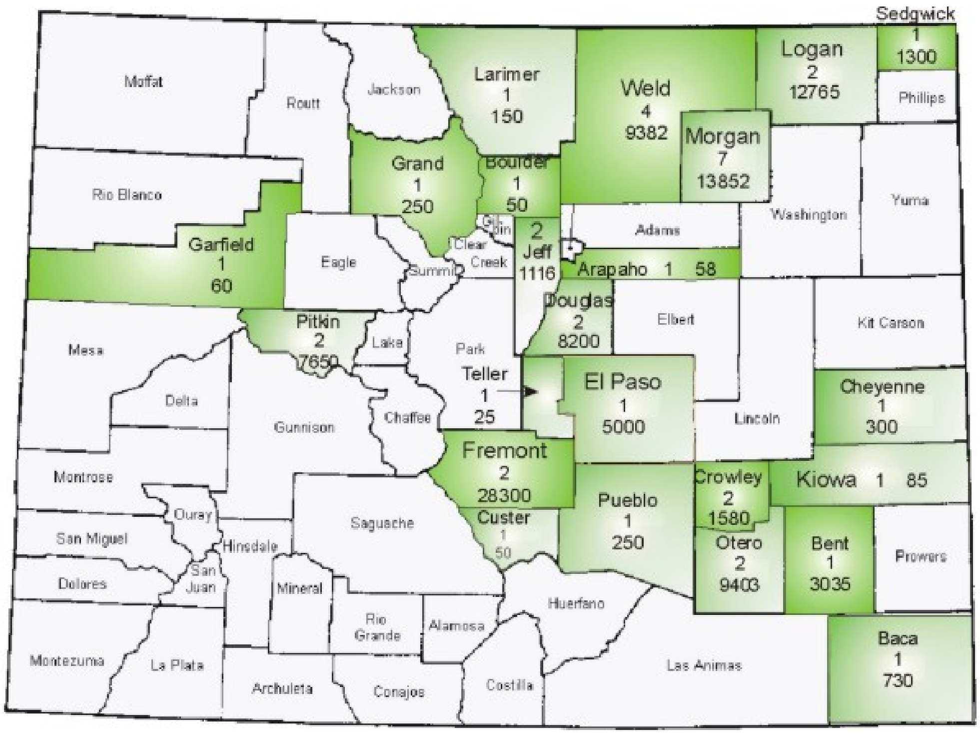


Figure 2. Counties with at least one PWS that exceed the uranium MCL and affected population as of the end of 2006. Source WQCD.

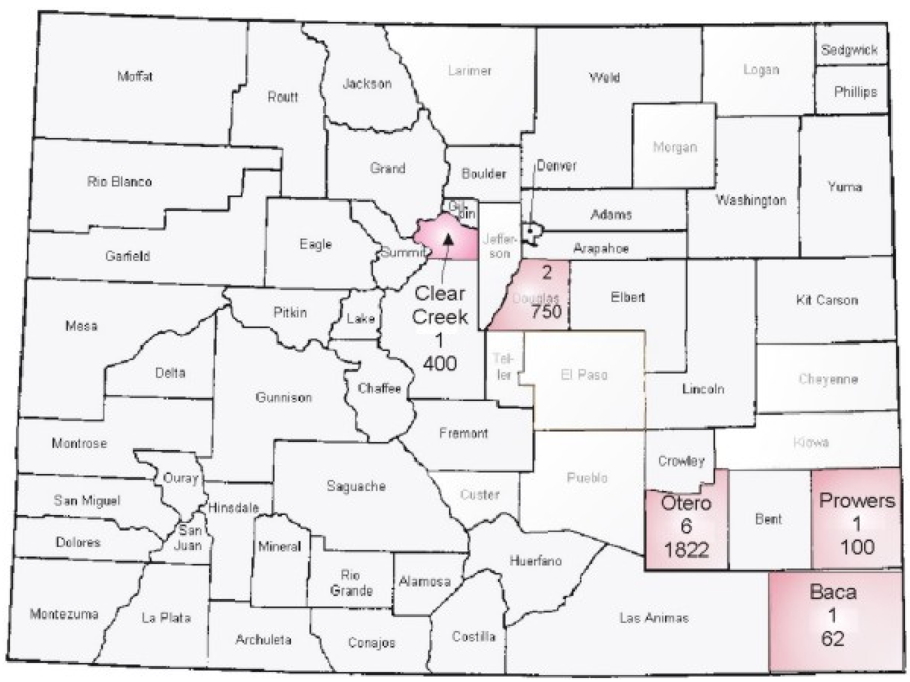


Figure 3. Counties that have at least on PWS that exceed the Radium MCL at the end of 2006 and affected population**.** Source WQCD

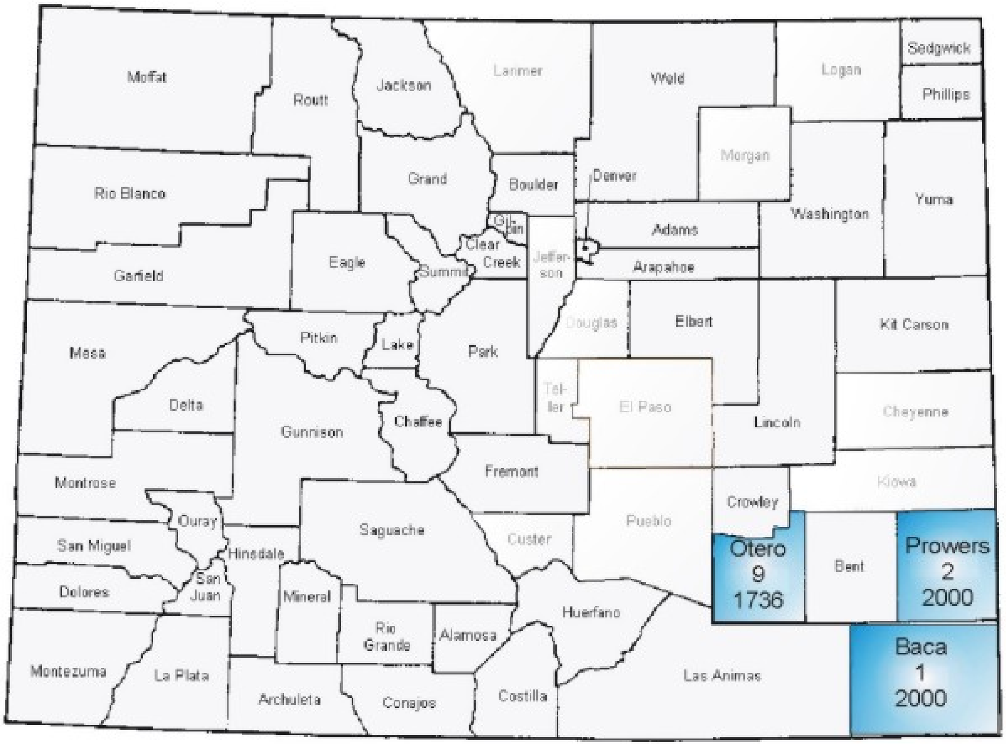


Figure 4. Counties with at least one PWS that exceed the gross alpha MCL and affected population as of the end of 2006. Source WQCD.

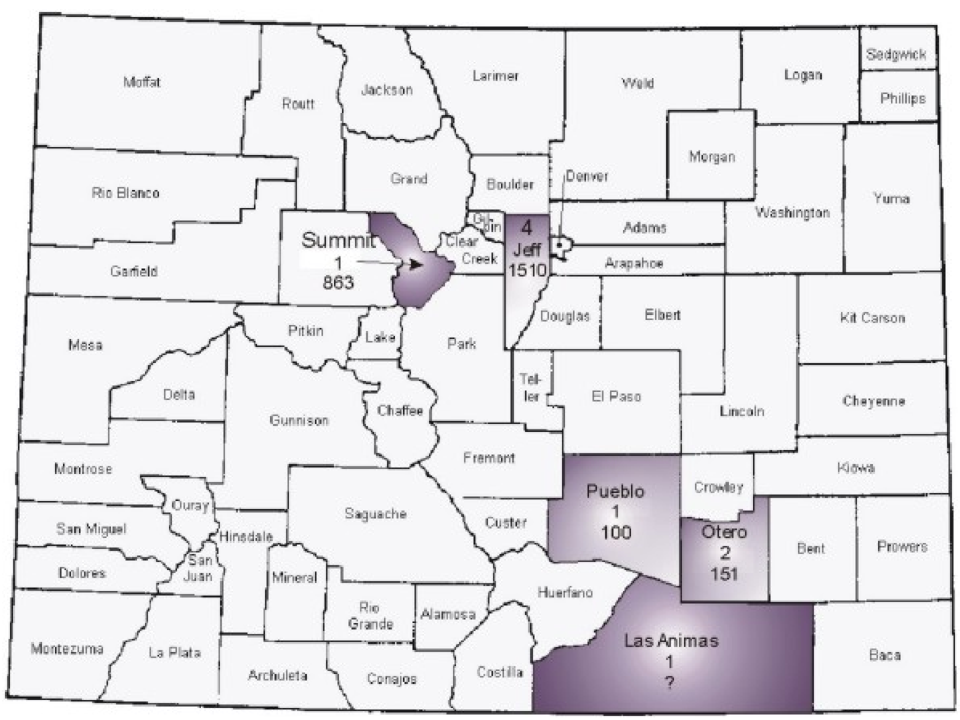


Figure 5. Counties with at least one PWS that exceed multiple MCLs and affected population as of the end of 2006. Source WQCD.

Disposal of most commercial low-level radioactive waste (LLRW) is prohibited in Colorado. Many wastes that contain small amounts of radioactivity are not classified as radioactive waste. By law, TENORM in Colorado may be considered solid waste, depending on the dose and risk of the particular waste. Therefore, the final disposition of wastes containing TENORM depends on the amount of radioactivity in the waste.

1.2 Characteristics of TENORM in Drinking Water and Residuals

In order to evaluate the exposure risks to TENORM, it is compared to background radiation. Sources that contribute to background radiation include terrestrial and cosmic radiation, radon, and other smaller contributors. The level of background radiation varies with location and elevation, and can vary significantly around the country. Average background radiation in the U.S. and Canada is 360 mrem/y (NCRP 1994). The range of variation according to EPA is from 131 to 963 mrem/y. EPA (2005a) estimates average background for Colorado at 700 mrem/y, due to increased radon, terrestrial and cosmic radiation.

The radioactivity of an isotope is related to its mass and half-life, which is calculated as its specific activity. Uranium isotopes present in the environment are ^{238}U, ^{234}U, and ^{235}U. In natural conditions, over 99% of the mass of uranium is ^{238}U, which has 47% of the specific activity. This natural abundance can be upset by nature and processing. In source water and residuals, it is the chemistry of the water and the treatment processes involved that determine radionuclide content. These elements are metals and act as such chemically. Therefore, if a process removes ^{226}Ra, it also removes ^{228}Ra at the same efficiency irrespective of the initial ratios of the isotopes. Table 1-2 shows the relationship for uranium isotopes.

Table 1-2. Characteristics of Uranium Isotopes

Isotope, type of activity	Natural abundance, %	Half life, y	Specific activity, pCi/µg	Relative activity, %
^{238}U, α	99.276	4.51×10^{9}	0.333	47.33
^{235}U, α, γ	0.7196	7.1×10^{8}	2.144	2.21
^{234}U, α	0.0057	2.47×10^{5}	6189	50.51

Source: Clifford 2004

Radium in groundwater occurs as Ra^{2+} at all pH levels. Uranium occurs in different states, depending on pH, as shown in Table 1-3 below.

Table 1-3. Effect of pH on chemical speciation

pH Range	Predominant Species	Predominant Species Charge
All	Ra^{2+}	a divalent cation
< 5	UO_2^{2+}	a divalent cation
5 to 6.5	$UO_2CO_3^0$	a neutral molecule
6.5 to 7.6	$UO_2(CO_3)_2^{2-}$	a divalent anion
> 7.6	$UO_2(CO_3)_3^{4-}$	a tetravalent anion

Source: Clifford 2004

The amount of residuals that are found in TENORM wastes are dependent on a variety of variables, including:

- Radionuclide concentrations in the source water,
- Removal efficiency of the treatment technology,
- Frequency of filter backwash and maintenance,
- Frequency of exchange resin regeneration and replacement,
- Coagulant or lime dosage rate and raw water pH,
- Loading capacity and ion selectivity of the media,
- Membrane type and operating pressure.

The residual radioactivity removed by treatment is concentrated in the wastes, except with aeration, which disperses radiation directly to the environment. Because alpha, beta, and/or gamma radiation may occur, each waste needs an evaluation to determine the hazards to treatment plant workers, material transport workers and the public (EPA 2005).

1.3 Non-Treatment Compliance Options

There are a few compliance options available to public water systems (PWS) that do not require installing treatment. Given that the above MCL values apply at the entry points of the distribution system, a combination of source inactivation and blending may be sufficient to comply with the RR. Sources exceeding an MCL may be blended with another water source to produce water below the MCL. If an alternate source is not available for blending, the non-compliant source must be replaced, treated or officially inactivated. More detailed discussion can be found in EPA's *Implementation Guidance for Radionuclides* (2002).

1.3.1 Inactivation of Sources which exceed an MCL

In order to inactivate a non-compliant source, a PWS may need to institute water-use restrictions to reduce consumer demand or obtain a new source. If a new source is not required from a capacity standpoint, then the PWS must submit a Safe Drinking Water Information System (SDWIS) Inventory Form that indicates the inactivation of the non-compliant source. Inactivation can be achieved by physically disconnecting the source or utilizing it only for emergency purposes. A source utilized as an emergency source must be isolated from the distribution system by a manually operated valve and put on-line through a standard operating procedure that includes public notification and bacteriological testing. Emergency sources may not be used to satisfy peak seasonal demands, except with Department approval due to extenuating circumstances.

1.3.2 Controlled Blending

Since compliance is determined at the entry points of the distribution system, controlled blending of multiple water sources is an acceptable means of compliance with the RR. The feasibility of a blending scheme can be approximated through a mass balance analysis. The contaminant concentration and flowrate of each stream must be known. From this analysis, the system can determine the operating range for the blending ratios of each stream according to the following equation:

$$\frac{(Q_1 * C_1) + (Q_2 * C_2) + (Q_3 * C_3) + \ldots + (Q_n * C_n)}{(Q_1 + Q_2 + Q_3 + \ldots + Q_n)} = C_{final}$$

Where:
$C_{final} < MCL$
Q = flowrate in gpm
C = concentration in mg/L or pCi/L

Systems should be aware of the risks involved with controlled blending. A blending scheme may not appreciably reduce the radionuclide concentrations in the drinking water. This may lead to buildup of radionuclides in wastewater sludge and the soils of a leach field. Current and future regulations may require wastewater plants to deal with similar treatment and disposal issues. Additional information is available in EPA 2005.

A PWS intending to implement a controlled blending scheme to achieve compliance with the Radionuclides Rule must submit an engineering report for state approval per Article 1.11.2 (b) CPDWR. This report must include the following:

- Project summary,
- Construction Approval Application with local or county health department approval,
- Plans and specifications for all piping and appurtenances, including blending control equipment,
- Colorado Registered Professional Engineer's Seal on drawings and calculations,
- Historical data of contaminant concentrations for all blend streams,
- Calculations for blending ratio operating range,
- Procedure to determine effectiveness and adjust blending ratio,
- Other requirements based on scope of project, as necessary,

1.3.3 New Raw Water Source

If a new raw water source is to be developed, the PWS must submit an engineering report for state approval per Article 1.11.2 (b) CPDWR. This report must include the following:

- Project summary,
- Construction Approval Application with local or county health department approval,
- SDWIS Inventory Form,
- 100-year Flood Plain Certification,
- Plans and specifications for all piping and appurtenances,
- Colorado Registered Professional Engineer's Seal on drawings and calculations,
- Calculations for disinfection and other treatment, as necessary,
- Water rights certification,
- Well permit, if applicable,
- Well construction and test report, if applicable,
- Water rights certification,
- Water quality testing for the following parameters:
  - Organic Parameters (VOCs and SOCs),
  - Inorganic Contaminants,
  - Nitrate/Nitrite,
  - Corrosivity,
  - Radionuclides,
  - Bacteriological,
  - Unregulated Contaminants, as necessary;
  - Microscopic Particulate Analysis, as necessary.

1.3.4 New Purchased Water Source

It may be possible for a PWS to purchase treated drinking water by connecting directly to or hauling water from another PWS.

A PWS connected directly to another PWS is classified as either a consecutive or integrated water system. A consecutive water system assumes all regulatory responsibility for distribution system monitoring and operational requirements. For an integrated water system, the PWS supplying the water assumes all regulatory responsibility; this arrangement is at the sole discretion of the supplier. Division approval will also be required to form an integrated system.

A PWS utilizing purchased water as a compliance option must submit a SDWIS Inventory Form indicating the inactivation of any non-compliant sources and the activation of any new purchased water sources. Modifications to a public water supply may require the Division's review and approval. Contact the Engineering Section at 303-692-3500 for additional information.

Water hauling is another option for a PWS to purchase treated water. This setup is typically used on an interim basis for systems with relatively low demand, but can be used for compliance indefinitely. Chlorine residual management will be a critical aspect of the project. The PWS must propose a method to add chlorine (or alternate disinfectant) and have a procedure to monitor and adjust the chlorine residual as necessary.

A PWS that plans to use purchased water as a compliance option must submit plans and specifications for state approval per Article 1.11.2 (b) CPDWR. The submittal must include the following:

- Project summary,
- Construction Approval Application with local or county health department approval,
- SDWIS Inventory Form reflecting source changes,
- Plans and specifications for all storage, piping, and appurtenances,
- Professional Engineer Seal,
- Bacteriological Sampling Plan (if hauler is utilized),
- Agreement with water hauler or supplier, including:
  - the PWSID number of the water supplier,
  - roles and responsibilities of each party;
- Chlorine residual management plan,
- Other requirements based on scope of project, as necessary

2 Treatment Options

A PWS that has determined that no satisfactory non-treatment options exist to attain compliance with the RR must install a water treatment system to reduce the radionuclide concentrations to compliant levels. As part of the RR, the EPA has designated certain treatment technologies as Small System Compliance Technologies (SSCT) and/or Best Available Technologies (BAT) for radionuclide removal. SSCTs are BATs that EPA has determined to be economically viable alternatives for small systems. There are incentives for installing a BAT or SSCT that are not available for other treatment alternatives. If a system installs a BAT, and it does not successfully bring them into compliance, then variances are available. Information on specific technologies and their classification as either SSCT or BAT are discussed in subsequent sections of this chapter. Additional information is available from EPA in their Small Systems Information and Guidance web site.

The treatment technologies and associated costs for radionuclide removal can be relatively complex. An experienced professional engineer should be consulted to assist in choosing a cost effective treatment that will meet the needs of a specific water system, including long-term residual disposal.

2.1 Design Considerations

A number of factors should be considered when designing a treatment system for radionuclide removal, including raw water quality, consumer demand, worker safety, exposure risks, operation and maintenance costs, residual disposal options and regulatory requirements. Each water system should analyze the available treatment technologies to find one that meets the system's specific needs.

Radionuclide removal treatment will produce a concentrated residual. Some technologies will produce a liquid waste stream. Adsorptive resins, membranes and filtration media all can accumulate radionuclides. Solid sludges may also be created from coagulation/sedimentation, precipitation, or intermediate de-watering processes. Many treatment types will produce multiple residuals. The resulting waste materials may be significantly concentrated with radionuclides and pose worker safety risks and require stringent and expensive disposal methods. Worker safety, licensing, disposal options and associated costs all can affect the selection of a particular technology. Often times a system will be limited to certain technologies due to the disposal options, such as an inability to directly discharge liquid residuals to a wastewater treatment plant or to waters of the state.

The raw water quality and consumer demand will dictate the size of treatment and the overall amount of radionuclides that must be removed. Treatment specific data, such as removal efficiencies, will be required to estimate the quality and quantity of residuals produced. Site-specific data, such as evaporation rates, may also be required to perform a thorough investigation. A mass balance analysis can be used to predict the finished water quality and characterize the waste. Systems should be aware that competing or co-removal of other contaminants present in the raw water might reduce removal efficiencies. In some instances, a particular treatment may be infeasible or require intensive operations and maintenance such as frequent backwashing or media replacement. Pre-treatment may be required depending on the raw water quality and the technology selected.

Since different technologies produce different types of residuals, it may be difficult to estimate such residual's quality and/or quantity. The Software Program to Ascertain Residuals Radionuclide Concentrations (SPARRC) is an EPA model developed to estimate the amount and concentration of residuals for various types of technology. The technologies covered in SPARRC include coagulation/filtration, lime softening, ion exchange, reverse osmosis, activated alumina and greensand filtration. SPARRC is not intended to be a primary method for sizing and designing treatment, but can be a useful tool to predict the system's disposal options. SPARRC may be downloaded, at no charge, from the following link: http://www.npdespermits.com/sparrc/.

The layout of a radionuclide treatment plant should take into account various aspects of worker safety. The design must include measures to minimize the radiation exposure of workers. Many technologies will accumulate radionuclides, whether by design or accident. Due to the high activity levels, filtration media, membranes and exhausted adsorptive media may pose an immediate worker safety risk if not properly managed. Please see Sections 7 and 8 of this document for further info on worker safety considerations and workplace evaluations.

Each treatment technology has different operational and maintenance requirements that should also be taken into account, especially when performing a cost analysis. Some technologies, such as reverse osmosis, are relatively straightforward to design and operate, while other technologies, such as lime softening, are more operationally intensive and require further attention from the operators. Additionally, there are regulatory requirements for operator certification; these will be discussed later.

2.2 Intermediate Processing

Since the available disposal options may dictate the selected treatment, it may be necessary to conduct intermediate processing of the residuals in order to meet disposal requirements. This may include, but is not limited to, evaporation, storage in lagoons, or filtering. The HMWMD should be contacted as part of the planning process for construction and maintenance requirements for surface impoundments. An evaluation of worker and environmental exposure should also be conducted.

2.3 Drinking Water Treatment Facilities Under the WQCD.

A PWS must meet a number of regulatory requirements in order to legally install any treatment unit. Any treatment change made to a public water system must receive state approval prior to construction, per Article 1.11.2 (b) CPDWR (5 CCR 1003-1). Plans and specifications must be submitted for review to ensure compliance with CPDWR and Colorado Design Criteria for Potable Water Systems (Design Criteria). The submittal will also be reviewed for compliance with regulatory and policy requirements of the HMWMD.

Plans and specifications must be submitted according to the guidelines outlined in subsequent sections of this guidance. Other regulatory requirements will be discussed in other chapters and with the water system during the review process. Permitting, residuals management and worker safety requirements must be addressed before approval will be issued. A discharge permit will be required if liquid residuals will be discharged into state waters. If liquid residuals will be discharged to a lined evaporation pond, there are impoundment requirements that must be met in the Solid Waste Regulations (Section 9) or WQCD, which may include groundwater monitoring. All onsite storage, intermediate processing and disposition of residuals must conform to all HMWMD requirements.

2.3.1 Operator Certification

All public water systems must be under the responsible charge of an operator certified at the level appropriate for the treatment and size, per *Regulation No. 100* (5 CCR 1003-2). The minimum level of operator required for any type of radionuclide treatment is Class C; if the size of the treatment plant exceeds 2 million gallons per day (MGD), then the requirement will increase to Class B, whereas at 10 MGD it will increase to Class A. Any sediment or water treatment that utilizes chemical addition will require a Class B operator at minimum. Systems should be aware that some types of treatment may pose minor worker safety issues (e.g., exposure to elevated gamma exposure rates near ion exchange (IX) columns) and in a very few instances, require special licensing requirements. Later sections of this document discuss workplace evaluation, health and safety and instrumentation. Additionally, there may be transportation-related requirements for shipments of residuals above DOT.

2.4 Submittal of Plans and Specifications

2.4.1 General Requirements

Modifications to public water systems, including the addition of new sources and treatment processes, require the prior approval of the Department. WQCD conducts reviews and issues approvals based on the *State of Colorado Design Criteria for Potable Water Systems (Criteria)* (CDPHE 1997). Contact the Engineering Section at 303-692-3500 prior to submission of plans and specifications to determine the appropriate review engineer, as well as other system specific considerations.

WQCD shall, within forty-five (45) days after the receipt of a request for approval of the complete set of final plans and specifications, review the documents submitted. Based on the information therein, shall approve or conditionally approve the plans and specifications in writing, or issue a written denial of approval, stating the reason for any such denial, or submit in writing to the project engineer, a list of items which must be addressed prior to further action regarding review and approval.

Where commencement of construction of the project has not occurred within one year of approval, such approval shall expire. An expired approval may be reinstated by submittal of the former plans and specifications to the Department for review and approval.

The following documentation must be submitted for review of Plans and Specifications:

- Project summary,
- Construction Approval Application with local or county health department approval,
- SDWIS Inventory Form,
- 100-year Flood Plain Certification,
- Engineering report,
- Plans and specifications for all equipment, piping, and appurtenances including evidence of appropriate National Sanitation Foundation (NSF) certifications,
- Colorado Registered Professional Engineer's Seal on drawings and calculations,
- Calculations for disinfection and other treatment, as necessary,
- Well permit, if applicable,
- Well construction and test report, if applicable,
- Water rights certification, if applicable,
- Raw water chemical analysis, if applicable,
- Technical, managerial, and financial capacity review, applicable to new Community and Non-Transient Non-Community Water Systems.

2.4.2 Engineering Report

The engineering report must include the following information:

- Summary of the existing water system, proposed treatment, and storage facilities,
- An estimation of the number of people served daily and at peak times,
- An estimation of average daily, maximum daily, peak hour, and peak instantaneous water demands,
- Proposed implementation timeline,
- Process flow diagram including all unit processes, chemical application points, valves, cross-connection control devices, sampling taps, and monitoring equipment, including flow meters and controls,
- Information about the proposed treatment system, including:
    - Raw water quality and variability,
    - Analysis of treatment alternatives considered, including capital and operational cost estimates,
    - Results of pilot or bench top studies;
    - Listing of all design parameters and assumptions, as applicable, including:
        - Unit loading rates,
        - Hydraulic detention times,
        - Filter area and filtration rate,
        - Backwash rate,
        - Regeneration rate;
    - Technical justification of project feasibility,
    - Supporting calculations;
- Residual Management Plan including waste characterization.

2.4.3 Residual Management Plan

To receive state approval for any type of radionuclide treatment, the system must submit a Residual Management Plan (RMP) with the plans and specifications to the WQCD. The RMP must identify all residuals generated by the treatment process, outline intermediate processing and handling of residuals, and specify ultimate disposal methods.

