Policy and Implementing Guidance for Control and Disposition of Drinking Water Treatment Residuals Containing Technologically Enhanced Naturally Occurring Radioactive Material (TENORM)

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of Public Health
and Environment

Water Quality Control Division
Hazardous Materials and Waste Management Division

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1. ACRONYMS, ABBREVIATIONS AND SYMBOLS

μ	Micro
^{226}Ra	Radium-226
^{228}Ra	Radium-228
ALARA	As Low As Reasonably Achievable
BAT	Best Available Technologies
Bq	Becquerel
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
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
g	Gram
HMWMD	Hazardous Materials and Waste Management Division
L	Liter
LLMW	Low-Level Mixed Waste
LLRW	Low-Level Radioactive Waste
m	Milli
MCL	Maximum Contaminant Level
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
PWS	Public Water Systems
RAA	Running Annual Average
RCA	Radiation Control Act
RCP	Radiation Control Program
RCRA	Resource Conservation And Recovery Act
Rem	Radiation Equivalent Man
RMP	Residual Management Plan
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

2. INTRODUCTION

Radioactivity is naturally present in rocks, soils, surface water and groundwater at trace concentrations. Drinking water sources may contain naturally occurring radioactive elements, sometimes 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. 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 (CDPHE) 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 technologies recommended by the EPA, basic radiation safety principles, effluent-sampling frequencies, and waste treatment and disposal options are reviewed. 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 Colorado Department of Public Health and Environment, 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.

Sources of drinking water are protected under the Federal *Safe Drinking Water Act* to the same regulatory levels as the drinking water itself. Interest has been renewed with the publication of the Radionuclides Rule in the Federal Register (EPA 2000). The Radionuclides Rule is implemented by CDPHE in the *Colorado Primary Drinking Water Regulations* [5 CCR 1003-1],

Part 2.6. This rule applies to all community water systems and includes requirements for uranium (not previously regulated) and revisions to the monitoring requirements for combined radium-226 (^{226}Ra) and radium-228 (^{228}Ra), gross alpha particle radioactivity, and beta particle and photon radioactivity. The Rule retains the existing maximum contaminant levels (MCLs) for combined ^{226}Ra and ^{228}Ra, gross alpha particle radioactivity and beta particle and photon radioactivity. The MCLs are listed in Table 1. The effective date of the Radionuclides Rule was December 7, 2003. Public water systems must monitor in accordance with a State-specified plan between the effective date and December 3, 2007, unless they use grandfathered data.

Table 1. Maximum Contaminant Levels

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

In addition to the Radionuclides Rule, 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). Additionally, a Final Rule for Filter Backwash Recycling was promulgated (EPA 2001), which may concern drinking water treatment facilities.

The regulation of radioactive material is the responsibility of the Radiation Control Program (RCP) of the Hazardous Materials and Waste Management Division (HMWMD) of CDPHE. 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.

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 2003). In Colorado, some water sources contain enough natural radioactivity to cause elevated TENORM concentrations when the waters are treated.

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. Detailed discussions of the regulations follow in later sections.

3. 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 radionuclides that contribute to terrestrial radiation, which is the source of radionuclides in drinking water residuals, are found in the natural decay series of the uranium, thorium and the actinium series. The decay series and information on half-life for the uranium and thorium series are presented in Appendix A (the actinium series is not significant in this situation). 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. Not all isotopes are of concern, as most are not found in drinking water. Background soil concentrations are reported as ranging from 4 – 141 Bq/kg (0.1 to 3.8 pCi/g), with an average of 37 Bq/g (1.0 pCi/g) for uranium in the U.S., and from 18 – 126 Bq/kg (0.48 to 3.4 pCi/g) with an average of 52 Bq/kg (1.4 pCi/g) for ^{226}Ra in Colorado (Myrick 1983).

The radioactivity of an isotope is related to its mass and half-life, which is called 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. For example, ^{228}Ra is found at about a third of the concentration of ^{226}Ra. The same applies for uranium isotopes. Table 2 shows the relationship for uranium isotopes.

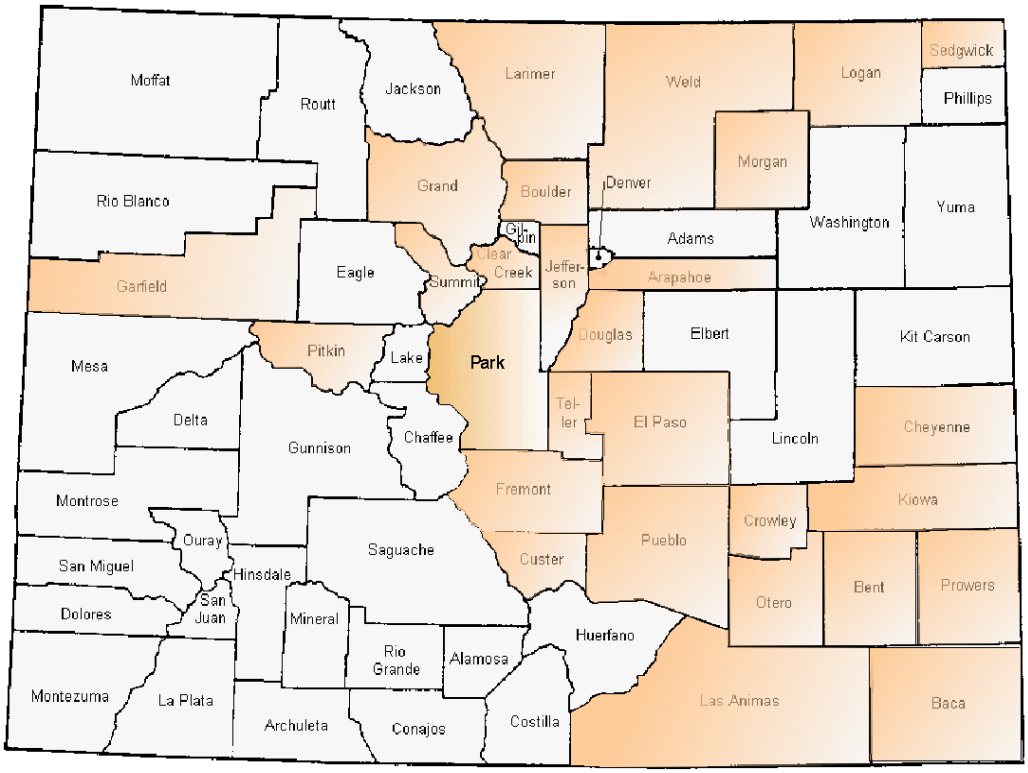

Figure 1. Counties with elevated source waters

Table 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 3 below.

Table 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: EPA 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).

4. COMPLIANCE OPTIONS AND TREATMENT TECHNOLOGIES FOR THE RADIONUCLIDE RULE

The Radionuclides Rule 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 4). The U.S. EPA originally created and promulgated the Radionuclide Rule in 1976 as part of the Safe Drinking Water Act (SDWA). The rule 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 Colorado Department of Public Health and Environment (CDPHE) 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 4. 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

4.1 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 Radionuclides Rule. 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.

4.2 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 CDPHE approval due to extenuating circumstances.

4.3 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 Radionuclides Rule. 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:

[Eq.1]

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

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.

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

4.4 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

4.5 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 Technical Services Unit 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

4.6 TREATMENT OPTIONS

A PWS that has determined that no satisfactory non-treatment options exist to attain compliance with the Radionuclides Rule must install a water treatment system to reduce the radionuclide concentrations to compliant levels. As part of the Radionuclides Rule, 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.

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.

4.7 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 removal efficiencies may be reduced by competing or co-removal of other contaminants present in the raw water. 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 13 and 15 of this document for further info on workplace evaluations and worker safety considerations.

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 below.

4.8 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. Additional information may be found in Sections 14, 15 and 16 of this document.

5. State Approval Requirements for Radionuclide Treatment

5.1 Regulatory Requirements

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. The requirements of residual disposition and handling will be discussed in Sections 7 and 8 of this document. Plans and specifications must be submitted for review to ensure compliance with CPDWR and the State of 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 chapter. Other regulatory requirements will be discussed in other chapters and with the water system during the review process. Permitting, licensing 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 from the Solid Waste Unit, which may include groundwater monitoring. All onsite storage, intermediate processing and disposition of residuals must conform to all HMWMD requirements.

5.2 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. 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, 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 licenses may be required, depending on the amount of radioactivity in the residuals. 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.

5.3 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 radionuclide treatment that utilizes chemical addition will require a Class B operator at minimum. Systems should be aware that some types of treatment may pose worker safety issues and require special licensing requirements. Sections 14, 15 and 16 of this document discuss workplace evaluation, health and safety and instrumentation. Regulation 100 can be found at the following web address: http://www.cdphe.state.co.us/op/ocb/reg100/reg1000508revision.pdf

5.4 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

5.5 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: www.dola.co.us/LGS/TA/TA_publications.htm. 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.

5.6 Submittal of Plans and Specifications

5.6.1 General Requirements

Modifications to public water systems, including the addition of new sources and treatment processes, require the prior approval of the Colorado Department of Public Health and Environment. WQCD conducts reviews and issue approvals based on the State of Colorado Design Criteria for Potable Water Systems (Criteria). Contact the Technical Services Unit 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 dept. 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
- Water rights certification
- 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

5.6.2 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

5.6.3 INTERNET RESOURCES

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_New System_Capacity.pdf

The SDWIS Inventory Form can be found at:
http://www.cdphe.state.co.us/wq/Drinking_Water/pdf/ReportForms/SDWISInventoryForm_Ver 3.pdf

The "100-Year Flood Plain" Certification can be found at:
http://www.cdphe.state.co.us/wq/Drinking_Water/pdf/CapacityDevelopment/Attachment3_New System_Capacity.pdf

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

5.7 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
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
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.

6. SAMPLING AND ANALYSIS FOR TENORM IN DRINKING WATER RESIDUALS

6.1 BACKGROUND

With the recent implementation of the drinking water Radionuclide Rule (RR), 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. Section 6.2 of this document 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 PicoCuries per gram (pCi/g) of gross alpha radioactivity is not compatible with current, risk-based 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 and biosolids regulations are amended. If properly implemented, this guidance should minimize uncertainty introduced by different sampling and analysis protocols.

Section 6 of this 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 16 of this document has additional information on facility monitoring.

6.2 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 sludges may require very aggressive digestion techniques in the laboratory in order to accurately measure their radionuclide content. Other sludges 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 treat 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 sludge, 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 of liquid residuals are when they are finally disposed of by offsite discharge, deep well injection or some other method.

6.3 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. However, since some treatment processes are highly efficient, raw water with radionuclide results below the detection limit may result in a sludge 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. 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 when modifications are made to the system or process that could result in a change in radionuclide concentration in the residuals.

Sample results of residuals should be scientifically and legally defensible prior to final disposition. In some cases, this will mean approval of a formal Sampling and Analysis Plan by State and Local authorities. EPA guidance regarding the content and format of such a plan is available online, and other assistance may be available from the CDPHE Compliance Assistance an Data Management Unit of the WQCD or the treatment system vendor. Samples will usually need to be collected on a random basis. EPA SW846 (http://www.epa.gov/epaoswer/hazwaste/test/main.htm) 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.

6.3.1 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 significant amounts of TENORM may be very difficult to dispose of, and their generation should be kept to a minimum. In many cases, liquid residuals may be treated by evaporation, thereby generating solid wastes. See Chapter 11 for further discussion of interim treatment.

6.3.2 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 6 shows the approximate number of samples required for adequate analysis of small, medium, and large filter beds, sludge lagoons or similar facilities. Regulators may need to adjust these recommendations based on data quality objectives, process knowledge, or facility specific information.

Table 6. 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

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.

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.

Sludges 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 sludge 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.

Sludge 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 sludge 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 sludge to be characterized, but at least one kilogram of material should be collected per sample.

6.4 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 sludge 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 sludge sample will lead to faulty assumptions about the radioactivity in the material.

Under the current 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 sludges 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 sludge 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. These are bound to be present in most sludges 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.

6.4.1 DRINKING WATER METHODS

Analytical methods for radionuclides in drinking water are listed in 40 CFR 141.25, Table 1-8. These are limited to gross alpha/gross beta, uranium, ^{226}Ra, ^{228}Ra and gamma emitting, man-made nuclides like cesium-137 and iodine-131. 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 solid 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 sludge. 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. When complete, the round robin of residual testing performed by Colorado certified labs should allow some recommendations to be made regarding appropriate dissolution techniques for alum sludge and ferric chloride sludge. It is hoped that these will be transferable to other residuals as well. Results of the round robin testing are presented in Appendix C.

Preliminary results of gross alpha analysis of two sludge 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.

6.5 INTERPRETATION

The regulations specify, and laboratories deliver, analysis on a dry weight basis. Both alum and ferric chloride sludges 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 sludge has a similar effect the interpretation of analytical results. Sludges measured by CDPHE 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.

6.6 Recommendations

Preliminary results for the analysis of sludge 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. Recommendations for specific sample preparation and analysis techniques will follow when round robin testing of the sludges is complete.

7. Disposition Of Solid Water Treatment Residuals

There are limited disposition options for the various residual waste streams. TENORM is a classification or category of materials, and can be considered a solid waste, including residual liquids. The regulatory basis for disposal of TENORM under a variety of laws and regulations is complex and discussed in later sections. The activity levels of naturally occurring radionuclides in residuals can vary greatly. Therefore, the ultimate disposition of any particular solid residuals waste stream must include an assessment of the relative risk from the disposal (which can be almost zero) to workers and the public in the short term and the environment in the long-term. Additionally, there are regulatory and societal limitations to disposal options.

Current treatment technologies produce three basic types of wastes: spent media, solids/sludges, and liquids. The disposition of 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 criteria established in Section 8.2.3 of this guidance or 40 pCi/g total alpha screening limit cited in the Section 12 of the Regulations Pertaining to Solid Waste Sites and Facilities, 6 CCR 1007-2 ("the 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 oversight. 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 Regulations, unless governed by other regulations.

7.1 APPLICABILITY

This guidance is applicable to CDPHE review of water treatment plant solids residuals waste streams (solids residuals) that contain TENORM materials. In Colorado, solid waste is regulated under dual authority, with CDPHE 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.

Examples of disposal options for the three categories are shown in Table 7.

Table 7. Disposal options

	Disposal Options				
	Direct discharge	**Discharge to sanitary sewer**	**Beneficial reuse**	**Underground injection**	**Disposal**
Liquid Wastes	X	X[1]	X	X	X
Solids and Sludges		X[1]	X		X
Spent resins and other media					X

Note 1: when approved by the local Publicly Owned Treatment Works (POTW)
Source: EPA 2005

Disposition of solid residuals mainly occurs through beneficial reuse (e.g., land application or composting) and disposal at an approved, or permitted, 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 waste disposal facility (those wastes all go to Washington State). There is only one permitted hazardous waste disposal site in the state, and it is not

currently permitted to receive radioactive materials. This may change depending on future business opportunities. Colorado has one industrial landfill, and it has been allowed to receive TENORM on a case-by-case basis in the past. There is one operating uranium mill in Colorado, and it could be a candidate to receive both liquid and solid residuals; however, the site is not currently accepting offers. It is possible that in the future they could be able and willing to take solids residuals. Therefore, MSWLs, monofills, and the industrial landfill are the only current options in-state for disposal of solid residuals containing TENORM. Disposal of solids residuals into some MSWLs has occurred on a case-by-case basis. Monofills have been permitted by the Department for disposal of solids residuals, and remains an option for some utilities. The Department is concerned about the site-specific conditions and a solid waste facility's design, construction, operations and maintenance. Therefore, while these facilities are appropriate for the disposal of solids residuals, not all solid waste facilities are appropriate for the receipt of this waste streams.

