WASTE MANAGEMENT OF COLORADO, INC.
CONSERVATION SERVICES, INC

UPDATED RISK ASSESSMENT REPORT

Prepared for

CONSERVATION SERVICES, INC.

41800 E. 88th Avenue,

Bennett, CO 80102

Prepared By:

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and

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REVISIONS SHEET

Record of Issue/Revisions

Revision No.	Date	Change Description
1	May 2006	Updated report per CDPHE letter dated February 17, 2006

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LIST OF ACRONYMS AND ABBREVIATIONS

ALARA	As Low As Reasonably Achievable
CDPHE	Colorado Department of Public Health and Environment
RMLLRWC	Rocky Mountain Low Level Radioactive Waste Compact
DOD	United States Department of Defense
DOE	United States Department of Energy
DIA	Denver International Airport
DOT	Department of Transportation
EPA	United States Environmental Protection Agency
REM	Radiant Energy Management
NORM	Naturally Occurring Radioactive Material
RCRA	Resource Conservation and Recovery Act
NRC	Nuclear Regulatory Commission
TENORM	Technologically Enhanced Naturally Occurring Radioactive Material
Ra-226	Radium-226
CSI	Conservation Services, Inc.
POTW	Public Owned Treatment Works
ISCORS	Interagency Steering Committee on Radiation Standards
MSW	Municipal Solid Waste
CEDE	Cumulative Effective Dose Equivalent
NSPS	New Source Performance Standards
TEDE	Total Exposure Dose Equivalent
μR/hr	MicroRoentgens per hour
μCi/ml	microcuries per milliliter
cm^2	Square centimeters
cpm	Counts per minute
dpm	disintegrations per minute
m^2	Square meters
pCi/g	picocuries per gram

1.0 CERTIFICATION STATEMENT

The information and findings described in this Risk Assessment Report has been carefully reviewed and approved by professionals, which possess knowledge, experience and expertise specific to the technical information contained in this report. Their opinions represent professional judgment based on site-specific data, engineering design, executed and established quality assurance monitoring programs, site-specific computer codes and models and appropriate operational protocol.

Based on this information, the undersigned hereby certify to the best of their knowledge and professional judgment that the information provided in this assessment is accurate and demonstrates that Conservation Services Inc. (CSI) is suitable for the safe and proper management of industrial waste with small amounts of NORM/TENORM. The results of the dose risk assessment further demonstrates that CSI can comply with the dose based standard of 25 mrem/yr derived from C.C.R. 1007-1 and 4.61.2 and is protective of public health and the environment.

Approvals

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2.0 EXECUTIVE SUMMARY

Managing naturally occurring radioactive materials (NORM) and technically enhanced naturally occurring radioactive materials (TENORM) has been a topic of discussion for regulators and the industrial community for many years. This type waste stream is generated from a variety of industries including petroleum, mining and natural gas to name a few. More recently municipalities will be required to remove radium from drinking water as a result of changes in federal drinking water regulations. Agencies having regulations dealing with radioactivity are extensive with the following providing various levels of oversight; US Department of Energy, US Department of Defense, US Environmental Protection Agency, Rocky Mountain Low Level Radioactivity Waste Compact, and the Colorado Department of Public Health and Environment (CDPHE).

Considering the number of regulatory agencies and extensive regulations, little if any oversight is specifically designed for NORM/TENORM materials. The regulatory agency in Colorado with the ability and authority to exercise discretion and implement control over low activity waste is CDPHE. Additionally CDPHE has authority to exempt a facility from specific licensing requirements under Part 3 of the Radiation Control Regulations and approve values for NORM/TENORM from industrial activities to be accepted by a disposal facility based on risk assessments. The waste materials would be regulated as industrial solid waste under Colorado Solid Waste Regulations and the Certificate of Designation issued by the local governing body.

Colorado is one of many states with higher occurrences of NORM. Over the past decade the need for a facility that can safely dispose of NORM and TENORM has increased. Conservation Services, Inc. (CSI) is an industrial waste facility that has previously provided disposal services for these types of industrial wastes (hereinafter referred to collectively as industrial waste with small amounts of NORM/TENORM). CSI received the industrial wastes with small amounts of NORM/TENORM based on case-by-case reviews conducted by CDPHE and Adams County. Approximately 30,000 cubic yards of industrial waste with small amounts of NORM/TENORM has been approved and disposed of at CSI.

Case-by-case waste approvals are an administrative burden for the generator and the reviewing agencies. After continued applications for case-by-case review CDPHE has requested that CSI develop a waste acceptance protocol for waste with small amounts of NORM/TENORM. In combination with the waste acceptance protocol CDPHE also requested CSI perform risk assessments for future industrial waste with NORM/TENORM and on all the industrial wastes with NORM/TENORM currently at the facility. To accomplish this task CSI retained Molen & Associates, LLC and Radiant Energy Management and American Environmental Consulting, LLC (AEC) to assemble and evaluate information, perform risk assessments concerning radioactivity, and prepare this report for submittal to CDPHE and Adams County.

This Updated Risk Assessment Report (Report) is specifically designed to fulfill CDPHE's request and to provide CDPHE and Adams County with comprehensive, accurate technical data, site-specific risk assessments and a waste acceptance protocol that ensures safe and proper management of industrial waste with NORM/TENORM at CSI. This updated Report includes information in response to CDPHE's February 17, 2006 letter summarizing the review of the January 2005 submittal. The Updated Waste Identification Plan for Conservation Services, Inc.

(Plan), referred to in this Report and submitted under separate cover, outlines a waste acceptance protocol that eliminates the administrative burden of case-by-case reviews as requested by CDPHE. The Updated Plan does not change CSI's long-standing practice of accepting industrial waste with NORM/TENORM. Rather, it is merely formalizing and streamlining the administrative process by which CSI previously accepted this waste and respond to CDPHE's request to reduce the administrative burden on CDPHE, and obviate case-by-case determinations for acceptance of industrial waste with NORM/TENORM at CSI. The Updated Plan for CSI incorporates the relevant information submitted in response to the February 17, 2006 letter from CDPHE.

Finally, this updated Report demonstrates that based on site specific technical data including engineer designed containment structures, executed and established quality assurance and monitoring systems, results of appropriate computer codes and models, and waste acceptance protocol and safe and appropriate operational controls, that CSI can manage industrial waste with small amounts of NORM/TENORM in compliance with applicable regulatory requirements. This updated Report demonstrates that CSI can comply with the dose standard of 25 mrem/yr derived from C.C.R. 1007-1 and 4.61.2 and is protective of public health and the environment.