Best Management Practices must be developed to minimize worker risks and environmental hazards. A waste characterization must be provided, either theoretically based on mass balances, or measured by operating systems treating water of similar quality using the same technology. This characterization may then be used to identify possible disposal options and associated costs. Disposal of wastes such as spent media and membranes must be considered as well.

As part of the approval process, the system must demonstrate the financial capacity to operate, maintain, and properly dispose of residuals from a radionuclide treatment technology. The RMP should specify the amount of workplace monitoring (if any), results of waste characterizations (solid and liquid), health and safety plan, hazard communication plan, and if necessary, a waste management plan.

Spent resins, filters and some liquid residuals may require additional permitting or radioactive materials licenses may be required, depending on the amount of radioactivity in the residuals. This can be either to control exposure to the material, or more often, in order to meet the administrative needs of waste brokers, who can only accept waste from someone who is licensed to possess it.

The RMP will be reviewed by both WQCD and HMWMD to ensure compliance with all applicable regulations. Further guidance on risk management, intermediate processing and disposal issues is discussed elsewhere in the document.

Waste disposal options are discussed in the generic TENORM Disposal Policy.

2.4.4 Cost Analysis of Compliance Options

When assessing the various compliance options to determine the most cost effective option available, the PWS should evaluate the trade-off between capital costs and operations and maintenance (O&M) costs. Some compliance options, such as installing a transmission line to connect to a nearby system, may require significant initial capital costs, but relatively little O&M costs. A present worth analysis should be performed to determine the most cost effective option for long-term compliance from a complete life cycle perspective. Cost factors to be compared in the analysis include, but are not limited to:

- Capital investment,
- Equipment maintenance and/or replacement,
- Media replacement,
- Chemicals usage,
- Power requirements,
- The required operator level and time commitment,
- Monitoring requirements, both regulatory and process control,
- Residual management including intermediate processing and waste disposal costs.

2.4.5 Financial Assistance

In Colorado, publicly owned water systems are eligible for a wide-range of state and federal low-interest loan and grant fund assistance. Systems that are privately owned (usually non-profit corporations operated by water or homeowner associations) have fewer opportunities to access assistance. A list of state and federal assistance programs to fund water utility improvements for both public and private systems is available by visiting the Colorado Department of Local Affairs (DOLA) website. Click on "Available Financial Assistance."

Some private, non-profit owned water systems have determined that forming a public entity for the purposes of taking advantage of a greater array of financial assistance options is an effective strategy to fund needed capital improvements. Systems must carefully consider the costs and benefits of this action. Help to study the various public entity types and incorporation processes is available through DOLA and their eight regional manager offices throughout the state. See DOLA's website for questions and contact information.

3 Management Of Solid Water Treatment Residuals

Current treatment technologies produce three basic types of wastes: spent media, solids/sludges, and liquids. The disposition of these residuals in Colorado is linked to relevant existing regulations for similar materials, considering the radioactivity in the residuals, and the risk from those concentrations. Any materials containing radioactivity above the threshold criteria established in the generic TENORM Policy or 40 pCi/g total alpha screening limit cited in Section 12 of the Solid Waste Regulations will require some level of review prior to controlled disposal. There are options for beneficial reuse of solids residuals, which also require some level of regulatory review. Residuals that fall below the radioactivity cutoff limits are still a solid waste. Therefore, all residuals remain subject to the provisions of the Solid Waste Disposal Sites and Facilities Act (C.R.S. 30-20-100.5 et. seq.), and the Solid Waste Regulations. Table 3-1 lists a tiered approach to disposal of residuals containing TENORM in various waste disposal facilities. Table 3-2 provides background concentrations acceptable to the Department to be used in calculations in lieu of site-specific background concentration values.

This guidance is applicable to Department review of water treatment residuals waste streams (solids residuals) that contain TENORM materials. In Colorado, solid waste disposal is regulated under dual authority, with the Department and the local governing body having jurisdiction. Unless there were changes to regulation and statute, disposal options conceptually available at the state level would still be subject to local government approval as well.

Table 3-1. Disposal tiers for solid residuals

	Combined $^{226/228}Ra$ (pCi/g above background)	^{NAT}U (pCi/g above background)	^{NAT}Th (pCi/g above background)
Exempt (includes any MSWLF)	< 3	< 30	< 3
Approved MSWLF or Compost feed	< 10	< 100	< 10
Industrial Landfill	< 50	< 300	< 50
RCRA C Hazardous Waste Landfill	< 400	0.05% by weight	0.05% by weight

Table 3-2. Background concentration values

^{226}Ra	^{NAT}U	^{228}Ra	^{NAT}Th
1.4	2.4	1.3	1.3

Source: Myrick 1983

3.1 Treatment Processes that Generate Solid Residuals

3.1.1 Interim Treatment, Storage and Handling

- Pond/Lagoon/Impoundment Storage: Ponds, lagoons, or other impoundment should be managed in accordance with all applicable regulatory requirements. Impoundments are addressed in Section 9 of the Solid Waste Regulations. Lagoon storage is not intended as a permanent disposal feature. Groundwater monitoring is required in accordance with Appendix B of the Solid Waste Regulations. The groundwater monitoring must be implemented to account for site-specific hydrogeology and waste streams managed.
- Slurry transport: It is recommended that treatment plants visually monitor exposed piping for leaks.
- Dewatering: Dewatering may be through evaporation, or through an underdrain system. Facilities must use liners unless an adequate demonstration is made by the facility and approved by the Department that solids or liquids will not migrate beyond the confines of the lagoons or other drying unit. The water removed may either be permitted for discharge or sent back through the treatment process. Section 9 of the Solid Waste Regulations applies to these units.
- Belt filter press: Further drying may be necessary prior to storage, stockpiling, and disposal depending on the effectiveness of prior water removal processes.
- Storage pad: Storage pad must provide containment for both surface water and groundwater protection. Tarping or other dust suppression method is recommended for the solid residuals whose surface may dry out and be susceptible to wind erosion. Tarping can also provide a benefit by minimizing or eliminating the run-off of stormwater containing solids residuals. The containment area may have an outflow to the sanitary sewer with approval from the POTW. Silt fencing or other sediment capture mechanism around the outflow may be required. Please refer to Section 7, Basic Health and Safety Precautions, for worker safety recommendations.

3.1.1.1 Run-on and Run-off Control During Interim Storage

Onsite storage should be designed to prevent the release of solids or liquids into the surrounding environment or infrastructures not contained by the facility. Following are examples of structural controls to minimize run-on and eliminate the runoff of stormwater or process wastewater:

- Berming around drying beds
- Tarping and covering
- Dry lined lagoon with containment
- Retention ponds
- Run-on diversion structures
- Up gradient diversion structures

It is important to minimize stormwater from contacting any of the processes to prevent the stormwater from becoming classified as additional process wastewater.

3.2 Preparation For Final Disposition

- Analytical Testing: Analytical testing must be consistent with Section 12 of the Solid Waste Regulations and Section 5 of this guidance document. Solids residuals with activity levels greater than those values identified in this guidance or gross alpha of 40 pCi/g dry weight are only to be disposed of after consultation with the Department's Radiation Control Program. Further testing, including isotopic analysis, is usually required in order to accurately characterize the waste prior to final disposition. Uranium isotopes can be analyzed economically. Radium analysis is more expensive at this time, including ^{228}Ra. Other isotopes may be needed for waste acceptance purposes at the receiving facility. Sample early enough for safety, budgeting, and planning purposes. Safety, facility evaluation, and instrumentation are discussed in Sections 7 and 8.
- Additionally, just as any person who produces a solid waste must determine if that waste is hazardous, a water treatment plant must make a hazardous waste determination as part of its residuals management program, per 6 CCR 1007-3 § 262.11. Based on the generator's knowledge of this particular waste stream, analytical testing might be limited to Toxicity Characteristic Leaching Procedure (TCLP) metals analysis to evaluate whether the residuals are toxic. Corrosivity is already an analytical requirement under Section 12 of the Solid Waste Regulations.
- All regulatory requirements (if any) need to be met. There are a few requirements that must be met prior to transfer of material. The local authorities may have an approval or review process. There may be transportation requirements, depending on the activity of the residuals. The disposal facility is responsible for meeting the requirements of their CD and D&O Plans. Following this guidance should ensure that residuals are handled appropriately at the state level. Residuals that are elevated in TENORM can be disposed of as discussed in the next section. A graded approach has been taken based on the radioactivity of the material and safety of workers, the public and the environment.

Examples of disposal options for the three categories are shown in Table 3-2.

Table 3-3. Disposal options

	Disposal Options				
	Direct discharge[18]	**Discharge to sanitary sewer**[19]	**Beneficial reuse**	**Underground injection**	**Disposal**
Liquid Wastes	X	X	X	X	X
Solids and Sludges		X	X		X
Spent resins and other media					X

3.3 Transportation

- The DOT regulations were significantly modified in 2004. Transportation of residuals containing elevated radioactivity need to follow the DOT requirements of 49 CFR 172 – 178. A certified hazardous/radioactive waste shipper should be consulted prior to transport of the materials. For materials that are processed for their radionuclide content, materials containing 27 pCi/g of ^{226}Ra would be transported as radioactive material. Note that there is a relaxation of the cutoff values for NORM of a factor of 10, so drinking water residuals would not be regulated as radioactive for transport if they are below 270 pCi/g ^{226}Ra. Many other provisions apply with respect to total activity, paperwork, packaging, and labeling.
- Dust Management: The facility should take steps to minimize dust generation during load-out of dried residuals. There should be continuous visual observation during load-out to ensure dust is not being spread beyond the confines of the immediate loading area.
- Moisture: Having water spray available during load-out can be a useful dust control measure. A fine mist aimed in the downwind direction would help remove particulates from the air. However, the utility of misting will depend in part on the presence of other drying beds nearby. If misting is used, it should be used sparingly to avoid creating a surface water runoff, as well as to avoid excessive wetting of the residuals, which must be devoid of free liquids prior to disposal.
- Low wind speed: It may be necessary to avoid loading out during periods of high wind. While the maximum allowable wind speed may vary from facility to facility, depending on water content of sludge, site topography, and other factors,

[18] May require an NPDES permit.
[19] When approved by the local Publicly Owned Treatment Works (POTW)
Source: Modified from EPA 2005. EPA will allow recycling of residuals back through the system, but has not endorsed beneficial reuse through land application or as feed to compost.

individual sites may wish to establish a wind speed limit so as to maintain awareness that wind speed is a factor critical to dust control.

- Lined trucks/end dumps: Trucks used for the transport of residuals should have the tailgate diapered or sealed and be properly covered to prevent escape of residuals while in transit. Refer to Air Pollution Control Division Regulations on dust emissions.
- Direct load-out: Loading residuals directly from the belt filter press or other dewatering methods into the truck can reduce the need for dust suppression, although the facility should still employ visual observation and take appropriate precautions as necessary. In addition, load-out areas should be policed following each load-out operation to ensure that any spilled material is placed into the storage area or loaded into the transport vehicle.

4 Disposition Of Water Treatment Residuals

Disposition of solids residuals mainly occurs through beneficial reuse (e.g., land application or composting) or disposal at an approved solid waste facility. Utilities may store and perform interim treatment of residuals on-site in features such as lagoons, tanks, basins and drying beds prior to disposal.

There are numerous categories of disposal facilities that may receive TENORM; however, each increasing level of protection comes with increased costs and regulatory oversight. Examples are municipal solid waste landfills (MSWL), monofills, industrial landfills, hazardous waste landfills, uranium mill tailings impoundments, and commercial low-level waste disposal sites. Colorado has no commercial low-level radioactive waste disposal facility (those wastes are sent out of state).

- There is only one permitted hazardous waste landfill in the state; it is currently licensed to receive TENORM up to 400 pCi/g ^{226}Ra and at less than source material concentrations for uranium and thorium.

- Colorado has one industrial landfill, and it has been allowed to receive TENORM on a case-by-case basis in the past, and can take residuals up to 50 pCi/g ^{226}Ra, 300 pCi/g ^{NAT}U, 50 pCi/g ^{NAT}Th and 150 pCi/g of other isotopes.

- There is one uranium mill in Colorado, and it could be a candidate to receive both liquid and solids residuals containing uranium as an alternate feed, however the site is not currently accepting offers. It is possible that in the future this or another mill could be able and willing to take residuals. DOE does not favor direct disposal of radium-bearing drinking water treatment residuals in uranium mill tailings impoundments at this time.

- Disposal of solids residuals into some MSWLs has been approved by the Department on a case-by-case basis.

- Monofills have been approved by the Department and the local governing body for disposal of solids residuals, and remains an option for some utilities.

There are over 70 MSWLFs in Colorado. Some of them were designed before EPA updated the design criteria in the 1990s to require adequate groundwater protection; others sited in rural locations may have received waivers from the design criteria. The Department is concerned about the site-specific conditions and a solid waste facility's design, construction, operations and maintenance, particularly for sites that do not satisfy modern design criteria. Therefore, while these facilities are generally appropriate for the disposal of solids residuals, any generic approach to disposal of TENORM in MSWLFs needs to be conservative. Not all solid waste facilities are appropriate for the receipt of this waste stream due to the lack of adequate liner or leachate collection systems. The tiered approach presented in the TENORM Policy is considered adequately protective by the Department for MSWLFs that want to accept TENORM.

In addition to the safety of the various sites with respect to handling the solids residuals, there are regulatory limitations. Solids residuals that are above the Colorado definition of radioactive (2,000 pCi/g total activity) must to go to a facility licensed for those materials. Additionally, solids residuals that are above about 350 pCi/g natural uranium, and 55 pCi/g natural thorium are considered source material and must to go to a facility licensed or permitted for those materials (this is a Colorado, not a federal requirement). Residuals that require disposal in a licensed facility may also require a radioactive materials license (general or specific) for the generator in order to deal with potential exposure, waste brokers and disposal facilities. The discharge of liquid residuals requires a specific permit from the Water Quality Control Division (WQCD).

4.1 Liquid residuals

Disposal of liquid residuals have very limited economic options, and may involve interim treatment, such as evaporation prior to final disposition. The individual options are discussed in the following sections. For more information, the reader should consult the EPA *Small Systems Compliance Guide* (EPA 2002) or the *Implementation Guidance for Radionuclides* (EPA 2002a).

In any process that concentrates water taken from streams, rivers, reservoirs and wells in Colorado, there arises a potential concern of buildup of TENORM. State regulations control where these waters can then be discharged. It is imperative that this issue be resolved prior to deciding what type of system to implement. This is to be addressed in the various Plans and Specifications that need to be submitted to the WQCD for review and approval. See Section 2.2.

4.1.1 Direct Discharge to Surface Waters

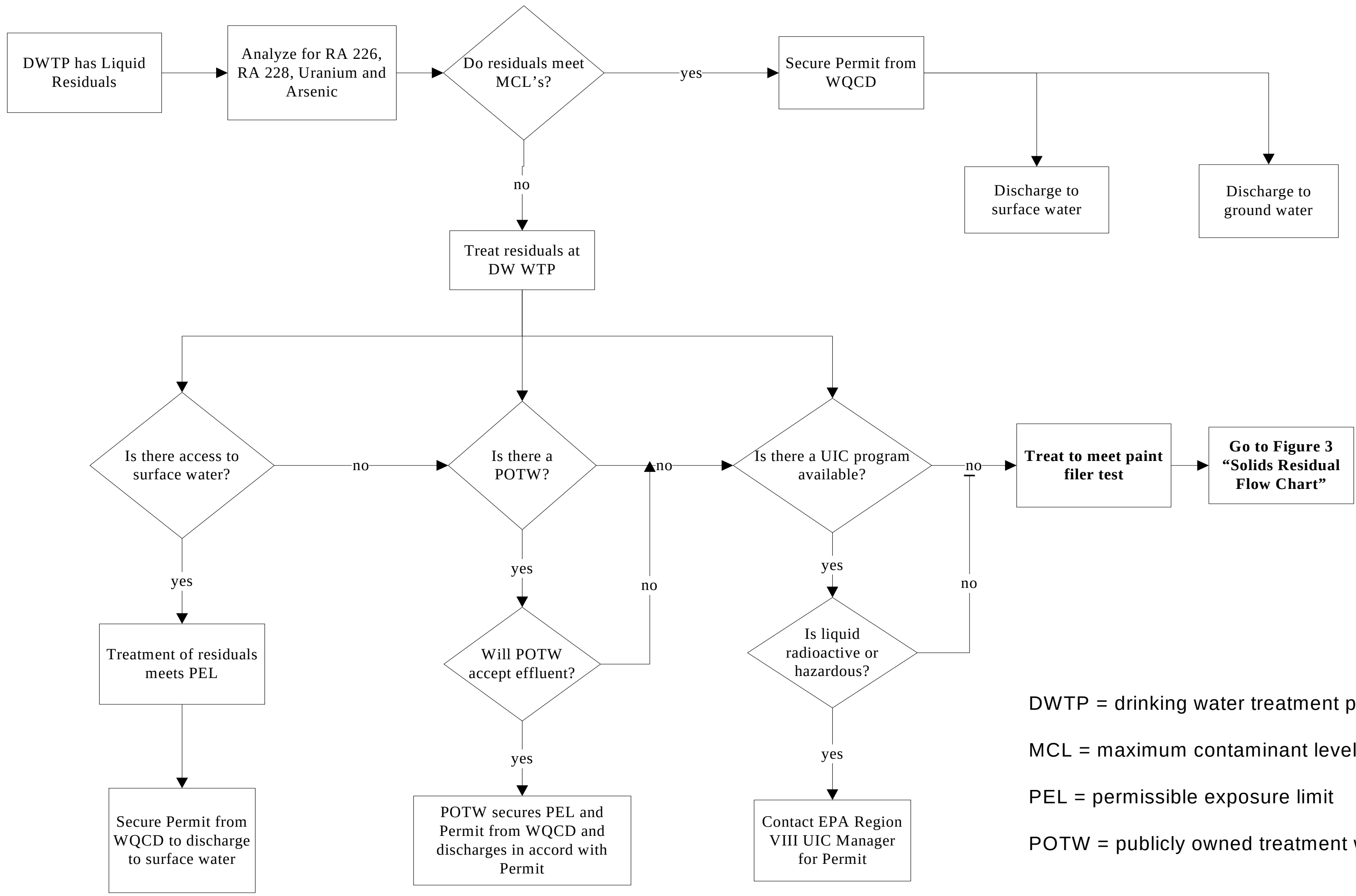
The limits on discharging radionuclides to a Colorado waters is contained in the surface water regulations (5 CCR 1002-31). They are presented in Table 4-1:

Table 4-1. Discharge parameters

Parameter	pCi/liter
Americium 241	0.15
Cesium 134	80
Plutonium 239 and 240	0.15
Radium 226 and 228	5
Strontium 90	8
Thorium 230 and 232	60
Tritium	20,000
Uranium	Based on hardness of receiving water

These limits can be modified downward for waters that are not designated as "Use Protected." If not designated as "Use Protected" [i.e., undesignated], the water can only be degraded over water quality existing on 9/30/2000 by an additional 15%. The amounts that can be discharged are also affected by the diluting potential of the upstream low flow values.

Many of the radionuclides listed above are scarce in the environment and seldom applicable. The ones that would most influence any decisions on disposal are $^{226/228}$Radium and Uranium.



DWTP = drinking water treatment plant

MCL = maximum contaminant level

PEL = permissible exposure limit

POTW = publicly owned treatment works

Figure 6. Flow chart for disposal of liquid residuals

Table 4-2. Treatment/residuals matrix

Treatment	Usage[1]	Type of Residual							
		Solid			Liquid				
		Spent resins/media	Spent Membranes	Sludge	Brine	Backwash water	Rinse water	Acid Neutralizer Solution	Concentrate
Ion Exchange (IX)/ Point of Use (POU) IX	R, U, B								
Cation exchange	R	X			X	X	X		
Anion exchange	U	X			X	X	X		
RO/ POU RO	R, U, A, B		X						X
Lime softening	R, U	X		X		X			
Greensand filtration	R	X		X		X			
Co-precipitation with barium sulfate	R	X		X		X			
Hydrous manganese oxide filtration	R	X		X		X			
Activated Alumina	U	X			X	X	X	X	
Coagulation/filtration	U	X		X		X			
Electrodialysis and electrodialysis reversal	R		X						X
Zeolite filtration	R, U	X				X	?		
Granulated Activated Carbon	Rn	X							
Aeration	Rn								

Source: EPA 2005

[1] Where: R= radium, U= uranium, A= gross alpha, B = beta/photon, IX= ion exchange, Rn = radon, RO = reverse osmosis

If the “liquid residuals” from the drinking water treatment facility are within Water Quality Standard limits, it may be possible to discharge to surface water with a discharge permit. This option is regulated by Colorado Discharge Permits System (CDPS). Contact the Water Quality Control Division Permits Section for guidance if contemplating this option.

4.1.2 Indirect Discharge to Sanitary Sewer System

The Colorado Radiation Regulations (§ 4.35) allows for disposal of licensed radioactive materials meeting specified limits into sanitary sewers. They must be readily soluble or readily dispersible biological material in water. The NRC issued an Information Notice on acceptable methods of determining solubility (NRC 1994). If material to be released would not qualify as being "readily soluble," the regulations would prohibit release to sanitary sewerage unless an exemption has been granted. Exemptions will be judged on a case-by-case basis, when it is demonstrated that release to sanitary sewerage is in accordance with the ALARA principle, consistent with applicable regulations, and in the public interest.

Discharges from any non domestic source to a Publicly Owned Treatment Works (POTW) in Colorado is regulated by EPA pursuant to 40 CFR Part 403. In addition, there are additional CDPS Pretreatment regulations that apply (Regulation No. 63 (5 CCR 1002 63). Many POTWs in Colorado have federally approved pretreatment programs with specific requirements and standards that must be met prior to and upon discharge.

Where a water treatment plant is considering discharge to a POTW with an approved pretreatment program, a full characterization of the wastestream and a completed permit application would have to be submitted. Where discharge to a POTW without an approved pretreatment program is being considered, the discharger should contact the POTW to get information on standards and requirements that must be met. In any case, the discharger must receive approval from the POTW prior to initiating any discharge to the sewerage system. The POTW may impose limitations and requirements more stringent than state or federal requirements. The Department believes that discharge to the sanitary sewer and hence the POTW is the option that is results in the greatest risk reduction, both by keeping the public from contacting TENORM in concentrated forms and by dealing with TENORM in the most economical manner.

4.1.3 Underground Injection

The EPA - Underground Injection Control (UIC) Program regulates well injection of down hole disposal of radioactive waters (6 CCR 1007-3 Section 100.21). The objective of these regulations is to protect underground sources of drinking water. The regulation describes five classes of wells. Class I (hazardous waste injected below lowermost formation containing drinking water sources) and Class II wells (produced water from oil and gas operations that is injected into the formation from whence the produced water came) are constructed such that waters injected will be below the lowermost drinking water aquifers with a confining layer between them. Class III wells (in-situ production of uranium or other metals) are not candidates for injection, as they are exclusively used in solution mining. Class IV wells are shallow hazardous and radioactive injection wells, defined in 40 CFR 165.5(d). These wells are prohibited unless the injection wells are used to inject contaminated ground water that has been treated and is being injected into the same formation from which it was drawn. These wells are authorized by rule for the life of the well if such subsurface emplacement of fluids is approved by EPA, or a state, pursuant to provisions for cleanup of releases under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA), 42 U.S.C. 9601-9675, or pursuant to requirements and provisions under the RCRA, 42 U.S.C. 6901-6992k.

Class V wells allow for limited injection but, since they are above drinking water aquifers, no radioactive wastes may be injected.

Septic systems are considered by EPA to be Class V injection wells. The UIC Program does not regulate single-family residential waste disposal systems such as single-family septic systems. However, SDWA (Section 1431) gives U.S. EPA the authority to take action on a residential waste disposal system if the system introduces contaminants into an underground source of drinking water whose presence or likely presence causes an imminent and substantial endangerment to public health.

4.2 Spent Resins and other media

Spent resins, filters and membranes generally contain elevated levels of radioactivity that must be sent to a facility licensed for disposal of radioactive materials. A specific radioactive materials license may be required due to elevated radioactivity in the resins and membranes, particularly if they are not back flushed in a timely manner. Facilities should conduct planning and modeling to avoid activity levels (particularly of radium) that will require disposal in licensed radioactive waste disposal sites; such disposal is very expensive. See Section 2 of this document for additional information on treatment technologies.

4.3 Solid/Sludge Residuals

Solid residuals with activity levels less than those threshold values identified in this guidance [3/30] or gross alpha < 40 pCi/g (See 6 CCR 1007-2) would not be regulated for its radioactive content, but would still be a solid waste, and would still need to be disposed per the Solid Waste Regulations at an appropriate disposal facility previously approved to accept this type of waste.

Note that beneficial reuse of these wastes would be subject to Department approval. The types of facilities are discussed below, with a decision chart in Figure 7.

All solids residuals must pass the paint filter test, EPA SW-846, Method 9095 (EPA 2004) prior to disposal. Some facilities, such as industrial landfills and hazardous waste facilities, may also provide dewatering services.

Since the solids may possess a wide range of radioactivity, suggested cut-off limits are used to segregate higher activity wastes from disposal at some landfills.

4.3.1 Beneficial Reuse

Beneficial re-use, or recycling as approved by the Department, of drinking water residuals is allowed under certain circumstances. The two main options are use as a soil amendment in direct land application or as an additive or feedstock in compost[20]. Flexibility inherent in the Solid Waste Regulations could allow the Department to entertain other uses on a case-by-case basis. No matter which use is being proposed, a demonstration of benefit must be made in order to support that particular use. If no benefit can be demonstrated, or if the potential environmental impacts exceed those associated with the product for which residuals are being substituted, the Department may view this practice as disposal. Utilities may be performing direct application on their own properties, which is regulated under 5 CCR 1007-3. Some reclamation projects may consider using the residuals in certain situations. Composting facilities do take drinking water residuals as a source feed, and so it is discussed in further detail below.

[20] EPA does not endorse these practices because it has not explicitly evaluated the land application of water treatment residuals.