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 definition of radioactive (2,000 pCi/g total activity) and solids residuals that are above about 350 pCi/g natural uranium are considered source material and must to go to a facility licensed for those materials. Residuals that require disposal in a licensed facility may also require some sort of radioactive materials license (general or specific) in order to deal with waste brokers and disposal facilities. The discharge of liquids requires specific permit from the Water Quality Control Division (WQCD).

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." 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. The local permitting authority is often the County. The ultimate disposition of residuals is a dual process. State and local approval is required to be consistent with the regulation.

Table 8 presents a matrix of residuals generated for the most common technologies.

7.2 LIQUID RESIDUALS

Disposal of liquid residuals have very limited economic options, and may involve intermediate 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 use.

Table 8. 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
IX/ 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			
AA	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	?		
GAC	Rn	X							
Aeration	Rn								

Source: EPA 2004

[1] Where: R= radium, U= uranium, A= gross alpha, B = beta/photon

7.2.1 DIRECT DISCHARGE TO SURFACE WATERS

The limits on discharging radionuclides to a Colorado waters is contained in regulation 31:11(2). They are presented in Table 9:

Table 9. Discharge parameters

Parameter	PicoCuries/liter
Americium 241	.15
Cesium 134	80
Plutonium 239 and 240	.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.

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.

7.2.2 INDIRECT DISCHARGE TO SANITARY SEWER SYSTEM

The Colorado radiation regulation (RH 4.35) allows for disposal of licensed radioactive materials meeting specified limits. They must be readily soluble or readily dispersible biological material in water into sanitary sewers.

However, discharges to Publicly Owned Treatment Works (POTW) are regulated by CDPS Pretreatment regulations. There is no requirement or guarantee that a POTW will permit the discharge of radionuclides into their system. Consult with the local POTW prior to embarking on this option.

7.2.3 UNDERGROUND INJECTION

The underground injection control program of the Colorado Hazardous Materials and Waste Management Division along with 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 Resource Conservation and Recovery Act (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 (Section 1431 SDWA).

Figure 2 is a flow sheet showing the various options available.

7.3 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 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 11 of this document for additional information.

7.4 Solid/Sludge Residuals

Solids are to be screened for radioactivity as required by the Regulations Pertaining to Solid Waste Sites and Facilities, 6 CCR 1007-2, Section 12.2.1. Unless previously approved, solids residuals with activity levels less than those values identified in this guidance or gross alpha ≤ 40 pCi/g (See 6 CCR 1007-2) still require consultation with, and/or approval from, CDPHE and local governing body prior to disposition. Likewise, solids residuals below these levels would still be a solid waste, and hence the beneficial use of these wastes would be subject to Department approval. The types of facilities are discussed below, with a decision chart in Figure 3. All solids residuals must pass the paint filter test (EPA SW-846, Method 9095) 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.

7.4.1 TREATMENT PROCESSES THAT GENERATE SOLID RESIDUALS

Please see Section 4.6 (Treatment Options) and Table 5.7 of this guidance for a discussion of treatment technologies that generate solids residuals.

7.4.2 INTERIM TREATMENT, STORAGE AND HANDLING (> 6 MONTH STORAGE)

- Pond/Lagoon Storage: Ponds and lagoons should be managed in accordance with all applicable regulatory requirements. 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 CDPHE 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.
- 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 15, Basic Health and Safety Precautions, for worker safety recommendations.

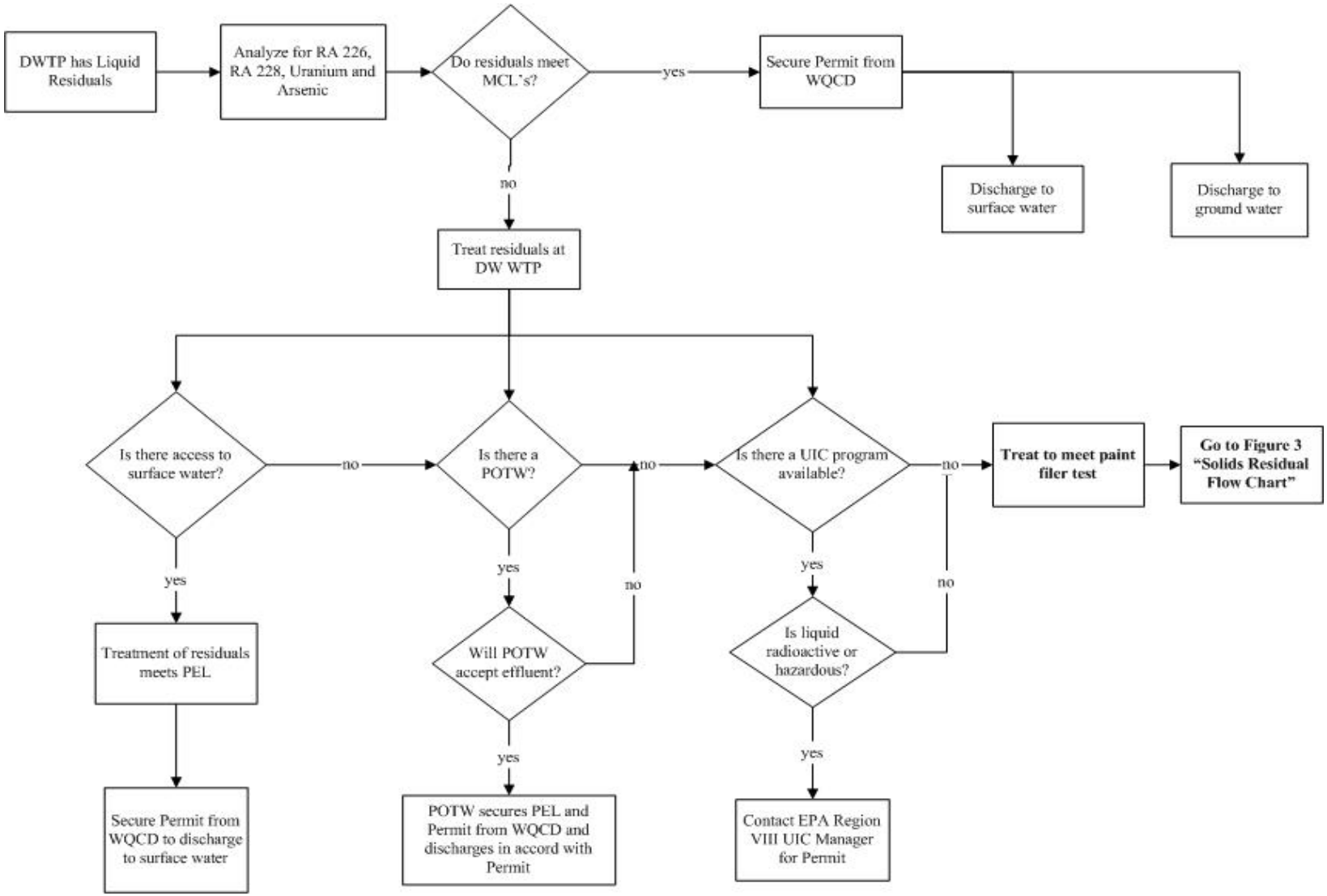

Figure 2. Liquid residuals flow chart

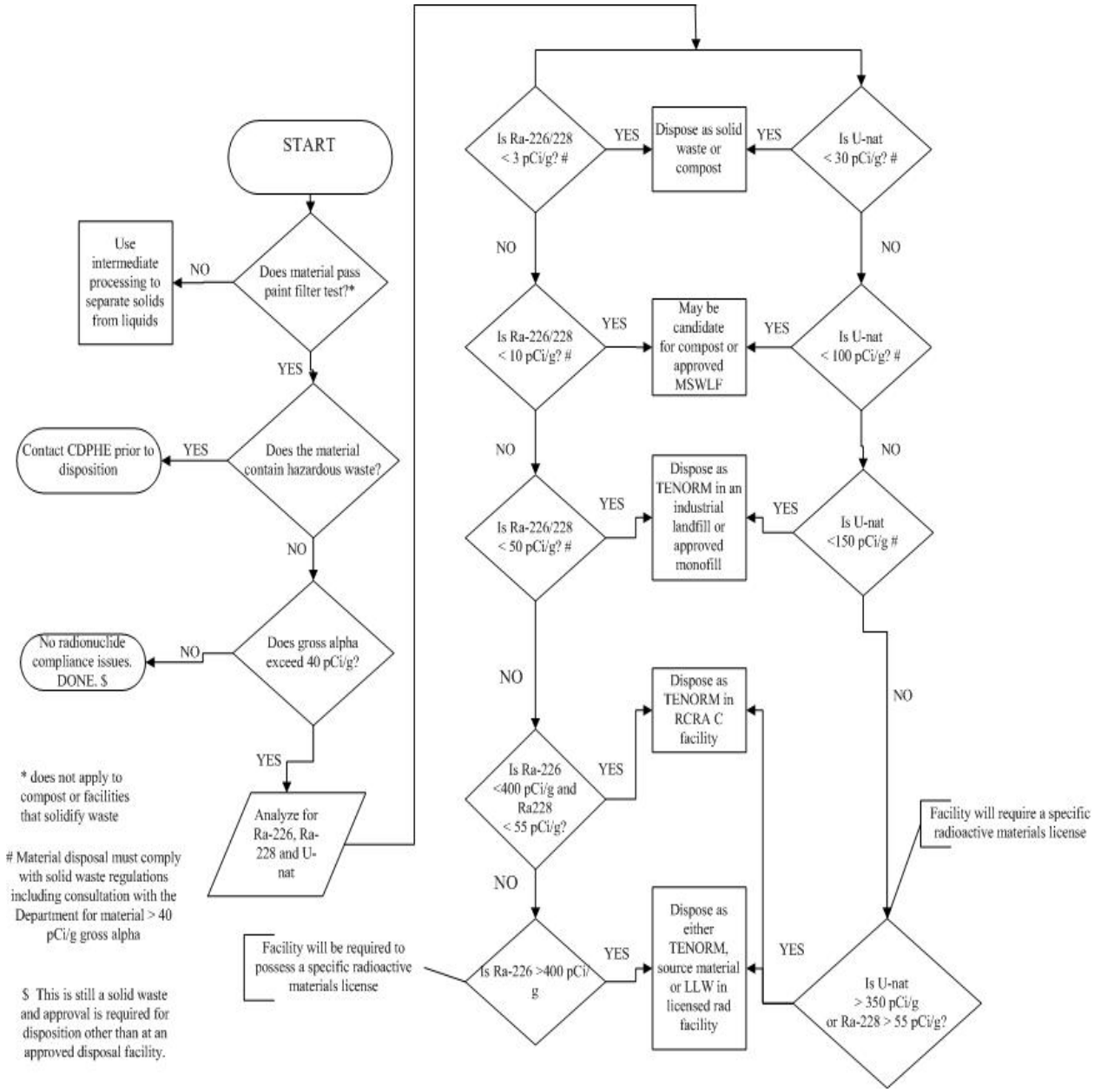

Figure 3. Solids residuals flow chart

7.4.3 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

Minimize stormwater from contacting any of the processes to prevent the stormwater from becoming classified as addition process wastewater.

7.4.4 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 less than those values identified in this guidance or gross alphaof 40 pCi/g (See 6 CCR 1007-2) are only to be disposed of after consultation with CDPHE. If the 40 pCi/g or isotope specific screening level is exceeded, the Regulations require the generator to seek guidance from CDPHE's Radiation Management Unit. Further testing, including isotopic analysis, may be required in order to accurately characterize the waste prior to final disposition. Uranium can be analyzed economically. Radium analysis is more expensive at this time. Sample early enough for safety, budgeting, and planning purposes. Testing is discussed in more detail in Section 6. Evaluation, safety, and instrumentation are discussed in Sections 14, 15 and 16.
- 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. 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 Regulations.
- All regulatory requirements (if any) need to be met. There are a few permit and or license requirements that must be met prior to transfer of material. The local authorities may have an approval or review process. 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.

7.4.5 TRANSPORTATION

- The transportation regulations were significantly modified in 2004. Transportation of residuals containing elevated radioactivity need to follow the Department of Transportation (DOT) requirements of 49 CFR 172 – 178. A certified hazardous/radioactive waste shipper should be consulted prior to transport of the materials. Note that there is a relaxation of the cutoff values for NORM, so many residuals will not be affected by the regulations; materials of higher concentration will still fall under the regulations.
- 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, 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, loadout 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.

7.5 DISPOSITION OPTIONS

7.5.1 BENEFICIAL REUSE

Beneficial re-use, or recycling as approved by CDPHE, 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. Flexibility inherent in the solid waste regulations could allow CDPHE 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, CDPHE may view this practice as disposal. Discussion with industry representatives indicated little or no use of drinking water residuals through direct land application as a soil amendment in Colorado.

Direct land application as a commercial enterprise does not appear to be attractive. Utilities may be performing direct application on their own properties, which is regulated under 5 CCR 1007-3 (See Section 7.5.3). 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.

7.5.2 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. Therefore, CDPHE stipulates that the finished compost must not contain radionuclide concentrations elevated above the range of background in Colorado soils for radium. An average Colorado background concentration in soil for 226Ra was determined to be 1.4 pCi/g (Myrick 1983). That value can be used as a reference background for residuals management.

Use of residuals as a 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, as well as a Department-approved design and operation plan. In general, a compost facility could accept solid residuals up to 3 pCi/g $^{226/228}$Ra and 30 pCi/g ^{nat}U, above background. 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 8.2. These process controls would constitute a significant change to the facility design and operation plan, subject to Department approval. Notice of the change must also be given to the local governing authority, because nothing would preclude review and approval by the local governing authority as well. 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 design and operation 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
- Collection and analysis of surface water samples 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 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 MSWLs at closure of the solid waste disposal site and facility.

7.5.3 DIRECT LAND APPLICATION

The WQCD regulates direct land application under authority of 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 CDPHE for approval prior to distribution of residuals or the application of residuals. The plan needs to describe the legal description of the parcel, the number of pounds of sludge per acre, the types of crops to be grown on the land, the number of acres of each crop, and analytical data. There are additional approvals and requirements of the plan. 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. Drinking water residuals may not be used where root crops, or low hanging fruit and vegetables are grown for human consumption. Facilities that have a certificate of designation, however, are exempt from these regulations.

The Certificate of Designation process is intended to address the siting and operation of landfills and similar activities. The legislature has recognized that the Certificate of Designation 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 Certificate of Designation 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., incineration or dedicated disposal) remain subject to the certificate of designation requirement.

Monitoring, in accordance with Section 6 of this guidance document, 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 CDPHE 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.

Beneficial use of co-applied water treatment sludge and biosolids shall comply with all applicable requirements of the Colorado Water Quality Control Commission Biosolids Regulations, 64.
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 Chapter 15, Basic Health and Safety Precautions, for worker safety recommendations.

7.5.4 SOLID WASTE LANDFILLS

At this point, it may be helpful to define the three basic types of solid waste landfill: municipal solid waste landfill, 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.