3.0 INTRODUCTION

This Updated Risk Assessment Report (Report) provides relevant information concerning the previous and future disposal of industrial waste with small amounts of NORM/TENORM at Conservation Services, Inc. (CSI) located near Bennett Colorado. The report includes:

- a description of subsurface conditions at CSI;
- current status of dose risk for waste previously disposed on site;
- an assessment of future dose risks for industrial wastes with small amounts of NORM/TENORM to be disposed at the facility
- other related technical information
- radon emanation calculations
- and a dose risk assessment for workers at CSI

This Report refers to the updated Plan for Conservation Services, Inc. (updated May 2006), submitted under separate cover, that describes safe and proper management of industrial waste with NORM/TENORM in accordance with applicable regulatory requirements.

Additional information is provided in this updated Report in response to issues listed in the February 17, 2006 letter from the Colorado Department of Public Health and Environment. Specific responses to the February 17, 2006 letter are outlined in Section 3.4.

3.1 Background

CSI is a wholly owned subsidiary of Waste Management of Colorado, Inc. The CSI facility has been in operation since 1989, after receiving a Certificate of Designation from Adams County following an extensive regulatory review process. CSI is a permitted facility encompassing approximately 383 acres located in Section 25, Township 2 North, Range 64 West, approximately seven miles north of the town of Bennett, Colorado. The physical and mailing address for the facility is:

Conservation Services, Inc.
41800 E. 88th Avenue
Bennett, Colorado 80102
(303) 644-4332 phone
(303) 644-4306 fax

CSI is a unique waste disposal facility and the only industrial waste facility in Colorado. Initially created in 1984, the CSI facility was designed to meet the needs of industries generating non-hazardous industrial waste. In the early 1980's many industries were very concerned with protecting their assets from CERCLA (Superfund) liability. Over the past decade the need for a facility that can safely handle non-hazardous industrial waste with small amounts of NORM/TENORM has increased. CSI can continue to meet the needs of the generators in the future.

Generators of industrial wastes with small amounts of NORM/TENORM have chosen CSI in the past because it is the only industrial waste disposal facility in Colorado and based upon its unique design features for proper management of non-hazardous industrial waste. The CSI facility was designed similar to Subtitle C Hazardous Waste disposal facilities by having discrete disposal cells and executing and establishing environmental monitoring systems and waste tracking and control systems to ensure all waste delivered to the facility is non-hazardous (see facility Design and Operations Plan dated 1996 and the updated Plan dated May 2006 for further design and operational protocol). The discrete disposal cells have a composite liner consisting of compacted clay and synthetic liners, see Figure 1. Furthermore, because CSI is an industrial waste landfill, typical issues associated with municipal solid waste landfills such as the collection and control of landfill gas is not a concern at CSI.

Historically, CDPHE and Adams County approved industrial wastes with small amounts of NORM/TENORM for disposal at CSI on a case-by-case basis. Of the case-by-case approvals, the largest was approximately 30,000 cubic yards of waste with NORM/TENORM approved and disposed of at the facility in 1994. Recently drinking water residuals from a Colorado municipality were approved and disposed at CSI during the review phase of this risk assessment report.

The case-by-case approval process of industrial waste with small amounts of NORM/TENORM by CDPHE and Adams County has been scrutinized by CDPHE in recent years. Specifically, CDPHE has requested CSI develop a waste acceptance protocol to eliminate the administrative burden placed on CDPHE as a result of conducting case-by-case reviews. CDPHE also requested CSI perform a risk assessment for future industrial waste with small amounts of NORM/TENORM and a risk assessment on all the waste with small amounts of NORM/TENORM currently at the facility. Accordingly, this updated Report is specifically designed to fulfill CDPHE's request and provide both CDPHE and Adams County with comprehensive, accurate technical data sufficient to establish and execute a waste acceptance protocol, for safe and proper management of industrial waste with small amounts of NORM/TENORM at CSI. The time difference between the initial Report submittal and this updated Report submittal has been lengthy and new risk assessments incorporating the waste received since the initial submittal are not included. The amount of waste received is less than 1350 cubic yards and the waste streams have Ra-226 concentrations less than 15 pCi/g. These wastes will be accounted for as future waste submitted.

3.2 Regulations

There are currently no Federal regulations that specifically address industrial wastes with small amounts of NORM/TENORM. The US EPA governs solid and hazardous waste landfilling under RCRA; however, radioactivity is not covered under the solid waste regulations under Subtitle D (rules for municipal solid waste). Subtitle D regulations are not strictly applicable to CSI because the facility has not handled municipal solid waste and disposes of industrial waste. Colorado has been granted the authority to administer the Subtitle D permitting program and promulgate their own regulations within their boundaries. Currently the Colorado Solid Waste Regulations are the governing rules for the types of industrial waste with small amounts of NORM/TENORM that would be appropriate for disposal at CSI

The CDPHE Radiation Control Division does have authority to exercise discretion in implementing control over low activity materials. CDPHE has authority to exempt a facility from specific licensing requirements under Part 3 of the Radiation Control Regulations and approve values for NORM/TENORM to be accepted by the facility based on risk assessments. Accordingly, these wastes have been traditionally managed on a case-by-case basis under the Certificate of Designation process and Solid Waste Regulations. The Radiation Management Unit, the Solid Waste Unit, and the Water Quality Control Division are utilizing a stakeholder process to evaluate the regulatory scheme for handling control and disposal of TENORM in Colorado.

NORM waste, which may be considered industrial waste under certain circumstances, is defined in Colorado pursuant to CRS 25-11-101.

Naturally Occurring Radioactive Waste (NORM) means,

> "Naturally occurring radioactive materials that contain any nuclide that is radioactive in it's natural physical state and is not manufactured. Naturally occurring radioactive materials does not include source material, special 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."

In Section 12 of the Colorado Solid Waste Regulations, water treatment plant sludges are addressed. Water treatment sludges have maximum limits of gross alpha activity up to 40 pCi/g that are allowed by regulation to be managed in a permitted solid waste disposal facility and higher concentrations may be allowable with further guidance from the Radiation Control Division of CDPHE. The EPA has issued guidelines for drinking water residuals with small amounts of radioactivity; however, this is the only type of materials they have addressed. A few other states have regulations for NORM waste. In Colorado, CDPHE is the agency responsible for the disposal of industrial waste with small amounts of NORM/TENORM.

Colorado is one of many states with higher occurrences of natural occurring radioactivity. Regulations dealing with radioactivity are extensive with the following agencies providing a variety of oversight:

- US Department of Energy (DOE);
- US Nuclear Regulatory Commission (NRC);
- Occupational Safety and Health Administration (OSHA);
- US Department of Defense (DOD);
- US Environmental Protection Agency (EPA);
- Rocky Mountain Low Level Radioactivity Waste Compact (RMLLRWC);

- Colorado Department of Public Health and Environment (CDPHE).

Nevertheless, considering all the agencies and regulations little if any oversight exists for naturally occurring radioactive materials that contain very small concentrations of radioactivity. The agency managing the disposal of these types of materials in Colorado is CDPHE.