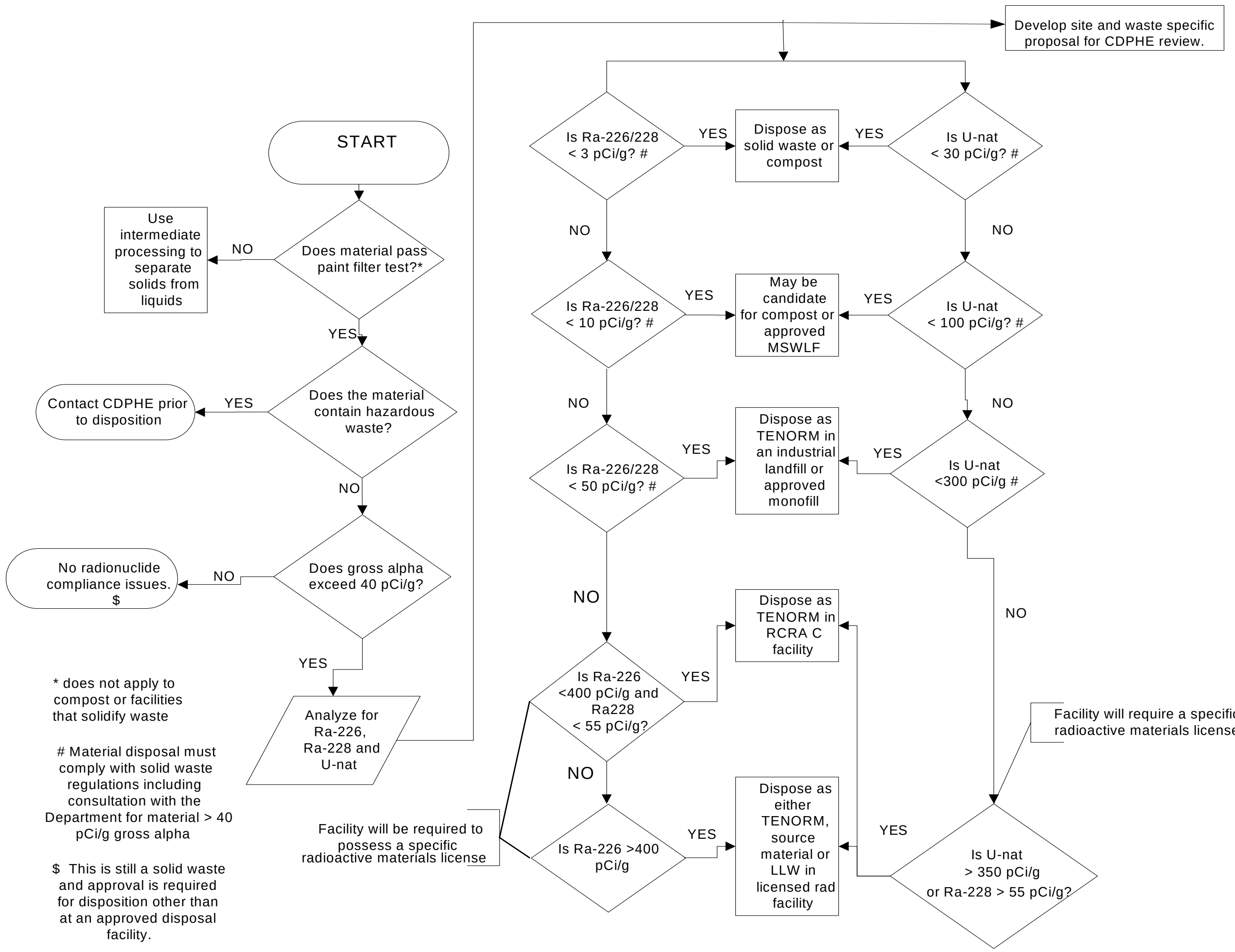


Figure 7. Flow chart for disposal of solid residuals

4.3.2 Composting

In contrast to disposal options in which some degree of engineered containment is in place to limit the release of contaminants, beneficial reuse can involve unrestricted release or distribution of a commercial product. This is the case when residuals are used as a compost additive. Furthermore, compost may be used as a soil amendment where food is grown for human consumption. Therefore, the Department stipulates that the finished compost should not contain radionuclide concentrations elevated above the range of background in Colorado soils for radium. Generic Colorado background values are provided in Table 3-2. Site-specific background values may be determined and applied with Department approval.

Use of residuals as a feedstock or compost additive is allowed at a Class I composting facility, provided all regulatory requirements are met. Chief among these is that the facility must have a Certificate of Designation (CD), as well as a Department-approved Design and Operation Plan (D&O). In general, the compost facility whose recipe would benefit from solid residuals could accept solid residuals up to 3 pCi/g $^{226/228}$Ra and 30 pCi/g ^{nat}U above background, since those levels are below the threshold where the Department controls the residuals for its radioactive content. Finished compost must be tested for radionuclides.

Facilities that develop enhanced process controls to ensure adequate protection of the workers may propose to accept residuals within an intermediate tier ranging up to activity levels of 10 pCi/g $^{226/228}$Ra and 100 pCi/g ^{nat}U, consistent with Section 4.4. These process controls could constitute a significant change to the facility D& O Plan, subject to Department approval. Notice of the change must also be given to the local governing authority, and review and approval by the local governing authority is necessary.

While specific techniques or methodologies may vary from facility to facility, the following factors, at a minimum, would have to be addressed in the site D& O Plan by compost facilities proposing to accept residuals within the intermediate tier:

- Techniques to prevent windblown dispersion, such as wetting or tarping of stockpiles,
- Protection of groundwater and surface water ,
- Composting facilities are required to remove water from collection or impoundment facilities within 15 days. Collection and analysis of surface water samples for gross alpha, beta, and gamma activity on an annual basis for screening may be required for large facilities that generate large volumes of surface water. The data will be evaluated using trend analysis tools to determine if the solids residuals have affected the leachate. Should the screening evaluation indicate the potential release of alpha, beta or gamma activity into the surface water, then speciated analysis of surface water will be required.

- If the facility does not have a surface water collection system, then the groundwater monitoring wells must be sampled and analyzed for speciated radioactivity.
- Periodic soil sampling to ensure no elevation above free release criteria (e.g., as a check on windblown dispersion controls). An initial soil survey to yield site soil background levels would be desirable.
- Techniques to achieve thorough mixing and homogenization must be employed to ensure that the solids residuals in windrows/static piles/in vessel/ anaerobic digesters/and other treatment techniques are all completely mixed both horizontally and vertically. Decontamination of equipment may also require consideration.
- The baseline testing frequency for finished compost is 1 test per 20,000 cubic yards. Testing of finished compost made from residuals will be required at a greater frequency to demonstrate that target levels are being achieved in the finished compost. The degree of testing may be tied to the activity level and variability of the incoming material and treatment processes.
- Groundwater monitoring parameters must include radionuclides if the materials received exceed the established free release criteria.
- The closure plan should be revised to include soil sampling to ensure no elevation above free release criteria.
- Financial assurance coverage may also require adjustment to account for the incremental cost of disposing of unprocessed residuals, or in process compost containing residuals. The purpose of this is to cover the costs of closure and post-closure care, should the facility fail to meet these obligations.
- Institutional controls and an Environmental Covenant may be required for MSWLFs at closure of the solid waste disposal site and facility.

4.3.3 Direct Land Application

The WQCD regulates direct land application under authority of *Regulations Pertaining To The Beneficial Use Of Water Treatment Sludge And Fees Applicable To The Beneficial Use Of Sludges.* (5 CCR 1003-7), in which beneficial use is narrowly defined as: "… the use of the nutrients and/or moisture in the sludge to act as a soil conditioner or low grade fertilizer for the promotion of vegetative growth on the land." Beneficial re-use based on that regulation is restricted to those residuals that contain ≤ 40 pCi/g gross alpha on a dry weight basis. In addition, the regulations require a Beneficial Re-use Plan be submitted to the Department for approval prior to distribution of residuals or the application of residuals.

The plan needs to describe the:
- legal description of the parcel,
- number of pounds of sludge per acre,
- types of crops to be grown on the land,
- number of acres of each crop, and
- analytical data.

Drinking water residuals may not be used where root crops, or low hanging fruit and vegetables are grown for human consumption. This regulation has been moved under the authority of the Hazardous Waste Commission. The Department has 30 days to review the plan and accept or reject the application. The Department will issue a certification upon approval for beneficial reuse, if approved. Facilities that already have a certificate of designation (CD) that includes these residuals, however, are exempt from these regulations[21].

Monitoring, is required either annually, or if done infrequently, prior to disposal. The department may require groundwater, soils, or plant tissue monitoring and/or the analysis of solids residuals for additional parameters if the Department has reasonable grounds to believe that a particular water treatment sludge may contain any elements or compounds that could cause a hazard to public health or the environment.

Because of proposed changes to the Biosolids Regulations, Water Treatment Sludges can no longer be co-applied with Biosolids.

Storage and handling requirements are defined as follows: Facilities for the storage of water treatment sludges located at an application site shall be bermed or otherwise protected so as to prevent movement of spillage or runoff from the storage facilities off of the permitted site. Water treatment sludge shall be stored in such a manner as to prevent windblown sludge from escaping the storage facility. Please refer to Section 7, Basic Health and Safety Precautions, for worker safety recommendations.

4.4 Solid Waste Landfills

At this point, it may be helpful to define the three basic types of solid waste landfill: municipal solid waste landfill (MSWLF), industrial landfill and monofill. A municipal solid waste landfill is one that receives household waste (not necessarily exclusively), an industrial landfill accepts only wastes generated by manufacturing or industrial operations, and a monofill is a landfill or section of a landfill that receives a single waste stream. While these three landfill types share some attributes in common, there are important distinctions among them. Therefore, we have given each its own subsection below, recognizing that this gives rise to a certain amount of redundancy.

---

[21] The CD process is intended to address the siting and operation of landfills and similar activities. The legislature has recognized that the CD requirement was inappropriate for certain modes of waste recycling and utilization and therefore amended the statute in 1986. This amendment provides an exemption to the CD requirement for "the final use for beneficial purposes, including fertilizer, soil conditioner, fuel, and livestock feed, of sludge which has been processed and certified or designated as meeting all applicable regulations, including fees, of CDPHE and the Department of Agriculture shall not require a certificate of designation for such final use." (§30-20-102 (6)). Other modes of sludge disposal (i.e., composting or dedicated disposal) remain subject to the CD requirement.

The CD process is intended to address the siting and operation of landfills and similar activities.

4.4.1 Municipal Solid Waste Landfills

Dry solids that are not considered hazardous waste may be disposed of in RCRA Subtitle D MSWLFs , depending on radioactivity content. There are protocols that must be followed under the Solid Waste Regulations (6 CCR 1007-2). Not all MSWLFs accept water treatment residuals, and those that do will require documentation prior to acceptance of the waste. A facility's approved waste characterization plan will specify which types of wastes are accepted for disposal. MSWLs take putrescible wastes, and therefore require methane gas mitigation, pumping gas from the landfill into the air. Therefore, care should be taken that radium concentrations in the landfill do not pose a radon problem since these landfills generally have methane mitigation systems that may become conduits for radon and subject to the requirements of the Department's Air Pollution Control Division. MSWLs can receive solids residuals with gross alpha activity less than 40 pCi/g and combined $^{226/228}$Ra concentrations of less than 3 pCi/g above background, and less than 30 pCi/g above background for natural uranium, respectively, without Department approval. These materials may still be subject to local restrictions, however. If a MSWLF meets the current design specifications for protection of groundwater, the disposal of solids residuals with higher activity levels (up to 10 pCi/g $^{226/228}$Ra and 100 pCi/g ^{nat}U above background) is acceptable, but the landfill will need specific Department approval and potentially separate approval from the local governing body since acceptance of the residuals may require a modification to the CD or the D&O Plan.

The implementation of enhanced facility controls are as follows:

- Disposal facilities must be approved by the Department and the local governing authority for acceptance of solids residuals at the activity levels up to 10 pCi/g $^{226/228}$Ra and 100 pCi/g ^{nat}U above background.
- For planning purposes, no more than 1-10% of the volume of the cell should contain these subject materials [22].
- The subject materials are to be disposed of in a discrete area and covered immediately. A civil survey should be performed, preferably by a licensed professional surveyor for record keeping purposes. If GPS is used to locate the areas, the data should be differentially corrected to within 1m. No subject materials are to be disposed within 3 meters of the final repository cover.
- The disposal facilities must conduct appropriate training of workers. Please refer to Section 7, Basic Health and Safety Precautions, for worker safety recommendations.
- The disposal facilities must employ dust control as necessary during staging and application of the materials, but may not add free liquids to a disposal cell.

[22] Risk assessments show that the volumes could be higher. The amount of material allowed will be a function of the local approval process through the Certificate of Designation.

- The volume release levels should not be construed as provisions for the disposal of higher activity waste by mixing and dilution with clean material.
- The volume release levels may be superseded when materials are shipped to authorized disposal facilities that have site-specific waste acceptance criteria, including TENORM concentration limits. For instance, this might come into play in the case of a dedicated cell (i.e., monofill) at an MSWLF with a Department approved risk assessment.
- The facility should have a liner and leachate collection and recovery system.
- Leachate samples should be collected and analyzed for gross alpha, beta and gamma activity on an annual basis for screening. The data will be evaluated using trend analysis tools to determine if the solids residuals have affected the leachate. Should the screening evaluation indicate the potential release of alpha, beta or gamma activity into the leachate, then speciated analysis of leachate will be required.
- Additional groundwater monitoring requirements may be incorporated into the facility D & O Plan predicated on the above analytical results and data evaluation.
- If the facility does not have a leachate collection system, then the groundwater monitoring wells must be sampled and analyzed for speciated radioactivity.
- If the facility does not have groundwater monitoring wells, then an appropriate groundwater monitoring network must be established.
- Waste Acceptance: The landfill's approved waste acceptance plan should contain specific protocols for handling water treatment plant residuals. These will require the generator ensure the residuals contain no free liquids as demonstrated by use of the paint filter test (US EPA Method 9095) prior to disposal. Likewise, pH of the residuals must not be below 6.0 for landfill disposal. Finally, the generator must make a hazardous waste determination (based either on generator process knowledge or analytical results) to ensure the sludge does not fail toxicity characteristic for metals.
- Institutional controls and an Environmental Covenant will be required for MSWLFs at closure of the solid waste disposal site and facility.

Disposal facilities that wish to accept materials above the limits need to demonstrate that the resulting dose to workers and the public from conservative assumptions will not yield a dose to the reasonably maximally exposed individual greater than 0.25 mSv (25 mrem/y). The conservative assumptions are the total projected inventory of radionuclides from all disposal practices at the facility. A further constraint of no more than 40 uSv/y (4 mrem/y) from groundwater from beta/photon emitters may also be applicable.

4.4.2 Industrial Landfill /Cell

An industrial landfill cell is one that accepts only wastes generated by manufacturing or industrial operations, and is one that does not take putrescible waste. An industrial landfill is presumed to have discrete disposal cells, a composite liner and leachate collection system, and stringent waste acceptance handling protocol and manifesting requirements. Therefore, dry treated wastes with slightly higher concentrations can be safely disposed of in an industrial landfill cell. Concentrations of up to 50 pCi/g combined $^{226/228}$Ra, 50 pCi/g ^{NAT}Th, and concentrations up to 300 pCi/g ^{Nat}U may be disposed of based on Department and local governing body approval. An industrial landfill cell that has a solidification basin may be able to perform intermediate treatment of residuals containing free liquids. Thus, in that respect, the waste acceptance criteria may be different than for a municipal solid waste landfill, which cannot accept waste containing free liquids. The disposal of materials with higher activity levels (up to 50 pCi/g combined $^{226/228}$Ra and 300 pCi/g ^{Nat}U) requires specific approval from the local governing body; however, the Department has approved these levels for one existing facility. The implementation of enhanced facility controls are as follows:

- Disposal facilities must be approved by the Department and the local governing authority for acceptance of solids residuals at the activity levels up to 50 pCi/g combined $^{226/228}$Ra and 300 pCi/g ^{Nat}U.
- For planning purposes, no more than 1-10% of the volume of the cell can contain these subject materials (disposal in the cell at these concentrations will yield effective concentrations at or below background ranges)[23].
- The subject materials are to be disposed of in a discrete area and covered immediately. A civil survey should be performed, preferably by a licensed professional surveyor for record keeping purposes. If GPS is used to locate the areas, the data should be differentially corrected to within 1m. No subject materials are to be disposed within 3 meters of the final repository cover.
- The disposal facilities must conduct appropriate training of workers. Please refer to Section 9, Basic Health and Safety at Disposal Facilities, for worker safety recommendations.
- The disposal facilities must employ dust control as necessary during staging and application of the materials.
- The volume release levels shall not be construed as provisions for the disposal of higher activity waste by mixing and dilution with clean material.
- The volume release levels may be superseded when materials are shipped to authorized disposal facilities that have site-specific waste acceptance criteria, including TENORM concentration limits.
- Leachate samples must be collected and analyzed for gross alpha, beta, and gamma activity on an annual basis for screening. The data will be evaluated using trend analysis tools to determine if the solids residuals have affected the leachate. Should the screening evaluation indicate the potential release of alpha, beta or gamma activity into the leachate, then speciated analysis of leachate will be required.
- Additional groundwater monitoring requirements may be incorporated into the facility D & O Plan predicated on the above analytical results and data evaluation.

[23] Risk assessments show that the volumes could be higher. The amount of material allowed will be a function of the local approval process through the Certificate of Designation.

- The presumption is that an industrial landfill would have a liner and leachate collection and recovery system. If the facility does not have a leachate collection system, then the groundwater monitoring wells must be sampled and analyzed for speciated radioactivity (uranium isotopes and radium isotopes, ^{40}K).
- If the facility does not have groundwater monitoring wells, then an appropriate groundwater-monitoring network must be established.
- Waste Acceptance: The landfill's approved waste acceptance plan should contain specific protocols for handling water treatment plant residuals. These will require the generator ensure the residuals contain no free liquids as demonstrated by use of the paint filter test (US EPA Method 9095) prior to disposal. Likewise, pH of the residuals must not be below 6.0 for landfill disposal. Finally, the generator must make a hazardous waste determination (based either on generator knowledge or analytical results) to ensure the sludge does not fail toxicity characteristic for metals.
- Institutional controls and an Environmental Covenant will be required for industrial landfills at closure of the solid waste disposal site and facility.

4.4.3 Monofills

Monofills are solid waste disposal facilities that take only one type of waste. Monofills are approved by the Department and permitted by the local governing authority. Since residuals are disposed of on these sites, they will have permanent institutional controls to protect the public and environment. The requirements for monofills are addressed under the Solid Waste Regulations (6 CCR 1007-2, Section 12). Disposal of residuals up to 50 pCi/g $^{226/228}$Ra and 150 pCi/g ^{nat}U requires specific approval from the local governing body and the Department. The implementation of enhanced facility controls are as follows:

- Disposal facilities must be approved by the HMWMD of the Department and the local governing authority for acceptance of solids residuals at the activity levels specified above.
- The disposal facilities must conduct appropriate training of workers; Please refer to Section 9, Basic Health and Safety at Disposal Facilities, for worker safety recommendations.
- The disposal facilities must employ dust control as necessary during staging and application of the materials.
- The volume release levels shall not be construed as provisions for the disposal of higher activity waste by mixing and dilution with clean material.
- Leachate samples must be collected and analyzed for gross alpha, beta, and gamma activity on an annual basis for screening. The data will be evaluated using trend analysis tools to determine if the solids residuals have affected the leachate. Should the screening evaluation indicate the potential release of alpha, beta or gamma activity into the leachate, then speciated analysis of leachate will be required.

- Additional groundwater monitoring requirements may be incorporated into the facility D & O Plan based on the above analytical results and data evaluation.
- If the facility does not have a leachate collection system, then the groundwater monitoring wells must be sampled and analyzed for speciated radioactivity.
- If the facility does not have groundwater monitoring wells, then an appropriate groundwater-monitoring network must be established.
- A monofill must follow its site specific, approved waste acceptance plan. The acceptance criteria would be identical to that noted above for a municipal solid waste landfill.
- Only soil-like solids from the treatment of drinking water may be disposed of in the monofill.
- No subject materials are to be disposed within 3 meters of the final repository cover, unless it can be demonstrated that radon levels will not exceed 20 pCi/m/s with less cover.
- Monofill must meet requirements of all applicable Department regulations, including groundwater protection and surety requirements.
- A risk assessment is required based on the total expected inventory of radioactivity in the monofill at closure. The risk assessment shall demonstrate the reasonably maximally exposed individual of the critical group will not receive a dose of > 25 mrem/y, including a constraint of 4 mrem/y from beta/photon emitters.
- Institutional controls and an Environmental Covenant will be required for monofills at closure of the solid waste disposal site and facility.

4.4.4 Hazardous Waste Landfill

Disposal of TENORM in the only RCRA Subtitle C landfill in Colorado has been approved for up to 400 pCi/g ^{226}Ra and up to 2,000 pCi/g total activity, with a constraint on source material limits for uranium and thorium. The facility has acquired a radioactive materials license to accept both unlicensed and licensed TENORM. This facility also has a treatment facility, and may be able to treat some waste streams. Numerous provisions have been written into the license containing strict operational and monitoring requirements.

There are at least three other Subtitle C facilities in the country that accept TENORM up to 2,000 pCi/g total activity and to source material limits for uranium. Additionally, TENORM residuals that contain hazardous waste (e.g., arsenic) may need to be disposed of in either a Subtitle C or low-level waste facility. There is one facility in Utah specifically permitted to receive mixed wastes.

4.4.5 Rocky Mountain Low Level Radioactive Waste Compact

There are no commercial low-level radioactive waste disposal sites in Colorado (radioactive materials containing TENORM can be disposed in-state). Colorado belongs to the Rocky Mountain Low Level Waste Compact, which includes Colorado, New Mexico, and Nevada. Because of the agreement between the Rocky Mountain Compact and the Northwest Compact, Colorado generators have access to the American Ecology Hanford facility in Washington state. Permits for export outside of the Compact states (Colorado, New Mexico and Nevada) are approved for other facilities that accept low-level waste on a regular basis, such as Energy Solutions (formerly Envirocare) in Utah. In-region disposal of TENORM is addressed in Rule 12 (RMLLRWB 2006) of the Rocky Mountain Low Level Radioactive Waste Board. It allows for in-region disposal of TENORM in accordance with state policies and regulations regarding the disposal of such waste. This means that Colorado TENORM can be disposed in Colorado per the requirements of the Department without additional costs to the generators by having to go through the Rocky Mountain Compact.

The RMLLRWB will continue to regulate the import and export of TENORM in and out of the Compact. Persons who wish to import NORM/TENORM for disposal in-region shall obtain authorization pursuant to Rule 7 *Application for Permission to Manage Waste Generated Outside the Region* (RMLLRWB 2006a). Persons wishing to export in-region TENORM wastes shall obtain authorization pursuant to Rule 6 *Exportation of Waste from the Region* (RMLLRWB 2006b).

TENORM that is greater than the limits cited above or 0.05% uranium or thorium (e.g., spent resins, media, filters that contain higher concentrations) must go to a licensed radioactive waste facility. A radioactive materials license is generally required to send material to these facilities. These facilities also have strict packaging and burial requirements. It is recommended that a consultant or radioactive waste broker be retained to address the numerous administrative hurdles in getting material accepted at a low-level waste site.

5 Sampling and Analysis for TENORM in Drinking Water Residuals

5.1 Background

With the recent implementation of the drinking water *Radionuclide Rule* (RR), The *Basic Standards for Groundwater* (5 CCR 1002-41), and other drivers such as the *Stage 2 Disinfectants and Disinfection Byproducts Rule* (D/DBP), *Stage 1 and Stage 2 Long Term 2 Enhanced Surface Water Treatment Rule* (EPA 1998, EPA 2006) , as well as improved finishing techniques, municipalities and other public water systems are accumulating, and eventually disposing of, quantities of TENORM that were never planned for. As regulation of such material evolves, accurate sampling and analysis of these materials becomes critical. This section will define the matrices to be considered, recommend sampling strategies and define the analytical protocols for ensuring compliance with whatever regulatory limits may ultimately be imposed.

This effort is driven by the recognition that the long-standing limit of 40 pCi/g of gross alpha radioactivity is not compatible with current, risk-informed regulatory philosophy.

Although the utility of gross alpha measurements for such materials has been questioned because of the high uncertainty and lack of specificity inherent in the method, the test will be required until the Solid Waste Regulations and Biosolids Regulations are amended. It is anticipated that a limited list of alternate methods and a corresponding screening limit will be proposed to replace the gross alpha value currently in the solid waste regulations. If properly implemented, this guidance should minimize uncertainty introduced by different sampling and analysis protocols.

This section of the guidance document is geared primarily for analysis of residuals to be disposed of, given that intermediate products that do not leave the facility are not likely to need detailed analysis. Those materials may need to be monitored to ensure worker health and safety, as high dose rates may be found in proximity to tanks, pipes, piles or equipment containing TENORM. In cases where operators need more specific information about their intermediate processes, it is expected that these recommendations will at least provide consistent results. Section 7 of this document has additional information on facility monitoring.

5.2 Matrices

In large water treatment plants alum (aluminum sulfate), ferric chloride or other chemicals are added to raw water, forming a sort of gel that gradually coagulates or flocculates, and finally settles to the bottom of the tank as solid waste. Radionuclides and other impurities precipitate along with the solids with relatively high efficiency. Depending on the characteristics of the source water and other factors affecting their solubility, these residuals may require very aggressive digestion techniques in the laboratory in order to accurately measure their radionuclide content. Other residuals may be relatively easy to dissolve, especially if the chemical composition is known.

Some type of sedimentation and filtration usually follows coagulation. A variety of filter media are available for use after coagulation and in combination with other processes, such as fluoridation and disinfection. Activated carbon, sand, diatomaceous earth, greensand and membrane filters are all used. These filters may be backwashed and/or regenerated a number of times, but must ultimately be replaced and disposed of.

Smaller systems most likely remove radionuclides and other contaminants with technologies such as reverse osmosis, ion exchange or softening, which are technologies that generate solid waste as resins and membranes. These are likely generated in small amounts that are relatively easy to sample. Large amounts of filter media or residuals, by contrast, may require relatively complicated sampling plans, depending on the process, facility layout and matrix to be sampled.

Drinking water plant residuals are categorized as resins, membranes, filter media, sludges and liquids. Liquid residuals include brines, concentrates, backwash water, rinse water, and acid neutralization solutions. Similar to solid residuals, the concerns related to liquid residuals arise when they are finally disposed of by offsite discharge, deep well injection or some other method.

5.3 Sampling

Every public water supply must analyze finished water for gross alpha, ^{226}Ra, ^{228}Ra and uranium. The presence of radioactive materials in raw water virtually assures their presence in treatment plant residuals, and sometimes in high concentrations on media. However, since some treatment processes are highly efficient, raw water with radionuclide results below the detection limit may result in a sludge or media containing measurable amounts radionuclides.