7.5.5 MUNICIPAL SOLID WASTE LANDFILLS

Dry solids that are not considered hazardous waste or wastes from conditionally exempt small quantity generators may be disposed of in RCRA Subtitle D MSWLs under certain regulatory conditions, depending on radioactivity content. There are protocols that must be followed under the solid waste regulations (6 CCR 1007-2, Section 12). Most MSWLs take putrescible wastes. Care should be taken that radium concentrations in the landfill do not pose a radon problem since these landfills generally have methane mitigations systems that may become conduits for radon and subject to the requirements of CDPHE's Air Pollution Control Division. For planning purposes, 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. Consistent with Section 8.2 of this guidance, the disposal of solids residuals with higher activity levels (up to 10 pCi/g $^{226/228}$Ra and 100 pCi/g ^{nat}U) requires specific Department approval and potentially separate approval from the local governing body. The implementation of enhanced facility controls are as follows:

- Disposal facilities must be approved by CDPHE and the local governing authority for acceptance of solids residuals at the activity levels specified above

- For planning purposes, no more than 1% 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).
- The subject materials are to be disposed of in a discrete area and covered immediately. A civil survey must be performed by a licensed professional surveyor for record keeping purposes. 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 Chapter 15, 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.
- 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. For instance, this might come into play in the case of a dedicated cell (i.e., monofill) at an MSW with a Department approved risk assessment.
- 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 Design & Operation Plan predicated on the above analytical results and data evaluation.
- If the facility doe 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 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 MSWLs 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 maximally exposed individual or population greater than 0.25 mSv (25 mrem/y). The conservative assumptions are the total projected inventory of radionuclides from all disposal

practices in the impoundment. A further constraint of no more than 40 uSv/y (4 mrem/y) from groundwater from beta/photon emitters may also be applicable.

7.5.6 INDUSTRIAL LANDFILL /CELL

An industrial landfill cell is one that does not take putrescible waste. 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 and concentrations up to 150 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. Consistent with Section 8.2 of this guidance, the disposal of materials with higher activity levels (up to 50 pCi/g combined $^{226/228}$Ra and 150 pCi/g ^{Nat}U) requires specific CDPHE approval and potentially separate approval from the local governing body. The implementation of enhanced facility controls are as follows:

- Disposal facilities must be approved by CDPHE and the local governing authority for acceptance of solids residuals at the activity levels specified above.
- For planning purposes, no more than 1% 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).
- The subject materials are to be disposed of in a discrete area and covered immediately. A civil survey must be performed by a licensed professional surveyor for record keeping purposes. 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 15, 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.
- 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 Design & Operation 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 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.

7.5.7 MONOFILLS

Monofills are solid waste disposal facilities that take only one type of waste. Monofills are approved by CDPHE 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. Consistent with Section 8.2 of this guidance, disposal of residuals up to 50 pCi/g Ra-226/228 and 150 pCi/g ^{nat}U requires specific CDPHE approval and potentially separate approval from the local governing body. The implementation of enhanced facility controls are as follows:

- Disposal facilities must be approved by the Hazardous Materials and Waste Management Division of CDPHE 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 15, 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.
- 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. For instance, this might come into play with a dedicated monofill cell at an MSW facility with an approved site-specific risk assessment.
- 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 Design & Operation 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.
- Monofill only (i.e., only soil-like solids from the treatment of drinking water may be disposed of in the monofill).
- 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.

7.5.8 HAZARDOUS WASTE LANDFILLS

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 both a permit modification and 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 permit containing strict operational and monitoring requirements.

There are at least three other Subtitle C facilities in the country that accept TENORM up to the old DOT limits for radium 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.

7.5.9 COMMERCIAL LOW LEVEL WASTE SITES

There are no commercial low-level waste sites in Colorado. Colorado belongs to the Rocky Mountain Low Level Waste Compact, and as such, all low-level waste from Colorado is sent to a facility in Washington State. TENORM that is greater than the old DOT regulations for definition of radioactive material or 0.05% uranium should go to a licensed 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.

8. DISPOSAL POLICY FOR SOLID AND LIQUID RESIDUALS

8.1 CONTEXT

The Department has broad authority under Colorado statutes and regulations that are relevant to radioactivity in drinking water and residuals, on which the guidance is based. The statues 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 goes beyond the scope of, the U.S. Nuclear Regulatory Commission program, which does not regulate NORM. Since few of the above-mentioned statues and regulations anticipated the generation of radioactivity in drinking water residuals, with the exception of the solid waste regulations, it is difficult to point to a clear and concise disposal path for all residuals. Since the WQCD regulatory drivers (e.g., MCLs, sampling requirements) have been previously discussed, they are not included in this policy.

The Department should base its decisions relative to disposition of diffuse NORM/TENORM on an evaluation of risk to workers, the public, and the environment. Disposition decisions should also incorporate the As Low As Reasonably Achievable (ALARA) concept, regulatory constraints and social and economic factors that are consistent with other government sectors (i.e., local permitting authorities).

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

Control and disposition of diffuse NORM/TENORM shall be addressed through WQCD discharge permits, HMWMD solid waste permits or radioactive materials licenses, or exemptions. Disposition is dependant on the origin and concentration of materials and CDPHE approval.

Control and release of discrete NORM (e.g., sealed sources and radium needles) should follow the established *Rules and Regulations Pertaining to Radiation Control*.

8.2 IMPLEMENTATION

Facilities generating solid diffuse NORM/TENORM shall representatively analyze their materials for gross alpha and natural uranium. Material with an upper 90% confidence interval of gross alpha concentrations greater than 40 pCi/g or uranium values greater than 30 pCi/g shall

consult with the Division prior to disposition and provide an isotopic characterization of the materials for 226Ra, 228Ra and ^{nat}U .

For purposes of this guidance, background values for ^{226}Ra of 1.4 pCi/g, ^{228}Ra of 1.3 pCi/g, 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.

Diffuse concentrations of TENORM may be released from radiological control if the upper 90% confidence interval of combined ^{226}Ra or ^{228}Ra is less than 3 pCi/g above background, natural uranium is less than 30 pCi/g above background, and natural thorium is less than 3 pCi/g above background. This material is still a solid waste and may be disposed of or composted at a permitted solid waste facility, or it may also be beneficially used in accordance with 5 CCR 1003-7 and Item 11 below[1].

Diffuse concentrations of NORM/TENORM may be disposed of in a RCRA Subtitle D municipal solid waste landfill or a compost facility with Department approval, consistent with local land use authority, if the upper 90% confidence interval of combined ^{226}Ra or ^{228}Ra is less than 10 pCi/g above background, natural uranium is less than 100 pCi/g above background, and natural thorium is less than 10 pCi/g above background, providing appropriate worker training and process controls are in approved disposal and operation plans (included in WQCD discharge permits, HMWMD solid waste permits or radioactive materials licenses).

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 upper 90% confidence interval of combined ^{226}Ra or ^{228}Ra is less than 50 pCi/g above background, ^{nat}U is less than 150 pCi/g above background and ^{nat}Th is less than 50 pCi/g above background.

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 upper 90% confidence interval of combined ^{226}Ra or ^{228}Ra less than 400 pCi/g above background ^{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.

[1] 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).

Diffuse concentrations of NORM/TENORM containing combined ^{226}Ra or ^{228}Ra greater than 400 pCi/g above background, and 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[2].

Material and equipment with surface TENORM contamination at drinking water treatment facilities shall meet the release limits specified in ANSI N13.12 prior to free release from the facility. Decontamination of equipment is to be only 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.

Any facility wishing to receive a variance from the limits set forth in this policy may submit documentation to CDPHE 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 Part 4.34 and pertinent sections of Section 1.5 of the Solid Waste Regulations apply. The Department shall make the final determination that the variance will meet compatibility, regulatory limits and design criteria. Risk assessments shall be reviewed and stamped by a professional engineer for geotechnical parameters and signed by a certified health physicist or certified industrial hygienist for human exposure parameters.

All land disposal of NORM/TENORM shall meet the radon standard found at Part 18, Appendix A, criterion 6(1) of the Rules and Regulations Pertaining to Radiation Control (20 $pCi/m^3/s^{-1}$). Review criteria for categories of land disposal facilities are contained in the Section 7 of this document.

In addition to meeting the criteria established above, beneficial reuse of diffuse NORM/TENORM shall meet the requirements of the Water Quality Control Division drinking water sludge regulation [1003-7], and the Biosolids Regulation 64, where applicable. Review criteria for beneficial reuse facilities are contained in the Section 6.

Liquids containing NORM/TENORM discharged to sanitary sewers shall meet the permitting requirements of the NPDES pre-treatment permit program and be explicitly approved by the

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[2] 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.

local sewer authority. Disposal shall not exceed effluent limits of Part 4.35 of the *Colorado Rules and Regulations Pertaining to Radiation Control*.

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

Workers exposed to NORM/TENORM in non-licensed facilities are considered incidentally exposed workers who are members of the public. Workplaces generating NORM/TENORM in non-licensed facilities shall ensure that the maximally exposed individual incidentally exposed to NORM/TENORM does not exceed a radiation dose constraint of 25 mrem/y above background (excluding radon).

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

Facilities that generate TENORM in concentrations greater than 10 pCi/g ^{226}Ra, or source material concentrations for natural uranium or thorium (in excess of the exemptions in Part 3.5.1) shall be required to apply for a license, or demonstrate that existing operational and environmental permits and programs provide equivalent protection to the environment, workers and other members of the public.

Records of transfer or disposal of TENORM shall be maintained as required by Part 4.48 of the *Colorado Rules and Regulations Pertaining to Radiation Control*.

8.3 Regulatory Basis

8.3.1 Radiation Control Act

While most utilities may be familiar with drinking water regulations, and even the solid waste regulations, many are not familiar with regulation of the radionuclide content of their residuals. The EPA has federal jurisdiction over TENORM, but has chosen to not promulgate specific regulations yet for these wastes. Colorado has broad 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*, CRS 25-11-101 et seq. The Act 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 low-level radioactive waste and regulation of direct disposal at uranium mills. However, for the location of the definition, TENORM is regulated under Part 1 of the Act.

The regulatory scheme is not discrete, but is rather distributed throughout the Act and the implementing regulations. The Act requires that 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 RCRA facility can provide the same level of protection (NCRP 2004).

Some definitions are provided in the Radiation Control Act that are germane to TENORM. They are found in C.R.S. 25-11-101:

25-11-101 (2.7) "Naturally occurring radioactive material" 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 (3) "Radioactive material" means any material, solid, liquid, or gas, which emits ionizing radiation spontaneously.

Part 2 of the Act contains the definition for TENORM and the statement that it can be regulated as solid waste.

25-11-201 (1)(b)(4) "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)((c) 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).

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.

Part 1 of the Act also addresses authority and duties:

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.

Since TENORM consists of radioactive material as defined in the statute, it is regulated and should require a license. 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. 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.

A previous effort to promulgate specific regulations for disposal of NORM 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 Act 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."

This constraint implies NORM disposal should be treated from a regulatory standpoint as any other radioactive residual. Fortunately, the Act also allows TENORM to be considered solid waste (CDPHE discretion is a risk-informed basis).

Therefore, TENORM is regulated under the Act, and may be considered generally licensed (unless CDPHE 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,oo.

There are implications not only to disposal of residuals, but also to worker safety at facilities that treat the water and generate the residuals. This will be discussed in a later section.

Staying with the discussion of disposal of residuals under the Act, Colorado Revised Statutes –

Section 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 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.

Section 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 strict interpretation of this section is that the residuals are sources of ionizing radiation, and therefore are captured by the Act.

8.4 Colorado Rules and Regulations Pertaining to Radiation Control

In addition to the Act, there are implementing regulations to be considered. The *Colorado Rules and Regulations Pertaining to Radiation Control* Parts 1, 3, 4,10 and 17 are of interest. They can be found on-line at http://www.cdphe.state.co.us/op/regs/radiationregs.asp. The rules and regulations (the regulations) address licensing, protection of the public and workers from radiation, disposal, worker education, and transportation requirements.

8.4.1 PART 1. GENERAL REQUIREMENTS

Part 1 of the Rules and Regulations Pertaining to Radiation Control are general requirements and definitions. Definitions that are germane to this discussion are found in Part 1 and include:

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

"NORM" means any naturally occurring or accelerator-produced radioactive material. It does not include byproduct, source or special nuclear material.

"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.

"Radioactive material" means any solid, liquid, or gas, which emits radiation spontaneously.

"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.

"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.

Of particular importance is an exemption found in RH 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:

RH 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.

8.4.2 PART 3. LICENSING

Part 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:

RH 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.

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 CDPHE 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. The Radiation Management Unit 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 8 of this document has additional detail on the basis and justification for the licensing approach used in this guidance.

8.4.3 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.

RH 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.

RH 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.

RH 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 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 shall not 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.

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), which was discussed earlier 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 Part 4.61, which require doses to the public to be less than 25 mrem/y. Disposal facilities must show that they will meet this requirement post closure if they request a variance from the generic levels proscribed in this guidance.

8.4.4 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.

8.4.5 PART 17. TRANSPORTATION

Transportation requirements are the same as those of the Federal DOT regulations. It must be noted that the transportation regulations were rewritten, effective October 2004. There may be instances where TENORM is considered radioactive for purposes of transportation. All disposal of TENORM that involves transporting the material must be compliant with DOT requirements.

8.5 SOLID WASTE REGULATIONS 6 CCR 1007-2

There are numerous definitions and provisions of the Solid Waste regulations that are used in the management of TENORM. Some of the most pertinent definitions are:

“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.

"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 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.

"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.

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

"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.

"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.

8.6 Additional requirements of the 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.

8.7 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 Section 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.

8.8 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.

9. 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. 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 Hazardous Waste statutes (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*" and of solid waste disposal sites under the *Colorado Solid Waste Disposal Sites and Facilities Act*. 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 about Environmental Covenants can be found at http://www.cdphe.state.co.us/hm/envcovenants.asp.

10. LICENSING

The original scope of the Atomic Energy Act 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 sources of radiation.

Considering that there are already controls at many of these sites to protect workers and the public, it may not be necessary to implement full licensing of facilities at lower levels of exposure, 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 concentrations of materials results in increases in regulatory control.

Since the Department has various permitting and licensing authorities, it may not be necessary to invoke dual regulation (i.e., permits *and* licenses) for some facilities, providing we can be assured of adequate protection. There are some regulatory and operational constraints that trigger licensing. Again, the structure of the regulations is predicated on 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 regulations on when to specifically license a water treatment facility.

There are two approaches to licensing TENORM – exposure to workers and the public and possession limits (that are also tied back to health).

There are two types of radioactive materials licenses, general and specific. General licenses do not have a fee 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.

10.1 Basic Department Radioactive Material Authorizations

10.1.1 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.

10.1.2 Inspections

The Department has authority under the Act 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.

Since the Department already has the authority to inspect facilities, there is no significant affect on generators or disposal facilities.

10.1.3 Measurements, Samples and Tests

The Department also has the authority to require generators to make tests (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

Detailed requirements are found in Part 4 of the radiation regulations. See Section 6 of this document for sampling and Appendix G for additional guidance on selection of instruments.

10.2 General Licenses

RH 3.4.1. A general license is provided by regulation and grants authority to a person for certain activities involving 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. However, registration or filing of a certificate with the Department may be required by the particular general license. The general licensee is subject to all other applicable portions of these regulations and any limitations of the general license.

RH 3.6.6 Ownership of Radioactive Material. 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 disposal and operations plans and Certificates of Designation. 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 shall 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 RH 3.5. This section has exemptions for source material, but not for radium.

RH 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 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.

RH 3.5.1.1 Persons who receive, possess, use or transfer source material pursuant to the general license in RH 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.

RH 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.

Specific Licenses are discussed in Section 10.3. Specific licenses will be required for residuals that are elevated in activity (e.g., disposal of radium selective resins) or when worker exposure would be greater than 25 mrem/y. Specific licenses are more detailed, entail annual fees, have reporting requirements and may also have surety requirements.

RH 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 TENORM residuals that do not provide a dose to workers or the public < 25 mrem/y, no specific reporting to the Radiation Management Unit is required.

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 Radiation Management Unit 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.