3.3 Project Description

Molen & Associates, LLC and Radiant Energy Management are retained by CSI to assemble and evaluate information, perform risk assessments concerning radioactivity, and prepare this report for submittal to CDPHE and Adams County. To accomplish this task, American Environmental Consulting, LLC (AEC) was utilized for their expertise in understanding the subsurface conditions, geology, and permit requirements at CSI. This report is designed to provide CDPHE and Adams County with the requested information needed to establish and execute a protocol as described in the updated Plan for disposal of industrial waste with small amounts of NORM/TENORM at CSI without the administrative burden of case-by-case reviews. The major activities conducted during the project are summarized below.

Evaluate Risk Associated with Materials Currently at WM/CSI

Currently there are several projects where industrial waste with small amounts of NORM/TENORM was disposed of at CSI. Each industrial waste disposal project was approved on a case-by-case basis and included a risk assessment specific to the industrial waste with small amounts of NORM/TENORM proposed for management at CSI. Differences in the risk assessment for the past projects included the computer model, the parameters used, and actual volumes received compared with proposed volume estimates. Separate RESRAD dose risk assessments for each of the projects are included in this report. The original RESRAD output results were included in Appendix A of the January 2005 report and are found in the file folder titled Previous NORM TENORM Waste Disposal on the Compact Disk (CD) attached to the inside binder of this updated Report.

Additional waste was approved on a case-by-case basis since the January 2005 submittal. These wastes are limited (less that 1350 cubic yards), are not modeled separately and results are not included in this report.

Evaluate Risk Associated with Future Waste Disposal Activities

In the January 2005 report RESRAD risk assessment modeling was done on each disposal cell individually. The area of the disposal cell, the depth, and the amount of cover were used along with site-specific conditions of the subsurface, which were validated by a registered professional geologist. The results of the risk assessments were summed together to determine the overall dose risk at the facility. Concentrations are derived based upon information from other documents and reviewing the maximum concentrations of industrial waste with small amounts of NORM/TENORM already received.

The RESRAD output results included in Appendix A of the January 2005 report are found in the file folder titled Previous NORM TENORM Waste Disposal on the Compact Disk (CD) attached to the inside binder of this updated Report. The industrial waste disposal cells are individual units and can be managed as such. Industrial waste placed in the disposal cells is tracked and the location of waste in a cell can be identified if the need to locate waste in the future was necessary.

Worker Risk Assessments

Risks associated with working with wastes with small amounts of NORM/TENORM are evaluated using RESRAD and TSD-DOSE models and considering radon.

3.4 Revisions in the May 2006 Updated Report Respond to Comments Regarding the January 2005 Report

The February 17, 2006 letter from CDPHE outlined the following conditions for acceptance.

> "State that the covers for the cells will/will not meet the post-closure radon emission requirements and will be robust for a 1,000 year post-closure period. This can be demonstrated by a bounding scenario, and a realistic scenario."

CSI Response:

The landfill covers (both existing and proposed alternative final cover designs) will meet post-closure radon emission requirements as shown by bounding studies, radon flux calculations and dose exposure modeling described in this report.

Additional CDPHE Comments:

Waste Identification Plan Conditions for acceptance:

1. Quantities of natural thorium greater than 55 pCi/g are considered source material (0.05% be weight), and cannot be accepted by CSI without a radioactive materials license. Therefore, the authorization request needs to be modified.
2. Leachate (or groundwater) monitoring is to be conducted on a routine basis and should include gross alpha, and gross beta, combined Ra-226/228 and U-nat.
3. Based on discussion with County and other regulators, the *Waste Characterization Plan* should still be submitted for notification and review. Please set up procedures such that CSI will submit the characterization reports

to the Division and to the County Commissioners prior to accepting wastes from a project. As long as the material meets the modeled acceptance criteria, additional risk assessments will not be required.

4. Please describe in the *Waste Characterization Plan* the type of detector used, its sensitivity, and its ability to discern natural radioactivity from man-made.
5. Please provide the Division a syllabus of the training program for review.

CSI Response:

1. The text in Section 3 and Table 1 of the updated Plan has been modified to reflect the quantities of natural thorium that cannot be accepted at CSI. The specific activity of the radionuclide determines the concentration. The results from making the calculation are listed for each radionuclide in Table 1 of the updated Plan.
2. Section 8 of the updated Plan includes an annual leachate analyses for gross alpha, gross beta, combined Ra-226/228 and U-nat. Results will be submitted to CDPHE, Adams County and Tri-County Health Department.
3. Section 2.2 of the updated Plan includes procedures for submittal of characterization reports to CDPHE, Adams County and Tri-County Health Department prior to accepting the waste at the facility.
4. Section 2.5 of the updated Plan describes the type of radiation monitoring equipment that will be used at CSI. Although CSI has not yet installed a detector at the gate that has the ability to discern natural radioactivity from man-made, we will purchase the necessary equipment once the updated Plan is approved and prior to accepting industrial waste with small amounts of NORM/TENORM at the facility. CSI will send CDPHE, Adams County and Tri-County Health Department details and specifications of the monitoring equipment purchased for use at CSI.
5. A typical training syllabus is include in Appendix G of the updated Plan

Additional specific comments from CDPHE with regard to the January 2005 report are corrected and or revised in this updated Report.

3.5 Risk Assessment Software

Approximately twenty computer codes for radiation dose from residual radioactivity have been developed. RESRAD is the most used for sites with residuals in Colorado including its use at Rocky Flats. Accordingly, RESRAD was chosen as the appropriate computer model for the CSI project. An earlier version of RESRAD, version 6.22 (2/6/04) was used for the January 2005 report and the more recent RESRAD version 6.3 (8/25/05) was used for this updated Report. The differences between the two versions are minor and do not effect the outcomes of the RESRAD runs.

3.6 Other Studies

The National Petroleum Technology Office and the US DOE have studied the disposal of NORM/TENORM in non-hazardous waste landfills. This study has determined that states should consider the acceptance of NORM/TENORM with an average Ra-226 concentration of 50 pCi/g or less at certain non-hazardous landfills[1].

The Interagency Steering Committed on Radiation Standards completed an assessment of radioactivity in disposal options for wastewater treatment residuals known as the ISCOR study[2]. ISCORS final report assessed the radioactivity in sewage sludge for several disposal scenarios including landfilling, land application, and incineration. The assessments evaluated a wide variety of publicly owned treatment works (POTW's) sewage sludges and calculated doses for the different scenarios.

[1] An Assessment of the Disposal of Petroleum Industry NORM in Non-hazardous Landfills, DOE/BC/W-31-109-ENG-38-8, Argonne National Laboratory, October 1999

[2] ISCORS Assessment of Radioactivity in Sewage Sludge: Radiological Survey Results and Analysis, EPA 832-R-03-002, November 2003.