Most large systems in Colorado have sampled their residuals. In the future, small systems generating limited amounts of residuals, either liquid or solid, may be required to sample and analyze these waste products. Any system that has not analyzed their residuals for radionuclides is strongly encouraged to begin as soon as possible. With some idea of the content of these materials, systems may begin planning and budgeting for eventual disposal or reuse. General knowledge of the concentration of TENORM and other contaminants is essential to ensure that all relevant regulations can be addressed before a system's storage capacity is exceeded.

Seasonal changes have been noted in the quality of both surface and ground water sources, so quarterly sampling is recommended until the range of concentrations for the waste stream is determined. Sampling will likely be required by the receiving facility at the time of disposal if there is not sufficient characterization data available. Additional sampling is recommended, and may ultimately be required, when:

- a new source of water is introduced into the system,
- a new process for water treatment is utilized, or
- modifications are made to the system or process that could result in a change in radionuclide concentration in the residuals.

Deep-water sources are less likely to fluctuate, and may be candidate for reduced sampling.

Sample results of residuals should be scientifically and legally defensible prior to final disposition. Sampling parameters and methods should be spelled out in the Residuals Management Plan submitted to the WQCD. EPA guidance regarding the content and format of sampling and analysis plans is available online, and other assistance may be available from the WQCD Compliance Assistance and Data Management Unit or the treatment system vendor. Samples will usually need to be collected on a random basis. EPA SW846 provides guidance on laying out grids and generating random samples. In every case, samples submitted to a laboratory need to be identified by:

- the plant name,

- sampling location within the plant,
- time and date collected, and
- person collecting the sample.

5.3.1 Liquids

In some treatment systems, backwash water is simply mingled with the source water, so no residual exists to be sampled. In other systems, backwash water, brines, acid neutralization solutions or other liquid residuals are incompatible with the raw water and must be disposed of separately. These solutions should be collected at the last possible point in the system before the liquids are released from the facility, following any dilution or pretreatment. Collect the sample in a one-gallon cubitainer or other plastic container provided by the lab, seal tightly and deliver to the lab as soon as convenient. Samples should be acidified in the lab upon arrival. Holding time for radionuclides is six months. Liquid residuals with concentrations of TENORM above water quality control discharge or source water protection limits may be very difficult to dispose of. In many cases, liquid residuals may be treated by evaporation or other interim treatment, thereby generating solid wastes.

5.3.2 Solids

It is impossible to give specific sampling guidance that will apply to all systems because of the variety of configurations possible for membrane filters, ion exchange systems, reverse osmosis systems, softeners, or other systems. A sampling plan for a treatment system should be discussed with the vendor when the system is purchased or installed. What follows is general guidance that may or may not apply to a given treatment system.

Table 5-1 shows the approximate number of samples required for adequate analysis of small, medium, and large filter beds, sludge lagoons or similar facilities prior to disposal. Regulators may need to adjust these recommendations based on data quality objectives, process knowledge, or facility specific information.

Table 5-1. Number of samples to ensure representiveness

System Size	Number of samples
Small (<100 yds^3)	4
Medium (>100, < 1000 yds^3)	6
Large (> 1000 yds^3)	9

5.3.2.1 Media

Ion exchange resins, zeolite or greensand filter media and softener salts may be chemically regenerated numerous times, but will eventually lose their exchange capacity and must be disposed of. Resins usually take the form of small plastic beads packed in columns or arrayed in “beds.” Some types of filter media are used in similar configurations. Sampling will need to be performed prior to disposal and should probably be performed prior to replacing the material, unless the facility has a suitable long-term storage location. Samples should be taken shortly after regeneration, but care should be taken to flush acid or caustic solutions from the resin or media before collecting the sample.

It may be possible to sample resins or filter media in columns using a “core” type sampler, if it is of suitable length and has a means to plug the lower end. This should provide a representative sample of the column in question, but may not represent all columns in a treatment system. Columns in series, especially using different types of media, will retain different kinds and amounts of TENORM and other materials, and each will need to be characterized before all disposal requirements can be defined. Core samples should be taken from the full length of a column and placed in a clean, one-liter plastic bottle obtained from the lab, repeating the process until the bottle is full.

Sampling from a resin or filter bed can be done in a similar manner. Dow Chemical (DOW 1994) gives a sampling procedure using a sampling tool that can be built using PVC pipe, nylon string, two rubber stoppers, and an eyebolt. They recommend collecting one quart (one liter) of resin for analysis, but were not planning to analyze for TENORM. Large beds will need multiple samples to ensure representativeness. These should be distributed through the bed, along the axis of water flow.

5.3.2.2 Membranes

Membranes from reverse osmosis systems may be small enough that the entire membrane may be submitted to the lab. More likely, this membrane will need to be removed from its container and sampled by cutting pieces 4 inches by 4 inches (10 cm by 10 cm) for submission to the lab. The number of samples will depend on the total area of the membrane, but the area sampled should rarely have to exceed 10% of the total area. Samples should be randomly distributed across the area of the membrane. Cut samples should be placed in plastic zip-lock bags for submission to the lab.

Large membrane filter cartridges should be allowed to dry and then be cut into pieces of manageable size using a hacksaw, chainsaw, or other suitable cutting tool. Filter cartridges should be chosen for sampling based on the system plumbing: if it is expected that all cartridges will be equally contaminated, a single cartridge may be an adequate sample. Systems in which cartridges are plumbed in series, or where some cartridges treat more water than others, would require sampling of more cartridges. Three slices, a minimum of two inches thick, should be taken from near the top, middle, and bottom of each cartridge. If the structural integrity of the “slice” cannot be maintained, thicker slices should be cut. Each slice should be placed in a clean plastic bag and submitted to the lab. Laboratories need procedures for compositing and/or sub-sampling these slices.

5.3.2.3 Sediment and Sludge

Residuals are often held in lagoons for dewatering and may be processed through a belt-press or by other means in order to produce material that will pass the “paint test” for solid waste. Collecting samples of material leaving a belt press is usually a straightforward matter of scooping several ounces of residuals into a clean plastic container, such as a bucket, with a garden trowel or similar tool on a regular schedule throughout the dewatering “run.” Once in the bucket, the material should be thoroughly mixed and transferred to a large mouthed bottle. At least one kilogram (2.25 lb) of material should be submitted to the lab per sample.

Residuals samples from a tank or lagoon may be collected with the same device used for sampling IX resin. Augers, thin walled tubes or other soil sampling devices will work, providing they reach the bottom of the container, for it is important to ensure that samples are collected from the entire depth of the residuals and not just the upper layers. Free liquids in such samples must be kept to a minimum, either by filtering, evaporation, or other methods. The number of samples will vary depending on the total volume or mass of residuals to be characterized, but at least one kilogram of material should be collected per sample.

5.4 Analysis

In a closed system, long-lived radionuclides such as ^{238}U or ^{226}Ra decay to short-lived radionuclides. In a process called ingrowth, the activity of the progeny increases until it is approximately equal to that of the parent nuclide. The total amount of radioactivity increases until all the decay products in the “decay chain” are equal in activity. This condition is known as secular equilibrium and is perhaps best observed in certain minerals with high uranium or thorium content (Cember 1989). Disruption of secular equilibrium is a frequent consequence of many natural and industrial processes, such as the processes that lead to NORM in water concentrating as TENORM in residuals and filter media. Radiochemists are sometimes able to take advantage of these processes, measuring short-lived decay products as proxies for longer-lived parent material. Failure to consider the age and ingrowth status of a filter or residuals sample will lead to faulty assumptions about the radioactivity in the material.

Under the current Solid Waste Regulations, analysis for gross alpha radioactivity is required. The regulation only speaks of gross alpha, but the nature of the test is such that gross beta results are generated at the same time. It should be noted that there are technical limitations to gross alpha/beta analysis, and that it is more useful as a screening tool than as an input to risk assessment. The failure to account for the presence or absence of short-lived decay products may lead to anomalous or confusing results when trying to account for the observed gross alpha activity, because a sample with a given amount of ^{226}Ra, for example, may show various amounts of alpha activity depending on radon off-gassing, decay of ^{224}Ra or many other variables. It is also worth noting that ^{228}Ra, one of the significant constituents of some forms of TENORM, is a beta emitter and does not directly correlate with gross alpha activity.

Gross alpha measurements may be influenced by the choice of calibration standard, air pressure, humidity and the kind and amount of inert material present in the sample. All of these can be controlled or compensated for in the lab, but the last is probably the biggest contributor to uncertainty in the gross alpha measurement. Alpha radiation is easily absorbed by solid material, and for this reason, gross alpha methods approved for drinking water limit the amount of solids allowed on the planchet when counting the sample. Within the limits allowed by the method, self-absorption is corrected for mathematically, a solution that can introduce substantial error if not performed correctly.

Liquid residuals may contain high amounts of dissolved and suspended solids. In order to achieve a reliable measurement and appropriate detection limit, the sample aliquot may be much smaller than that used in drinking water analysis, and the measurement uncertainty is likely to increase unless other steps are taken. Filtering the suspended solids may ease this situation somewhat, but leaves questions about accurate measurement of the solids.

Solid residuals are subject to all of the pitfalls of gross alpha analysis in liquids, and have the additional challenge of needing a homogenization step prior to analysis. Most labs do this with a variety of mixing and grinding techniques, but procedures are not consistent, and results may vary. Significant differences in methods could have important implications for the ultimate fate of some residuals. Alum residuals can be quite hygroscopic, meaning that they absorb water from the air. Failure to account for alpha self-absorption of the water mass may lead to incorrect gross alpha results.

Historically, high gross alpha results in residuals have led to specific analyses for total uranium, ^{226}Ra and, in some cases, ^{228}Ra. Totaling the results of the measured alpha emitters rarely accounts for the gross alpha activity. Therefore, further analyses for ^{224}Ra, ^{210}Po or thorium isotopes may be justified when high alpha activity cannot be accounted for by uranium and radium analyses. ^{210}Pb is generally analyzed instead of ^{210}Po. These are bound to be present in most residuals and filter media to some degree, but it is not clear if or when they may be significant contributors to the total alpha activity in the residuals or how knowledge of their concentration would affect a given risk assessment.

Analysis of solid residuals is not standardized from lab to lab. Discussion of one's analytical needs with regulators and the laboratory's staff is imperative if all parties are to be satisfied.

5.4.1 Analytical methods for water

Analytical methods for radionuclides in drinking water are listed in 40 CFR 141.25 (EPA 2004a). A comprehensive list of analytical methods for drinking water are listed on the EPA Ground Water and Drinking Water web site.

These are limited to gross alpha/gross beta, uranium, ^{226}Ra, ^{228}Ra and gamma emitting, man-made nuclides like ^{137}cesium and ^{131} iodine. There is currently no federal or state requirement for analysis of residuals using these or any other method, but approved methods are generally familiar to operators and regulators alike. The problem with these methods is that they were developed for radionuclides in aqueous solution, with little or no material to interfere with the analysis. Their adaptation for analysis of sediments, sludges and other materials, or wastewater with high concentrations of inert materials, is largely a matter of proper sample digestion, so that the radionuclides are once again in solution and available for analysis. Unless the radionuclides are completely re-dissolved, it is possible that the common nuclide-specific drinking water methods will underreport the activity in the sample. A cursory literature search has not discovered any comparison of digestion methods relevant to radiochemical analysis of sludges and filter media; although it is possible such testing has been done.

Gross alpha analysis of solid materials is most simply done by mounting a known mass of finely ground sample, usually 0.1 gram or less, on a planchet and counting on a gas flow proportional counter as if the solids were from a water sample. Alternatively, some labs digest an aliquot of the sample in acid and treat the digestate as a liquid sample, counting the materials dissolved in the digestion, and then calculate the result based on the mass of the solid sample. Gross alpha analysis by liquid scintillation has been investigated for soils and solid wastes, but a number of issues would need to be resolved before any recommendations could be made.

For analysis of ^{226}Ra, the two approved methods are radiochemical (co-precipitation) and radon emanation, but ^{226}Ra is detectable by gamma spectrometry, many labs measure radium in soil using this technique, and EPA is considering approval of the method for drinking water. The only approved method for ^{228}Ra in drinking water is radiochemical, but gamma spectrometry can easily quantify its decay product, actinium-228 (^{228}Ac), which can serve as a good proxy for this radium isotope.

For uranium, several methodologies are available – Inductively Couple Plasma/Mass Spectrometry (ICP/MS), fluorometric, alpha spectrometry, and laser phosphorimetry have all been approved for drinking water. Any of these should be acceptable if the uranium in the sample is rendered completely soluble and interfering compounds are eliminated. Some of these techniques measure the mass of uranium rather than its radioactivity, and conversion factors must be used to equate the two types of measurements. The most common conversion factor (0.67 pCi/μg) assumes that ^{234}U and ^{238}U are in secular equilibrium, as they typically are in soils. In groundwater however, ^{234}U/^{238}U ratios have been measured between 2 and 10, which may be reflected in residuals. More information will be needed if this becomes an important factor in regulatory decision-making.

Beta and photon emitters as regulated in drinking water are not considered NORM, and have not been important parameters in the analysis of water treatment residuals. As mentioned above, the approved analytical methodologies, especially gamma ray spectrometry and liquid scintillation counting, may be adaptable to residual analysis.

Detection limits vary depending on the isotope, type of detector and count time, but these analyses are relatively simple to perform and have the capability to quantify multiple radionuclides at the same time. Method development and adequate QA/QC procedures would have to be demonstrated to convince regulators that these data would be sufficient for decision-making, but the potential for these methods should not be disregarded.

All of these methods and more are likely to provide accurate measurements of radioactive material in solids, if the sample is adequately prepared. A round robin of residual testing performed by Colorado certified labs showed that any analytical method provides more accurate results than gross alpha with respect to alum residuals. Results of the round robin testing are presented in Appendix C.

Preliminary results of gross alpha analysis of two residuals samples demonstrate that results between laboratories are more variable than those from a single laboratory. This is most likely due to the lack of standard methods for drying and preparing samples for gross alpha analysis. The comparison between direct mounting of the sample and acid digestate shows that, on average, the two methods give results of a similar order of magnitude, but that the results in a single lab may vary by a large factor. In either case, the gross alpha results are poor estimators of the total speciated alpha activities.

5.5 Interpretation

The regulations specify, and laboratories deliver, analysis on a dry weight basis. Both alum and ferric chloride residuals have been shown to contain more than 80% moisture. The loss of mass in the drying process is an important consideration for laboratory workers and regulators, and is the main reason for collecting samples of one kilogram or more. Many labs normally dry solid samples at 104°C for approximately 24 hours, but samples such as these may require longer drying times. For true percent moisture measurements, the samples should be dried until the sample mass remains constant. Such percent moisture measurements should be of interest to regulators, since the mass of material being disposed of (or reused) will not actually have the TENORM concentrations reported by the labs, but will be considerably more dilute. Once dried, the sample may absorb water from air and gain mass unless stored in a dessicator. Failure to control this property may lead to biased results.

The organic content of the residuals has a similar effect the interpretation of analytical results. Residuals measured by the Department had organic content (of the dry weight) ranging from 22% to 37%. Such high amounts of organic material may interfere with the analysis of metals, including uranium, thorium and radium. Treatment to deal with organic material must be done in such a way that the results are not unduly influenced by the treatment. Since both moisture and organic content are likely to vary from system to system, and season to season, regulators may need to factor these issues into their policies in order to treat all systems equitably.

Waste acceptance criteria are not defined here, but certain data will most likely be universally required. Limits on uranium and thorium concentration will, at a minimum, be based on the definition of source material, 0.05% by mass. This is equivalent to 500 μg/g, 500 mg/kg, or 500 ppm. Uranium measurements may be reported as, or converted to, parts per million (ppm) and then converted to percent by dividing by 10,000. Other criteria may include limits on total radium concentration. Total radium is defined as ^{226}Ra plus ^{228}Ra. Other measurable radium isotopes such as ^{223}Ra and ^{224}Ra are excluded, since their short half-lives preclude any significant risk in the absence of the parent nuclides.

5.6 Recommendations

Preliminary results for the analysis of residuals by labs certified to test radionuclides in drinking water show that the uncertainty associated with the gross alpha test is much greater than the counting uncertainties would indicate, and that the test generates qualitative data only. In other words, high results give no indication of what radioactive material is in the sample, and only estimate the total radioactivity of the sample within an order of magnitude at best. Gross alpha testing appears to be inappropriate for the regulation of TENORM in solid materials such as drinking water residuals. The Sampling and Analysis workgroup recommends amending the appropriate regulations to require testing for uranium and radium specifically, and to base regulatory decisions on those results, rather than gross alpha results.

6 Radioactive Materials Licensing

Considering that there are already controls at drinking water treatment facilities to protect workers and the public, it is not necessary to implement full radioactive materials licensing of drinking water treatment facilities at lower levels of exposure and concentration, providing the controls are also adequate to protect the workers and the public from the additional hazards of exposure to radiation. Therefore, the Department is taking a graded approach to licensing, as it is for disposal. Increases in exposure potential and increases of concentrations of radioactive materials can result in increases of regulatory control.

The WQCD and HMWMD review of the Residuals Management Plan will generally be the basis for determining the regulatory path for a particular drinking water treatment facility in most cases. Disposal facilities other than the RCRA C Hazardous Waste landfill (which already has a radioactive materials license) will be controlled through their CDs and D&O Plans rather than through licensing.

Department practice has been to regulate naturally-occurring sources of radiation consistently with those of man-made radioactive materials, and uses the applicable portions of the Radiation Regulations accordingly on a case-by-case basis. While residuals traditionally have been managed as solid waste, some residuals may fall under radioactive materials licensing, and are essentially dual-regulated.

There are two types of radioactive materials licenses: general and specific. General licenses generally are automatically granted by nature of possession of the material, and have very limited requirements. Specific licenses are fee-based and have more controls and reporting requirements. The Department has basic authority to require maintenance of records, inspections, and tests and to define acceptable disposal mechanisms in both cases.

A specific Radioactive Materials License may be required if:

- If a worker receives, or is anticipated to receive, > 25 mrem/y above background (this is almost exclusively from external gamma radiation). Since workers spend very little time around the residuals, it is likely that few, if any, facilities will require a license from this criteria. Additional information on calculating doses is presented in Apendix F.

- If a utility generates residuals containing source material (uranium or thorium in any combination > 0.05% by weight), they may be required to obtain a specific radioactive materials license. There are two exemptions that reduce that likelihood:
    - < 15 lbs of source material at a time, and
    - < 150 lbs of source material in a year.

  Note that the concentrations address actual uranium and thorium, and do not include the matrix. The NRC is currently in rulemaking to relax the specific license requirement for uranium, and is proposing that a general license approach be implemented for drinking water treatment residuals containing greater than source material concentrations (USNRC 2006). Colorado may consider promulgating a similar regulation, depending on the outcome of the NRC rulemaking.

- Utilities that generate $^{226/228}Ra$ in their residuals may be required to obtain a radioactive materials license, depending on the concentrations in the residuals. There is no exempt concentration or exempt quantity for radium in the Radiation Regulations. The Department will exercise discretion and require a specific radioactive materials license if the residuals contain greater than 50 pCi/g $^{226/228}Ra$, unless they can demonstrate that sufficient controls are in place to protect workers and the environment.[24] Residuals below that concentration still are regulated as solid waste.

- A waste broker may not accept residuals containing radium with any concentration without a license; in those situations, the Department will issue a

[24] This value is consistent with the disposal policy in that residuals > 50 pCi/g combined Ra must go to the licensed Subtitle C facility, whereas materials < 50 pCi/g combined Ra can go to the permitted industrial landfill.

Provisional license in order to transfer the materials. The provisional license is free and is good for six months. Contact the Radiation Control Program for additional assistance.

Requirements for specific licenses are discussed below and include:

- The licensee must develop an As Low As Reasonably Achievable (ALARA) plan, and an annual review of the ALARA program,
- development of a radiation protection program, including written operating procedures related to radiation safety (not plant operating procedures),
- making surveys and measurements,
- recording and reporting of doses to workers,
- posting and labeling requirements,
- documentation of worker training and experience,
- a description of the instruments and equipment used to analyze the residual streams,
- procedures for storage and control of radioactive material, and
- transfer and disposal procedures.

Airborne emissions from licensed sites are constrained to 10 mrem/y to any member of the public.

6.1 Regulatory Basis for Radioactive Material Authorizations

The original scope of the Atomic Energy Act (40 USC 121) was limited to the nuclear fuel and weapons cycles for strategic purposes and did not address other areas until later years, including public safety. The radiation regulations were crafted with the premise that entities want to possess radioactive material for various purposes, e.g., industrial gauges, medical applications, generating electricity. The regulations were not specifically crafted for sectors that inadvertently come to possess radioactive material, such as from treating drinking water. It has become apparent over the last few decades that sources of radiation other than those from the fuel and weapons cycles can cause health issues (e.g., radon and radium). In radiation protection, a dose is a dose, no matter whether the source originated in nature or in a reactor. Our bodies don't differentiate a dose from nature or from industry. This is a reason why regulating TENORM has come into practice; to ensure that there is consistent protection of workers and the public from the hazards associated with sources of ionizing radiation.

There are some regulatory and operational constraints that trigger licensing. Again, the structure of the regulations is predicated on entities who want to possess radioactive material applying to the Department prior to authorization to possess, something that is not the case in industry where the presence of the radioactivity is not discovered until later. Therefore, the Department will use its discretion granted in the Radiation Regulations on when to specifically license a drinking water treatment facility. Since the facility may not be aware they possess the material, or when they will exceed a trigger level, the Department recommends that a 60-day notification period be utilized once a utility is aware they possess TENORM.

Licensing is addressed in Part 3 of the Radiation Regulations.

6.1.1 General licenses

Current Department policy is to waive the general license requirement, providing the WQCD and solid waste permits and other controls are adequate to protect workers and the environment. A review is still provided for completeness.

A general license is provided by the radiation regulations (§ 3.4.1 of The Radiation Regulations) and grants authority to a person for certain activities involving radioactive material, for example when one realizes they possess radioactive material. A general license is effective without the filing of an application with the Department or the issuance of a licensing document to a particular person. The general licensee is subject to all other applicable portions of these regulations and any limitations of the general license, and are discussed in more detail below.

> Ownership of Radioactive Material (§ 3.6.6). "A general license is hereby issued to own radioactive material without regard to quantity. Notwithstanding any other provisions of this part, this general license does not authorize the manufacture, production, transfer, receipt, possession, or use of radioactive material."

This is interpreted to mean that a facility that generates TENORM is covered by this blanket provision to own the material they generate with respect to the regulatory process. It does not automatically authorize any other activity. The control and transfer of TENORM, therefore, can be addressed through either requirements specified in the Radiation Regulations, or under solid waste permits and facility D & O Plans and CDs. It gives the Department the authority to require measurements be made, to ensure that workers and the public are not being exposed, that concentrations of residuals are characterized, controlled and properly transferred.

Employees or contractors under control and supervision of a general licensee may perform routine maintenance on equipment, facilities, and land owned or controlled by the general licensee. Maintenance that provides a pathway for exposure different from that found in periodic maintenance operations and that increases the potential for additional exposure is not considered routine maintenance. The decontamination of equipment, facilities, and land should be performed only by persons specifically licensed by the Department, the NRC or another Agreement state to conduct such work.

Specifics for general licenses are found in § 3.5. This section has exemptions for source material, but not for radium.

> § 3.5.1 A general license is hereby issued authorizing commercial and industrial firms, research, educational and medical institutions, and state and local government agencies to use and transfer not more than 15 pounds (6.82 kg) of source material (this only refers to the uranium, not the weight of the matrix) at any one time for research, development, educational, commercial or operational purposes. A person authorized to use or transfer source material, pursuant to this general license, may not receive more than a total of 150 pounds (68.2 kg) of source material in any one calendar year.
>
> § 3.5.1.1 Persons who receive, possess, use or transfer source material pursuant to the general license in § 3.5.1 are prohibited from administering source material, or the radiation there from, either externally or internally, to human beings except as may be authorized in a specific license.
>
> § 3.5.2 Persons who receive, possess, use, or transfer source material pursuant to the general license issued in RH 3.5.1 are exempt from the provisions of Parts 4 and 10 of these regulations to the extent that such receipt, possession, use, or transfer is within the terms of such general license; provided, however, that this exemption shall not be deemed to apply to any such person who is also in possession of source material under a specific license issued pursuant to this part.

These exemption limits are quite small and generally do not provide relief for generators of residuals.

§ 3.22 addresses transfer of material, which includes sending residuals to a waste broker or a landfill.

> "No licensee shall transfer radioactive material except as authorized pursuant to RH 3.22."
>
> RH 3.22.2 Except as otherwise provided in his license and subject to the provisions of RH 3.22.3 and
>
> RH 3.22.4, any licensee may transfer radioactive material:
> 3.22.2.1 to the Department
> 3.22.2.2 to the U.S. Department of Energy
> 3.22.2.3 to any person exempt from the regulations in this part to the extent permitted under such exemption
> 3.22.2.4 to any person authorized to receive such material under terms of a general license or its equivalent, or a specific license or equivalent licensing document, issued by the Department, the U.S. Nuclear Regulatory Commission, any Agreement state or any Licensing state, or to any person otherwise authorized to receive such material by the federal government or any agency thereof, the Department, an Agreement state, or a Licensing state
> 3.22.2.5 as otherwise authorized by the Department in writing.

These provisions allow for the Department to facilitate disposition of residuals, in conjunction with the Solid Waste Regulations.

For facilities that generate TENRORM residuals below the source material exemption limits or $^{226/228}Ra$ concentrations < 3 pCi/g above background, no specific reporting to the RCP is required (if the gross alpha measurement is exceeded, notification is still required per the Solid Waste Regulations). In short, below those thresholds, there are no additional requirements.

6.1.2 Specific Licenses

In addition to the requirements of a general license, there are additional requirements for specific licenses.

There is only one drinking water treatment facility in Colorado that currently holds a specific radioactive materials license due to both possession limits and worker exposure. It is anticipated that some additional facilities that generate spent media and filters may be required to obtain a specific license, or facilities that generate high activity sludges or residuals from interim treatment of liquid residuals.

Licensed TENORM material may be sent to a RCRA-permitted facility with Department approval. Since the Department granted the disposal facilities the permit modifications to receive these materials, there should be no problems with obtaining the authorization (up to the approved TENORM disposal limits for that facility). The disposal facility will have the onus of notification to the Department. The requirement for notification is to provide the Department the ability to track disposition of residuals.

If on-site disposal is considered, or if the potential exists for contamination of the facility (including the environment under the facility), a financial warranty may be required, as per § 3.9.5.4.