10.3 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 additional facilities that generate spent media and filters may be required to obtain a license, or facilities that generate high activity sludges or residuals from interim treatment of liquid residuals.

A specific license, per Part 3 of the regulations, will be required for water treatment facilities that generate doses to the maximally exposed worker above 0.25 mSv/y (25 mrem/y) above background (excluding radon), unless proven otherwise. Additional requirements beyond those for the general licensee include recording and reporting of doses to workers, posting and labeling requirements, training of workers, storage and control of radioactive material, and development of radiation protection programs. The program also must have an As Low As Reasonably Achievable (ALARA) component, and an annual review of the ALARA program. Airborne emissions from licensed sites are constrained to 10 mrem/y to any member of the public.

A specific license will be required per Part 3 for generators of residuals containing TENORM radionuclides above source material concentrations for uranium and thorium, or above 10 pCi/g $^{226/228}$Ra in order to ensure that wastes are managed and disposed of properly, unless a demonstration is made to otherwise show that a specific license is not warranted. Furthermore, waste brokers can only receive material from parties licensed to possess radioactive material.

Licensed material may be sent to a 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 disposal limits for that facility). The requirement for notification is to provide the Department the ability to track disposition of residuals.

The primary focus is on facilities that treat water to meet the MCLs for radionuclides. Facilities that treat drinking water to remove other metals may also be subject to review to ensure that radionuclides are not inadvertently being concentrated.

Specific license applications would include written operating procedures, a description of the instruments and equipment used to analyze the residual streams and documentation of worker training and experience, in addition to disposal procedures. 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 RH 3.9.5.4.

Removal of spent media will generally be limited to companies that specialize in handling elevated levels of radioactivity. The contractor must be licensed to handle and package radioactive material for transport.

Contact the Radiation Management Unit for guidance on filing an application for a specific license. Additional information may be found at the RMU web site: http://www.cdphe.state.co.us/hm/rad/radiationservices.asp.

11. RISK ASSESSMENT

We all deal with hazards and risks in our lives, but many people confuse the two terms. Hazards are obstacles, or possible sources of danger. We evaluate the risks from hazards.

In general terms, risk is about chance. Risk is the chance that someone or something this is valued is adversely affected (NRPB 2004). What are our chances for happiness if we take that job, buy that car or go on that date? How will our health be affected if we smoke that cigarette, drive that highway or climb that mountain? Our perception of risk also influences our evaluation of the chances. Is the risk something we control, or is it controlled by others? Is it a natural or manmade risk? Is the risk affecting our children or us? We use a combination of knowledge, perceptions and intuition to evaluate our daily risks and determine the chances for a good or bad outcome.

When we examine risk in relationship to the health effects caused by hazardous substances, it takes on a more refined meaning. Chance is now replaced by the term probability and has numerical value determined by scientific studies. Risk is usually defined as our probability of developing cancer and dying. However, many factors go into the determination of this risk including the characteristics of the substance, the time of exposure, the amount of exposure, the route of exposure, etc. Risk assessment is the process used to determine the amount of risk to exposed individuals (receptors).

Risk assessment is the process of establishing information regarding acceptable levels of a risk and/or levels of risk for an individual, group, society, or the environment (ORNL 2005).

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.

Exposure scenarios describe the process by which individuals or population groups might become exposed to TENORM. Scenarios typically consider inhalation and ingestion pathways, external radiation and inhalation of radon and its progeny.

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.

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.

Computer models are used to evaluate the hazards and risks. Some hazards, such as drums, containers and columns are evaluated for their gamma radiation using the MICROSHIELD model (Grove Software Engineering). The most popular model for radiological risk assessment in soils and soil-like media is the RESRAD model, managed by Argonne National Laboratory. 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). 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-DOSE model, which evaluates exposures from radioactive materials at treatment, storage, and disposal facilities (DOE 199x).

Risk assessment results are reviewed by health professionals, and other stakeholders to determine what an acceptable risk is. Knowledgeable individuals can then apply their personal perceptions to determine if they consider it an acceptable risk. Acceptable risk from chemical

hazards at CDPHE is generally accepted as a one in a million chance of dying of cancer (probability $1x10^{-6}$).

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 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. The probability calculated by a risk assessment is the best estimate of risk based on current knowledge.

12. 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 (ANAL 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, scales, or resins. 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.

The radioactivity concentrations in this guidance are based on 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 composting facility, industrial landfill, and hazardous waste landfill. Limits for the threshold values are based on ANSI N13.12. Other limits are based on regulatory drivers that already exist relative to radionuclide concentrations (i.e., source material).

All 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. For this reason, earlier risk assessments provided insufficient information to show compliance with post-closure requirements found in Part 4.61 of the 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. 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 little value for demonstrating regulatory compliance and protection of human health and environment during the post-closure period. Others relied on

institutional controls to evaluate potential pathways. It should be noted that in all instances, worker exposure is the limiting factor at these various facilities.

Table 10 is a summary of risk assessments considered in the preparation of this guidance.

12.1 HAZARDOUS WASTE LANDFILL

Colorado has one RCRA Subtitle C Hazardous Waste landfill. 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 also [has/applied for] a specific license for disposal of low level radioactive 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.

12.2 INDUSTRIAL LANDFILL

Colorado has one RCRA Subtitle D landfill that exclusively accepts industrial waste. 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 CDPHE and the local governing authority (i.e., the 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 150 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.

12.3 MUNICIPAL SOLID WASTE LANDFILL

Three risk assessments have been provided to CDPHE to evaluate disposal of TENORM at a Municipal Solid Waste Landfill (MSWLF). One risk assessment is for tailings and residues from legacy processing at a research facility over many decades to be disposed of at a local solid waste landfill. 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 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.

The other two assessments are for alum sludges 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 material would not pose an unacceptable risk, 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.

CDPHE staff has concerns relative to the practice of co-disposing of TENORM above threshold limits with putrescible wastes and does not endorse that practice. These concerns include, but are not limited to, increased risk of exposure to the general public when commingling occurs, as well as potential radon emissions due to gas collection and venting system at MSWLFs. 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 ofwithout additional efforts. MSWLFs that meet current design requirements can seek Department approval to accept TENORM at concentrations up to 9 pCi/g $^{226/228}$Ra- and 100 pCi/g ^{nat}U.

12.4 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 CDPHE and permitted 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 to include stationary radioactivity monitoring, dedicated equipment to prevent gross contamination between the monofill and the MSWLF cell and appropriate personal protective equipment. Monofills may be located either at permitted locations and could be permitted at MSWLFs. In order to mitigate the proliferation of TENORM disposal facilities that will require long-term tracking and control, it is desired 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.

12.5 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 sludge 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 0.8957 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 CDPHE 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 Certificate of Designation (CD) and beneficial reuse plan would need to demonstrate appropriate health and safety controls for worker and environmental protections. Additionally, design, operation 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. The final product shall have ^{226}Ra concentrations at or below the background mean value of 1.4 pCi/g ^{226}Ra, ^{nat}U concentrations shall 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 2004 did evaluate land application from municipal sewage sludge (ISCORS 2004).

12.6 Other Assessments

The U.S. DOE commissioned an evaluation and risk assessment for the disposal of oil and gas residuals containing TENORM. 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.

12.7 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.

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 (ANAL 2003) and provides guidance on selecting the most sensitive parameters for a specific situation (ACOE 2002). Appendix E is taken from the ACOE white paper for those that do not have access to the document.

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. CDPHE evaluates the TENORM "inventory" expected at the time of the facility closure and estimates dose to the public. Part 4.61 of the Rules 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 14 of this document.

In addition to RESRAD, there are other models and software packages that can be useful in determining doses from TENORM source terms. These include, but are not limited to TSD-DOSE from Argonne National Laboratory http://www.ead.anl.gov/project/dsp_topicdetail.cfm?topicid=43, WISE radon-flux calculator http://www.wise-uranium.org/ctc.html, and Microshield, http://www.radiationsoftware.com/mshield.html, from Grove Software Engineering.

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.

12.8 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 (Kennedy 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. Worker protection is the limiting factor due to radioactivity concentration limitations, robust facility construction, local oversight, and durable institutional controls.

13. 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 (1999) that evaluated guidelines for TENORM provided numerous conclusions relative to managing risks from TENORM. 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 (BEIR 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. 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

13.1 Radiation Protection Concepts

This section is taken largely from Kennedy (2005).
Consistent with the International Atomic Energy Agency's (IAEA) guidance (IAEA 1996) and the authority of CDPHE, the scope of regulatory controls for radioactive material have been defined as exclusion, exemption, clearance, and regulation.

13.1.1 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 1993; IAEA 2005). 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/HPS 1999; 2005; IAEA 2005).

13.1.2 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.

13.1.3 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 1996). 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 is 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).

13.1.4 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.

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Table 10. Comparison table of risk assessments for TENORM				
	Isotopes Evaluated	Scenarios evaluated	Dose to workers	Dose to the public
Subtitle C (Kennedy 2005)	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 10. 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 10. Comparison table of risk assessments for TENORM				
MSWLF 3 (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 cy/y	0.35 mrem/y	Trivial (> 10^{-7} mrem/y)
Monofills				
Denver Water	To be included			
Colorado Springs	To be included			
Arvada	To be included			
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

Table 10. 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

14. DRINKING WATER TREATMENT FACILITY EVALUATIONS

14.1 OVERVIEW

14.2 OCCUPATIONAL

A screening survey should be conducted of water treatment facilities and their residual streams to determine if a facility needs licensing (discussed below). A graded approach may be used for designing the program. Surveys should be conducted if source waters exceed the MCLs, or if modeling or calculations predict elevated concentrations of radioactivity in the residuals. The screening survey should include a combination of gamma exposure rate radiation scans, equipment monitoring (surface activity) for beta and alpha emitters and radon monitoring.

Most workers at water treatment plants are incidentally exposed workers, whose activities would not expose them to TENORM at levels requiring monitoring or special programs. They are subject to protection as members of the public and are limited to an exposure of 1 milliSievert (mSv)/y (100 mrem/y) above background from all activities. A level of 0.25 mSv/y (25 mrem/y) above background may be considered as a threshold, which indicates additional workplace evaluation may be required. These facilities should undergo a thorough dose assessment and develop a TENORM management program. For facilities that have worker exposures above 0.25 mSv/y, a specific radioactive materials license shall be required, and impacted workers shall be trained as radiation workers. Suggested syllabus for training TENORM workers is presented in Appendix E. A Radiation Protection Program as outlined in RH 4.5 shall be required for licensed facilities.

External gamma radiation, inhalation and ingestion of particulates are the main exposure pathways of concern. The prime concern during maintenance is residual handling and disposal and inhalation of particulates.

A worker that is continuously exposed to gamma exposure rates 0.15 μSv/h hour (~15 μR/h) above background over 2000 hours of a work year, triggers the 0.25 mSv (25 mrem) annual threshold. Therefore, if gamma exposure rates exceeding 0.15 μSv/h hour (~15 μR/h) 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 0.5 μSv/h (50 μR/h) may lead to an annual exposure of 1 mSv (100 mrem).

The foremost methods of reducing exposure are time, distance and shielding. These simple concepts can be used to reduce workplace exposure ALARA. For example, if an IX column is 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.

A demonstration of meeting the public dose limits is required for facilities that apply for a license. The Department has a guidance document to assist in calculating and demonstrating compliance with the public dose. See Appendix F.

Part 4 of the regulations has annual limits on intake and derived concentrations of radionuclides for occupational exposure, including radon. This information should be taken into account when designing the facility and choosing the drinking water treatment process. Incremental increases in radon above ambient levels are the amount that needs to be evaluated.

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 Appendix B may necessitate the need for a general or specific license. 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.

14.3 ENVIRONMENTAL MONITORING

Environmental monitoring may be necessary during the operational phase and in the post-closure phase of the facility's life cycle. 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.

15. BASIC HEALTH AND SAFETY PRECAUTIONS

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. Based on the results of surveys or calculations, a monitoring program may need to be set up. 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 three basic pathways of exposure for workers are inhalation of alpha or beta emitting nuclides, ingestion or the swallowing of alpha, beta, or gamma-emitting isotopes and direct exposure from gamma radiation.

Crawford-Brown (2004) evaluated the proposed limits by Colorado. He notes that the 5 pCi/g exemption limit from 10 CFR 192 was based on the Radiation Protection Guidance of 500 mrem/y to the public. EPA has used this value for cleanup of other sites under certain scenarios. It is based primarily on exposure to external gamma, although other pathways were evaluated. The basis for the EPA value of 5 pCi/g ^{226}Ra was calculated on an exposure rate of 20 μR/h, which is about 175 mrem/y, assuming continuous exposure. If the BEIR V conversion factors of 0.06 per Sv are used, the 5 pCi/g limit translates to 6 x 10^{-4} per rem or 6 x 10^{-7} per mrem. The continuous exposure converts to 6 x 10^{-7} x 175 or 1 x 10^{-4}. Note that this is the annual risk, not lifetime risk. Therefore, under very conservative scenarios, the 5 pCi/g exemption limit could exceed the current limit for the public in Colorado regulation of 100 mrem/y.

The proposed 3 pCi/g ^{226}Ra limit would yield an annual risk of cancer equal to approximately 6 x 10^{-5}.

When ^{226}Ra and ^{228}Radium are commingled, the exemption limit is applicable to the sum of these two isotopes. Similarly, the combined concentration of the radionuclides produced by both chains by the decay of radium is recommended to be below the limit. The total mixture, therefore, should be less than 10 (or 6) pCi/g, depending on which exemption level is adopted.

Radiation areas need to be considered. Areas that exceed 2 mrem/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.

16. INSTRUMENTATION AND RADIATION SURVEYS

16.1 INSTRUMENTATION

A variety of instrumentation is available for measuring radiation and radioactivity. Choosing the proper instrument does not need to be difficult. MARSSIM (Multi Agency Radiological Site Survey Investigation Manual) is a good primer on instrumentation and, also provides a description of detector types. Section 16 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. Appendix G of this document contains some useful information from MARSSIM on instrumentation.

Instrumentation needs to 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 (2003) provides calibration and performance requirements of instruments to be used at or near background.

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.

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 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.

16.2 RADIATION SURVEYS

Ambient radiation readings should be taken to establish the background radiation 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.

Contamination surveys are performed to identify material that can spread contamination and reduce the potential for external exposure. Surveys also are made in areas where personnel work or where equipment can be contaminated. Background measurements are made on similar materials. Scans are made by slowly moving the detector over the surface area, holding it about one inch from the surface. Areas of elevated radioactivity should be identified and investigated further. Make measurements in fixed locations for periods of one minute and convert to activity.