4.0 SITE SPECIFIC CONDITIONS AND ADVANTAGES TO CSI

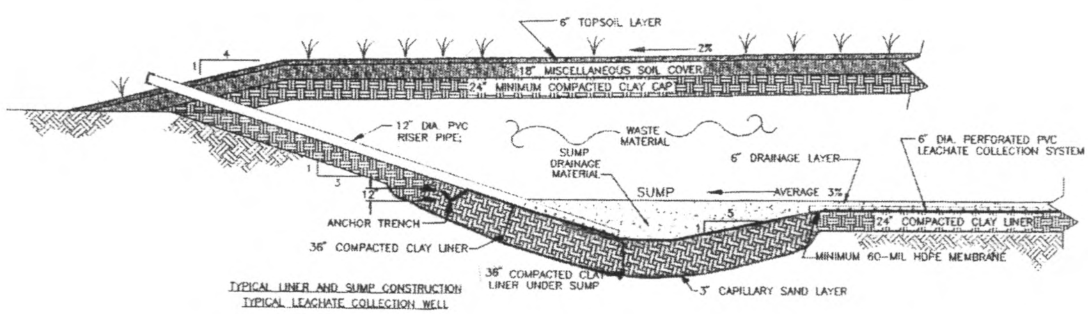
CSI was selected to be a suitable site for the disposal on non-hazardous industrial waste after a site location was done. Sufficient clay is available to be used for liner and cover materials with the material descriptions identified in this section.

4.1 Disposal Cells at CSI

A total of seven disposal cells are currently available for disposal of industrial waste with small amounts of NORM/TENORM at the CSI facility. Any one of the disposal cells may contain industrial waste with small amounts of NORM/TENORM. The cell sizes and configurations are listed in Table 1. A diagram of the site is shown in Figure 1.

Figure 1

CSI Landfill Liner System Design Diagram



Generators of industrial waste with small amounts of NORM/TENORM have chosen CSI in the past because it is the only industrial waste disposal facility in Colorado and based upon its unique design features for proper management of non-hazardous industrial waste. The CSI facility was designed similar to Subtitle C Hazardous Waste disposal facilities by having discrete disposal cells and executing and establishing environmental monitoring systems and waste tracking and control systems to ensure all waste delivered to the facility is non-hazardous (see facility Design and Operations Plan dated 1996 and the updated Waste Identification Plan dated May 2006 for further design and operational protocol). The discrete disposal cells have a composite liner consisting of compacted clay and synthetic liners (see Figure 1). Furthermore, because CSI is an industrial waste landfill, typical issues associated with municipal solid waste landfills such as the collection and control of landfill gas is not a concern at CSI.

Industrial wastes with small amounts of NORM/TENORM are securely disposed in engineered containment structures, or disposal cells. Environmental isolation of the waste materials is provided by lining the entire disposal area with a combination of compacted clay and synthetic materials, constructed to stringent standards and protocols approved by regulatory agencies. The cells also incorporate a leachate collection and removal system designed to remove liquids (primarily stormwater) that may accumulate in the cells. This leachate collection system consists of sloping the base of the disposal cells to a sump area to collect any liquids in the cell, and a piping system to allow the removal of the accumulated liquids. Transport of the liquids to the sump is facilitated by a permeable layer of sand or gravel in the base of the cell. Finally, when a cell is filled to pre-approved elevations, an approved final cover system is constructed to reduce the chance for precipitation or surface water to infiltrate into the cell and contact the waste. Executed and established quality assurance plans ensure all components of the containment system are constructed to approved design and specifications. All portions of the disposal cells are constructed under strict third party oversight to specifications approved by the regulatory agencies. All soils, synthetic materials, and leachate collection and removal components are constantly tested during construction to ensure they meet the project requirements. Prior to placing any waste in a disposal cell, CSI is required to complete a final construction report and submit it to the regulatory agencies for approval.

Table 1

WM/CSI Disposal Cell Dimensions

Cell Number	Length in Meters N-S	Width in Meters E-W	Area in Square Meters	Length Parallel to GW Flow in Meters	Average Depth in Meters
1	Full				
2	107.29	171.30	18,384	202.12	5.61
3	Full				
4/5/8	173.19	240.79	41,701	296.61	12.91
6/7/9	187.10	234.70	43,910	300.15	9.34
10/11/12	171.35	243.84	41,163	298.02	12.53
13-17	327.66	349.00	114,313	478.71	17.98
18/21/22/23	339.85	230.12	78,624	410.43	16.60
19/20	243.84	158.50	38,646	290.82	11.63
24	365.76	152.40	55,740	396.24	12.36
25	297.60	259.08	77,100	394.57	16.18
Average Depth					12.79

4.2 Background Radioactivity Levels at the Site

Radiant Energy Management (REM) performed background measurements for the CSI facility in 1995. Based upon the REM study background external radiation exposure at the CSI facility is 8-10 μR/hr. Table 2 shows the average concentrations of NORM nuclides in soil samples taken at CSI.

Table 2

Background Average Concentrations of Radionuclides

Radionuclide	Average Concentration
Radium 226	1.37 pCi/g
Radium 228	1.33 pCi/g
Thorium 228	1.69 pCi/g
Thorium 230	0.77 pCi/g
Thorium 232	1.49 pCi/g
Lead 210	2.11 pCi/g
Uranium natural	1.56 ug/g

4.3 Sub-surface Conditions

The sub-surface conditions at the CSI facility were originally evaluated as part of site characterization activities required for the initial permit. Molen & Associates, LLC conducted a thorough review of this information on sub-surface conditions with assistance from CSI and AEC. A summary of the sub-surface conditions and the basis for the values used in the RESRAD model is found in Table 3. These values, which were derived from site characterization field activities including soil borings, water levels etc. represent actual sub-surface conditions at the site. A registered professional geologist with AEC reviewed the geotechnical data to ensure parameters were accurate and appropriate for their use in the model.

Table 3

CSI RESRAD INPUT VALUES			
Future Waste in All Cells			Times for Calculations 1000 years
	Value	Units	
Area of contam zone	Varies	m^2	From Table 1
Thickness of contam zone	Varies	m	From Table 1
Length parallel to aquifer	Varies	m	From Table 1