Removal of spent media will generally be limited to companies that specialize in handling elevated levels of radioactivity (> source material concentrations for uranium; the amount of radium in a residual does not have a specific exemption limit.) The contractor must be licensed to handle and package radioactive material for transport.

6.1.3 Records

Various records need to be maintained as a matter of business; records relating to TENORM (i.e., sample analysis, workplace measurements) are also to be maintained. The basic requirement is in Part 1 of the radiation regulations. Additional requirements for specific licenses are found in Part 4 of the radiation regulations.

> RH 1.6 Records. Each licensee and registrant shall maintain records showing the receipt, transfer, and disposal of all sources of radiation. Additional record requirements are specified elsewhere in these regulations.

Therefore, it is recommended that all records of transfer and disposal of solid and liquid residuals be maintained. Sample analysis results should also be maintained. These records should be maintained for a minimum of three years.

6.1.4 Inspections

The Department has authority under the RCA and the regulations to inspect facilities. It is called out in Part 1 of the radiation regulations:

> RH 1.7 Inspections
> RH 1.7.1 Each licensee and registrant shall afford the Department at all reasonable times opportunity to inspect sources of radiation and the premises and facilities wherein such sources of radiation are used or stored.
>
> RH 1.7.2 Each licensee and registrant shall make available to the Department for inspection, at all reasonable times, records maintained pursuant to these regulations.

The Department already has the authority to inspect facilities under solid waste and WQCD regulations.

6.1.5 Measurements, Samples and Tests

The Department also has the authority to require generators to make tests or surveys (measurements and/or samples) of facilities, equipment and residuals. The basic authority is also found in Part 1 of the radiation regulations:

> RH 1.8 Tests.
> Each licensee and registrant shall perform, upon instructions from the Department, or shall permit the Department to perform, such reasonable tests as the Department deems appropriate or necessary including, but not limited to, tests of
> **1.8.1 Sources of radiation**
> **1.8.2 Facilities wherein sources of radiation are used or stored**
> **1.8.3 Radiation detection and monitoring instruments**
> 1.8.4 Other equipment and devices used in connection with utilization or storage of licensed or registered sources of radiation

Additional requirements are found in Part 4.17 of the Radiation Regulations:

> 4.17.1 Each licensee or registrant shall make, or cause to be made, surveys that:

4.17.1.1 Are necessary for the licensee or registrant to comply with Part 4; and
4.17.1.2 Are necessary under the circumstances to evaluate:
(1) The magnitude and extent of radiation levels; and
(2) Concentrations or quantities of radioactive material; and
(3) The potential radiological hazards.

See Section 5 of this document for further discussion of sampling and analysis.

Contact the Radiation Control Program for guidance on filing an application for a specific license.

6.2 Institutional Controls and Environmental Covenants

An issue of concern is the use of institutional controls (IC) over material buried or left in place at sites. Institutional controls are designed to restrict future use of a site. Deed annotations, fencing and environmental covenants are a few examples of ICs. Many landfills already have some type of institutional control already defined in their permits. Post-closure requirements for landfills licensed for radioactive materials (e.g., low-level disposal facilities) have longer post-closure periods than other landfills. Since we are permitting Subtitle D and C landfills to accept low-activity TENORM, computer models were used to calculate potential doses to future residents in and around the landfill area. See Appendix B.

Numerous agencies have shared their experiences with ICs, often with poor results in the implementation and institutional knowledge of the ICs (EPA 2001b). The Department has taken those lessons and incorporated them into its Environmental Covenant requirements. These provisions modified the *Colorado Hazardous Waste Act* (25-15-101 et. seq.). Environmental real covenants are enforceable agreements, which are recorded with the deed and run with the land, provide a mechanism to ensure that institutional controls that are part of environmental remediation projects are properly implemented and that engineered structures are protected and maintained, so that implemented remedies continue to be protective of human health and the environment for as long as any residual contamination remains a risk. It also applies to closure of hazardous waste management units under the *Colorado Hazardous Waste Act* [25 CRS 15-101 et. seq] and of solid waste disposal sites under the *Colorado Solid Waste Disposal and Facilities Act* [30 CRS 20, Pt.1]. Sites that have been used for disposal of solid or hazardous waste will almost certainly require environmental covenants if they close after July 1, 2001 (the effective date of Senate Bill 145). Sites that closed before that date may choose to grant such covenants to the Department. Creation of an Environmental Covenant does not exempt the site from the obligation to have a separate deed notice as required by the Solid Waste Regulations and § 25-15-303(4)(a).

More information can be found at the Environmental Covenants web page.

7 Health & Safety at Drinking Water Treatment Facilities

7.1 Overview

Workers at water treatment plants are incidentally exposed workers, whose activities would generally not expose them to TENORM at levels requiring monitoring or special programs, with a few exceptions (e.g., IX columns). A screening survey should be conducted of water treatment facilities and their residual streams to determine if a facility needs increased controls due to TENORM if source waters exceed the MCLs, or if current data or modeling or calculations predict elevated concentrations of radioactivity in the residuals. Disposal facilities will have a similar program under their D&O Plans.

Workers at utilities are subject to protection as members of the public and are limited to an exposure of 100 mrem/y (1 milliSievert (mSv)/y) above background from all activities. A level of 25 mrem/y (0.25 mSv/y) above background may be considered as a threshold, which indicates additional workplace evaluation (and potential licensing) may be required. These facilities should undergo a thorough dose assessment and develop a TENORM management program. For facilities that have worker exposures above 25 mrem/y, a specific radioactive materials license may be required, and impacted workers should be trained as radiation workers.

A graded approach may be used for designing the program. Information on conducting the surveys is provided in the next section.

The three basic pathways of exposure for workers are direct exposure from gamma radiation, inhalation of alpha or beta emitting nuclides, ingestion or the swallowing of alpha, beta, or gamma-emitting isotopes. Gamma radiation, as well as beta and alpha surface activity measurements, may need to be made. Radon measurements also may be warranted. Measurements are made for both worker safety and to monitor residuals for elevated radioactivity.

Utility workers can accumulate doses from working in the proximity of ion exchange columns and sludge, during media replacement, backwashing filters, during maintenance of contaminated pumps or piping, or remediating and/or transporting residuals. Radiation sources include pipes and pumps where scales accumulate, lagoons, flocculation and sedimentation tanks, and facilities where filter backwash, brines or other contaminated waters accumulate. Other alternatives are changing existing practices, altering methods for managing contaminated equipment or wastes, or establishing worker radiation safety and education programs (EPA 2005).

The foremost methods of reducing exposure are time, distance and shielding. These simple concepts can be used to reduce workplace exposure ALARA, and avoid the licensing issue. For example, if an IX column were located in an area near a desk, it would be prudent to move the desk away from the column to lower the dose rate at the desk. Another example is to reduce time in an area by sharing tasks among workers.

Shielding blankets or other shields can be used to reduce dose when working in an area with radioactivity.

Risk from radioactive materials comes from the energy and action of the particles/rays (radiation) emitted by each radioactive substance. Although there are numerous types of radiation, three types are of importance when evaluating health effects. Alpha particles are identical with the nuclei of helium atoms, two protons, plus two neutrons. A sheet of paper or four centimeters of air will stop them, but they can do considerable tissue damage inside a lung or other organ. Beta particles are identical to electrons. It takes about three millimeters of aluminum to stop them. They are not as massive as electrons but can still do damage because of their greater speed. Gamma rays have the properties of very energetic electromagnetic radiation or photons ($1x10^4$ to $1x10^7$ more energetic than visible light photons). Six centimeters of lead or a meter of concrete is needed to stop them. Gamma rays are significantly smaller and lighter than either the alpha or beta particle, but their net energy can still be considerable. The intensity of gamma radiation is a factor in their risk.

Some radioactive materials also have toxic properties. Typically, the radiation presents the greater risk but toxicity may increase create additional health problems.

The Department has a guidance document to assist in calculating and demonstrating compliance with the public dose. See Appendix F.

A Radiation Protection Program as outlined in § 4.5 of the Radiation Regulations is required for licensed facilities, which would include surveys and training (see Section 6 for all the license requirements). A suggested syllabus for training TENORM workers is presented in Appendix E.

7.1.1 External gamma radiation

A worker that is continuously exposed to gamma exposure rates ~15 μR/h (0.15 μSv/h) above background over 2000 hours of a work year, triggers the 25 mrem (0.25 mSv) annual threshold. Therefore, if gamma exposure rates exceeding ~15 μR/h (0.15 μSv/hour) above background are encountered in the workplace, then occupancy times and distance from the source to work spaces should be evaluated. Reasonable assumptions of workplace exposure times should be utilized to estimate the true worker exposure at a facility. A dose rate of 50 μR/h (0.5 μSv/h) may lead to an annual exposure of 100 mrem (1 mSv).

Areas that exceed 2 mrem/h (2,000 μR/h) need to be posted as radiation areas. In facilities that have ion exchange columns or filter media, radiation levels in the area of the columns or filters can exceed 10 mrem/h (10,000 μR/h).

7.1.2 Inhalation and ingestion

General industrial hygiene practices at drinking water treatment plants should provide adequate protection from inhalation or ingestion of radioactive material. A brief overview of the requirements is presented for completeness. Part 4 of the Radiation Regulations has annual limits on intake and derived concentrations of radionuclides for occupational exposure, including radon.

Another concern is during maintenance of equipment. Radionuclides can accumulate in piping systems, flanges, welds and other areas. Particulates may accumulate in the form of a thin film or buildup of scale in the systems. When the systems are opened, the radionuclides can be accessed and disturbed by maintenance work. Treatment plants processing NORM radionuclides should check system components for the presence of alpha and beta emitters. Equipment with radionuclide concentrations above the values in Table 7-1 may necessitate the need for a general or specific license for transfer or disposal of the equipment if it is contaminated. Maintenance workers should have training and appropriate protective measures when working on internals, and the facility equipment may not be released for unrestricted use until cleaned to limits listed in ANSI N13.12 (ANSI 1999).

Further information about workplace evaluation is available from the HMWMD upon request.

7.2 Environmental Monitoring

Environmental monitoring may be necessary during the operational phase and in the post-closure phase of the facility's life cycle (e.g., for old facilities that do not have adequately lined impoundments). External gamma, airborne exposures, ground- and surface-water transport and cycling through the food chain may need to be evaluated to ensure no TENORM off-site releases above regulatory limits. Site characterization data could include information about types of soils, hydraulic conductivity, groundwater depth, aquifer flow rates, aquifer porosity, precipitation rate, surface-water runoff coefficients, watershed area and local land use. The need for monitoring would be determined based on the data provided in the Residuals Management Plan or on a case-by-case basis.

8 Instrumentation and radiation surveys

8.1 Instrumentation

A variety of instrumentation is available for measuring radiation and radioactivity. Choosing the proper instrument does not need to be difficult. The *Multi Agency Radiological Site Survey Investigation Manual* (MARSSIM) (EPA 2000a) is a good primer on instrumentation and, also provides a description of detector types. The next section of this document addresses survey methods and Appendix H (in MARSSIM) describes numerous types instrumentation types. People conducting radiation surveys should have sufficient training in the use of instruments and making measurements to ensure the generation of useful data that are representative of site conditions.

Instrumentation should be calibrated at least annually. Daily response checks also are conducted whenever the instruments are used. Maintain calibration records on file, and record daily response checks in a bound logbook. ANSI N323-B (ANSI 2003) provides calibration and performance requirements of instruments to be used at or near background. Instruments may be rented or purchased.

Exposure rates are easily measured with a sodium iodide scintillation detector, a GM detector, ion chamber or plastic scintillator. The gamma instrument needs to be sensitive enough to measure differences in gamma exposure rates at or near background.

Beta measurements are made with a Geiger-Muller (GM) detector, and alpha measurements are made with zinc sulfide scintillators calibrated to activity reported in $dpm/100cm^2$. These detectors are primarily used to measure activity on piping and equipment. GM detectors also can be calibrated to measure radioactivity in air.

In addition to hand held instruments, passive monitors, such as thermo luminescent dosimeters (TLD) or optically stimulated luminescence (OSL) dosimeters are deployed to measure radiation over time at a location. These passive dosimeters can be placed in work areas (such as near IX columns) and background areas. They measure cumulative exposure, generally over a period of one to three months. After the exposure period ends, the dosimeters are sent in for analysis. Take care when placing dosimeters so that NORM in building materials won't interfere with the area trying to be measured.

8.2 Radiation Surveys

Ambient radiation readings should be taken to establish the background gamma exposure rate ranges at a facility. Work areas and break areas at a facility should be screened. Areas to check for elevated radioactivity are in piping bends, pumps, drains, traps, columns, waterboys, discharge points, storage lagoons and storage tanks. Home systems also may have a potential for elevated gamma exposure rates in water softeners and some water heaters. Note areas that exceed two to three times background for further evaluation.

Measurements for particulates on internal components should be made when selling or servicing components that are likely to accumulate TENORM – flanges, settling areas, and bends in piping for example. A pancake GM detector calibrated to surface activity (rather than exposure rate) should be used. Smears for detection of removable contamination are also recommended if readings indicate elevated concentrations.

Most drinking water treatment facilities have good air exchange, and as such, radon is generally not a hazard at drinking water treatment facilities. It may still be prudent to check for radon to establish a baseline. Indoor radon in the workplace is currently not specifically regulated in the US.

9 Health & Safety at Disposal Facilities

Just as workers at drinking water treatment facilities are members of the public who may be incidentally exposed to some low levels of radiation in the course of their work, so are workers at the disposal facilities. Worker safety requirements for solid and hazardous wastes generally provide adequate protection from particulate radioactivity, and are spelled out in the CD and D&O Plans for the facilities. Risk assessments show that the landfill worker is the most likely exposed individual (rather than a member of the public at the landfill). Measurements made at landfills, and these assessments show that exposure to workers at landfills are extremely low. Basic instruction and reasonable precautions will keep doses to workers well below limits and ALARA. The proposed limits also are protective of the environment now and in the future. A recommended syllabus for training of landfill workers and suggested health and safety requirements for permitting authorities to consider for use in incorporating into CDs or D&O are provided in Appendix E. An evaluation of the risk assessments provided to the Department are discussed in Appendix B.

References

6 CCR 1007-2. *Regulations Pertaining To Solid Waste Disposal Sites and Facilities.* 6 CCR 1007-2. Colorado Department of Public Health and Environment, Denver, CO. April

6 CCR 1007. *Colorado Rules and Regulations Pertaining to Radiation Control* [6 CCR-1007] Colorado Department of Public Health and Environment, Denver, CO.

6 CCR 1003-7. *Regulations Pertaining To The Beneficial Use Of Water Treatment Sludge And Fees Applicable To The Beneficial Use Of Sludges.* [5 CCR 1003-7] Colorado Department of Public Health and Environment, Denver, CO. October.

5 CCR 1003-2. *Water and Wastewater Facility Operators Certification Requirements.* Regulation #100. Water Quality Control Commission. Colorado Department of Public Health and Environment, Denver, CO. .

5 CCR 1002-41. *The Basic Standards for Groundwater*. Regulation #41. Water Quality Control Commission. Colorado Department of Public Health and Environment, Denver, CO. March

5 CCR 1002-31. *Basic Standards and Methodologies for Protection of Surface Water* [5CCR 1002-31] August.

5 CCR 1003-1. *Colorado Primary Drinking Water Regulations* [5 CCR 1003-1] Colorado Department of Public Health and Environment, Denver, CO. March

6 CCR 1007-3. *Hazardous Waste Commission Regulations* [6CCR 1007-3] Colorado Department of Public Health and Environment, Denver, CO. August

25 CRS 11. *Radiation Control Act* [25 CRS 11-101]

25 CRS 15. *Colorado Hazardous Waste Act* [25 CRS 151

30 CRS 20. *Colorado Solid Waste Disposal and Facilities Act* [30 CRS 20, Pt.1]

33 USC. 1251 *Federal Water Pollution Control Act*. (33 U.S.C. 1251 et seq.) P.L. 107–303, November 27, 2002.

40 USC 121 *Atomic Energy Act* [40 USC 121] as amended.

42 USC 15801 *Energy Policy Act of 2005*. Public Law 109-58

42 USC. 9601-9675. *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* (CERCLA). 1980

42 USC. 6901-6992k. Resource Conservation and Recovery Act (RCRA)

ACOE 2002. *White Paper: Using RESRAD in a CERCLA Radiological Risk Assessment.* U.S.Army Corps of Engineers, Buffalo, NY. October.

ANL 2003. *An Assessment of the Disposal of Radioactive Petroleum Industry Waste in Non-hazardous Landfills Using Risk-Based Modeling.* Smith, K.P., et al. Environmental Science and Technology 37(10): 2060-2066.

ANSI 2003. *Installed Radiation Protection Instrumentation Test and Calibration - Portable Survey Instruments for Near Background Operation.* N323B -2003. American National Standards Institute. New York, NY.

ANSI 1999. *Surface and Volume Radioactivity Standards for Clearance*. ANSI/HPS N13.12-1999, American National Standards Institute/Health Physics Society. Health Physics Society, McLean, VA. August.

CDM 2005. *City of Englewood Allen Water Filtration Plant Residuals Disposal Risk Assessment*. CDM, Denver, CO. August.

CDPHE *Ground-Water Discharge Permit Program, General Comments for the Application To Discharge.* Date Unknown. Colorado Department of Public Health and Environment, Denver, CO.

CDPHE 2003. *Pretreatment Regulations.* Regulation #63. 5 CCR 1002-63. Water Quality Control Commission, Colorado Department of Public Health and Environment, Denver, CO. September.

CDPHE 1997. *Design Criteria for Potable Water Systems*. Water Quality Control Division. Colorado Department of Public Health and Environment, Denver, CO. March.

CDPHE 1993. *Biosolids Regulation.* Regulation No. 64. Water Quality Control Commission, Colorado Department of Public Health and Environment, Denver, CO. April

Cember 1989. *Introduction to Health Physics;* Cember, H. Pergamon Press, New York, 1989

CHDT 2005. *Safety Assessment*. Section 6. Radioactive Materials License application. Clean Harbor's Deer Trail Facility. Clean Harbors, Inc. January.

Chem-Nuclear 1991. *Pathway Analysis and Risk Assessment Calculation of Doses to Workers and the Public from Sludge Disposal at the Denve Water Department Foothills Treatment Plant.* Chem-Nuclear Environmental Services, Columbia, SC. February.

Clifford 2004. *Fundamentals of Radium Removal and Uranium Removal from Drinking Water Supplies*. Dennis Clifford, University of Houston.

CRCPD 2004. *Technical White Paper: Radon in Drinking Water Regulations: A Brief History*. E-04-04. Conference of Radiation Control Program Directors, Frankfort, KY. September 2.

CRCPD 2004a. *Regulation And Licensing Of Technologically Enhanced Naturally Occurring Radioactive Material (Tenorm).* Part N. Conference of Radiation Control Program Directors, Frankfort, KY. April.

DOE 1999. *Guidance for Conducting Risk Assessments and Related Risk Activities for the DOE-ORO Environmental Management Program.* BJC/OR-271. U.S. Department of Energy, Office of Environmental Management. April

DOE 1998. *Potential Radiological Doses Associated With the Disposal of Petroleum Industry NORM via Land spreading*. DOE/BC/W-31-109-Eng-38-5. Argonne National Laboratory, EAD, Lakewood, CO, for the U.S. Department of Energy. December.

DOW 1994. *Ion Exchange Resin Analysis Kit for the Americas/Pacific, Form no. 177-01771-804*; Dow Chemical Company August 1994.

EPA 2006. *National Primary Drinking Water Regulations: Stage 2 Disinfectants and Disinfection Byproducts Rule.* Federal Register, FR: 71(2). U.S. Environmental Protection Agency, Washington, D.C. January 4.

EPA 2005. *A Regulators' Guide to the Management of Radioactive Residuals from Drinking Water Treatment Technologies*. EPA 816-R-05-04. U.S. Environmental Protection Agency, Washington, DC. July.

EPA 2005a. *Assessment of Variations in Radiation Exposure in the United States*. Contract # EP-D-05-005, Work Assignment No. 1-03. U.S. Environmental Protection Agency, Washington, DC. July.

EPA 2004. *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods*. EPA publication SW-846. U.S. Environmental Protection Agency, Washington, DC. August

EPA 2004a. *National Primary Drinking Water Regulations*. 40 CFR 141. U.S. Environmental Protection Agency, Washington, D.C. August

EPA 2002. *Implementation Guidance for Radionuclides.* EPA 816-F-00-002. U.S. Environmental Protection Agency, Office of Water, Washington, D.C. March.

EPA 2002a. *Radionuclides in Drinking Water: A Small Entity Compliance Guide*. 815-R-02-001. Environmental Protection Agency, Office of Ground Water and Drinking Water, Washington, D.C. February.

EPA 2001. *Final Rule. National Primary Drinking Water Regulations; Filter Backwash Recycling Rule.* Federal Register, FR: 66(111):31086**.** U.S. Environmental Protection Agency, Washington, D.C. June 8.

EPA 2001a. *National Primary Drinking Water Regulations; Arsenic and Clarifications to Compliance and New Source Contaminants Monitoring; Final Rule.* FR: 66 (14) 6975-7066. U.S. Environmental Protection Agency, Washington, D.C. January 22.

EPA 2001a. *Final Rule: Transportation, Storage Treatment and Transportation of Mixed Waste*. Federal Register. FR66 **(**95):27218**.** U.S. Environmental Protection Agency, Washington, D.C. May 16.

EPA 2001b. *Long-Term Stewardship Consequences of Remedy Decisions*. Tom Schnieder. U.S. EPA Region 5, Office of Federal Facilities Oversight. Proceedings of the 4th Annual Long-Term Stewardship Workshop, Grand Junction, Colorado. July 30.

EPA 2000. *Radionuclides Rule*, Federal Register. U.S. Environmental Protection Agency, Washington, D.C. December 7.

EPA 2000a. *Multi Agency Radiological Site Survey Investigation Manual*. EPA-402-R-97-016, Rev. 1, NUREG-1575, Rev. 1., DOE-EH-0624, Rev. 1. U.S. Environmental Protection Agency, Washington, D.C. August

EPA 1999. *Notice of Proposed Rulemaking. National Primary Drinking Water Regulations; Radon-222.* Federal Register, FR: 64(211)59246. U.S. Environmental Protection Agency, Washington, D.C. November 2.

EPA 1999a. *Cancer Risk Coefficients for Environmental Exposure to Radionuclides*. Federal Guidance Report 13. EPA 402-R-99-001, U.S. Environmental Protection Agency, Washington, D.C. September.

EPA 1998. *The Stage 1 Disinfectants and Disinfection Byproducts Rule*. Federal Register, FR: 63(241). U.S. Environmental Protection Agency, Washington, D.C. December 16.

EPA 1996. *Safe Drinking Water Act Amendments of 1996*. 42 USC 201 Public Law 104-182 104th Congress.

EPA 1994. *Suggested Guidelines for Disposal of Drinking Water Treatment Wastes Containing Radioactivity*. U.S. Environmental Protection Agency, Office of Ground Water and Drinking Water, Washington, D.C. June.

EPA 1990. *Suggested Guidelines for the Disposal of Drinking Water Treatment Wastes Containing Naturally Occurring Radionuclides*. U.S. Environmental Protection Agency, Office of Drinking Water, Washington, D.C. July.

EPA 1989. *Suggested Guidelines for the Disposal of Naturally Occurring Radionuclides Generated By Drinking Water Treatment Plants*. U.S. Environmental Protection Agency, Office of Drinking Water, Criteria and Standards Division, Washington, D.C. March.

Hazle 1988. Letter from Al Hazle to Steve Orzynski, Hazardous Materials and Waste Division, Colorado Department of Health. December 13.

IAEA 2004. *International Basic Safety Standards for Protection Against Ionizing Radiation and for the Safety of Radiation Sources.* Safety Series No. 115. International Atomic Energy Agency, Vienna, Austria.

ICRP 1993. *Protection Against Radon-222 at Homes and Work. ICRP Publication 65.* International Commission on Radiation Protection, Oxford, England: Pergamon Press.

ISCORS 2005. *"Final Report: ISOCRS Assessment of Radioactivity in Sewage Sludge: Recommendations on Management of Radioactive Materials in Sewage Sludge and Ash at Publicly Owned Treatment Works"*. Interagency Steering Committee on Radiation Standards, 2005, ISCORS Technical Report 2004-04, DOE/EH-0668, EPA 832-R-03-002B. Washington, DC.

Kennedy 2004. *Development Of Waste Acceptance Criteria For The Disposal Of Norm/Tenorm Waste At The Deer Trail, RCRA Subtitle C Landfill*. DMA-TR-11, REV. 0. William Kennedy, Jr. Dade-Moeller and Associates, Inc. Richland, WA. May.

Kocher 1999. *National Research Council's Evaluation of Guidelines for Exposures to Naturally Occurring Radioactive Materials.* David Kocher, Oak Ridge Natinoal Laboratory. Presentation for Health Physics Society Professional Enrichment Program. June.

Makhijani et al, 2006. *Science for the Vulnerable Setting Radiation and Multiple Exposure Environmental Health Standards to Protect Those Most at Risk.* Arjun Makhijani, Ph.D., Brice Smith, Ph.D., Michael C. Thorne, Ph.D..

Institute for Energy and Environmental Research, Tacoma Park, MD. October 19

Molen 2004. *Risk Assessment Report*. Waste Management of Colorado, Inc. Conservation Services, Inc., Bennett, CO. Prepared by Molen and Assoc. and Radient Energy Management. December

Myrick 1983. *Determination of Concentrations of Selected Radionuclides in Surface Soil in the U.S.*, Health Physics Vol. 45, 631-642

NCRP 2004. Approaches to Risk Management in Remediation of Radioactively Contaminated Sites. NCRP Report No.146. National Council on Radiation Protection and Measurements. Bethesda, MD. October 15.

NCRP 1999. *Recommended Screening Limits for Contaminated Surface Soil and Review of Factors Relevant to Site-Specific Studies.* NCRP Report No. 129. National Council on Radiation Protection and Measurements. Bethesda, MD. January 29.

NCRP. 1994. *Exposure of the Population in the United States and Canada from Natural Background Radiation*. NCRP Report No. 94. National Council on Radiation Protection and Measurements, Bethesda, Maryland.

NCRP 1993. *Limitation of Exposure to Ionizing Radiation*. NCRP Report No. 116. National Council on Radiation Protection and Measurements. Bethesda, MD. March 31.

NRC 2005. *Health Risks to Exposure to Low Levels of Ionizing Radiation.* BEIR-VII. National Research Council. Washington, DC.

NRC 1999. *Evaluation of Guidelines for Exposures to Technologically Enhanced Naturally Occurring Radioactive Materials*. National Research Council. National Academy Press. Washington, D.C.