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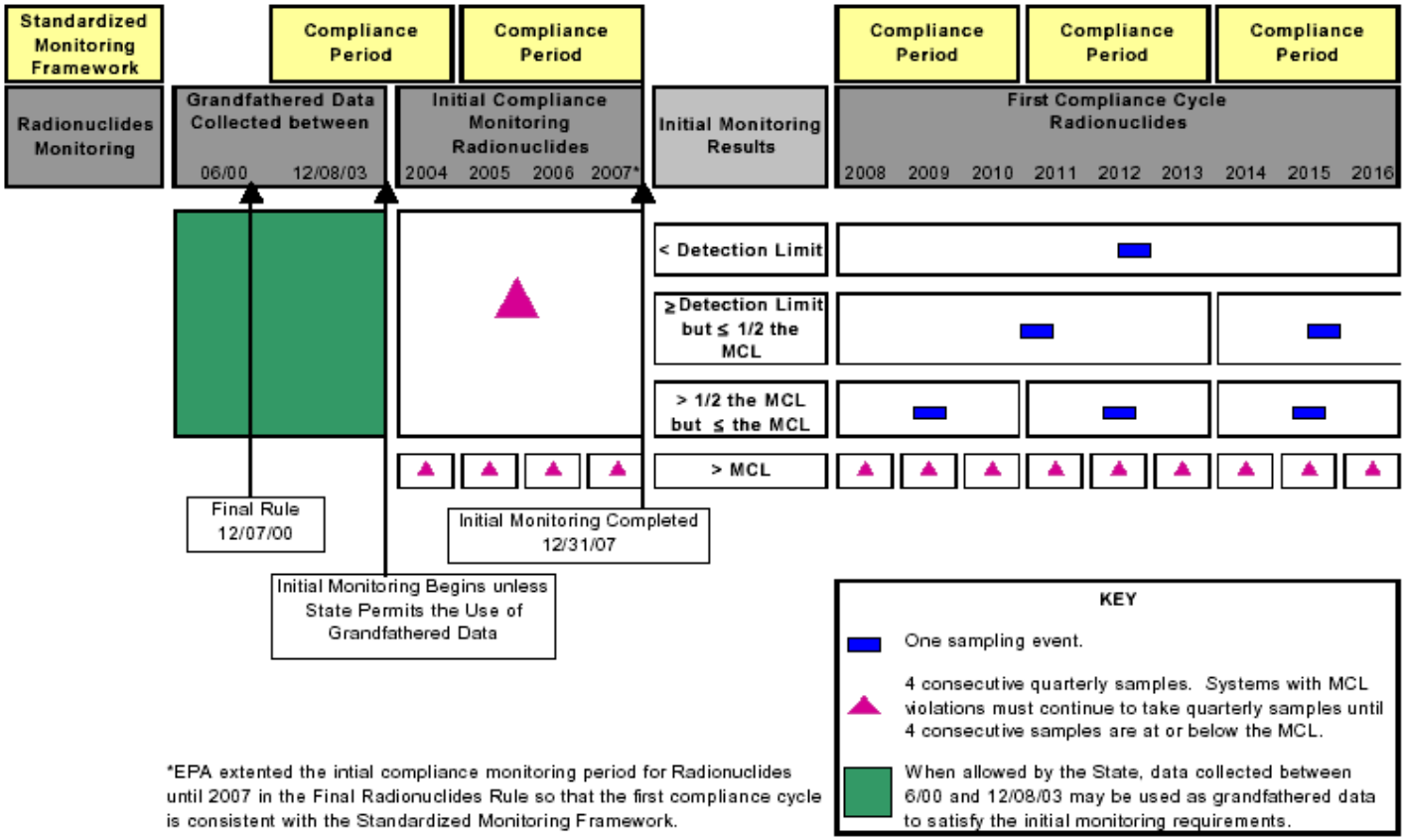
18. APPENDIX A. DECAY SERIES FOR PRIMORDIAL NUCLIDES

Principal Natural Radionuclide Decay Series

Nuclide	Half-Life	Major Radiations
Actinium-228	6.13 hours	beta, gamma, x-rays
Bismuth-210	5.01 days	beta
Bismuth-212	60.6 minutes	alpha, beta, gamma, x-rays
Bismuth-214	19.7 minutes	beta, gamma
Lead-206	stable	
Lead-208	stable	
Lead-210	22.3 years	beta, gamma, x-rays
Lead-212	10.64 hours	beta, gamma, x-rays
Lead-214	26.8 minutes	beta, gamma, x-rays
Polonium-210	138 days	alpha
Polonium-212	0.305 microseconds	alpha
Polonium-214	164 microseconds	alpha
Polonium-216	0.15 seconds	alpha
Polonium-218	3.05 minutes	alpha
Protactinium-234m	1.17 minutes	beta, gamma
Radium-224	3.66 days	alpha, gamma
Radium-226	1600 years	alpha, gamma
Radium-228	5.75 years	beta
Radon-220	55.6 seconds	alpha
Radon-222	3.83 days	alpha
Thallium-208	3.07 minutes	beta, gamma
Thorium-228	1.91 years	alpha, gamma, x-rays
Thorium-230	77,000 years	alpha, x-rays
Thorium-232	14.1 billion years	alpha, x-rays
Thorium-234	24.1 days	beta, gamma, x-rays
Uranium-234	245,000 years	alpha, x-rays
Uranium-238	4.47 billion years	alpha, x-rays

19. APPENDIX B. SAMPLING FREQUENCY FOR INCOMING WATERS

Figure I-1: Applicability of the Standardized Monitoring Framework to Radionuclides
(Excluding the Beta Particle and Photon Emitters)



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20. APPENDIX C. RESULTS OF ROUND ROBIN TESTING

RESULTS OF ROUND ROBIN TESTING

Intra-laboratory testing of alum and ferric chloride 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.

21. APPENDIX D. RISK ASSESSMENT PARAMETERS FROM ACOE 2003

Table 3-1. Receptor-Specific and Scenario-Specific RESRAD Parameter Values

RESRAD Parameter	Units	RESRAD Default	Risk Variability #	Proposed Values	Receptor or Scenario	Comment/Reference
Area of contaminated zone	m^2	10,000	3	Site-specific[a] 100 2000	All receptors All receptors All receptors	Intake/exposure directly proportional to surface area Corresponds to UMTRCA exposure unit Corresponds to default Class 1 MARSSIM unit; equivalent to a half acre lot.
Thickness of contaminated zone	m	2.0	1	Site-specific	All receptors	Intake/exposure can be directly proportional to thickness
Length parallel to aquifer flow	m	100	4	Site-specific	All receptors	Relevant for surface water dependent pathways
Time since placement of material	yr	0.0	-	Site-specific	All receptors	Old data may not reflect current conditions
Cover depth	m	0.0	3	Site-specific	All receptors	Cover will eliminate direct ingestion and inhalation pathways
Density of cover material	g/m^3	1.5	3	Site-specific	All receptors	See Manual Appendix A and E and DCH Section 2; omitted if cover depth = 0; consult geologist/hydrologist
Cover depth erosion rate	m/yr	0.001	5	Site-specific 0.00006 0.0006	All receptors Non-farming Farming	If cover erodes, direct ingestion and inhalation pathways are relevant See DCH Section 14; 2% slope, no farming/gardening See DCH Section 14; 2% slope, significant farming/gardening
Density of contaminated zone	g/m^3	1.5	4	Site-specific	All receptors	See Manual Appendix E and DCH Section 2; consult geologist/hydrologist
Contaminated zone erosion rate	m/yr	0.001	3	Site-specific 0.00006 0.0006	All receptors Non-farming Farming	Can erode entire contaminated lens if large enough; assumed 0.0 until cover erodes See DCH Section 14; 2% slope, no farming/gardening See DCH Section 14; 2% slope, significant farming/gardening
Contaminated zone total porosity	unitless	0.4	5	Site-specific	All receptors	See Manual Appendix E and DCH Section 3; consult geologist/hydrologist
Contaminated zone field capacity	unitless	0.2	7	Site-specific	All receptors	See Manual Appendix E; consult geologist/hydrologist
Contaminated zone hydraulic conductivity	m/yr	10	7	Site-specific	All receptors	See Manual Appendix E and DCH Section 5; consult geologist/hydrologist
Contaminated zone b parameter	unitless	5.3	7	Site-specific	All receptors	See Manual Appendix E and DCH Section 13; consult geologist/hydrologist
Average annual wind speed	m/sec	2.0	6	Site-specific	All receptors	See Manual Appendix B and DCH Section 21; consult geologist/hydrologist
Humidity in air	g/m^3	8.0	7	Site-specific	All receptors	Only relevant for tritium (hydrogen-3); see Manual Appendix L
Evapotranspiration coefficient	unitless	0.5	5	Site-specific	All receptors	See Manual Appendix E and DCH Section 12; consult geologist/hydrologist
Precipitation	m/yr	1.0	5	Site-specific	All receptors	See Manual Appendix E and DCH Section 9
Irrigation	m/yr	0.2	5	Site-specific	Farming or gardening	See Manual Appendix E and DCH Section 11
Irrigation mode	unitless	Overhead	-	Site-specific	Farming or gardening	See Manual Appendix E and DCH Section 11
Runoff coefficient	unitless	0.2	5	Site-specific 0.2 0.4 0.65 0.8	All receptors Farming Non-farming Non-farming Non-farming	See Manual Appendix E and DCH Section 10; consult geologist/hydrologist See DCH Section 10; flat, sandy, cultivated land See DCH Section 10; flat urban, area (30% impervious) See DCH Section 10; moderately steep, urban area (50% impervious) See DCH Section 10; moderately steep, built-up area (70% impervious)
Watershed area for nearby stream or pond	m^2	1E+06	5	Site-specific	All receptors	Surface water dependant pathways; see Manual Appendix E and DCH Section 17
Accuracy for water/soil computations	unitless	0.001	-	Site-specific	All receptors	Related to water/soil concentration ratios; see Manual Appendix E
Saturated zone density	g/m^3	1.5	4	Site-specific	All receptors	See Manual Appendix E and DCH Section 2; consult geologist/hydrologist
Saturated zone total porosity	unitless	0.4	4	Site-specific	All receptors	See Manual Appendix E and DCH Section 3; consult geologist/hydrologist
Saturated zone effective porosity	unitless	0.2	3	Site-specific	All receptors	See Manual Appendix E and DCH Section 4; consult geologist/hydrologist
Saturated zone field capacity	unitless	0.2	7	Site-specific	All receptors	See Manual Appendix E; consult geologist/hydrologist
Saturated zone hydraulic conductivity	m/yr	100	3	Site-specific	All receptors	See Manual Appendix E and DCH Section 5; consult geologist/hydrologist
Saturated zone hydraulic gradient	unitless	0.02	3	Site-specific	All receptors	See Manual Appendix E and DCH Section 15; consult geologist/hydrologist
Saturated zone b parameter	unitless	5.3	7	Site-specific	All receptors	See Manual Appendix E and DCH Section 13; consult geologist/hydrologist
Water table drop rate	m/yr	0.001	7	Site-specific	All receptors	See Manual Appendix E and DCH Section 18; consult geologist/hydrologist
Well pump intake depth (m below water table)	m	10	5	Site-specific	All receptors	See Manual Appendix E and DCH Section 19; consult geologist/hydrologist
Model: Nondispersion (ND) or Mass-Balance (MB)	unitless	ND	-	Site-specific	All receptors	See Manual Appendix E
Well pumping rate	m^3/yr	250	4	Site-specific	All receptors	See Manual Appendix E; consult geologist/hydrologist
Number of unsaturated zone strata[##]	unitless	1	-	Site-specific	All receptors	See Manual Appendix E; consult geologist/hydrologist
Unsaturated zone thickness	m	4.0	4	Site-specific	All receptors	See Manual Appendix E; consult geologist/hydrologist
Unsaturated zone soil density	g/m^3	1.5	7	Site-specific	All receptors	See Manual Appendix E and DCH Section 2; consult geologist/hydrologist
Unsaturated zone total porosity	unitless	0.4	7	Site-specific	All receptors	See Manual Appendix E and DCH Section 3; consult geologist/hydrologist
Unsaturated zone effective porosity	unitless	0.2	7	Site-specific	All receptors	See Manual Appendix E and DCH Section 4; consult geologist/hydrologist
Unsaturated zone field capacity	unitless	0.2	7	Site-specific	All receptors	See Manual Appendix E; consult geologist/hydrologist

Table 3-1. Receptor-Specific and Scenario-Specific RESRAD Parameter Values (continued)

RESRAD Parameter	Units	RESRAD Default	Risk Variability #	Proposed Values	Receptor or Scenario	Comment/Reference
Unsaturated zone b parameter	unitless	5.3	7	Site-specific	All receptors	See Manual Appendix E and DCH Section 5; consult geologist/hydrologist
Unsaturated zone hydraulic conductivity	m/yr	10	7	Site-specific	All receptors	See Manual Appendix E and DCH Section 13; consult geologist/hydrologist
Distribution coefficients	cm^3/g	*	4	Site-specific	All receptors	Radionuclide-specific; impacts all pathways, not just groundwater
Inhalation rate	m^3/yr	8,400	6	Site-specific	All receptors	Average over entire 365-day year; default equivalent to 0.9589 m^3/hr
				5,548	Subsistence adult	Assuming adult male rate of 15.2 m^3/day (EFH, Table 1-2)
				2,765	Subsistence child	Assuming 1-5 year old rate of 7.55 m^3/day (EFH, Table 5-23)
				5,548	Resident adult	Assuming adult male rate of 15.2 m^3/day (EFH, Table 1-2)
				2,765	Resident child	Assuming 1-5 year old rate of 7.55 m^3/day (EFH, Table 5-23)
				7,300	Industrial worker	Assuming RAGS default rate of 20 m^3/day for workers
				7,300	Maintenance worker	Assuming RAGS default rate of 20 m^3/day for workers
				7,300	Construction worker	Assuming RAGS default rate of 20 m^3/day for workers
				5,548	Recreational adult	Assuming adult male rate of 15.2 m^3/day (EFH, Table 1-2)
				5,110	Recreational teen	Avg. for 7-16 year old male of 14 m^3/day (EFH, Table 5-23)
Mass loading for inhalation	g/m^3	0.0001	5	Site-specific	Non-construction	Similar to 1/PEF; calculate region-specific PEF values using SSG Section 2
				6.0E-04	Construction	See DCH Section 35
Exposure duration	yr	30	7	Site-specific	All receptors	Same as ED in standard RAGS equations
				30	Subsistence adult	RME duration for resident (EFH, RAGS)
				6	Subsistence child	Assuming 6 years of childhood spend at site
				30	Resident adult	Duration for resident (EFH, RAGS)
				6	Resident child	Assuming 6 years of childhood spend at site
				25	Industrial worker	Duration for occupational receptor (EFH, RAGS)
				25	Maintenance worker	Duration for occupational receptor (EFH, RAGS)
				1	Construction worker	Assuming construction activities during one calendar year
				30	Recreational adult	Duration for (off-site) resident (EFH, RAGS)
				10	Recreational teen	Assumed for off-site adolescent receptor through ages 7-16
Shielding factor, inhalation	unitless	0.4	6	Site-specific	All receptors	Fraction of outdoor air that is filtered/diluted; 1.0 = no filtering/dilution
Shielding factor, external gamma	unitless	0.7	4	Site-specific	All receptors	Fraction of outdoor gamma that is shielded; 1.0 = no shielding
				0.4	Building occupant	See SSG Section 2; 60% shielding for all indoor receptors
Fraction of time spent indoors	unitless	0.5	5	Site-specific	All receptors	Fraction of 8760 hours spent indoors on-site
				0.655	Subsistence adult	16.4 hr/day for 350 days/yr for resident (EFH, Table 1-2)
				0.655	Subsistence child	16.4 hr/day for 350 days/yr for resident (EFH, Table 1-2)
				0.655	Resident adult	16.4 hr/day for 350 days/yr for resident (EFH, Table 1-2)
				0.655	Resident child	16.4 hr/day for 350 days/yr for resident (EFH, Table 1-2)
				0.20	Industrial worker	7 of 8 hours per day for 250 days per year (assumed)
				0.0	All other receptors	No indoor exposure
Fraction of time spent outdoors (on site)	unitless	0.25	5	Site-specific	All receptors	Fraction of 8760 hours spent outdoors on-site
				0.0799	Subsistence adult	2 hrs/day for 350 days/yr for resident (EFH, Table 1-2)
				0.223	Subsistence child	5 hrs/day on weekdays or 7 hrs/day on weekends for 350 days per year for children ages 3-11 (EFH, Table 1-2)
				0.0799	Resident adult	2 hrs/day for 350 days/yr for resident (EFH, Table 1-2)
				0.223	Resident child	5 hrs/day on weekdays or 7 hrs/day on weekends for 350 days per year for children ages 3-11 (EFH, Table 1-2)
				0.0285	Industrial worker	1 of 8 hrs/day for 250 days/yr (assumed)
				0.0228	Maintenance worker	4 hr/week for 50 weeks/yr (assumed)
				0.228	Construction worker	Assumes one full work-year for a supervisor-type worker
				0.0119	Recreational adult	4 hr/wk for averaged over 26 wks/yr, warm season only (assumed)
				0.0119	Recreational teen	4 hr/wk for averaged over 26 wks/yr, warm season only (assumed)
Shape factor flag, external gamma	unitless	1.0	-	Site-specific	All receptors	Default = uniform circular; see Manual Appendix A and DCH Section 30