Table 3 Continued			
COVER AND CONTAMINATED ZONE HYDROGEOLOGIC DATA			
	Values	Units	
Cover depth	3.5	m	Assume cover thickness of approx. 12 feet
Dry Dens of cover mats	1.56	g/cm^3	Ave. waste samples P-19-2 and P-19-3
Cover erosion rate	0.000815	m/yr	From "01 D&O-**see note 1**
Dry Dens of contam zone	1.56	g/cm^3	Average of previous waste received
Contam zone erosion rate	0	unitless	No erosion to contaminated zone, cover maintained
Contam zone total porosity	0.39	unitless	Average of previous waste received
Contam zone effec. Porosity	0.23	unitless	Average number for silts and sands
Contam zone hydr conduct	315	m/yr	Molycorp number matches ave. waste from samples P-19-2 and P-19-3
Contam zone b parameter	5.3	unitless	RESRAD Default supported by hyd. cond.
ET coefficient	0.7	unitless	Information from AEC on arid climate
Wind Speed	3.89	m/s	Updated information from DIA & NOAA
Precipitation	0.391	m/yr	Updated information from DIA & NOAA
Irrigation	0	m/yr	No irrigation
Runoff Coefficient	0.45	unitless	From 1996 D&O
Watershed area stream/pond	1400000	m^2	Molycorp number based upon Figure 3-2 in CSI EDOP
Accuracy for water/soil comps	0.001	unitless	Use RESRAD default value
Moisture Content	15.3	%	Average moisture of soils
Diffusion Coefficient		cm^2/s	Use RESRAD default value
SATURATED ZONE HYDROGEOLOGIC DATA			
Dry density of sat mats	1.65	g/cm^3	Reasonable for silty sands beneath most of site
Saturated zone total porosity	0.35	unitless	Silt/Sand mix, agrees with RESRAD defaults
Saturated zone effec. porosity	0.23	unitless	Ave of RESRAD defaults for silt/sand
Saturated zone field capacity	0.22	unitless	Loam-Geraghty and Miller
Saturated zone hydr. conduct	78.84	m/yr	Ave. slug tests from 1996 D&O
Saturated zone hydr. Gradient	0.17	unitless	From 90 D&O.
Saturated zone b parameter	5.5	unitless	Ave. RESRAD default sand/silt/clay.
Water table drop rate	0.61	m/yr	Based on midrange of Piezo measurements
Well pump intake depth....	15.24	m	Assumed from depths of most perched interval
Well pumping rate	5970	m^3/yr	Don't expect to pump, if pumped be < 2-3 gpm
UNSATURATED ZONES			
	Values	Units	
ZONE 1 Waste in Disposal Cells			
Thickness	0	m	Assume cover of drainage layer with industrial solid waste
Soil Density	1.56	g/cm^3	Ave. waste samples P-19-2 and P-19-3
Total porosity	0.366	unitless	Ave. waste samples P-19-2 and P-19-3
Effective porosity	0.23	unitless	Average number for silts and sands
Soil specific b parameter	5.3	unitless	RESRAD default and supported by hyd. cond.
Hydraulic conductivity	315	m/yr	Molycorp number matches ave. waste P-19-2 and P-19-3

Table 3 Continued			
ZONE 2 Clay and synthetic liner			
Thickness	2.61	m	2 m synthetic (6.56 ft) + 2 ft clay used by Molycorp
Soil Density	1.4	g/cm^3	Equal to 95% of average max density in Cell 18 just built
Total porosity	0.427	unitless	Reasonable for compacted clay liner
Effective porosity	0.06	unitless	RESRAD default for Clay
Soil specific b parameter	11.4	unitless	RESRAD default for Clay
Hydraulic conductivity	0.031	m/yr	Max permitted value
ZONE 3 Sand under Cell #25			
Thickness	3.66	m	12 feet - the minimum distance to water based upon permit
Soil Density	1.75	g/cm^3	Reasonable for sands
Total porosity	0.4	unitless	Good estimate for sands, agrees with RESRAD defaults
Effective porosity	0.23	unitless	Ave of RESRAD defaults for silt/sand
Soil specific b parameter	4.38	unitless	RESRAD default loamy sand under Cell 25
Hydraulic conductivity	16.4	m/yr	Slug test MW-311 in Cell 25 area
Notes:	1. 5 t/a/yr was calculated in '01 EDOP based on 25% slope for a 150' run.		

4.4 Advantages of landfilling at CSI

The CSI facility is uniquely suited and specifically designed, constructed and operated to manage industrial waste. Industrial waste with small amounts of NORM/TENORM is appropriate for disposal at CSI for the following reasons:

1. A system of waste controls and approval processes have been executed and established since the site began operations over 18 years ago. The waste approval process provides for a technical review and evaluation of waste streams in order to ensure that industrial waste with small amounts of NORM/TENORM is suitable for disposal at the facility. Details regarding the waste acceptance program for industrial waste with small amounts of NORM/TENORM are included in the updated Plan dated May 2006 for Conservation Services, Inc. submitted separately.
2. A system of monitoring including a stationary radioactivity gate monitor to screen loads entering the site and a hand held radiation detection device will be used. Currently the hand held radiation meter and a single gate monitor is used at the CSI facility. An updated gate monitoring detection system will be installed. The radiation detection system will be capable of discerning natural radioactivity from man-made. Additional information on the detector system is found in the Updated Waste Characterization Plan submitted separately.
3. The unique design of the facility provides discrete disposal cells allowing for waste to be segregated.

4. Only non-hazardous industrial waste is currently accepted at the facility. No putrescible or MSW waste, which is commonly associated with landfill gas production, is received at the facility. Accordingly, there is no potential mixing of landfill gas and radon, and therefore there are no concerns at CSI regarding emission controls that are required under the New Source Performance Standards (NSPS) for municipal solid waste facilities. Regardless of the NSPS, if landfill gas were produced it would likely be used as a carrier for radon gas even if there were no gas collection system in place. The landfill gas is lighter than air and has a greater affinity to escape the landfill and be released to the atmosphere and could carry radon gas with it.
5. The waste is placed in locations within the disposal cell that can be tracked. If appropriate and arranged with the generator, waste deliveries can be surveyed to locate the industrial waste with small amounts of NORM/TENORM in the future.
6. Because CSI only manages industrial waste and has previously managed industrial waste with small amounts of NORM/TENORM, site personnel are trained and have experience in managing this waste stream. Ongoing training is provided to the staff to ensure safe and proper management of wastes received at the facility.
7. A restriction has been placed on the deed for the facility. The deed restriction provides institutional controls for future uses of the facility.

Past generators of industrial waste with small amounts of NORM/TENORM have specifically chosen the facility because of the unique design features. CSI is not a MSW facility and is the only industrial waste facility in Colorado. In addition, industrial waste with small amounts of NORM/TENORM may not be appropriate for disposal at a MSW landfill due in part to the potential to emit radon gas as part of the landfill gas collection systems required for MSW facilities under NSPS. Since CSI is exempt from NSPS requirements because the facility does not accept MSW, there is no concern regarding radon gas emissions under NSPS at CSI. Adequate protection against radon flux as described in NESHAPS as it applies to uranium mills, is also provided. The radon flux was calculated and shown not to exceed 20 pCi/m^2s with the results summarized in section 8.8 and found in Appendix 1. Therefore, along with composite lined containment cells, approved monitoring networks and waste acceptance controls, CSI is an appropriate facility to manage industrial wastes with small amounts of NORM/TENORM.

5.0 WASTE ACCEPTANCE AT CSI

This report refers to the updated Plan submitted separately, which outlines a waste acceptance protocol that eliminates the administrative burden of case-by-case reviews as requested by CDPHE. CSI is permitted to accept non-hazardous industrial and commercial solid waste for disposal by burial, and includes a treatment solidification facility for non-hazardous liquid wastes. Although CSI is permitted to accept municipal solid waste there is no separate cell constructed for this waste at this time. In addition, the facility has bio-treatment capabilities to remediate certain petroleum containing sludges and solid wastes, and a specific area designated for the disposal of asbestos containing wastes. No regulated quantities of hazardous wastes, radioactive wastes, or polychlorinated biphenyl's (PCB's) are accepted at the facility.