Ogden 1992. *Radiologial Risk Assessment for The Proposed City of Arvada Alum Sludge Monofill*. Ogden Environmental and Energy Services Co. Denver, CO July.

RMLLRWB 2006. *Disposal Of In-Region Naturally-Occurring Radioactive Material And Technologically-Enhanced Radioactive Material Waste*s. Rule 12. Rocky Mountain Low Level Radioactive Waste Board. Denver, CO. November

RMLLRWB 2006a. *Application for Permission to Manage Waste Generated Outside the Region* Rule 7. Rocky Mountain Low Level Radioactive Waste Board. Denver, CO. November

RMLLRWB 2006b. *Exportation of Waste from the Region*. Rule 6. Rocky Mountain Low Level Radioactive Waste Board. Denver, CO. November

Stoller 2006. *Human Health Risk Assessment for Primary Water Treatment Residuals*. S.M. Stoller Corporation, Lafayette, CO. May.

Stoller 2005. *Dose Assessment for the Emplacement of the CSMRI Site Containerized and Remaining Subsurface Soil into a RCRA Subtitle D Solid Waste Landfill.* S.M. Stoller Corporation, Lafayette, CO. April

Stone, et al. 1999. *Spatial Variations in Natural Background Radiation: Absorbed Dose Rates in Air in Colorado.* J.M. Stone, R.D. Whicker, S.A. Ibrahim, F.W. Whicker. Health Physics. Vol. 76, No. 5, May 1999.

UNSCEAR 2000. *Sources and Effects of Ionizing Radiation*. United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) 2000 Report to the General Assembly, with Scientific Annexes. Vienna, Austria.

URS 2006. *Evaluation of Risk Associated with Exposure to Water Treatment Plant Residuals* URS Corporation. Denver, CO March.

USNRC 2006. *Guidance For Receiving Enforcement Discretion When Concentrating Uranium At Community Water Systems*. RIS 2006-20. U.S. Nuclear Regulatory Commission, Washington, DC.

USNRC 2006a. *Consolidated Decommissioning Guidance, Characterization, Survey, and Determination of Radiological Release*. NUREG-1575, Vol. 2. Rev. 1. U.S. Nuclear Regulatory Commission, Washington, DC. September

USNRC 1998. *White Paper On Risk-Informed And Performance-Based Regulation* SECY-98-144. U.S. Nuclear Regulatory Commission, Washington, DC.

USNRC 1994. Information Notice 94-07: Solubility Criteria For Liquid Effluent Releases To Sanitary Sewerage Under The Revised 10 CFR Part 20 U.S. Nuclear Regulatory Commission, Washington, DC.

Internet Resources

Radiation Control Program web site:
http://www.cdphe.state.co.us/hm/rad/index.htm.

The WQCD homepage can be found on the Internet at:
http://www.cdphe.state.co.us/wq/wqhom.asp

A copy of the Design Criteria can be found on the Internet at:
http://www.cdphe.state.co.us/op/regs/waterregs/1003p001.pdf

The Colorado Primary Drinking Water Regulations can be found at:
http://www.cdphe.state.co.us/op/regs/waterqualitycontroldivision/100301primarydrinkingwater.pdf

The Application for Construction Approval can be found at:
http://www.cdphe.state.co.us/wq/Drinking_Water/pdf/CapacityDevelopment/Attachment2_NewSystem_Capacity.pdf

Engineering Section
http://www.cdphe.state.co.us/wq/engineering/techhom.html

The SDWIS Inventory Form can be found at:
http://www.cdphe.state.co.us/wq/Drinking_Water/pdf/ReportForms/SDWISInventoryForm_Ver3.pdf

The “100-Year Flood Plain” Certification can be found at:
http://www.cdphe.state.co.us/wq/Drinking_Water/pdf/CapacityDevelopment/Attachment3_NewSystem_Capacity.pdf

Chemical Analysis reporting forms can be found at:
http://www.cdphe.state.co.us/wq/Drinking_Water/New_Systems.htm

Environmental Covenants can be found at
http://www.cdphe.state.co.us/hm/envcovenants.htm

U.S. EPA
http://www.epa.gov/

A Regulators’ Guide to the Management of Radioactive Residuals from Drinking Water Technologies
http://www.epa.gov/safewater/radionuclides/pdfs/guide_radionuclides_regulatorsguide.pdf

EPA Ground Water and Drinking Water web site
http://www.epa.gov/safewater/index.html

EPA's *Implementation Guidance for Radionuclides*
http://www.epa.gov/OGWDW/radionuclides/pdfs/guide_radionuclides_stateimplementation.pdf

Small Systems Information and Guidance web site
http://www.epa.gov/safewater/smallsys/ssinfo.htm

Small System Compliance Technologies (SSCT)
http://www.epa.gov/docs/ogwdw000/standard/tlstnm.pdf

Risk Assessment Guidance for Superfund
Risk Assessment Guidance for Superfund (RAGS)

ISCORS Catalogue of Risk Assessment Parameters
http://web.ead.anl.gov/iscors/home.cfm

MARSSIM Manual
http://www.epa.gov/radiation/marssim/

The Software Program to Ascertain Residuals Radionuclide Concentrations (SPARRC)
http://www.npdespermits.com/sparrc/

U.S. DOE
http://www.energy.gov/

APPENDICES

Appendix A. Decay Series For Primordial Nuclides

Principal Natural Radionuclide Decay Series

Uranium Decay Series (including ^{226}Ra)

Radionuclide	Symbol	Half-life	Major emissions
Uranium 238	^{238}U	4.47×10^{9} y	alpha
Thorium 234	^{234}Th	24.1 d	beta
Protactinium 234 IT (99.84% feeds 234U)	^{234m}Pa	1.17 m	beta, gamma
Protactinium 234 (0.16% feeds 234U)	^{234}Pa	6.7 h	beta, gamma
Uranium 234	^{234}U	2.46×10^{5} y	alpha
Thorium 230	^{230}Th	7.54×10^{4} y	alpha
Radium 226	^{226}Ra	1,600 y	alpha, gamma
Radon 222	^{222}Rn	3.82 d	alpha
Polonium 218	^{218}Po	3.10 m	alpha
Lead 214	^{214}Pb	26.8 m	beta, gamma
Bismuth 214	^{214}Bi	19.9 m	beta, gamma
Polonium 214	^{214}Po	1.64×10^{-4} s	alpha
Lead 210	^{210}Pb	22.3 y	beta, gamma
Bismuth 210	^{210}Bi	5.0 d	beta
Polonium 210	^{210}Po	138.4 d	alpha
Lead 206	^{206}Pb	stable	none

Thorium decay series (including ^{228}Ra)

Radionuclide	Symbol	Half-life	Major emissions
Thorium 232	^{232}Th	1.41×10^{10} y	alpha
Radium 228	^{228}Ra	5.75 y	beta
Actinium 228	^{228}Ac	6.15 h	beta, gamma
Thorium 228	^{228}Th	1.91 y	alpha, gamma
Radium 224	^{224}Ra	3.66 d	alpha, gamma
Radon 220	^{220}Rn	55.6 s	alpha
Polonium 216	^{216}Po	0.14 s	alpha
Lead 212	^{212}Pb	10.64 h	beta, gamma
Bismuth 212	^{212}Bi	1.01 h	alpha, gamma
Polonium 212 (64% from 212Bi)	^{212}Po	3.00×10^{-7} s	alpha
Thallium 208 (36% from 212Bi)	^{208}Tl	3.05 m	beta, gamma
Lead 208	^{208}Pb	stable	none

Appendix B. Risk assessment and risk management

B.1. Risk Assessment

Risk assessment is defined as the process that evaluates the potential for adverse health effects resulting from exposure to chemicals (including radionuclides) under a given set of circumstances (DOE 1999). A simpler definition is probability times consequences.

When evaluating the risk, one is really asking three questions: "What can go wrong?" "How likely is it?" and "What are the consequences?" These three questions can be referred to as the "risk triplet." (USNRC 1998)

Exposure assessment is the process of measuring or estimating the intensity, frequency, and duration of human exposures to an agent (hazard) currently present in the environment or of estimating hypothetical exposures that might arise from the release of new chemicals into the environment.

The first question, "What can go wrong?" is usually answered in the form of an exposure scenario (a combination of events and/or conditions that could occur) or a set of scenarios. Scenarios typically consider inhalation and ingestion pathways, external radiation and inhalation of radon and its progeny.

Radiological risk assessments involve measuring or estimating the intensity, frequency and duration of exposures to radioactive elements during the day-to-day activities of individuals or groups. These day-to-day activities, or exposure scenarios, may include pathways such as inhalation, ingestion, or skin exposure, proximity to radiation sources and inhalation of radon and its progeny. They are also used for less likely scenarios (because things go wrong), and future exposures (e.g., landfill failure).

Computer models are used to evaluate the hazards and risks. Some hazards, such as drums, containers and columns containing radioactive material are evaluated for their gamma radiation using the MICROSHIELD model, among others[25]. The most popular model for radiological risk assessment in soils and soil-like media is the RESRAD[26] model, managed by Argonne National Laboratory. A new application, RESRAD-OFFSITE is also suited for evaluating doses to off-site receptors, but has had limited use at this time. Radioactivity on building surfaces and indoor radon is modeled using RESRAD-BUILD. EPA also has a methodology for assessing radiological risk called the Risk Assessment Guidance for Superfund (RAGS). EPA uses 1×10^{-4} to 1×10^{-6} increased incidence of cancer as an acceptable risk range. NRC (and most state radiation programs) use dose instead of risk as the metric. The online Risk Assessment Information System (RAIS) is another source that provides both risk and hazard information. RAIS was developed by the U.S. Department of Energy (DOE). DOE also maintains the TSD-

[25] Grove Software Engineering
4925 Boonsboro Road# 257
Lynchburg, Virginia 24503 USA

[26] Argonne National Laboratory
Environmental Assessment Division
9700 South Cass Avenue
EVS/900
Argonne, IL 60439

DOSE model, which evaluates exposures from radioactive materials at treatment, storage, and disposal facilities.

The U.S. Army Corps of Engineers has published a white paper discussing the use of RESRAD that focuses on naturally occurring isotopes on sites that they deal with. It is a useful companion to the RESRAD manual and provides guidance on selecting the most sensitive parameters for a specific situation (ACOE 2002). There are numerous other references and tools, these are listed to provide an example of the types of approaches and programs that are available.

Risk assessment results are reviewed by health professionals, and other stakeholders to determine what an acceptable risk is. Knowledgeable individuals can then determine if they consider it an acceptable risk. The Department generally defines acceptable risk from exposure to chemical hazards as a one in a million excess chance of developing cancer (probability $1x10^{-6}$). Risk assessment results are used as one part of managing risk. Colorado (and NRC) uses a risk-informed approach to risk management using risk assessment results and reasonable and prudent precautions. Much of the following three paragraphs are taken directly from USNRC 1998.

The second question, "How likely is it?" can be answered in terms of the available evidence and the processing of that evidence to quantify the probability and the uncertainties involved. In some situations, data may exist on the frequency of a particular type of occurrence or failure mode (e.g., accidental overexposures). In other situations, there may be little or no data (e.g., core damage in a reactor) and a predictive approach for analyzing probability and uncertainty will be required.

The third question, "What are the consequences?" can be answered for each scenario by assessing the probable range of outcomes (e.g., dose to the public) given the uncertainties. The outcomes or consequences are the "end states" of the analyses. The choice of consequence measures can be whatever seems appropriate for reasonable decision-making in a particular regulated activity and could involve combinations of end states.

A "risk-informed" approach to regulatory decision-making represents a philosophy whereby risk insights are considered together with other factors to establish requirements that better focus licensee and regulatory attention on design and operational issues commensurate with their importance to health and safety. A "risk-informed" approach enhances the traditional approach by: (a) allowing explicit consideration of a broader set of potential challenges to safety, (b) providing a logical means for prioritizing these challenges based on risk significance, operating experience, and/or engineering judgment, (c) facilitating consideration of a broader set of resources to defend against these challenges, (d) explicitly identifying and quantifying sources of uncertainty in the analysis, and (e) leading to better decision-making by providing a means to test the sensitivity of the results to key assumptions. Where appropriate, a risk-informed regulatory approach can also be used to reduce unnecessary conservatism in deterministic approaches, or can be used to identify areas with insufficient conservatism and provide the bases for additional requirements or regulatory action (USNRC 1998).

Risk assessments are not foolproof. Ethical implications prevent the use of human subjects to determine the amount of hazardous material that presents a health risk, so animal studies are used instead. Animal physiology typically varies from human physiology, at times resulting in misleading results. The vast majority of current toxicology information is for an individual substance, but research has shown that many can substances can act together, amplifying the effect (typically no one is exposed to one substance at a time). The assessments also use an "average" child or adult for the analysis, not taking into consideration specific problems, such as individuals with compromised immune systems (Makhijani et al, 2006). Some assessments evaluate cancer mortality (death), others evaluate morbidity (incidence). Since there are numerous parameters that need to be evaluated, default values are sometimes used, which increases the uncertainty of the results of the model. Site-specific data should be used whenever possible. The longer the time frame of the assessment, the greater the uncertainty, since one can never truly predict what is going to happen over long time frames. Reliance on institutional controls over long time frames is problematic, and after about 100 years, reasonable and prudent precautions should be used when making land use decisions. The probability calculated by a risk assessment is the best estimate of risk based on current knowledge and the quality of the model.

B.2. NORM/TENORM Risk Assessment

Numerous risk assessments, both nationally and locally, have been conducted with respect to TENORM. The early radium and uranium industries have a long history in Colorado, and there is ample experience with natural radioactivity. Some risk assessments that have been conducted nationally and in other states with respect to disposal of TENORM often were based on oil and gas residuals, since they have been traditionally the largest source of TENORM to dispose of (ANL 2003). Characteristics of TENORM vary from industry to industry, and within industries. For example, sludges will have different characteristics than scales or slags with respect to the radon emanation coefficients. Resins will have different characteristics than the sludges, or scales. One cannot assume homogeneity or equilibrium. Risk assessments for TENORM in Colorado have been prepared for municipal solid waste landfills, monofills, composting facilities, industrial landfills and hazardous waste landfills. These assessments however, all evaluated alum sludge at low concentrations and volumes, and did not address higher concentration residuals (e.g., IX resins, filters).

The radioactivity concentrations in this guidance are based on a risk-informed basis, a combination of the risk assessments, national consensus standards, stakeholder input and regulatory limitations. The limits chosen in the tiered approach are based on the site-specific risk assessments for the industrial landfill, and hazardous waste landfill. Limits for the threshold values are based on ANSI N13.12 (ANSI 1998). Other limits are based on regulatory drivers that already exist relative to radionuclide concentrations (i.e., source material).

The earlier risk assessments for the landfills were for limited volumes of specific waste streams. Since these volumes and concentrations were small, especially compared to the design capacity of the landfill, it was easy to demonstrate that an individual waste stream would not pose an undue risk. The assessments for the monofills looked at larger volumes, but low concentrations of residuals. In general, earlier risk assessments provided insufficient information to show compliance with post-closure requirements found in § 4.61 of the Radiation Regulations, which need to demonstrate that hypothetical receptors would not receive more than 25 mrem/y for a post-closure period of 1,000 years (i.e., what can go wrong). Therefore, the Department is requiring landfills to estimate volumes and concentrations that will be present over the life of the facility, and model that scenario. Some have chosen not to do that, and only model the current residual in question, making those risk assessments of less value for demonstrating regulatory compliance and protection of human health and environment during the post-closure period. Others relied on institutional controls to eliminate potential pathways (another situation where something can go wrong). .

Since there are a universe of scenarios and plausible events that can occur over the next 1,000 years (the closure period for uranium mill tailings impoundments, the closest analogue), it is impossible to completely model every potential event. Rather, a likely scenario is modeled (i.e., day-to-day volumes and concentrations), as well as a bounding scenario (i.e., failure of the landfill containing the estimated inventory of TENORM post closure resulting in gw contamination and uptake by receptors.)

When these facilities and assessments are reviewed, one can deduce that:

- On a day-to-day basis, disposal of diffuse TENORM from alum processing can be disposed of safely at a properly constructed, permitted, and operated landfill or monofill.
- Risks from higher activity materials have not been fully evaluated (except for the hazardous waste landfill), and so it can't be stated that they can be disposed in a landfill on a day-to-day basis.
- Landfills have failed, and it is likely others will fail in the future.
- The consequences of landfill failure can be both an environmental risk and a legal liability.
- ICs are and should be put in place, but should not be relied on soley in risk management. If ICs fail, it is probable that homes could be built over these landfills, which may cause a radon inhation or groundwater ingestion issue in homes, particularly if basements were built down into the cover, or if there is shallow groundwater in the area. Reliance on institutional controls to mitigate future consequences is debatable.
- Predicting what can go wrong over long time frames, such as with uranium and radium, is highly uncertain. NRC only evaluates future land use out about 100 years (USNRC 2006a). For time frames longer than that, other considerations must be considered (e.g., durability of ICs). The Department believes that reasonable and prudent precautions should be used when setting the limits due to the inherent uncertainty.
- Lack of understanding of risk by stakeholders and decision makers continues to be problematic. While these assessments show that risks are extremely low in most situations, elected officials, insurers, and other decision makers are sensitive to radiation issues and are likely to make conservative decisions.

Table 1 is a summary of risk assessments considered in the preparation of this guidance.

Hazardous Waste Landfill

Colorado has one RCRA Subtitle C Hazardous Waste landfill at this time. It is located in eastern Colorado and is located on a very large, impermeable shale layer that makes it suitable for isolation of a variety of wastes. It receives and processes hazardous industrial wastes that require treatment or stabilization prior to disposal. It has strict requirements on the types of materials it can accept, and robust training and worker protection requirements. This facility also has strict liner and cap requirements, along with environmental monitoring and long-term closure plans.

The risk assessment for this facility was conducted specifically for ^{226}Ra at concentrations up to 400 pCi/g, and up to 2,000 pCi/g (total activity) for other naturally occurring TENORM. The facility has a specific radioactive materials license for disposal of TENORM materials consisting of tailings, asphalt, and other similar materials at the same concentration levels. It estimated the total amount of radioactivity that would be present at closure (based on ~2.3 Mcy at highest allowable levels), and evaluated the long-term impacts of that total source term as a bounding scenario. Additional iterations used more reasonable assumptions for volumes and concentrations. The risk assessment also evaluated impacts to the site workers and the public from site operations. The result of the analysis showed that exposure to the site workers posed the most risk, and that off-site dose to the environment and the public was a fraction of the allowable limits (CHDT 2005).

Industrial Landfill

Colorado has one RCRA Subtitle D landfill that exclusively accepts industrial waste at this time. The facility was originally designed and operates similar to a RCRA Subtitle C landfill, with discrete disposal cells, including a composite liner and leachate collection system, stringent waste acceptance handling protocol and manifesting requirements, no public access and an on site laboratory and stationary radioactivity meter to screen loads arriving at the site to ensure wastes accepted at the site are appropriate for management. No putrescible wastes are allowed, and since the materials are dry solids or solidified and stabilized prior to burial, there is little leachate to manage. This facility also has strict liner and cap requirements, along with environmental and worker monitoring and approved closure and post-closure plans. This facility has prior NORM acceptance experience and has received NORM and TENORM on a case-by-case approval basis for decades. These approvals have been granted by both the Department and the local governing authority (i.e., Adams County). It has an approved and certified groundwater monitoring program consisting of 10 wells located close to the disposal cells. A restriction has been placed on the deed for the facility that provides institutional controls for future uses of the property.

Risk assessments were provided for each case-by-case approval of NORM or TENORM waste received previously. In addition, a risk assessment for this facility was conducted for all known materials already buried at the site (about 30,000 cy), and an additional review for TENORM containing ^{226}Ra up to 50 pCi/g, and the other isotopes of 300 pCi/g anticipated receiving over the remaining life of the facility. The assessment estimated the total inventory of radioactivity at closure and evaluated the long-term impacts of that total source term. It used a conservative resident farmer scenario. The risk assessment also evaluated impacts to the site workers and the public. Site-specific geotechnical and design input parameters were validated independently by a professional engineer and a registered professional geologist. The result of the analysis showed that exposure to the site workers posed the most risk, and that off-site dose to the environment and the public was considerably lower than the allowable limits (Molen 2004).

Municipal solid waste landfill

Four risk assessments have been provided to the Department to evaluate disposal of TENORM at a Municipal Solid Waste Landfill (MSWLF). Almost all of the risk assessments that were submitted only addressed alum sludges, none evaluated the residuals from ion exchange or other higher-activity media, a significant shortcoming with respect to setting limits. One risk assessment is for downblended tailings and residues from legacy processing at a research facility over many decades to be disposed of at a local solid waste landfill (Stoller 2005). There have been numerous issues relative to the extent and volumes of contamination at the research facility. The risk assessment uses data from sampling of remediated soils that have been down-blended with overburden and other less contaminated wastes. The assessment is for a one-time disposal only and does not anticipate other disposal of TENORM waste at the site, making it less useful for policy determinations. The disposal facility meets current design standards for a MSWLF. The worker exposure is the limiting scenario. With respect to public dose, the risk assessment did not account for possible failure of the containment system, a complete evaluation of additional volumes of TENORM waste related to methane collection systems and did not evaluate the groundwater pathway. It also showed that cover depth is a sensitive parameter.

Two assessments are for alum residuals from a local utility and evaluated two different solid waste disposal facilities. The facilities meet all current design regulations of the solid waste regulations. The assessments were based on radionuclide concentrations of 5.14 pCi/g for ^{226}Ra, 2.54 pCi/g for ^{228}Ra, and 185 pCi/g ^{tot}U. The assessment was based on 1,500 cy of material (one years production) for calculating annual occupational dose, and 23 years' worth of residuals to calculate public dose at closure of a cell. Radon was evaluated using a separate program from RESRAD, and showed that both facilities easily would meet the UMTRA performance objective. The assessment showed that the risks would be acceptable from the material, which is expected, due to the small amount of material when compared to the design capacity of the landfills. It also showed that ^{226}Ra was responsible for more of the dose than the uranium (CDM 2005).

A fourth risk assessment was conducted for the major alum producers to demonstrate that residuals can go to a MSWLF, compost, or a monofill (Stoller 2006). Doses were calculated to workers at the compost facility, landscaping company, MSWLF, and monofills; a resident on a Monfill, MSWLF, and a landscaped area, and a recreational user on a landscape area. As with the other assessments, it relies on institutional controls to eliminate pathways (e.g., groundwater), and so is not as helpful in the "what can go wrong," or bounding scenario. For example, groundwater impacts were only evaluated for the monofill, and not the MSWLF. It also used low concentrations in the model, which describe alum sludges, but not other higher-activity materials (e.g., IX resins). The model was only run out for 25 years, and as such, does not address post closure adequately. As with the other assessments, it shows that disposal of TENORM at low concentrations on a day-to-day basis can be done safely.

TENORM that is below the threshold limits of 3 pCi/g $^{226/228}$Ra and 30 pCi/g ^{nat}U are not constrained and can be co-disposed of without additional efforts. MSWLFs that meet current design requirements can seek Department approval to accept TENORM at concentrations up to 10 pCi/g $^{226/228}$Ra- and 100 pCi/g ^{nat}U.

Monofills

Some of the larger utilities have monofills to dispose of their drinking water residuals. Monofills are required to be reviewed and approved by the Solid Waste Unit at the Department and by the local governing authority. Monofills may provide another disposal option for utilities. Monofill sites will have institutional controls imposed on them that will have long-term impacts to the value of the property. Monofills must also have operational controls including controlled access, extensive employee training, waste handling protocol, dedicated equipment to prevent gross contamination between the monofill and the MSWLF cell and appropriate personal protective equipment. Monofills may be located at the utility or could be approved as a separate approved disposal area at a MSWLF. The Department prefers that TENORM not be commingled with trash at municipal solid waste disposal facilities. Rather, it is suggested that MSWLFs consider permitting discrete monofills at their locations.

Risk assessments have been reviewed by the Department for four monofills, one of which was not built (Ogden 1992, Chem-Nuclear 1991).

Beneficial Reuse

A specific risk assessment was conducted for one TENORM waste stream at a composting facility in Colorado. The risk assessment was conducted for a particular utility and used site-specific data from that facility. The residuals from that facility are an alum residual consisting primarily of ^{nat}U, with additional concentrations from ^{226}Ra and ^{228}Ra, at much lower concentrations. The concentrations used in the risk assessment used maximum values from sampling of residuals generated in 2003. The ^{nat}U concentrations were input at 185 pCi/g, and ^{226}Ra at 5.14 pCi/g, and ^{228}Ra at 2.54 pCi/g. Volumes were estimated at 1,300 – 1,500 cy. Site-specific input parameters were input to simulate worker practices at the site, which include the use of closed cabs on equipment and time studies. Worker time exposures were estimated at 240 hours per year exposure to the TENORM. The worker exposure estimate from this risk assessment provides an estimated dose of slightly less than 1 mrem/y. It should be noted that the greatest contributor to dose from these residuals is not from the ^{nat}U, but from ^{226}Ra, further supporting the need for controls on ^{226}Ra in residuals.

The evaluation, and subsequent improvements to operations and monitoring, show that composting facilities can accept TENORM below the threshold limits of 3 pCi/g ^{226}Ra and 30 pCi/g ^{nat}U without additional requirements. Specific approvals may be obtained from the Solid Waste Unit and the Radiation Management Unit at the Department and permit from the local governing jurisdiction for ^{226}Ra values of up to 10 pCi/g ^{226}Ra and 150 pCi/g ^{nat}U. The site CD and beneficial reuse plan would need to demonstrate appropriate health and safety controls for worker and environmental protections. Additionally, D & O and waste acceptance and processing plans will need to be reviewed, approved and implemented to ensure the end product meets free release criteria and are safe for public use. Since it may be used for growing food for human consumption, the final product should have ^{226}Ra concentrations that are ALARA, below the generic exemption level, preferably at or below the background mean value of 1.4 pCi/g ^{226}Ra, ^{nat}U concentrations should be at or below 10 pCi/g.

Neither a specific nor a generic risk assessment for direct application of TENORM as a soil amendment has been conducted in Colorado. The ISCORS dose assessment of 2005 did evaluate land application from municipal sewage sludge (ISCORS 2005).

Other Assessments

The U.S. DOE commissioned an evaluation and risk assessment for the disposal of oil and gas residuals containing TENORM (ANL 2003). It used a value of 50 pCi/g ^{226}Ra as the primary constituent. It only evaluated a source term of 2,000 m^3 per year, which makes the usefulness limited.