Table 3-1. Receptor-Specific and Scenario-Specific RESRAD Parameter Values (continued)

RESRAD Parameter	Units	RESRAD Default	Risk Variability[a]	Proposed Values	Receptor or Scenario	Comment/Reference
Fruits, vegetables and grain consumption	kg/yr	160	2	Site-specific	Farming or gardening	Average over entire 365-day year; see EFH Volume III; grains typically milled off-site and distributed, therefore not included in on-site exposure scenarios
				469	Subsistence adult	22.4 g/kg-day (12.4 for fruit and 10 for vegetables) minus leafy vegetable rate for 60 kg adult; 60kg used because intake rate data includes child data (EFH, Table 1-2)
				118	Subsistence child	22.4 g/kg-day (12.4 for fruit and 10 for vegetables) minus leafy vegetable rate for 15 kg child (EFH, Table 1-2)
				469	Resident adult	22.4 g/kg-day (12.4 for fruit and 10 for vegetables) minus leafy vegetable rate for 60 kg adult; 60kg used because intake rate data includes child data (EFH, Table 1-2)
				118	Resident child	22.4 g/kg-day (12.4 for fruit and 10 for vegetables) minus leafy vegetable rate for 15 kg child (EFH, Table 1-2)
				N/C	All other receptors	Not used
Leafy vegetable consumption	kg/yr	14	5	Site-specific	Farming or gardening	Average over entire 365-day year; see EFH Volume III
				21.4	Subsistence adult	NUREG/CR-5512 Volume 4 default for resident farmer
				4.59	Subsistence child	Adult value scaled by child-to-adult body weight factor
				21.4	Resident adult	NUREG/CR-5512 Volume 4 default for resident farmer
				4.59	Resident child	Adult value scaled by child-to-adult body weight factor
				N/C	All other receptors	Not used
Milk consumption	L/yr	92	4	Site-specific	Farming only	Average over entire 365-day year; see EFH Volume III
				131	Subsistence adult	Rate for 12-19 year old male conservatively assumed (EFH, Table 11-15).
				153	Subsistence child	Rate averaged over 0-5 year old male and female children (EFH, Table 11-15).
				N/C	All other receptors	Not used
Meat and poultry consumption	kg/yr	63	5	Site-specific	Farming only	Average over entire 365-day year; see EFH Volume III
				130	Subsistence adult	5.1 g/kg-day for a 70 kg adult (EFH, Table 1-2)
				27.9	Subsistence child	5.1 g/kg-day for a 15 kg child (EFH, Table 1-2)
				130	Recreational adult	5.1 g/kg-day for a 70 kg adult (EFH, Table 1-2)
				78.2	Recreational teen	5.1 g/kg-day for a 42 kg adolescent (EFH, Table 1-2)
				N/C	All other receptors	Not used
Fish consumption	kg/yr	5.4	7	Site-specific	Fishing only	Average over entire 365-day year; see EFH Volume III
				62.05	Subsistence adult	Native American rate recommended by EFH, Table 1-2 (170 g/day)
				25.55	Subsistence other	Native American rate recommended by EFH, Table 1-2 (70 g/day)
				9.125	Recreational adult	Freshwater fish rate recommended by EFH, Table 1-2 (25 g/day)
				2.90	Recreational other	Freshwater fish average rate recommended by EFH, Table 1-2 (8 g/day)
Other seafood consumption	kg/yr	0.9	7	Site-specific	Fishing only	Mollusks and crustacea; Average over entire 365-day year; see EFH Volume III
Soil ingestion rate	m/yr	36.5	4	Site-specific	All receptors	Average over entire 365-day year; default equivalent to 100 mg/day
				36.5	Subsistence adult	100 mg/day for residential adult (RAGS)
				73.0	Subsistence child	200 mg/day for residential child (RAGS)
				36.5	Resident adult	100 mg/day for residential adult (RAGS)
				73.0	Resident child	200 mg/day for residential child (RAGS)
				18.25	Industrial worker	50 mg/day for industrial worker rate (RAGS)
				36.5	Maintenance worker	100 mg/day for adult rate (RAGS)
				175.2	Construction worker	480 mg/day for assuming outdoor summer activities (EFH, Table 4-16)
				36.5	Recreational adult	100 mg/day for adult rate (RAGS)
				54.75	Recreational teen	150 mg/day assuming average of adult and child rates (RAGS)
Drinking water intake	L/yr	510	3	Site-specific	All receptors	Average over entire 365-day year; default equivalent to 1.397 L/day
				869	Subsistence adult	34 ml/kg-day for 70 kg adult (EFH, Table 1-2)
				186	Subsistence child	34 ml/kg-day for 15 kg child (EFH, Table 1-2)
				869	Resident adult	34 ml/kg-day for 70 kg adult (EFH, Table 1-2)
				186	Resident child	34 ml/kg-day for 15 kg child (EFH, Table 1-2)
				N/C	All other receptors	Typically limited to above residential or farming scenarios
Contamination fraction of drinking water	unitless	1.0	-	1.0	All receptors	Typically set to 1.0; see Manual Appendix E
Contamination fraction of household water	unitless	1.0	-	1.0	Resident only	Relevant for radon calculations only; see Manual Appendix C
Contamination fraction of livestock water	unitless	1.0	-	1.0	Farming only	Typically set to 1.0; see Manual Appendix D

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Table 3-1. Receptor-Specific and Scenario-Specific RESRAD Parameter Values (continued)

RESRAD Parameter	Units	RESRAD Default	Risk Variability #	Proposed Values	Receptor or Scenario	Comment/Reference
Contamination fraction of irrigation water	unitless	1.0	-	1.0	Farming or gardening	Typically set to 1.0; see Manual Appendix D
Contamination fraction of aquatic food	unitless	0.5	7	0.5	Fishing only	Typically set to 1.0; see Manual Appendix D
Contamination fraction of plant food	unitless	-1 **	-	-1	Farming or gardening	Typically contaminated surface area dependent; see Manual Appendix D
Contamination fraction of meat	unitless	-1 **	-	-1	Farming only	Typically contaminated surface area dependent; see Manual Appendix D
Contamination fraction of milk	unitless	-1**	-	-1	Farming only	Typically contaminated surface area dependent; see Manual Appendix D
Livestock fodder intake for meat	kg/day	68	5	68	Farming only	See Manual Appendix D
Livestock fodder intake for milk	kg/day	55	5	55	Farming only	See Manual Appendix D
Livestock water intake for meat	L/day	50	7	50	Farming only	See Manual Appendix D
Livestock water intake for milk	L/day	160	7	160	Farming only	See Manual Appendix D
Livestock soil intake	kg/day	0.5	6	0.5	Farming only	See Manual Appendix D
Mass loading for foliar deposition	g/m^3	0.0001	7	0.0001	Farming or gardening	See Manual Appendix E
Depth of soil mixing layer	m	0.15	5	Site-specific 0.05 0.0	All receptors Non-farming Non-farming	Relevant when contaminated thickness ≤ 0.15 m or cover thickness < 15 cm (original cover can erode to < 15 cm); default assumes tilling Assuming no-till, but some surface disturbance (e.g., industrial activities) No surface soil disturbances expected (e.g., with land-use controls or paved surfaces)
Depth of roots	m	0.9	3	Site-specific	Farming or gardening	See Manual Appendix D and DCH Section 37
Drinking water fraction from ground water	unitless	1.0	-	1.0	All receptors	Default assume 0% from surface water; set to 0.0 for 100% from surface water
Household water fraction from ground water	unitless	1.0	-	1.0	Resident only	Default assume 0% from surface water; set to 0.0 for 100% from surface water
Livestock water fraction from ground water	unitless	1.0	-	1.0	Farming only	Default assume 0% from surface water; set to 0.0 for 100% from surface water
Irrigation fraction from ground water	unitless	1.0	-	1.0	Farming or gardening	Default assume 0% from surface water; set to 0.0 for 100% from surface water
Wet weight crop yield for non-leafy	kg/m^2	0.7	5	Site-specific	Farming or gardening	See Manual Appendix D
Wet weight crop yield for leafy	kg/m^2	1.5	7	Site-specific	Farming or gardening	See Manual Appendix D
Wet weight crop yield for fodder	kg/m^2	1.1	7	Site-specific	Farming or gardening	See Manual Appendix D
Growing season for non-leafy	years	0.17	7	Site-specific	Farming or gardening	See Manual Appendix D; also see EPH Volume III for region-specific values
Growing season for leafy	years	0.25	7	Site-specific	Farming or gardening	See Manual Appendix D; also see EPH Volume III for region-specific values
Growing season for fodder	years	0.08	7	Site-specific	Farming or gardening	See Manual Appendix D; also see EPH Volume III for region-specific values
Translocation factor for non-leafy	unitless	0.1	7	Site-specific	Farming or gardening	See Manual Appendix D
Translocation factor for leafy	unitless	1.0	7	Site-specific	Farming or gardening	See Manual Appendix D
Translocation factor for fodder	unitless	0.1	7	Site-specific	Farming or gardening	See Manual Appendix D
Dry foliar interception fraction for non-leafy	unitless	0.25	7	Site-specific	Farming or gardening	See Manual Appendix D
Dry foliar interception fraction for leafy	unitless	0.25	7	Site-specific	Farming or gardening	See Manual Appendix D
Dry foliar interception fraction for fodder	unitless	0.25	7	Site-specific	Farming or gardening	See Manual Appendix D
Wet foliar interception fraction for non-leafy	unitless	0.25	7	Site-specific	Farming or gardening	See Manual Appendix D
Wet foliar interception fraction for leafy	unitless	0.25	6	Site-specific	Farming or gardening	See Manual Appendix D
Wet foliar interception fraction for fodder	unitless	0.25	7	Site-specific	Farming or gardening	See Manual Appendix D
Weathering removal constant for vegetation	1/yr	20	6	Site-specific	Farming or gardening	See Manual Appendix D
Storage time: fruits, non-leafy vegetables, and grain	days	14	7	Site-specific	Farming or gardening	Adjusts for radiological ingrowth and decay; see Manual Appendix D
Storage time: leafy vegetables	days	1.0	7	Site-specific	Farming or gardening	Adjusts for radiological ingrowth and decay; see Manual Appendix D
Storage time: milk	days	1.0	7	Site-specific	Farming or gardening	Adjusts for radiological ingrowth and decay; see Manual Appendix D
Storage time: meat and poultry	days	20	7	Site-specific	Farming or gardening	Adjusts for radiological ingrowth and decay; see Manual Appendix D
Storage time: fish	days	7.0	7	Site-specific	Fishing only	Adjusts for radiological ingrowth and decay; see Manual Appendix D
Storage time: crustacea and mollusks	days	7.0	7	Site-specific	Farming or gardening	Adjusts for radiological ingrowth and decay; see Manual Appendix D
Storage time: well water	days	1.0	7	Site-specific	Farming or gardening	Adjusts for radiological ingrowth and decay; see Manual Appendix D
Storage time: surface water	days	1.0	7	Site-specific	Farming or gardening	Adjusts for radiological ingrowth and decay; see Manual Appendix D
Storage time: livestock fodder	days	45	7	Site-specific	Farming or gardening	Adjusts for radiological ingrowth and decay; see Manual Appendix D
Thickness of building foundation	m	0.15	-	Site-specific	Building occupant	Relevant for radon calculations only; see Manual Appendix C
Bulk density of building foundation	g/cm^3	2.4	-	Site-specific	Building occupant	Relevant for radon calculations only; see Manual Appendix C
Total porosity of the cover material	unitless	0.4		Site-specific	Building occupant	Relevant for radon calculations only; see Manual Appendix C
Total porosity of the building foundation	unitless	0.1	-	Site-specific	Building occupant	Relevant for radon calculations only; see Manual Appendix C

Table 3-1. Receptor-Specific and Scenario-Specific RESRAD Parameter Values (continued)

RESRAD Parameter	Units	RESRAD Default	Risk Variability[#]	Proposed Values	Receptor or Scenario	Comment/Reference
Volumetric water constant of the cover material	unitless	0.05	-	Site-specific	Building occupant	Relevant for radon calculations only; see Manual Appendix C
Volumetric water constant of the foundation	unitless	0.03	-	Site-specific	Building occupant	Relevant for radon calculations only; see Manual Appendix C
Diffusion coefficient for radon gas in cover material	m/sec	2E+06	-	Site-specific	Building occupant	Relevant for radon calculations only; see Manual Appendix C
Diffusion coefficient for radon gas in foundation material	m/sec	3E-07	-	Site-specific	Building occupant	Relevant for radon calculations only; see Manual Appendix C
Diffusion coefficient for radon gas in contaminated zone soil	m/sec	2E-06	-	Site-specific	Building occupant	Relevant for radon calculations only; see Manual Appendix C
Radon vertical dimension of mixing	m	2.0	-	Site-specific	Building occupant	Relevant for radon calculations only; see Manual Appendix C
Average building air exchange rate	1/hour	0.5	-	Site-specific	Building occupant	Relevant for radon calculations only; see Manual Appendix C
Height of the building (room)	m	2.5	-	Site-specific	Building occupant	Relevant for radon calculations only; see Manual Appendix C
Building interior area factor	unitless	0.0	-	Site-specific	Building occupant	Relevant for radon calculations only; see Manual Appendix C
Building depth below ground surface	m	-1.0	-	Site-specific	Building occupant	Relevant for radon calculations only; see Manual Appendix C
Emanating power of Rn-222 gas	unitless	0.25	-	Site-specific	Building occupant	Relevant for radon calculations only; see Manual Appendix C
Emanating power of Rn-220 gas	unitless	0.15	-	Site-specific	Building occupant	Relevant for radon calculations only; see Manual Appendix C
Pathway – external gamma	unitless	active	-	Active	All receptors	See Manual Appendix A
Pathway – inhalation (w/o radon)	unitless	active	-	Active	All receptors	See Manual Appendix B
Pathway – plant ingestion	unitless	active	-	Active Inactive	Farming or gardening All other receptors	See Manual Appendix D Typically active for resident or subsistence farmer only
Pathway – meat ingestion	unitless	active	-	Active Inactive	Farming only All other receptors	See Manual Appendix D Typically active for subsistence farmer only
Pathway – milk ingestion	unitless	active	-	Active Inactive	Farming only All other receptors	See Manual Appendix D Typically for subsistence farmer only
Pathway – aquatic foods	unitless	active	-	Active Inactive	Fishing only All other receptors	See Manual Appendix D Typically active for subsistence farmer or recreational user only
Pathway – drinking water	unitless	active	-	Active Inactive	Resident/farmer All other receptors	See Manual Appendix E Typically active for resident or subsistence farmer only
Pathway – soil ingestion	unitless	active	-	Active	All receptors	See Manual Appendix F
Pathway – radon	unitless	active	-	Inactive	All receptors	Typically excluded from risk calculations; see Manual Appendix C

[#] From NUREG/CR-6697 Table 4.1; represents variability of radiological dose (same relationship with risk assumed) on parameter ranging from 1 (extremely sensitive) to 7 (insensitive). Dash (-) shown if no values listed in NUREG/CR-6697.