Prior to acceptance at the facility, industrial waste must undergo laboratory testing to ensure the waste meets CSI's strict acceptance criteria, and be pre-approved by CSI before being shipped to the facility. CSI also has the capability of conducting screening tests on site to ensure that the industrial waste arriving for disposal matches the waste that was pre-approved. Waste acceptance criteria are specified in CSI's waste acceptance plan which is part of CSI's solid waste permit and included in the facility Design and Operations (D&O) Plan dated February 5, 1996 which has been approved by the CDPHE and Adams County.

Additionally, based on the results of the RESRAD modeling, reviews of applicable regulatory requirements, facility permits and discussions with regulatory agencies, CSI enhanced its waste acceptance plan as further described in the Supplemental Waste Identification Plan dated December 2004 and updated May 2006. The updated Plan is an enhancement to the waste acceptance criteria described in the approved D&O Plan and includes protocol to manage industrial waste with NORM/TENORM. The Plan describes the types of gate monitors and other detectors used in screening for radioactivity at CSI. The updated Plan was voluntarily prepared in response to the request by CDPHE to develop a waste acceptance protocol that reduces the administrative burden by eliminating case-by-case reviews and approvals for acceptance of industrial waste with NORM/TENORM. The updated Plan provides an enhanced protocol for CSI to continue to accept industrial waste with small amounts of NORM/TENORM in an environmentally safe manner without case-by-case reviews performed by CDPHE.

Industrial wastes with small amounts of NORM/TENORM are securely disposed in engineered containment structures, or disposal cells. The design and location of the disposal cells are further described in the facility Design and Operations Plan. The current facility configuration consists of 12 individual and physically separate, discreet disposal cells. Each disposal cell consists of an area excavated to regulatory approved depths and elevations.

Environmental isolation of the waste materials is provided by lining the entire disposal area with a combination of compacted clay and synthetic materials, constructed to stringent standards and protocols approved by regulatory agencies. The cells also incorporate a leachate collection and removal system designed to remove liquids (primarily stormwater) that may accumulate in the cells. This leachate collection system consists of sloping the base of the disposal cells to a sump area to collect any liquids in the cell, and a piping system to allow the removal of the accumulated liquids. Transport of the liquids to the sump is facilitated by a permeable layer of sand or gravel in the base of the cell.

Depending on the waste type, periodic soil or other covers are applied to the wastes to minimize any nuisance conditions. Finally, when a cell is filled to pre-approved elevations, an approved final cover system is constructed to reduce the chance for precipitation or surface water to infiltrate into the cell and contact the waste. Executed and established quality assurance plans ensure all components of the containment system are constructed to approved design specifications. All portions of the disposal cells are constructed under strict third party oversight to specifications approved by the regulatory agencies. All soils, synthetic materials, and leachate collection and removal components are constantly tested during construction to ensure they meet the project requirements. Prior to placing any waste in a disposal cell, CSI is required to complete a final construction report and submit it to the regulatory agencies for approval.

CSI employs a number of techniques to minimize nuisance conditions as outlined in the EDOP. As described in the EDOP in section 7.4, depending on the waste type and nature of the materials, CSI applies soil or other approved cover material over the waste on a regular basis. This practice reduces dust, blowing litter, and odor generation.

CSI also has the capability to treat petroleum-contaminated soils through biological processes in their Prepared Bed Bio-Treatment (PBBT) facilities. This operation has been in use for a number of years, and provides an effective method for treatment and volume reduction of these types of wastes.

To protect groundwater and the surrounding environment, the D&O Plan provides for a series of 10 groundwater monitoring wells that are located close to the disposal areas. The groundwater monitoring network has been approved by a qualified groundwater scientist and regulatory agencies. The groundwater monitoring wells are sampled and analyzed on a routine basis. The monitoring results are submitted to appropriate agencies including CDPHE.

Section 8 of the updated Plan describes the environmental monitoring program for CSI. Environmental monitoring for leachate and groundwater is conducted in accordance with the approved Monitoring and Reporting Program prepared by BE&K/Terranext dated November 8, 1999. Leachate (if present) is currently sampled and analyzed semi-annually. In addition to the parameters listed in the monitoring plan, CSI will enhance the parameter list for leachate to include an annual analysis for gross alpha, gross beta, combined Ra-226/228 and U-nat All sampling results are placed in the site's operating record.

If radionuclides are verified to be detectable in the leachate at a statistically significant increase in concentration, radionuclide analysis will be incorporated into the groundwater-monitoring program. Results will be submitted to CDPHE, Adams County and Tri county Health Department in accordance with the approved monitoring plan.

6.0 THE RESRAD MODEL

The RESRAD computer model is designed to estimate dose risk from residual radioactivity in the material placed on site. The RESRAD computer code has been widely used by the US Department of Energy (DOE), the US Environmental Protection Agency (EPA), the US Army Corps of Engineers, the US Nuclear Regulatory Commission (NRC), industrial firms, universities, and foreign government agencies and institutions. The RESRAD computer model has also been used at other Colorado sites including Rocky Flats. RESRAD 6.3 (8/25/05) is the latest version available for use and was used for this updated report. The previous version RESRAD 6.22 was used for the previous submittal. The difference between the two versions is minor and does not effect the RESRAD results. Additional information about the RESRAD Family of Codes can be found on the Argonne National Laboratories web site at http://www.ead.anl.gov/. The RESRAD model and computer code is used to compute cumulative effective dose equivalent (CEDE) to workers or members of the public resulting from exposures to residual radioactive material in soil.

6.1 Exposure Pathways

The following exposure scenarios were evaluated in this report.

6.1.1 Direct Exposure to External Gamma Radiation

External gamma radiation from radionuclides in the contaminated soil has the largest influence for external exposure and is considered in all scenarios. The gamma radiation decreases fairly rapidly with increased cover depth.

6.1.2 Internal Dose from Airborne Radionuclides

Inhalation is another exposure pathway from the environmental conditions of the NORM/TENORM waste. Airborne dust associated with NORM/TENORM waste is a primary concern for workers. Radon gas is a potential concern both for the worker and to the general public after post-closure.

In the initial report (January 2005) radon gas was not considered as an exposure pathway in most the RESRAD models. In response to CDPHE questions and concerns on a robust cover a separate bounding scenario was completed to demonstrate low doses can be achieved even when institutional controls fail. We believe that institutional controls will succeed as they are developed for solid waste facilities in the Colorado Solid Waste Regulations. A notation is placed on the deed of the property stating that the property was used as an industrial waste landfill. Environmental covenants established in Colorado laws will also be in place controlling future activities on the site. Structures built on the property should not penetrate the cover and therefore would not include basements. Without a basement radon gas concentrations are very limited and considered insignificant. Inhalation of dust was considered for all scenarios.