The Interagency Steering Committee on Radiation Standards did a comprehensive evaluation of radioactivity in sewage sludge and ash. It examined both man-made and natural sources of radioactivity. It used a probabilistic approach for many of the scenarios, which is the current state of the practice. The result was a set of source/dose ratios normalized to 1 pCi/g that could be used by wastewater utilities. It may not be directly applicable to TENORM from drinking water treatment facilities in all scenarios. For example, the source/dose ratios for beneficial reuse were based on post-tilling concentrations, which do not help determine what the dose/source ratios are for the sludge itself prior to beneficial reuse (ISCORS 2005).

Future Risk Assessments

Because there are considerable ranges of radioactivity, geological conditions, worker scenarios and other inputs to the assessments, a generic risk assessment for monofills, landfills or direct application would need to be conservative in its assumptions in order to protect public health (including workers) and the environment. Site-specific risk assessments can be resource-intensive and require specific expertise. Instead of a deterministic approach, where one value is used for each parameter, a probabilistic approach, where a distribution of values is used for each parameter, may be the best approach. Since the risk assessments to date have not addressed one of the primary issues – higher activity residuals from new technologies, the Department will continue to make reasonable and prudent decisions and recommendations relative to disposal of TENORM.

Summary

Although intended for different purposes, the results of the case-by-case assessments appear to be largely consistent, when different radionuclide concentrations, disposal volumes, exposure pathways and exposure durations are considered. For example, ^{226}Ra is typically the most important radionuclide in a TENORM mixture of radionuclides since the most limiting exposure scenarios are for workers with concerns over the external exposure pathway. Other scenarios, including radon exposure and ground water transport, appear to be secondary (i.e., produce less individual radiation dose) and are considered for completeness (CHDT 2005).

The risk assessments for the composting facility, monofills and industrial and hazardous waste landfills show that TENORM materials can be safely handled at these facilities at the specified levels under normal conditions. Worker protection is the limiting factor due to radioactivity concentration limitations, robust facility construction, local oversight, and durable institutional controls.

Another useful resource for modelers is an onsite catalogue of risk assessment parameters that can be found at: http://web.ead.anl.gov/iscors/home.cfm. This on-line database can be searched for sources of input values that have been peer-reviewed in the literature.

TENORM radioactivity varies significantly in different waste streams received at a disposal facility, which could receive considerable volumes of TENORM over the life of the facility. The Department evaluates the TENORM "inventory" expected at the time of the facility closure and estimates dose to the public. Part 4.61 of the Radiation Regulations and list a closure requirement of less than 25 mrem/year to a receptor up to 1,000 years post closure.

Additionally, worker safety needs to be evaluated to discern what permitting or licensing requirements would be needed for a particular facility. More information about workplace evaluation is in Section 8 of this document.

Information that may need to be generated relative to a risk assessment for a working utility, composting facility, monofill, industrial landfill, or hazardous waste landfill could include:

- Disposal methods and containment barriers (natural or engineered),
- Disposal site size and disposal capacity,
- Depth of waste and waste-to-soil backfill ratio.
- Type and density of cover and cover thickness,
- Depth to water table and aquifer data,
- Leachate collection, treatment, and containment system,
- Waste acceptance criteria and testing requirements that ensure protection of human health and the environment, including current or potential sources of drinking water,
- Groundwater monitoring for expected radionuclides,
- Corrective action requirements for radioactivity expected to be in the waste,
- Stakeholder participation in evaluating disposal options for wastes containing radioactivity,
- Limits on waste disposal volumes,
- Land disposal and facility design restrictions,
- Locations of nearest well, stream residents, schools, etc.,
- Surrounding population densities and land-use applications,
- Operational and site closure requirements,
- Post-closure institutional care, controls (engineered and covenants).

Site-specific data should be used wherever possible in order to yield more accurate and useful results. If not, default data may be submitted and documented as to its applicability. Additionally, sensitivity analysis may be required for the most important parameters.

Table 1. Comparison table of risk assessments for TENORM

	Isotopes Evaluated	Scenarios evaluated	Dose to workers	Dose to the public
Subtitle C (Kennedy 2004)	Ra-226, 400 pCi/g, ^{nat}U, others to 2,000 pCi/g total activity. Worker: 500 m^2, 1.5 m thick (~981 cy) Public: 330,000 m^2, 10 m thick (~4,316,235 cy) Future disposal volume: ~2.3 Mcy total, including TENORM	Operations In-Cell Worker Gamma Inhalation Public Gamma Inhalation Post-Closure Residential Gamma Inhalation Ingestion (soil) Ingestion (plant, meat, milk) Radon	11 mrem/y	<1 mrem/y 0.0015 mrem/y
Subtitle D industrial landfill (Molen 2004)	Ra-226, 50 pCi/g Ra-228, 12.5 pCi/g ^{nat}U and other NORM isotopes to 150 pCi/g. Past disposal: ~30,000 cy Future disposal volume: 900,900 cy TENORM	Worker External, Inhalation, Ingestion (soil) Public Gamma Inhalation Ingestion (soil) Ingestion (plant, meat, milk) Drinking water	Maximum exposed worker 16.7 mrem/y (with 1 foot of cover) .4312 mrem/yr (with 2 foot cover)	Previously disposed material – 4.47E-15 mrem Future materials – 1.48E-10 mrem/y
Subtitle D MSWLF				

Table 1. Comparison table of risk assessments for TENORM

MSWLF 1 (Stoller 2005)	^{nat}U ~40 pCi/g Ra-226 - 28 pCi/g Ra-228 - 3.66 Th-230 - 21.45 pCi/g Th-232 - 3.66 pCi/g Allowable TENORM: 1,800 cy 10-days 30,000 cy 20-days One-time only (did not estimate or model closure volume).	Worker External, Inhalation, Ingestion Recreational External Inhalation Ingestion Off-Site current use Radon only Off-Site future use Radon only On-site Suburban resident Radon only	3.52 mrem/y – 1,800 cy 10.2 mrem/y – 30,000 cy	0.19 mrem/y – 1,800 cy 0.82 mrem/y – 30,000 cy 0.012 mrem/y – 1,800 cy 0.145 mrem/y – 30,000 cy 0.175 mrem/y – 1,800 cy 2.147 mrem/y – 30,000 cy. 0.662 mrem/y – 1,800 cy 1.028 mrem/y – 30,000 cy
MSWLF 2 (CDM 2005)	^{nat}U 185 pCi/g Ra-226 5.14 pCi/g Ra-228 2.54 pCi/g Radon (using Ra-226 value) 1,500 cy/year (occupational) (23 years x 1,500 cy/y public)	Landfill worker (5d/y) External, Inhalation, Ingestion (soil) Residential External Inhalation Ingestion Groundwater 23 years x 1,500 yr	0.27 mrem/y	Trivial (> 10^{-7} mrem/y)

Table 1. Comparison table of risk assessments for TENORM

MSWLF 3 (CDM 2005)	U-nat 185 pCi/g Ra-226 5.14 pCi/g Ra-228 2.54 pCi/g Radon (using Ra-226 value) 1,500 cy/year (occupational) (23 years x 1,500 cy/y public)	Landfill worker (5d/y) External, Inhalation, Ingestion (soil) Residential External Inhalation Ingestion Groundwater 23 years x 1,500 cy/y	0.35 mrem/y	Trivial (> 10^{-7} mrem/y)
MSWLF 4 (Stoller 2006)	U-238 200 pCi/g U-234 200 pCi/g U-235 4 pCi/g Ra-226 30 pCi/g Ra-228 6 pCi/g Th-230 30 pCi/g Th-232 6 pCi/g Th-228 6 pCi/g Pb-210 4 pCi/g Pa-231 4 pCi/g Ac-227 4 pCi/g	Landfill worker External Inhalation (no radon) Ingestion Recrational External Inhalation (no radon) Ingestion Residential External Inhalation (no radon) Ingestion	.00123 mrem/y	Trivial (> 9.9^{-12})
Monofills				

Table 1. Comparison table of risk assessments for TENORM

Denver Water (Chem-Nuclear 1991)	U-238 18 pCi/g U-234 28 pCi/g U-235 1.1 pCi/g Ra-226 2.3 pCi/g Ra-228 3.1 pCi/g Th-230 2.7 pCi/g Th-228 3.0 pCi/g Th-232 1.3 pCi/g 3 week/y 1,000 yr	Landfill worker during placement External Inhalation (including radon) Landfill worker during normal operations External Inhalation (including radon) Offsite public during placement Family Farmer 1000 y post-closure External Inhalation Ingestion	0.69 mrem/y 0.24 mrem/y	 0.11 mrem/y 444 mrem/y (50 y CEDE)
Colorado Springs (URS 2006)	U-238 73.2 pCi/g U-234 73.35 pCi/g U-235 3.45 pCi/g Ra-226 50 pCi/g Ra-226/228 50 pCi/g U-nat 150 pCi/g Th-230 73.2 pCi/g	Landfill worker External Inhalation (radon)	<<<< 1 mrem/y 0.11 mrem/y	

Table 1. Comparison table of risk assessments for TENORM

Arvada (Ogden 1992)	U- 238 pCi/g U-234 32 pCi/g U-235 4.8 pCi/g Ra-226 6.3 pCi/g Ra-228 1.1 pCi/g Th-228 1.1 pCi/g Th-230 3.7 pCi/g 30,000 cy/30yr 6- week/yr 1,000 yr post closure	Landfill worker (6 – wk/y) External Inhalation (incl radon) Public Inhalation (incl radon) Resident Farmer (1,000 yr post closure) External Inhalation (incl radon) Ingestion	0.043 mrerm/y Radon <<<<.01 WL	0.0043 mrem/y Radon <<<<.01 WL 2.94 mrerm/y
(Stoller 2006)	U-238 200 pCi/g U-234 200 pCi/g U-235 4 pCi/g Ra-226 30 pCi/g Ra-228 6 pCi/g Th-230 30 pCi/g Th-232 6 pCi/g Th-228 6 pCi/g Pb-210 4 pCi/g Pa-231 4 pCi/g Ac-227 4 pCi/g	Monofill worker External Inhalation (no radon) Recreation External Inhalation Residential External Inhalation Ingestion	0.0027 mrem/y	Trivial (9.7^{-12}) Trivial (5.9^{-11})

Table 1. Comparison table of risk assessments for TENORM

Compost	^{nat}U - 185 pCi/g Ra-226 – 5.14 pCi/g Ra-228 – 2.54 pCi/g 1,300 – 1,500 cy Not limited by volume, rather by concentration of incoming residuals.	Facility worker, 240 hours/y External, Inhalation, Ingestion	0.8957 mrem/y	N/A
(Stoller 2006)	U-238 200 pCi/g U-234 200 pCi/g U-235 4 pCi/g Ra-226 30 pCi/g Ra-228 6 pCi/g Th-230 30 pCi/g Th-232 6 pCi/g Th-228 6 pCi/g Pb-210 4 pCi/g Pa-231 4 pCi/g Ac-227 4 pCi/g	Facility worker External Inhalation Ingestion Landscape worker External Inhalation Recreational External Inhalation Ingestion Residential External Inhalation Ingestion Residential w/radon External Inhalation Ingestion	1.92 mrem/y	.11 mrem/y .0038 mrem/y 0.28 mrem/y 18.43 mrem/y

Table 1. Comparison table of risk assessments for TENORM				
DOE 1999	Ra-226, 50 pCi/g, 2,000 m^3. Slags, some sludges, also Pb-210 scales. Capacity predicated on total volume of radium wastes in the cell.	Operational phase: Occupational External, Inhalation Off-site residences External, Inhalation Ingestion Future Use: On-site resident External, Inhalation Ingestion On-site industrial worker External, Inhalation Recreational visitor External, Inhalation Offsite resident Groundwater ingestion	1.7 mrerm/y	 6.6×10^{-4} mrem/y 7.4 mrem/y 2.2 mrem/y 1.2×10^{-7} mrem/y 3.2×10^{-4} mrem/y

1. Risk Management Concepts Pertaining to TENORM

The guiding radiation protection principles at the core of controlling radiation exposures and doses are:

- Justification of a practice involving the use of radioactive materials on the basis that the expected benefits to society exceed the overall societal costs
- Optimization of radiation protection where doses are kept as low as reasonably achievable (ALARA), taking into account economic and social factors
- Limitation of individual risks by maintaining doses below limits established for radiation protection

A report conducted by the National Research Council (NRC 1999) that evaluated guidelines for TENORM provided numerous conclusions relative to managing risks from TENORM. Kocher (Kocher 1999) discussed some of the conclusions germane to this guidance:

- All organizations with guidelines for TENORM, other than indoor radon, currently assume approximately the same risk from uniform whole-body radiation (~5%/Sy for the general population). Note: This value was recently updated slightly by the BEIR VII report (NRC 2005). International methods for indoor radon differ from the U.S.
- All organizations involved in radiation protection have assumed a linear, no-threshold (LNT) dose-response relationship for the purpose of controlling exposures at low doses (i.e., < 10 rem lifetime). The BEIR VII report has recently revalidated use of the LNT.
- Different organizations have not used the same methods and assumptions in estimating radiation risks.
- Properties of NORM do not differ from those of man-made radionuclides in ways that necessitate different methods of dose and risk assessment.
- Differences in guidelines for TENORM are often based mainly on:
    - differences in judgments about doses or risks from exposure to TENORM that are acceptable; or
    - differences in judgments about levels of TENORM, doses, or risks that are reasonably achievable.
    - These judgments are entirely matters of policy.
- Some guidelines for TENORM (e.g., in soil) are based on judgments about whether existing guidelines for other exposure situations (e.g., uranium mill tailings) are transferable.
- The ALARA principle, rather than numerical criteria in forms of limits or goals, is the most important factor in determining acceptable doses (risks) to individuals or populations for any exposure situation.
- Guidelines for TENORM can be expressed in terms of concentrations of radionuclides in the environment.
- If such guidelines are derived from an assumed limit on acceptable dose or risk, the physical and chemical properties of sources of concern should be taken into account.
    - The emanation rate of radon can vary considerably in different materials
    - Intakes of radionuclides other than radon depend on leach ability, sorption, and biological availability of particular physical and chemical forms of materials

- Properties of TENORM may differ significantly from those of natural background of the same radionuclides

1.1 Radiation Protection Concepts

Consistent with the International Atomic Energy Agency's (IAEA) guidance (IAEA 2004) and the authority of the Department, the scope of regulatory controls for radioactive material have been defined as exclusion, exemption, clearance, and regulation.

1.1.1 Exclusion

Radiation sources for which no practical controls can be established are excluded from regulation. These sources include cosmic rays and radiation from radionuclides of natural origin in soil or minerals. Unaltered NORM waste is excluded from specific regulation by the IAEA, unless it also contains a regulated chemical species (for example under RCRA). This covers virtually all soils or other materials of natural origin that do not produce an increase in radionuclide concentrations, radiation exposures, or pose a threat to the accessible environment above natural levels. Regulation of unaltered NORM at low levels is not required since it will not achieve real improvements in radiation protection for workers, the public and the environment. As a threshold, the majority of TENORM wastes containing radium, uranium or thorium decay chain radionuclides in equilibrium, respectively, should have activity concentrations less than about 3/30 pCi/g above background (UNSCEAR 2000). Through radiation exposure scenario analysis, this level has been shown to be protective of an individual radiation dose to landfill workers or other members of the public of about 1 mrem/yr (ANSI 1999; IAEA 2004).

1.1.2 Exemption

Practices and sources may be exempted from regulatory requirements if they meet specific conditions and limitations. Exemption applies to sources such as smoke detectors. Specific exemptions are defined in Part 3 of the radiation regulations. Exempt items may be disposed of without further regulatory control. It is up to the individual landfills and the permitting authorities whether or not they will knowingly accept exempt items as a business practice.

1.1.3 Clearance

Clearance is the term used internationally for release of sources or materials from regulatory control (i.e., removal of regulatory control). The traditional term in America has been release. The two basic criteria for determining if a source can be cleared are: 1) individual risks (or doses) must be sufficiently low as to not warrant regulatory concern, and 2) radiation protection must be optimized, including the cost of regulation (IAEA 2004). In addition, these sources must be inherently safe with no appreciable likelihood of scenarios that could lead to failure to meet the two basic criteria. This option would apply to licensed TENORM waste and have the same threshold concentrations as defined for exclusion (3/30 pCi/g above background), or a multiple of this concentration if it can be shown to be protective of an individual radiation dose to landfill workers or other members of the public of about 1 mrem/yr.

There are two types of clearance in Colorado regulation – free release or restricted release. Free release has no constraints on future use of the material, whereas restricted release does have limitations on future use to control potential doses. Release to a landfill is considered a restricted release, since the disposition of the material is constrained to disposal in a landfill or monofill (or to a composting facility as feed material. The final product from a composting facility is considered free released and must be as free of radionuclides as is practicable due to its potential to be used to grow foodstuffs for human consumption).

1.1.4 Regulation

Full regulation as radioactive material would require implementation of the requirements of Parts 1, 3, 4 and 10 of the Radiation Regulations. These requirements include licensing for disposal of residual radioactive material and the establishment of a Radiation Protection Program, approved Standard Operating Procedures, training programs, records, and reporting, among others. The Colorado definition of radioactive wastes is restricted to high activity wastes that could cause deterministic effects. Therefore, these materials are considered either as radioactive material or solid wastes.

In addition to licensing, the Department has other regulatory instruments to use to regulate these materials, including those of the WQCD and the solid waste regulations. The local governing jurisdiction also has regulatory controls over TENORM that is managed as solid waste. TENORM may be regulated as solid waste or as a radioactive material.

References

ACOE 2002. *White Paper: Using RESRAD in a CERCLA Radiological Risk Assessment.* U.S.Army Corps of Engineers, Buffalo, NY. October.

ANL 2003. *An Assessment of the Disposal of Radioactive Petroleum Industry Waste in Non-hazardous Landfills Using Risk-Based Modeling.* Smith, K.P., et al. Environmental Science and Technology 37(10): 2060-2066.

ANSI 2003. *Installed Radiation Protection Instrumentation Test and Calibration - Portable Survey Instruments for Near Background Operation.* N323B -2003. American National Standards Institute. New York, NY.

ANSI 1999. *Surface and Volume Radioactivity Standards for Clearance*. ANSI/HPS N13.12-1999, American National Standards Institute/Health Physics Society. Health Physics Society, McLean, VA. August.

CDM 2005. *City of Englewood Allen Water Filtration Plant Residuals Disposal Risk Assessment*. CDM, Denver, CO. August.

CHDT 2005. *Safety Assessment*. Section 6. Radioactive Materials License application. Clean Harbor's Deer Trail Facility. Clean Harbors, Inc. January.

Chem-Nuclear 1991. *Pathway Analysis and Risk Assessment Calculation of Doses to Workers and the Public from Sludge Disposal at the Denve Water Department Foothills Treatment Plant.* Chem-Nuclear Environmental Services, Columbia, SC. February.

DOE 1999. *Guidance for Conducting Risk Assessments and Related Risk Activities for the DOE-ORO Environmental Management Program*. BJC/OR-271. U.S. Department of Energy, Office of Environmental Management. April

DOE 1998. *Potential Radiological Doses Associated With the Disposal of Petroleum Industry NORM via Land spreading*. DOE/BC/W-31-109-Eng-38-5. Argonne National Laboratory, EAD, Lakewood, CO, for the U.S. Department of Energy. December.

IAEA 2004. *International Basic Safety Standards for Protection Against Ionizing Radiation and for the Safety of Radiation Sources.* Safety Series No. 115. International Atomic Energy Agency, Vienna, Austria.

ISCORS 2005. *"Final Report: ISOCRS Assessment of Radioactivity in Sewage Sludge: Recommendations on Management of Radioactive Materials in Sewage Sludge and Ash at Publicly Owned Treatment Works"*. Interagency Steering Committee on

Radiation Standards, 2005, ISCORS Technical Report 2004-04, DOE/EH-0668, EPA 832-R-03-002B. Washington, DC.

Kennedy 2004. *Development Of Waste Acceptance Criteria For The Disposal Of Norm/Tenorm Waste At The Deer Trail, RCRA Subtitle C Landfill*. DMA-TR-11, REV. 0. William Kennedy, Jr. Dade-Moeller and Associates, Inc. Richland, WA. May.

Kocher 1999. *National Research Council's Evaluation of Guidelines for Exposures to Naturally Occurring Radioactive Materials.* David Kocher, Oak Ridge Natinoal Laboratory. Presentation for Health Physics Society Professional Enrichment Program. June.

Makhijani et al, 2006. *Science for the Vulnerable Setting Radiation and Multiple Exposure Environmental Health Standards to Protect Those Most at Risk.* Arjun Makhijani, Ph.D., Brice Smith, Ph.D., Michael C. Thorne, Ph.D. Institute for Energy and Environmental Research, Tacoma Park, MD. October 19

Molen 2004. *Risk Assessment Report*. Waste Management of Colorado, Inc. Conservation Services, Inc., Bennett, CO. Prepared by Molen and Assoc. and Radiant Energy Management. December

NRC 2005. *Health Risks to Exposure to Low Levels of Ionizing Radiation.* BEIR-VII. National Research Council. Washington, DC.

NRC 1999. *Evaluation of Guidelines for Exposures to Technologically Enhanced Naturally Occurring Radioactive Materials*. National Research Council. National Academy Press. Washington, D.C.

Ogden 1992. *Radiologial Risk Assessment for The Proposed City of Arvada Alum Sludge Monofill*. Ogden Environmental and Energy Services Co. Denver, CO July.

Stoller 2006. *Human Health Risk Assessment for Primary Water Treatment Residuals*. S.M. Stoller Corporation, Lafayette, CO. May.

Stoller 2005. *Dose Assessment for the Emplacement of the CSMRI Site Containerized and Remaining Subsurface Soil into a RCRA Subtitle D Solid Waste Landfill.* S.M. Stoller Corporation, Lafayette, CO. April

UNSCEAR 2000. *Sources and Effects of Ionizing Radiation*. United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) 2000 Report to the General Assembly, with Scientific Annexes. Vienna, Austria.

URS 2006. *Evaluation of Risk Associated with Exposure to Water Treatment Plant Residuals* URS Corporation. Denver, CO March.

USNRC 2006a. *Consolidated Decommissioning Guidance, Characterization, Survey, and Determination of Radiological Release*. NUREG-1575, Vol. 2. Rev. 1. U.S. Nuclear Regulatory Commission, Washington, DC. September

USNRC 1998. *White Paper On Risk-Informed And Performance-Based Regulation* SECY-98-144. U.S. Nuclear Regulatory Commission, Washington, DC.

Appendix C. Results Of Round Robin Testing

RESULTS OF ROUND ROBIN TESTING

Intra-laboratory testing of alum and ferric chloride residual (sludges) to determine optimum dissolution and analytical techniques is currently in process. Results of these tests will be documented when complete. The following summary of results so far gives an indication of the variability between certified labs and the problems associated with analyzing these matrices.

Alum sludge: The seven gross alpha results (direct mount) reported averaged 58.3 +/- 13.5 pCi/g and ranged from a low of 38 +/- 11 to a high of 73 +/- 25 pCi/g. Gross beta results averaged 64.6 +/- 21.2 pCi/g and ranged from a low of 29 +/- 18 to a high of 100 +/- 8 pCi/g. Results for gross alpha of acid digestates were similar, four results averaged 57.8 +/- 18.1 pCi/g, and ranged from 43 +/- 8 to 82 +/- 12 pCi/g. Gross beta results of the digestate were considerably lower, averaging 33.3 +/- 26.5 pCi/g, and ranging from 19 +/- 6 to 73 +/- 7 pCi/g. Two fluorometric total uranium (U-238) measurements by one lab gave an average of 93.0 ppm. Isotopic results for uranium were fairly consistent between the two labs reporting so far, showing U-234 activity averaging 70.1 pCi/g, while U-238 activity averaged 42.1 pCi/g. Thorium results were very low, with Th-228, Th-230 and Th-232 all averaging less than 1 pCi/g. Ra-226 and Ra-228 both averaged 1.4 pCi/g, based on three results each. Low levels of lead-210 and polonium-210 (1.5 and 1.1 pCi/g, respectively) were reported by one lab. Totaling the average speciated activities gave a result of 118 pCi/g, approximately twice the direct count value.

Ferric chloride sludge: Direct mount gross alpha results averaged 602.7 +/- 128.6 pCi/g and ranged from 364 +/- 72 to 751 +/- 34 pCi/g. Gross beta measurements averaged 327.9 +/- 149.9 pCi/g and ranged from 144 +/- 36 to 502 +/- 16 pCi/g. Gross alpha results for digested samples averaged 583.3 +/- 185.8 pCi/g and ranged from 471 +/- 29 to 860 +/- 37 pCi/g. Gross beta results for the digestate averaged 299.0 +/- 41.4 pCi/g and ranged from 270 +/- 12 to 360 +/- 13 pCi/g. Fluorometric total uranium measurements averaged 18.0 ppm. Isotopic uranium measurements averaged 13.2 pCi/g for U-234 and 9.5 pCi/g for U-238. Thorium results averaged 6.7 pCi/g for Th-228, 1.2 pCi/g for Th-230 and 0.1 pCi/g for Th-232. Three Ra-226 measurements averaged 296.7 pCi/g, and Ra-228 measurements averaged 42.7 pCi/g. No lead-210 was reported, but one lab reported 7.4 pCi/g of polonium-210.

Backwash water: Gross alpha results for the backwash water were more consistent, averaged 73.2 +/- 15.4 pCi/l and ranged from 54 +/- 8 to 93 +/- 10 pCi/l. Gross beta results averaged 20.7 +/- 36.4 pCi/g and ranged from –46 +/- 123 to 48 +/- 7 pCi/l. Two fluorometric uranium measurements averaged 1.4 ppm. Isotopic uranium measurements gave consistently low results, averaging 0.3 and 0.8 pCi/l for U-234 and U-238, respectively. Isotopic thorium results averaged 0.7, 0.5 and 0.1 pCi/l for Th-228, Th-230 and Th-232 respectively. Ra-226 averaged 25.0 pCi/l, while Ra-228 averaged 2.0 pCi/l.

Appendix D. Tables Of Available Radionuclide Treatment Technologies

The following tables present approved technologies and pertinent information.