[b] Site-specific information/data (either physical, behavioral, or metabolic) should be used whenever available. For this table, general information is provided in the Comment/Reference column when the Proposed Values is "site-specific."

[##] The unsaturated zone may contain as many as five distinct layers

[+] Radionuclide-specific and can be soil-type-specific. See RESRAD support documentation for potential defaults.

[++] Adjusted automatically by RESRAD based on the contaminated surface area.

DCH = *Data Collection Handbook to Support Modeling the Impacts of Radioactive Material in Soil* (ANL 1993)
EFH = *Exposure Factors Handbook* (EPA 1997)
Manual = *User's Manual for RESRAD Version 6* (ANL 2001)
MARSSIM = Multi-Agency radiation Survey and Site Investigation Manual (DoD et al. 2000)
N/C = not considered
RAGS = Risk Assessment Guidance for Superfund
RME = reasonable maximum exposure
SSG = *Soil Screening Guidance for Radionuclides: Technical Background Document* (EPA 2000)
UMTRCA = Uranium Mill Tailings Radiation Control Act

22. 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

23. 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 which 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**

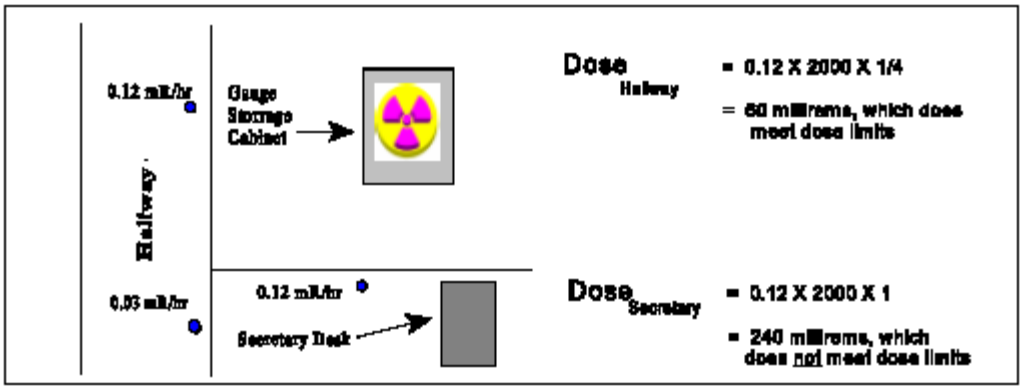
5. Dose rates must be multiplied by the time period of the possible exposure. For an individual over which you have no control (i.e., a neighboring house or office) you must assume an exposure time of 24 hours per day for 365 days per year, or 8760 hours. For general public within your facility, which 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.

24. APPENDIX G. INSTRUMENTATION

Instrumentation for measurement of gamma radiation

Detector Type	Detector Description	Application	Remarks
Gas Ionization	Pressurized ionization chamber; Non-pressurized ionization chamber	Exposure rate measurements	
Geiger-Mueller	Pancake (<2 mg/cm^2 window) or side window (~30 mg/cm^2)	Surface scanning; exposure rate correlation (side window in closed position)	Low relative sensitivity to gamma radiation
Scintillation	NaI(Tl) scintillator; up to 5 cm by 5 cm	Surface scanning; exposure rate correlation	High sensitivity; Cross calibrate with PIC (or equivalent) or for specific site gamma energy mixture for exposure rate measurements.
	NaI(Tl) scintillator; large volume and "well" configurations	Laboratory gamma spectrometry	
	CsI or NaI(Tl) scintillator; thin crystal	Scanning; low-energy gamma and x-rays	Detection of low-energy radiation
	Organic tissue equivalent (plastics)	Dose equivalent rate measurements	
Solid State	Germanium semi-conductor	Laboratory and field gamma spectrometry and spectroscopy	
Passive, integrating electret ion chamber	7 mg/cm^2 window, also window-less, window area 50-180 cm^2, chamber volume 50-1,000 ml		Useable in high humidity and temperature

System	Description	Application	Remarks	Cost of Equipment	Cost per Measurement
GM survey meter with gamma probe	Thick-walled 30 mg/cm^2 detector	Measure radiation levels above 0.1 mR/hr.	Its non-linear energy response can be corrected by using an energy compensated probe.	$400-$1,000	$5
Pressurized ion chamber (PIC)	A highly accurate ionization chamber that is rugged and stable.	Excellent for measuring gamma exposure rate during site remediation.	Is used in conjunction with radionuclide identification equipment.	$15K - $50K	$50 - $500
Electret ion chamber	Electrostatically charged disk inside an ion chamber	Gamma exposure rate	N/A, rented	included in rental price	$8 - $25
Hand-held ion chamber survey meter	Ion chamber for measuring higher radiation levels than typical background.	Measures true gamma exposure rate.	Not very useful for site surveys because of high detection limit above background levels.	$800-$1,200	$5
Hand-held pressurized ion chamber survey meter	Ion chamber for measuring higher radiation levels than typical background.	Measures true gamma exposure rate with more sensitivity than the unpressurized ion chamber.	Not very useful for site surveys because of high detection limit above background levels.	$1,000-$1,500	$5
Sodium Iodide survey meter	Detectors sizes up to 8"x8". Used in micro R-meter in smaller sizes.	Measures low levels of environmental radiation.	Its energy response is not linear, so it should be calibrated for the energy field it will measure or have calibration factors developed by comparison with a PIC for a specific site.	$2K	$5
FIDLER (Field Instrument for Detection of Low Energy Radiation)	Thin crystals of NaI or CsI.	Scanning of gamma/X radiation from plutonium and americium.		$6K-$7K	$10-$20

System	Description	Application	Remarks	Cost of Equipment	Cost per Measurement
Sodium iodide detector with multichannel analyzer (MCA)	Sodium iodide crystal with a large range of sizes and shapes, connected to a photomultiplier tube and MCA.	Laboratory gamma spectroscopy to determine the identity and concentration of gamma emitting radionuclides in a sample.	Sensitive for surface soil or groundwater contamination. Analysis programs have difficulty if sample contains more than a few isotopes.	$6K-$20K	$100 to $200
Germanium detector with multichannel analyzer (MCA)	Intrinsic germanium semiconductor in p- or n-type configuration and without a beryllium window.	Laboratory gamma spectroscopy to determine the identity and concentration of gamma emitting radionuclides in a sample.	Very sensitive for surface soil or groundwater contamination. Is especially powerful when more than one radionuclide is present in a sample.	$35K-$150K	$100 to $200
Portable Germanium Multichannel Analyzer (MCA) System	A portable version of a laboratory based germanium detector and multichannel analyzer.	Excellent during characterization through final status survey to identify and quantify the concentration of gamma ray emitting radionuclides and in situ concentrations of soil and other media	Requires a supply of liquid nitrogen or a mechanical cooling system, as well as highly trained operators.	$40K	$100
Field x-ray fluorescence spectrometer	Uses silicon or germanium semiconductor	Determining fractional abundance of low percentage metal atoms.		$15K-$75K	$200
Thermoluminescence dosimeters (TLDs)	Crystals that are sensitive to gamma radiation	Measure cumulative radiation dose over a period of days to months.	Requires special calibration to achieve high accuracy and reproducibility of results.	$5K-$50K for reader + $25-$40 per TLD	$25-$125

System: SODIUM IODIDE SURVEY METER
Lab/Field: Field
Radiation Detected: Primary: Gamma **Secondary:** None
Applicability to Site Surveys: Sodium iodide survey meters can be response checked against a pressurized ionization chamber (PIC) and then used in its place so readings can be taken more quickly. This check should be performed often, possibly several times each day. They are useful for determining ambient radiation levels and for estimating the concentration of radioactive materials at a site.
Operation: The sodium iodide survey meter measures gamma radiation levels in μR/hr (10^{-6} R/hr) or counts per minute (cpm). Its response is energy and count rate dependent, so comparison with a pressurized ion chamber necessitates a conversion factor for adjusting the meter readings to true μR/hr values. The conversion factor obtained from this comparison is valid only in locations where the radionuclide mix is identical to that where the comparison is performed and over a moderate range of readings. The detector is held at waist level or suspended near the surface and walked through an area listening to the audio and watching the display for changes. It is held in place and the response allowed to stabilize before each measurement is taken, with longer times required for lower responses. Generally, the center of the needle swing or the integrated reading is recorded. The detector is a sodium iodide crystal inside an aluminum container with an optical glass window that is connected to a photomultiplier tube. A gamma ray that interacts with the crystal produces light that travels out of the crystal and into the photomultiplier tube. There, electrons are produced and multiplied to produce a readily measurable pulse whose magnitude is proportional to the energy the gamma ray incident on the crystal. Electronic filters accept the pulse as a count if certain discrimination height restrictions are met. This translates into a meter response. Instruments with pulse height discrimination circuitry can be calibrated to view the primary gamma decay energy of a particular isotope. If laboratory analysis has shown a particular isotope to be present, the discrimination circuitry can be adjusted to partially tune out other isotopes, but this also limits its ability to measure exposure rate.
Specificity/Sensitivity: Sodium iodide survey meters measure gamma radiation in μR/hr or cpm with a minimum sensitivity of around 1-5 μR per hour, or 200-1,000 cpm, or lower in digital integrate mode. The reading error of 50% can occur at low count rates because of a large needle swing, but this decreases with increased count rate. The instrument is quite energy sensitive, with the greatest response around 100-120 keV and decreasing in either direction. Measuring the radiation level at a location with both a PIC and the survey meter gives a factor for converting subsequent readings to actual exposure rates. This ratio can change with location. Some meters have circuitry that looks at a few selected ranges of gamma energies, or one at a time with the aide of a single channel analyzer. This feature is used to determine if a particular isotope is present. The detector should be protected against thermal or mechanical shock which can break the sodium iodide crystal or the photomultiplier tube. Covering at least the crystal end with padding is often sufficient. The detector is heavy, so adding a carrying strap to the meter and a means of easily attaching and detaching the detector from the meter case helps the user endure long surveys.

System: GM SURVEY METER WITH GAMMA PROBE
Lab/Field: Field
Radiation Detected: Primary: Gamma **Secondary:** Beta
Applicability to Site Surveys: This instrument is used to give a quick indication of gamma radiation levels present at a site. Due to its high detection limit, the GM survey meter may be useful during characterization surveys but may not meet the needs of final status surveys.
Operation: This instrument consists of a cylindrical Geiger Mueller detector connected to a survey meter. It is calibrated to measure gamma exposure rate in mR/hr. The detector is surrounded on all sides by a protective rigid metal housing. Some units called end window or side window have a hinged door or rotating sleeve that opens to expose an entry window of Mylar, mica, or a similar material, allowing beta radiation to enter the sensitive volume. The detector requires approximately 900 volts for operation. It is normally held at waist height, but is sometimes placed in contact with an item to be evaluated. It is moved slowly over the area to scan for elevated readings, observing the meter or, preferably, listening to the audible signal. Then it is held in place long enough to obtain a stable measurement. Radiation entering the detector ionizes the gas, causes a discharge throughout the entire tube, and results in a single count being sent to the meter. Conversion from count rate to exposure rate is accomplished at calibration by exposing the detector at discrete levels and adjusting the meter scale(s) to read accordingly. In the field, the exposure rate is read directly from the meter. If the detector housing has an entry window, an increase in “open-door” over “closed-door” reading indicates the presence of beta radiation in the radiation field, but the difference is not a direct measure of the beta radiation level.
Specificity/Sensitivity: GM meters measure gamma exposure rate, and those with an entry window can identify if the radiation field includes beta radiation. Since GM detectors are sensitive to any energy of alpha, beta, or gamma radiation that enters the detector, instruments that use these detectors cannot identify the type or energy of that radiation, or the specific radionuclide(s) present. The sensitivity can be improved by using headphones or the audible response during scans, or by integrating the exposure rate over time. The instrument has two primary limitations for environmental work. First, its minimum sensitivity is high, around 0.1 mR/hr in rate meter mode or 0.01 mR/hr in integrate mode. Some instruments use a large detector to improve low-end sensitivity. However, in many instances the instrument is not sensitive enough for site survey work. Second, the detector’s energy response is nonlinear. Energy compensated survey meters are commercially available, but the instrument's sensitivity may be reduced.

Instrumentation for measurement of alpha particles

Detector Type	Detector Description	Application	Remarks
Gas Proportional	<1 mg/cm^2 window; probe area 50 to 1000 cm^2 <0.1 mg/cm^2 window; probe area 10 to 20 cm^2 No window (internal proportional)	Surface scanning; surface contamination measurement Laboratory measurement of water, air, and smear samples Laboratory measurement of water, air, and smear samples	Requires a supply of appropriate fill gas
Air Proportional	<1 mg/cm^2 window; probe area ~50 cm^2	Useful in low humidity conditions	
Scintillation	ZnS(Ag) scintillator; probe area 50 to 100 cm^2 ZnS(Ag) scintillator; probe area 10 to 20 cm^2 Liquid scintillation cocktail containing sample	Surface contamination measurements, smears Laboratory measurement of water, air, and smear samples Laboratory analysis, spectrometry capabilities	
Solid State	Silicon surface barrier detector	Laboratory analysis by alpha spectrometry	
Passive, integrating electret ion chamber	<0.8 mg/cm^2 window, also window-less, window area 50-180 cm^2, chamber volume 50-1,000 ml	Contamination on surfaces, in pipes and in soils	Useable in high humidity and temperature

System	Description	Application	Remarks	Equipment Cost	Measurement Cost
Alpha spectroscopy	A system using silicon diode surface barrier detectors for alpha energy identification and quantification	Accurately identifies and measures the activity of multiple alpha radionuclides in a thin extracted sample of soil, water, or air filters.	Sample requires radiochemical separation or other preparation before counting	$10K-$100K	$250-$400
Alpha scintillation survey meter	<1 mg/cm^2 window, probe face area 50 to 100 cm^2.	Field measurement of presence or absence of alpha contamination on nonporous surfaces, swipes, and air filters, or on irregular surfaces if the degree of surface shielding is known.	Minimum sensitivity is 10 cpm, or 1 cpm with headphones	$1000	$5
Alpha Track Detector	Polycarbonate plastic sheet is placed in contact with a contaminated surface and kept in place	Measures gross alpha surface contamination, soil activity level, or the depth profile of contamination	Alpha radiation produces holes that are enlarged chemically. Density of holes gives a measure of the radioactivity level.		$5-$25
Electret ion chamber	A charged Teflon disk in an open-faced ion chamber	Measures alpha or beta contamination on surfaces and in soils, plus gamma radiation dose or radon concentration	The type of radiation is determined by how the electret is employed, *e.g.*, the unit is kept closed and bagged in plastic to measure gammas	$4,000-$5,000	$8-$25
Long range alpha detector (LRAD)	1m x 1m detector measures ionization inside the box. Attached to tractor for movement. Has location finder and plots graph of contamination.	Measures surface contamination or soil concentration at grid points and plots curves of constant contamination. Intended for large areas.	Alpha detection limit is 20-50 dpm/100 cm^2 or 0.4 Bq/g (10 pCi/g).	$25,000	$80