Bounding scenarios were completed using radon and basements for a worst-case view of the exposure to radon. The RESRAD models used for the bounding scenarios are found in the file folder titled Future Waste Disposal Risk Assessments on the enclosed CD.

6.1.3 Internal Dose from Ingestion

Soil ingestion is considered for all pathways in the model because hand to mouth activities such as smoking, chewing tobacco, eating or unconsciously touching hands to face could result in ingestion of contaminated soil.

Plant ingestion is considered as a pathway in the model due to the close proximity of the crops grown and the contaminated zone, and the potential uptake of minerals from the contaminated residuals.

Meat, milk, and aquatic food ingestion is considered pathways in the model due to the close proximity of the contaminated zone to these potential food sources. A theoretical resident farmer can potentially raise livestock for food and milk and construct a pond that contains fish that are used for food.

Drinking water is considered a pathway when water is drawn from a pond or groundwater well for drinking water purposes. Drinking water is assumed to come from the shallowest groundwater found at the site, although the upper most groundwater beneath the majority of the site is found in isolated discontinuous silt and sand lenses within the claystone bedrock and would not be a viable drinking water source.

6.2 Exposure Scenario

The RESRAD computer model uses an exposure scenario that includes all patterns of human activity that can affect the release of radioactivity from the contaminated zone and the amount of exposure received at the exposure location. The typical exposure scenario is a ***resident farmer***; a family that moves on to the site, builds a home, and raises crops and livestock for family consumption. A diagram of the resident farmer is shown in Figure 2. Resident farmer family members can incur a radiation dose by:

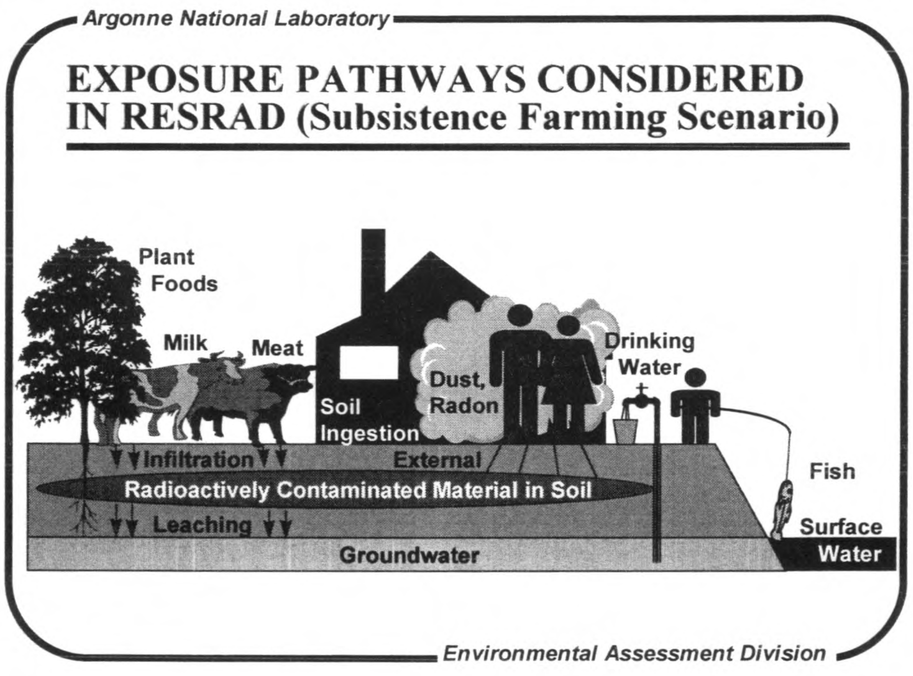
(1) direct radiation from radionuclides in the soil,
(2) inhalation of re-suspended dust (if the contaminated zone is exposed at the ground surface),
(3) inhalation of radon and its decay products (primarily in basements),
(4) ingestion of food from crops grown in the contaminated soil,
(5) ingestion of milk from livestock raised in the contaminated area,
(6) ingestion of meat from livestock raised in the contaminated are,
(7) ingestion of fish from a nearby pond contaminated by water percolating through the contaminated zone,
(8) ingestion of water from a well or pond contaminated by water percolating through the contaminated zone,

(9) ingestion of contaminated soil

The ***resident farmer*** is considered permanent and spends all their time on the site consuming foods grown and raised on the property. All aspects of exposure outlined in section 4.1 apply to the resident farmer family. A resident farmer family that spends all their time onsite and consumes 50% of all foods from the site is considered a worst case scenario because it is unlikely that a family would spend that much time and consume that much food from the site. The RESRAD computer model sets the criteria that the resident farmer family lives on the site for 30 years and is also exposed to the background radiation at the site. The background radiation is not considered in the residential farmer exposure.

Figure 2

RESRAD Exposure Pathways for Resident Farmer Family Scenario



6.3 *Waste Activity and Concentration*

A variety of radionuclides can be used in the RESRAD model. Only radionuclides commonly associated with NORM and TENORM are used. Analytical results from industrial waste with small amounts of NORM/TENORM previously disposed of at the facility are used for the risk analysis. RESRAD computer modeling for the future industrial waste with small amounts of NORM/TENORM at the site uses fixed concentrations that closely approximate those used for similar studies of wastes in landfills and the ISCOR studies described in this report.

6.4 Contaminated Zone Parameters

The RESRAD computer model allows for the use of a variety of contaminated zone parameters. The parameters set up the size, area and geometry of the contaminated zone. Details of parameters chosen to ensure a conservative analysis are discussed in later sections and the contaminated zone parameters are found in the Site Specific RESRAD Input Values in Table 3.

Dimensions of each of the disposal cells are taken from Plate 2 in D&O Plan[3]. This map along with Table 6-1 in the D&O Plan was used to determine the size of each of the disposal cells. The volume of each of the disposal cells was taken from Table 6-2 in the D&O Plan. For ease and continuity the dimension of the contaminated zone was rectangular based upon the area of the top of each disposal cell and averaged depth based upon the volume of the entire disposal cell.

This is conservative because the disposal cells are trapezoids and the area of the cell at the ground surface is the largest and the cell decreases with depth and height. Using the largest area of the cell results in calculations that increase the exposure to a resident farmer in the center of the contaminated zone. Actual exposures would likely be less when the waste is buried below grade.

6.5 Unsaturated and Saturated Zone Hydrologic Parameters

Hydrologic and geologic parameters for the saturated and unsaturated zones were taken from site-specific data as much as possible and validated by a registered professional geologist as appropriate for use in the model. The site-specific values used are found in Table 3. Soil type data was used when available, however whenever the soil type data closely approximated the default data, the default was used. When site specific values were not available, RESRAD defaults were used. Weather information (wind speed and precipitation) was taken from a national database service for Denver International Airport (DIA) located approximately 10 miles to the west.