Coagulation/Filtration		
Definition		Addition of metal salts, such as alum or ferric chloride, to destabilize colloidal suspensions allowing formation of aggregate flocc particles followed by settling and filtration.
Target Contaminant Removal		Uranium, suspended solids, organic carbon, precipitated contaminants
BAT/SSCT Designation		BAT and SSCT Uranium: 25-10,000 consumers
Design Considerations		Choosing the most suitable coagulant for a system requires an understanding of source water characteristics and seasonal fluctuations, especially pH. The coagulant type, dose rate, pH, temperature, and raw water quality will affect the removal efficiency and characteristics of the residuals produced during treatment.
Facility Site Considerations		The use of this technology for uranium removal is only practical if the system has coagulation/filtration in place and can modify the existing processes to optimize uranium removal.
Operator Skill Level Required		Advanced Basic
Process Control Requirements		Optimization and monitoring of coagulation/filtration process to maximize uranium removal.
Competing Co-Contaminant Removal		Heavy metals
Types of Residuals/Wastes Generated	**Solids**	Spent filter media, clarifier sludge/scum
	Liquids	Clarifier sludge/scum, filter backwash water
Waste Disposal Issues		Testing of backwash water and sludge for radioactivity levels to determine available disposal options.
Worker Safety		Accumulation of radioactive material in filter media and coagulant sludge may pose a risk to workers.
State Approval Requirements		Department must be notified prior to coagulation changes. Pilot testing may be required. Waste characterization must be performed including identification of disposal options and costs.

Lime Softening		
Definition		The addition of lime, soda ash, or caustic soda leads to an increase in pH, which causes the precipitation of calcium and magnesium, and coincidentally, heavy metals, organic compounds, and radionuclides. Precipitates are removed during the sedimentation and filtration processes. The pH must then be readjusted to the normal range for drinking water.
Target Contaminant Removal		Radium and uranium
BAT/SSCT Designation		BAT and SSCT Radium: 25-10,000 consumers Uranium: 501-10,000 consumers
Design Considerations		Choosing the most suitable dose rate for a system requires an understanding of source water characteristics and seasonal fluctuations, especially pH, alkalinity, and hardness. The dose rate, pH, raw water quality will affect the removal efficiency and characteristics of the residuals produced during treatment.
Facility Site Considerations		Generally would be used at surface water systems already using conventional filtration.
Operator Skill Level Required		Advanced
Process Control Requirements		Optimization and monitoring of softening process to maximize radium and uranium removal.
Competing Co-Contaminant Removal		Heavy metals, organic compounds
Types of Residuals/Wastes Generated	**Solids**	Spent filter media, clarifier sludge/scum
	Liquids	Clarifier sludge/scum, filter backwash water
Waste Disposal Issues		Testing of backwash water and sludge for radioactivity levels to determine available disposal options.
Worker Safety		Accumulation of radioactive material in filter media and coagulant sludge may pose a risk to workers.
State Approval Requirements		Submission of plans and specifications for review and approval, including chemical dosing, filter backwash, flux rate, and removal calculations. Pilot testing may be required. Waste characterization must be performed including identification of disposal options and costs.

Green Sand Filtration		
Definition		The active material in "green sand" is glauconite. Glauconite is a green clay mineral that contains iron and has ion exchange properties. Glauconite often occurs mixed with small pellets of other materials, thus the name "green sand." The glauconite is mined, washed, screened, and treated with various chemicals to produce a durable greenish-black product that has properties that allow it to adsorb soluble iron and manganese. Green sand filtration is often used in conjunction with a potassium permanganate feed to regenerate media and increase removal efficiency.
Target Contaminant Removal		Radium
BAT/SSCT Designation		SSCT Radium: 25-10,000 customers
Design Considerations		Raw water iron and manganese concentrations must be taken into consideration to determine regeneration and flux rates.
Facility Site Considerations		Applicable to surface or ground waters.
Operator Skill Level Required		Basic to Advanced
Process Control Requirements		Similar to normal filtration process. If potassium permanganate is used additional controls will be required.
Competing Co-Contaminant Removal		Iron, manganese, barium
Types of Residuals/Wastes Generated	**Solids**	Spent filter media, clarifier sludge/scum
	Liquids	Clarifier sludge/scum, filter backwash water
Waste Disposal Issues		Testing of backwash water and sludge for radioactivity levels to determine available disposal options.
Worker Safety		Accumulation of radioactive material in filter media and sludge may pose a risk to workers. Greensand media can accumulate significant amounts of radium.
State Approval Requirements		Submission of plans and specifications for review and approval, including backwash, regeneration, and flux rate calculations. Pilot testing may be required. Waste characterization must be performed including identification of disposal options and costs.

Ion Exchange		
Definition		Resin that selectively exchanges an undesired ion for another ion. The media is then regenerated using a brine solution to release the undesired ions. The brine solution will then be disposed of. Media can be of the cationic, anionic, or mixed media type.
Target Contaminant Removal		Radium, uranium, beta/photon
BAT/SSCT Designation		BAT and SSCT Radium, Uranium, beta/photon: 25-10,000 customers
Design Considerations		For radium removal a strong acid cation exchange resin must be used. For uranium removal a strong base anion exchange should be used. Pretreatment may be necessary.
Facility Site Considerations		Applicable to surface or ground water systems.
Operator Skill Level Required		Intermediate to Advanced
Process Control Requirements		Testing filter effluent for radium and uranium breakthrough.
Competing Co-Contaminant Removal		Cations such as calcium, magnesium, barium, and strontium, and anions such as nitrate, fluoride, fulvates, humates, arsenates, selenate, chromate and anionic complexes of uranium will be removed depending on the type of resin used.
Types of Residuals/Wastes Generated	**Solids**	Spent resin
	Liquids	Regeneration brine, backwash water, rinse water
Waste Disposal Issues		Direct discharge of liquid residuals is subject to permitting requirements. Spend media can accumulate radioactivity and must be disposed of accordingly. If intermediate processing is used for liquid residual processing then the dewatered sludge must be tested to determine disposal options.
Worker Safety		Accumulation of radioactive material in exchange media and backwash sludge may pose a risk to workers. Ion exchange media can accumulate significant amounts of radioactivity.
State Approval Requirements		Submission of plans and specifications for review and approval, including backwash, regeneration, and flux rate calculations. Pilot testing will be required to determine maximum flux rate and minimum regeneration rate. Waste characterization must be performed including identification of disposal options and costs.

POU/POE Ion Exchange		
Definition		Ion exchange technology applied at Point of Use or Point of Entry.
Target Contaminant Removal		Radium, uranium, beta/photon
BAT/SSCT Designation		SSCT Radium, Uranium, beta/photon: 25-10,000 customers
Design Considerations		For radium removal a strong acid cation exchange resin must be used. For uranium removal a strong base anion exchange should be used.
Facility Site Considerations		Generally economically competitive for systems with less than 100 taps. Backwash discharge stream must be addressed. System staff must have access for operations and maintenance.
Operator Skill Level Required		Intermediate to Advanced
Process Control Requirements		Similar to normal ion exchange process.
Competing Co-Contaminant Removal		Cations such as calcium, magnesium, barium, and strontium, and anions such as nitrate, fluoride, fulvates, humates, arsenates, selenate, chromate and anionic complexes of uranium will be removed depending on the type of resin used.
Types of Residuals/Wastes Generated	**Solids**	Spent resin
	Liquids	Regeneration brine, backwash water, rinse water
Waste Disposal Issues		State must determine whether backwash water can be discharged to residential septic systems; discharge from commercial or industrial customers is subject to class V injection well regulations. Individual POE/POU units may accumulate radioactivity and require additional disposal requirements.
Worker Safety		Accumulation of radioactive material in POE/POU devices may pose risk to operators and consumers.
State Approval Requirements		Submission of plans and specifications for review and approval, including regeneration and flux rate calculations. Pilot testing will be required to determine maximum flux and minimum regeneration rates and risk to consumers. Waste characterization must be performed including identification of disposal options and costs. System is responsible for operations and maintenance of units. O & M plan must be including in submittal.

Reverse Osmosis		
Definition		Water is forced through a porous membrane under pressure while suspended solids, larger molecules and ions are held back.
Target Contaminant Removal		Radium, uranium, gross alpha, beta/photon
BAT/SSCT Designation		BAT and SSCT Radium, gross alpha , beta/photon: 25-10,000 customers Uranium: 501-10,000 customers
Design Considerations		Requires pre-filtration to prevent excessive membrane fouling.
Facility Site Considerations		Applicable to surface or ground water systems. Liquid concentrate reject stream discharge must be addressed.
Operator Skill Level Required		Advanced
Process Control Requirements		Monitoring effluent for breakthrough of indicators such as TDS or conductivity, alarm conditions for pressure differential.
Competing Co-Contaminant Removal		Heavy metals, organic compounds
Types of Residuals/Wastes Generated	**Solids**	Spent membranes
	Liquids	Liquid concentrate reject stream
Waste Disposal Issues		Residuals produced can have very high concentrations of the contaminants removed from the water, including radionuclides, which may limit disposal options. The concentration depends on the efficiency of the RO unit: highly efficient units will produce low volumes of residual streams with high concentrations of contaminants while lower efficiency units will produce higher volumes of residual streams with lower concentrations of contaminants.
Worker Safety		Accumulation of radioactive material on membranes may pose risk to workers. Intermediate processing steps may further concentrate radioactivity.
State Approval Requirements		Submission of plans and specifications for review and approval, including flux rate calculations. Waste characterization must be performed including identification of disposal options and costs.

POU/POE Reverse Osmosis		
Definition		Reverse osmosis technology applied at Point of Use or Point of Entry
Target Contaminant Removal		Radium, uranium, gross alpha, beta/photon
BAT/SSCT DESIGNATION		SSCT Radium, Uranium, beta/photon: 25-10,000 customers Uranium: 501-10,000 customers
Design Considerations		Requires pre-filtration to prevent excessive membrane fouling.
Facility Site Considerations		Generally economically competitive for systems with less than 100 taps. Liquid concentrate reject stream discharge must be addressed. System staff must have access for operations and maintenance.
Operator Skill Level Required		Basic
Process Control Requirements		Monitoring effluent for breakthrough of indicators such as TDS or conductivity, alarm conditions for pressure differential
Competing Co-Contaminant Removal		Heavy metals, organic compounds
Types of Residuals/Wastes Generated	**Solids**	Spent membranes
	Liquids	Liquid concentrate reject stream
Waste Disposal Issues		State must determine whether reject concentrate can be discharged to residential septic systems; discharge from commercial or industrial customers is subject to class V injection well regulations. Individual POE/POU units may accumulate radioactivity and require additional disposal requirements.
Worker Safety		Accumulation of radioactive material in POE/POU devices may pose risk to operators and consumers.
State Approval Requirements		Submission of plans and specifications for review and approval. Pilot testing will be required to determine risk to consumers. System is responsible for operations and maintenance of units. O & M plan must be including in submittal. Waste characterization must be performed including identification of disposal options and costs.

Co-Precipitation with Barium Sulfate		
Definition		Co-precipitation of radium with barium sulfate is accomplished with the addition of a soluble barium compound, such as barium chloride, to waters containing sulfates. This results in the formation of highly insoluble barium sulfate sludge. When radium is present in the source water, it co-precipitates with the sludge. This process has primarily been used to remove radium from waste effluents, demonstrating the capability to remove over 95 percent of radium from mine wastewaters.
Target Contaminant Removal		Radium
BAT/SSCT DESIGNATION		SSCT Radium: 25-10,000 customers
Design Considerations		Sulfate concentrations must be adequate to allow for barium sulfate precipitation.
Facility Site Considerations		Generally would be used at surface water systems already using conventional filtration
Operator Skill Level Required		Advanced
Process Control Requirements		Optimization and monitoring of process to maximize radium removal.
Competing Co-Contaminant Removal		Unknown
Types of Residuals/Wastes Generated	**Solids**	Spent filter media, clarifier sludge/scum
	Liquids	Clarifier sludge/scum, filter backwash water
Waste Disposal Issues		Testing of backwash water and sludge for radioactivity levels to determine available disposal options.
Worker Safety		Accumulation of radioactive material in filter media and sludge may pose a risk to workers.
State Approval Requirements		Submission of plans and specifications for review and approval. Pilot testing will be required to determine efficacy and process control parameters. Waste characterization must be performed including identification of disposal options and costs.

Electrodialysis/Electrodialysis Reversal		
Definition		In electrodialysis (ED), electric current pulls charged ions through the ED membrane from the less concentrated solution to the more concentrated solution, relying on passage of the solute through the membrane as opposed to passage of the solvent. ED membranes are basically porous sheets of ion exchange resin with low permeability for water. The mechanism of separation and the physical characteristics of electrodialysis membranes differ significantly from membranes used in pressure driven filtration processes. Electrodialysis can effectively remove both radium and uranium with efficiencies of up to 95%.
Target Contaminant Removal		Radium
BAT/SSCT DESIGNATION		SSCT Radium: 25-10,000 customers
Design Considerations		Pilot testing will be required.
Facility Site Considerations		Applicable to surface or ground water, pretreatment may be necessary.
Operator Skill Level Required		Basic to Intermediate
Process Control Requirements		Monitoring effluent for breakthrough of indicators such as TDS or conductivity, alarm conditions for pressure differential.
Competing Co-Contaminant Removal		Unknown
Types of Residuals/Wastes Generated	**Solids**	Spent membranes
	Liquids	Liquid concentrate reject stream
Waste Disposal Issues		Direct discharge of liquid residuals is subject to permitting requirements. Spend membranes can accumulate radioactivity and must be disposed of accordingly. If intermediate processing is used for liquid residual processing then the dewatered sludge must be tested to determine disposal options.
Worker Safety		Accumulation of radioactive material in media and sludge may pose a risk to workers.
State Approval Requirements		Submission of plans and specifications for review and approval. Pilot testing will be required to determine efficacy, process control parameters, and potential co-contaminant removals. Waste characterization must be performed including identification of disposal options and costs.

Pre-Formed Hydrous Manganese Oxide Filtration		
Definition		Pre-formed hydrous manganese oxide (HMO) filtration for radium removal consists of the adsorption of radium onto manganese oxides, which are then removed through filtration.
Target Contaminant Removal		Radium
BAT/SSCT DESIGNATION		SSCT Radium: 25-10,000 customers
Design Considerations		Pilot testing will be required.
Facility Site Considerations		Generally would be used at surface water systems already using conventional filtration.
Operator Skill Level Required		Advanced
Process Control Requirements		Optimization and monitoring of process to maximize radium removal.
Competing Co-Contaminant Removal		Iron
Types of Residuals/Wastes Generated	**Solids**	Spent filter media, clarifier sludge/scum
	Liquids	Clarifier sludge/scum, filter backwash water
Waste Disposal Issues		Testing of backwash water and sludge for radioactivity levels to determine available disposal options.
Worker Safety		Accumulation of radioactive material in media and sludge may pose a risk to workers.
State Approval Requirements		Submission of plans and specifications for review and approval. Pilot testing will be required to determine efficacy and process control parameters. Waste characterization must be performed including identification of disposal options and costs.

Activated Alumina		
Definition		Activated alumina (AA) adsorption is a physical and chemical process by which ions in solution are removed by attachment to available adsorption sites on an oxide surface. Activated alumina processes are sensitive to pH and anions such as fluoride and arsenate are best adsorbed at pH less than 8.2. Activated alumina can be used for uranium removal, but has a higher affinity for arsenic, selenium, fluoride, and sulfate than for uranium. Bench scale tests have demonstrated that AA can achieve up to 99 percent removal of uranium (Sorg, 1988).
Target Contaminant Removal		Uranium
BAT/SSCT DESIGNATION		SSCT Uranium: 25-10,000 customers
Design Considerations		Pretreatment may be necessary to prevent media fouling.
Facility Site Considerations		Applicable to surface or ground waters.
Operator Skill Level Required		Advanced
Process Control Requirements		Testing of backwash water and regeneration solution for uranium, testing of backwash pond sludge for uranium, testing filter effluent for uranium breakthrough.
Competing Co-Contaminant Removal		Arsenic, selenium, fluoride, and sulfate
Types of Residuals/Wastes Generated	**Solids**	Spent media
	Liquids	Regeneration brine, backwash water, rinse water, and acid neutralization water
Waste Disposal Issues		Direct discharge of liquid residuals is subject to permitting requirements. Spend membranes can accumulate radioactivity and must be disposed of accordingly. If intermediate processing is used for liquid residual processing then the dewatered sludge must be tested to determine disposal options.
Worker Safety		Accumulation of radioactive material in media and sludge may pose a risk to workers.
State Approval Requirements		Submission of plans and specifications for review and approval. Pilot testing will be required to determine efficacy, maximum flux rate, minimum regeneration rate, and other process control parameters. Waste characterization must be performed including identification of disposal options and costs.

Appendix E. Suggested Training Syllabus For TENORM Workers

TRAINING TOPICS FOR UTILITIES AND DISPOSAL FACILITIES:

- Characteristics of ionizing radiation
  - Gamma
  - Beta
  - Alpha

- Types of radioactivity that could be encountered and under what conditions
  - Naturally occurring radioactive materials
  - Man-made radioactive materials
  - Bulk volumetric
  - Fixed
  - Removable

- Radiation Hazards and pathways
  - External
  - Internal
    - Inhalation
    - Ingestion

- Basic effects associated with chronic radiation exposure
  - Somatic
  - Genetic
  - Cancer

- Basic protective procedures and practices
  - Time, distance, shielding
  - Personal Protective Equipment
  - Ventilation
  - Housekeeping
  - Work practices
  - Personal hygiene
  - Tools/equipment
  - Vehicles

- Radiation monitoring programs, surveys
  - Site Monitoring
    - Passive monitoring (TLDs)
    - Air Sampling
    - Direct Measurements
    - Other sampling

- Effective dose, allowable limits
  - Background dose
  - Dose from site operations
  - Public dose limits

- Employee and organization responsibilities
    - Site Rules
    - Site entry and departure
    - Eating, tobacco, and drinking policy
    - Contamination control

- Emergency procedures
    - Spill control
    - Spill cleanup

Appendix F. Public Dose Calculations

COLORADO RULES AND REGULATIONS PERTAINING TO RADIATION CONTROL

Revisions to Part 4 of the State of Colorado Rules and Regulations
Pertaining to Radiation Control were implemented on January 1, 1994, changing the radiation dose limits for individual members of the public from licensed radioactive materials. Under the new requirements, a licensee or registrant shall conduct operations so that: (1) the dose in any unrestricted area from external sources does not exceed 2 millirems in any one hour, and (2) the dose to individual members of the public does not exceed 100 millirems in a year.

Before the Department can issue or amend a radioactive materials license, it must be determined that you can meet these general public dose limits. The dose limits apply to the actual doses received from licensed materials. However, the determination that you can meet the limits is based upon the types and quantities of materials that you have requested and the facilities in which they will be stored and used. When the Department issues a radioactive materials license, the license authorizes you to possess the maximum quantity identified on the license. Therefore, you must demonstrate that you can meet all applicable requirements for the maximum quantity requested.

The following guidance can be used to demonstrate that you can meet these requirements with the quantities of materials requested on the license.

1. A "restricted area" means an area, access to which is limited or controlled by the licensee or registrant for purposes of protecting individuals against exposure to sources of radiation. Anyone who can frequent a restricted area must be properly trained and must wear personnel monitoring, unless it has been determined that the individual will receive less than 10% of the occupational dose limit.

Any area outside of the restricted area (i.e., outside of the storage cabinet, rooms adjacent to the storage area, or outside the locked building), must not exceed 2 millirems per hour, and 100 millirems per year if the general public can occupy these areas.
General public includes any individual who is not an authorized user of the licensed devices. Therefore, if secretaries, the company president, visitors or customers, or a neighbor can be in any area near your sources, then those areas must meet the above dose limits.

2. Dose rates may be determined either by actual measurement or by calculation. Measurements require a calibrated survey meter and a survey completed by someone knowledgeable in interpreting the results. Qualified experts are available to help with these tasks. If no radioactive materials are currently possessed, then a calculation would be used to determine what dose rates could exist with licensed materials within an area of interest.

3. Measurements with the maximum number of authorized sources may not be possible. However, if you have one or more sources, it is acceptable to estimate the increase in the dose rate from a measured rate to the rate that could occur from a larger number of sources. For example, if the dose rate is measured outside a wall with one source present,

you may assume that two sources would cause 2 x measured dose rate. (This estimate assumes that all sources are at the same place within the room, and have the same activity. If the sources present do not have the maximum authorized activity, then a correction factor is needed.)

4. Calculation of dose rates at a location does require some information with which to begin and a simple mathematical calculation. To begin, the Transport Index (TI) can be read from the transportation label on the gauge shipping container. Alternatively, the manufacturer's representative can provide the Transport Index (TI) for the gauges you have requested. The TI is the dose rate in millirems per hour at one meter from the outside of the gauge shipping container. A total TI can be assumed to be the TI for a single gauge, multiplied times the number of similar gauges. For example, if the TI is "1.5" and you have five identical gauges, you may estimate the total dose rate at one meter to be 1.5 x 5, or 7.5 millirems per hour.
If a source has a measured dose rate at a given distance, and then you move away from the source, the dose rate will decrease with the square of the distance. That is, if you double the distance from a source you decrease the dose rate by a factor of four. The formula for this calculation is given below.

$$R_2 = \frac{R_1 (D_1)^2}{(D_2)^2}$$

EXAMPLE: If the dose rate at one meter from a source is 12 millirems per hour, what would be the expected dose rate at 3 meters?

R2 = ?
R1 = 12 millirems per hour
D1 = 1 meter
D2 = 3 meters
R2 = 12 x 1/9
R = **1.33 millirems per hour**

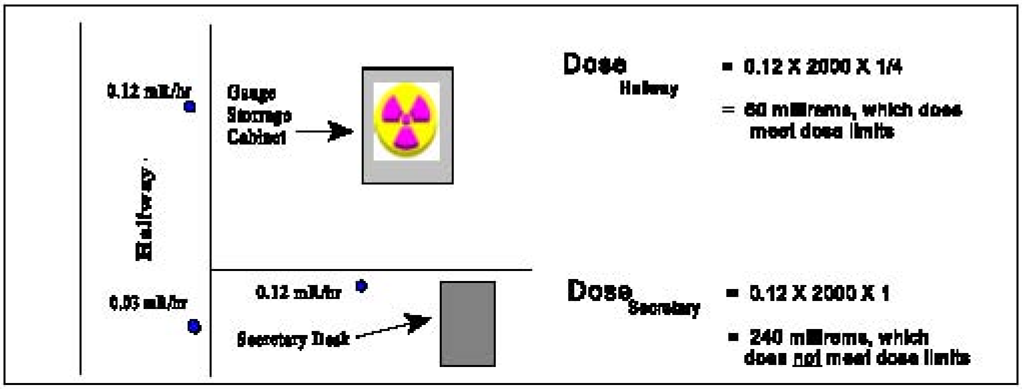
5. Dose rates must be multiplied by the time period of the possible exposure. For an individual over which you have no control (i.e., a neighboring house or office) you must assume an exposure time of 24 hours per day for 365 days per year, or 8760 hours. For general public within your facility, which you do control, the exposure time may be 8 hours per day, five days per week, for 50 weeks per year (2000 hours per year). For example, a full time secretary for the company would have the dose rate at her desk multiplied by 2000 hours per year to calculate the annual dose. Occupancy factors for other areas which may be used to adjust exposure times are:

Offices, work areas, living quarters - occupancy factor is 1

Hallways, unattended parking lots - occupancy factor is 1/4.

Stairways, toilets, sidewalks - occupancy factor is 1/16.

EXAMPLE: Again assume your company is open to employees or visitors for 8 hours per day, 5 days per week, for 50 weeks per year (2000 hours per year). Assume also that the measured dose rate outside of two walls equidistant from stored gauges is 0.12 millirem per hour. Behind one of the walls is an office with a secretary and behind the other wall is a hallway.



6. For the example above, action would have to be taken to reduce the dose to the area occupied by the secretary. Choices include:

1) Decrease the number of sources in this area; or
2) Add shielding to the storage cabinet or to the wall between the sources and the secretary; or
3) Increase the distance from the sources to the secretary; or
4) A combination of the above.

7. The above calculations do not include calculations for shielding provided by brick or concrete walls. Books are available regarding shielding calculations and materials. However, a qualified expert or the manufacturer's representative should be able to perform calculations for the shielding provided by existing walls, or to design additional shielding, as necessary.

8. To demonstrate that you can meet 2 millirems per hour, and 100 millirem per year to a member of the public, submit a diagram together with the calculated or actual measurements of radiation dose rate for **each** area adjacent to the storage area. This should also include above and below the storage are if these are occupiable areas. Include with the measurements a "background" measurement, which is the radiation dose rate from the natural environment (excluding all licensed radioactive materials). Also include any assumptions you have made regarding occupancy. If you are authorized multiple storage locations, compliance with the dose rate and annual dose limit to the general public must be demonstrated for each location.

CALCULATION SHEET FOR DETERMINING COMPLIANCE WITH RH 4.14 AND 4.15

The following work sheet may be used to calculate dose rate and total dose for a single model of device, and if the device is stored in the original shipping container. Note that no credit for walls or other shielding is provided in these calculations. If it is necessary to include the building shielding to meet RH 4.14 and 4.15, it may be necessary for you to contact a qualified expert to complete the shielding calculations.

(1) Transport Index (TI) from the shipping label. TI = ________mR/hr.
(2) Number of gauges authorized = ________________________
(3) Maximum exposure estimated at 1 meter (line 1 x line 2) = __mR/hr.
(4) Distance to nearest member of the public (in meters)____ meters.
(5) Square of the distance to nearest public (line 4 x line 4)_ meters2.
(6) Exposure rate to nearest general public (line 3 ÷ line 5)__ mR/hr.
If the dose rate calculated in (6) is greater than 2 millirem per hour, you do not meet RH 4.14 of the Regulations, and you must increase shielding or the distance to the member of the general public. If the calculated dose rate is less than 2 millirem per hour, proceed to the next section.
(7) Number of hours of exposure to the member of general public hrs.
Enter one of the following:

(8760 hrs. if you have no control, i.e., residence, separate building, or)

(2000 hrs. if this is a company employee which works 40 hrs. and 50 wks per year, or)

(the actual hours the individual is at the location for which the calculation is being completed)

(8) Occupancy factor for the member of the general public.
Enter one of the following:

(Offices, work areas, living quarters - occupancy factor is 1)
(Hallways, unattended parking lots - occupancy factor is 1/4)
(Stairways, toilets, sidewalks - occupancy factor is 1/16).

(9) Estimated dose to the member of the general public
(line 6 x line 7 x line 8)_________ mr per year.

If the dose calculated in (9) is greater than 100 millirem per year, you do not meet RH 4.14 of the Regulations, and you must increase the distance to the member of the general public or add shielding. If the calculated dose is less than 100 millirem per year, you have demonstrated that you can meet RH 4.14, for that particular member of the general public. The calculations in (7) through (9) must be repeated for other members of the general public and occupiable areas which may have a different occupancy factor and distance.