System	Description	Application	Remarks	Equipment Cost	Measurement Cost
Gas-flow proportional counter (field)	A detector through which P10 gas flows and which measures alpha and beta radiation. < 1-10 mg/cm^2 window, probe face area 50 to 100 cm^2 for hand held detectors; up to 600 cm^2 if cart mounted	Surface scanning, surface activity measurement, or field evaluation of swipes. Serves as a screen to determine if more nuclide-specific analyses are needed.	Natural radionuclides in samples can interfere with the detection of other contaminants. Requires P10 gas	$2K-$4K	$2-$10/m^2
Gas-flow proportional counter (lab)	Windowless (internal proportional) or window <0.1 mg/cm^2, probe face area 10 to 20 cm^2. May have a second or guard detector to reduce background and MDA.	Laboratory measurement of water, air, and swipe samples	Requires P10 gas. Windowless detectors can be contaminated.	$4K-$30K	$50
Liquid scintillation counter (LSC)	Samples are mixed with LSC cocktail and the radiation emitted causes light pulses with proportional intensity.	Laboratory analysis of alpha or beta emitters, including spectrometry capabilities.	Highly selective for alpha or beta radiation by pulse shape discrimination. Requires LSC cocktail.	$20K-$70K	$50-$200

System: ALPHA SCINTILLATION SURVEY METER
Lab/Field: Field
Radiation Detected: Primary: Alpha **Secondary**: None (in relatively low gamma fields)
Applicability to Site Surveys: The alpha scintillation survey meter is useful for determining the presence or absence of alpha-emitting contamination on nonporous surfaces, swipes and air filters, or on irregular surfaces if the degree of surface shielding is known.
Operation: This survey meter uses an alpha radiation detector with a sensitive area of approximately 50 to 100 cm^2 (8 to 16 $in.^2$). The detector has a thin, aluminized window of mylar that blocks ambient light but allows alpha radiation to pass through. The detecting medium is silver activated zinc sulfide, ZnS(Ag). When the discriminator is appropriately adjusted, the meter is sensitive only to alpha radiation. Light pulses are amplified by a photomultiplier tube and passed to the survey meter. The probe is generally placed close to the surface due to the short range of alpha particles in air.
A scanning survey is used to identify areas of elevated surface contamination and then a direct survey is performed to obtain actual measurements. Integrating the readings over time improves the sensitivity enough to make the instrument very useful for alpha surface contamination measurements for many isotopes. The readings are displayed in counts per minute, but factors can usually be obtained to convert readings from cpm to dpm. Conversion factors, however, can be adversely affected by the short range of alpha particles which allows them to be shielded to often uncertain degrees if they are embedded in the surface. Systems typically use 2 to 6 "C" or"D" cells and will operate for 100-300 hours.
Specificity/Sensitivity: When the alpha discriminator is correctly adjusted, the alpha scintillation survey meter measures only alpha radiation, even if there are other radiations present. A scanning survey gives a quick indication of the presence or absence of surface contamination, while integrating the readings provides a measure of the activity on a surface, swipe, or filter. Alpha radiation is easily adsorbed by irregular, porous, moist, or over painted surfaces, and this should be carefully considered when converting count rate data to surface contamination levels. This also requires wet swipes and filters to be dried before counting. The minimum sensitivity is around 10 cpm using the needle deflection or 1 to 2 cpm when using headphones or a scaler.
Some headphones or scalers give one click for every two counts, so the manual should be consulted to preclude underestimating the radioactivity by a factor of two.

Instrumentation for measurement of beta particles

Detector Type	Detector Description	Application	Remarks
Gas Proportional	<1 mg/cm^2 window; probe area 50 to 1,000 cm^2	Surface scanning; surface contamination measurement	Requires a supply of appropriate fill gas
	<0.1 mg/cm^2 window; probe area 10 to 20 cm^2	Laboratory measurement of water, air, smear, and other samples	
	No window (internal proportional)	Laboratory measurement of water, air, smear, and other samples	Can be used for measuring very low-energy betas
Ionization (non-pressurized)	1-7 mg/cm^2 window	Contamination measurements; skin dose rate estimates	
Geiger-Mueller	<2 mg/cm^2 window; probe area 10 to 100 cm^2	Surface scanning; contamination measurements; laboratory analyses	
	Various window thickness; few cm^2 probe face	Special scanning applications	
Scintillation	Liquid scintillation cocktail containing sample	Laboratory analysis; spectrometry capabilities	
	Plastic scintillator	Contamination measurements	
Passive, integrating electret ion chamber	7 mg/cm^2 window, also window-less, window area 50-180 cm^2, chamber volume 50-1,000 ml	Low energy beta including H-3 contamination on surfaces and in pipes	Useable in high humidity and temperature

System	Description	Application	Remarks	Equipment Cost	Measurement Cost
GM survey meter with beta pancake probe	Thin 1.4 mg/cm^2 window detector, probe area 10 to 100 cm^2	Surface scanning of personnel, working areas, equipment, and swipes for beta contamination. Laboratory measurement of swipes when connected to a scaler.	Relatively high detection limit making it of limited value in final status surveys.	$400-$1,500	$5-$10
Gas-flow proportional counter (field)	A detector through which P10 gas flows and which measures alpha and beta radiation. < 1-10 mg/cm^2 window, probe face area 50 to 100 cm^2	Surface scanning, surface activity measurement, or field evaluation of swipes. Serves as a screen to determine if more nuclide-specific analyses are needed.	Natural radionuclides in samples can interfere with the detection of other contaminants. Requires P10 gas, but can be disconnected for hours.	$2K-$4K	$2-$10/m^2
Gas-flow proportional counter (lab)	Windowless (internal proportional) or window <0.1 mg/cm^2, probe face area 10 to 20 cm^2. May have a second or guard detector to reduce background and MDA.	Laboratory measurement of water, air, and swipe samples	Requires P10 gas. Windowless detectors can be contaminated.	$4K-$30K	$50
Liquid scintillation counter (LSC)	Samples are mixed with LSC cocktail and the radiation emitted causes light pulses with proportional intensity.	Laboratory analysis of alpha and beta emitters, including spectrometry capabilities.	Highly selective for alpha and beta radiation by pulse shape discrimination. Requires LSC cocktail.	$20K-$70K	$100-$200

System: GM SURVEY METER WITH BETA PANCAKE PROBE
Lab/Field: Field
Radiation Detected: Primary: Beta **Secondary:** Gamma and alpha
Applicability to Site Surveys: This instrument is used to find and measure low levels of beta/gamma contamination on relatively flat surfaces.
Operation: This instrument consists of a flat "pancake" type Geiger-Mueller detector connected to a survey meter which measures radiation response in counts per minute. The detector housing is typically a rigid metal on all sides except the radiation entrance face or window, which is made of Mylar, mica or a similar material. A steel, aluminum, lead, or tungsten housing surrounds the detector on all sides except the window, giving the detector a directional response. The detector requires approximately 900 volts for operation. It is held within a few cm of the surface to minimize the thickness of air shielding in between the radioactive material and the detector. It is moved slowly to scan the surface in search of elevated readings, then held in place long enough to obtain a stable measurement. Radiation entering the detector ionizes the gas, causes a discharge throughout the entire tube, and results in a single count being sent to the meter. The counts per minute meter reading is converted to a beta surface contamination level in the range of 1,700 Bq/m^2 (1,000 dpm/100 cm^2) using isotope specific factors.
Specificity/Sensitivity: Pancake type GM detectors primarily measure beta count rate in close contact with surfaces to indicate the presence of contamination. They are sensitive to any alpha, beta or gamma radiation that enters the detector and causes ionization. As a result, they cannot determine the type or energy of that radiation, except by using a set of absorbers. To be detected, beta particles must have enough energy to penetrate through any surface material that the contamination is absorbed in, plus the detector window, and the layer of air and other shielding materials in between. Low energy beta particles from emitters like ^{3}H (17 keV) that cannot penetrate the window alone are not detectable, while higher energy betas like those from ^{60}Co (314 keV) can be readily detected. The beta detection efficiency at a field site is primarily a function of the beta energy, window thickness and the surface condition. The detection sensitivity can be improved by using headphones or the audible response during scans. By integrating the count rate over a longer period or by counting the removable radioactive material collected on a swipe, the ability to detect surface contamination can be improved. The nominal 2 in. diameter detector can measure an increase of around 100 cpm above background, which equates to 4,200 Bq/m^2 (2,500 dpm/100 cm^2) of ^{60}Co on a surface under the detector or 20 Bq (500 pCi) on a swipe. Larger 100 cm^2 detectors improve sensitivity and eliminate the need to swipe. A swipe's collection efficiency may be below 100%, and depends on the wiping technique, the actual surface area covered, the texture and porosity of the surface, the affinity of the contamination for the swipe material, and the dryness of the swipe. This will proportionately change the values above. The sensitivity to gamma radiation is around 10% or less of the beta sensitivity, while the alpha detection efficiency is difficult to evaluate.

Instrumentation for measurement of radon

System	Description	Application	Remarks	Equipment Cost	Measurement Cost
Large area activated charcoal collector	A canister containing activated charcoal is twisted into the surface and left for 24 hours.	Short term radon flux measurements	The LLD is 0.007 Bq $m^{-2}s^{-1}$ (0.2 pCi $m^{-2}s^{-1}$).	N/A, rented	$20-$50 including canister
Continuous radon monitor	Air pump and scintillation cell or ionization chamber	Track the real time concentration of radon	Takes 1 to 4 hours for system to equilibrate before starting. The LLD is 0.004-0.04 Bq/L (0.1-1.0 pCi/L).	$1K-$5K	$80
Activated charcoal adsorption	Activated charcoal is opened to the ambient air, then gamma counted on a gamma scintillator or in a liquid scintillation counter.	Measure radon concentration in indoor air	Detector is deployed for 2 to 7 days. The LLD is 0.007-0.04 Bq/L (0.2 to 1.0 pCi/L).	$10K-$30K	$5-$30 including canister if outsourced.
Electret ion chamber	This is a charged plastic vessel that can be opened for air to pass into.	Measure short-term or long-term radon concentration in indoor air.	Must correct reading for gamma background concentration. Electret is sensitive to extremes of temperature and humidity. LLD is 0.007-0.02 Bq/L (0.2-0.5 pCi/L).	N/A, rented	$8-$25 for rental
Alpha track detection	A small piece of special plastic or film inside a small container. Damage tracks from alpha particles are chemically etched and tracks counted.	Measure indoor or outdoor radon concentration in air.	LLD is 0.04 Bq $L^{-1}d^{-1}$ (1 pCi $L^{-1}d^{-1}$).		$5-$25

System: ACTIVATED CHARCOAL ADSORPTION
Lab/Field: Field
Radiation Detected: Primary: Radon gas **Secondary:** None
Applicability to Site Surveys: Activated charcoal adsorption is a passive low cost screening method for measuring indoor air radon concentration. The charcoal adsorption method is not designed for outdoor measurements. For contaminated structures, charcoal is a good short-term indicator of radon contamination. Vendors provide measurement services which includes the detector and subsequent readout.
Operation: For this method, an airtight container with activated charcoal is opened in the area to be sampled and radon in the air adsorbs onto the charcoal. The detector, depending on its design, is deployed for 2 to 7 days. At the end of the sampling period, the container is sealed and sent to a laboratory for analysis. Proper deployment and analysis will yield accurate results.
Two analysis methods are commonly used in activated charcoal adsorption. The first method calculates the radon concentration based on the gamma decay from the radon progeny analyzed on a gamma scintillation or semiconductor detection system. The second method is liquid scintillation which employs a small vial containing activated charcoal for sampling. After exposure, scintillation fluid is added to the vial and the radon concentration is determined by the alpha and beta decay of the radon and progeny when counted in a liquid scintillation spectrometer.
Specificity/Sensitivity: Charcoal absorbers are designed to measure radon concentrations in indoor air. Some charcoal absorbers are sensitive to drafts, temperature and humidity. However, the use of a diffusion barrier over the charcoal reduces these effects. The minimum detectable concentration for this method ranges from 0.007-0.04 Bq/L (0.2-1.0 pCi/L).

System: ALPHA TRACK DETECTOR
Lab/Field: Field
Radiation Detected: Primary: Radon Gas (Alpha Particles) **Secondary:** None
Applicability to Site Surveys: An alpha track detector is a passive, low cost, long term method used for measuring radon. Alpha track detectors can be used for site assessments both indoors and outdoors (with adequate protection from the elements).
Operation: Alpha track detectors employ a small piece of special plastic or film inside a small container. Air being tested diffuses through a filtering mechanism into the container. When alpha particles from the decay of radon and its progeny strike the detector, they cause damage tracks. At the end of exposure, the container is sealed and returned to the laboratory for analysis.
The plastic or film detector is chemically treated to amplify the damage tracks and then the number of tracks over a predetermined area are counted using a microscope, optical reader, or spark counter. The radon concentration is determined by the number of tracks per unit area. Detectors are usually exposed for 3 to 12 months, although shorter time frames may be used when measuring high radon concentrations.
Specificity/Sensitivity: Alpha track detectors are primarily used for indoor air measurements, but specially designed detectors are available for outdoor measurements. Alpha track results are usually expressed as the radon concentration over the exposure period (Bq/L-days). The sensitivity is a function of detector design and exposure duration, and is on the order of 0.04 Bq/L-day (1 pCi/L-day).

System: CONTINUOUS RADON MONITOR
Lab/Field: Field
Radiation Detected: Primary: Radon gas **Secondary:** None
Applicability to Site Surveys: Continuous radon monitors are devices that measure and record real-time measurements of radon gas or variations in radon concentration on an hourly basis. Since continuous monitors display real-time hourly radon measurements, they are useful for short-term site investigation.
Operation: Continuous radon monitors are precision devices that track and record real-time measurements and variations in radon gas concentration on an hourly basis. Air either diffuses or is pumped into a counting chamber. The counting chamber is typically a scintillation cell or ionization chamber. Using a calibration factor, the counts are processed electronically, and radon concentrations for predetermined intervals are stored in memory or directly transmitted to a printer.
Most continuous monitors are used for a relatively short measurement period, usually one to seven days. These devices do require some operator skills and often have a ramp-up period to equilibrate with the surrounding atmosphere. This ramp-up time can range from 1 to 4 hours depending on the size of the counting chamber and rate of air movement into the chamber.
Specificity/Sensitivity: Most continuous monitors are designed for both indoor and outdoor radon measurements. The limiting factor for outdoor usage is the need for electrical power. In locations where external power is unavailable, the available operating time depends on the battery lifetime of the monitor. The minimum detectable concentration for these detectors ranges from 0.004-0.04 Bq/L (0.1-1.0 pCi/L).

System: ELECTRET ION CHAMBER
Lab/Field: Field
Radiation Detected: Primary: Radon gas (alpha, beta) **Secondary:** Gamma
Applicability to Site Surveys: Electrets are used to measure radon concentration in indoor environments. For contaminated structures, the electret ion chamber is a good indicator of short-term and long-term radon concentrations.
Operation: For this method, an electrostatically charged disk (electret) is situated within a small container (ion chamber). During the measurement period, radon diffuses through a filter into the ion chamber, where the ionization produced by the decay of radon and its progeny reduces the charge on the electret. A calibration factor relates the voltage drop, due to the charge reduction, to the radon concentration. Variations in electret design enable the detector to make long-term or short-term measurements. Short-term detectors are deployed for two to seven days, whereas long-term detectors may be deployed from 1 to 12 months.
Electrets are relatively inexpensive, passive, and can be used several times before discarding or recharging, except in areas of extreme radon concentrations. These detectors need to be corrected for the background gamma radiation during exposure since this ionization also discharges the electret.
Specificity/Sensitivity: Electrets are designed to make radon measurements primarily in indoor environments. Care must be taken to measure the background gamma radiation at the site during the exposure period. Extreme temperatures and humidity encountered outdoors may affect electret voltage. The minimum detectable concentration ranges from 0.007-0.02 Bq/L (0.2 to 0.5 pCi/L).