A minimum separation of 15 feet (4.57 meters) from waste to ground water was an original design consideration at the CSI facility. The cohesive soil liner and drainage layer are a minimum of 2.5 feet (0.76 meters) thick. The synthetic liner represents two meters of clay, a value justified in the previous risk assessment for Molycorp waste and the waste approved and disposed at the site. This is a conservative value based on one-third the predicted thickness of clay that would represent a synthetic liner permeability of 1×10^{-12} cm per second. Accordingly, there is at least 15 feet (4.57 meters) total of separation below any of the disposal cells.

The unsaturated zone for many of the disposal cells is much greater than 15 feet (4.57 meters) however, the more conservative values were used. The eastern area of the CSI facility, below Cell #25, has different characteristics from the other areas of the site;

[3] Conservation Services Inc., Revised Design and Operations Plan, Adams County CD 86-88 CD (A), February 1996.

therefore different subsurface values were used. The site-specific conditions for the RESRAD models are found in Table 3.

6.6 Human Receptor Parameters

The RESRAD computer model estimates the annual dose by taking into account the occupancy, inhalation and ingestion data. Occupancy includes the time a subject will spend both inside and outside the structure. The residential scenario the model continues to calculate over 1000 years.

Inhalation rates and soil ingestion rates were not changed from the RESRAD default values. All details for the RESRAD input are found in Tables 3 and 1 or in the January 2005 submitted Appendix A preceding the RESRAD output results for waste previously received. Radon exposure was evaluated in a bounding scenario even when it is specifically excluded in the radiation dose standard of 25mrem/yr.

6.7 Resident Parameters

Default residential values were used for the inputs to RESRAD. The default parameters include the following:

- 30 year duration
- 52 weeks per year
- 7 days per week
- 12 hours per day inside
- 4 hours per day outside

Default values were used for inhalation, soil ingestion, drinking water rates, and foods consumed. In the January 2005 report the resident farmer's home was assumed to be slab on grade and not penetrate the ground surface. Radon in the house was not accounted for based upon the exclusion in Title 40 Code of Federal Regulations, Part 190 (40CFR190) and Colorado Radiation Control Regulations RH 4.5.4.

Radon in a basement was considered for a resident farmer on top of the facility based upon requirements from CDPHE to demonstrate a robust cover over 1000-year period. This radon in a basement scenario on top of the closed facility is an unrealistic scenario because there are institutional, environmental and physical constraints to prohibit a basement from being built. The radon in a basement scenario was evaluated using RESRAD and the results are reported. Results of radon exposure in basements should not be considered to be a waste volume or activity constraint at the facility but guidance for additional studies or activities in the future.

7.0 PREVIOUSLY DISPOSED WASTE EVALUATION

Approximately 30,000 cubic yards of industrial waste with small amounts of NORM/TENORM was disposed of at the facility previously. Each industrial waste disposal project included a risk assessment specific to the materials received. New RESRAD risk assessments for each of the disposal projects was completed and the results summed. Concentrations of radionuclides specific to the waste were used in all cases. Contaminated zone parameters were changed in size to reflect the actual volumes received. Exposure pathways were the same as those used for future waste activities.

7.1 Exposure Pathways

The following exposure scenarios were evaluated. External gamma radiation from radionuclides has the largest influence for external exposure and is considered in all projects.

- Inhalation exposure from contaminated dust. Radon gas was not considered as an exposure pathway because the site has institutional controls established in the Colorado Solid Waste Regulations. A notation is placed on the deed of the property stating that the property was used as an industrial waste landfill. Structures built on the property are not allowed to penetrate the cover and therefore cannot include basements. The areas for radon gas to accumulate in enclosed spaces without air movement are very limited and considered insignificant in structures without basements.
- Soil ingestion is considered for all pathways because hand to mouth activities such as smoking, chewing tobacco, eating or unconsciously touching hands to face could result in ingestion of contaminated soil.
- Plant ingestion is considered as a pathway due to the close proximity of the crops grown and the contaminated zone and the potential uptake of minerals from the contaminated residuals.
- Meat, milk, and aquatic food ingestion is considered as a pathway due to the close proximity of the contaminated zone. A theoretical resident farmer can potentially raise livestock for food and milk and construct a pond that contains fish that are used for food.
- Drinking water is considered a pathway when water is drawn from a pond or groundwater well for drinking water purposes. Drinking water is assumed to come from the shallowest groundwater found at the site; although this scenario is unlikely due to the quantity and quality of the shallowest groundwater.

7.2 Waste Activity and Concentration

Concentrations of radionuclides were taken from the analytical results available or the concentration values previously entered into the original risk assessment. Site-specific values used are summarized on Table 1 and Table 3 or in tables preceding each risk assessment in the Previous Risk Assessment file folder on the enclosed CD. The

RESRAD program handles the progeny for each of the radionuclides. The initial RESRAD runs did not show polonium-210 as a daughter product of radium-226. The RESRAD program has a default cut off half-life of 180 days and the half-life for Po210 is 138 days. The default half-life cut off was changed to 30 days to include Po210 in the long-term progeny. The results did not change the dose value and were not expected to. The RESRAD program considers the progeny in secular equilibrium and includes it in the dose calculations.

7.3 Contaminated Zone Parameters

Contaminated zone parameters were modified to account for the actual volume of waste received. The modified value for each waste disposal project is found on the input tables preceding their respective risk assessment in the file folder titled Previous Risk Assessment on the enclosed CD.

The dimensions of the contaminated zones are based upon waste manifest records including the date and knowledge of the area being filled. For ease and continuity the dimension of the contaminated zone is assumed to be a rectangle with the average depth based upon the volume of the waste disposed in the disposal cell.

7.4 Unsaturated and Saturated Zone Hydrologic Parameters

The site-specific data used is the same for all the risk assessments. Three unsaturated zones are used, one for each of the following layers.

- <u>Zone 1 – Non-hazardous waste layer</u>: Non-hazardous waste in the disposal cell below the industrial waste with small amounts of NORM/TENORM. This zone has been used in many of the RESRAD runs, however it is input with a thickness of zero to make the model more conservative.

- <u>Zone 2 –Liner system</u>: The entire liner system including the synthetic liner and cohesive soil liner is represented. Two meters of clay represent the synthetic liner. This is a conservative value base on one-third the predicted thickness of clay that would represent a synthetic liner permeability of 1×10^{-12} cm per second. The risk assessment completed for MolyCorp, Inc. and previously approved by CDPHE are included in this value.

- <u>Zone 3 – Unsaturated subsurface soil layer</u>: The conservative values of the sub-surface characteristics under Cell #25 are used for this layer. A minimum of 15 feet separation from the waste to the first water bearing zone is specified in the D&O Plan, which makes this layer 12 feet (3.65 meters) thick. Using 12 feet for this layer is conservative because there is three feet of clay liner in the sump, the lowest point of any one disposal cell, and an additional 0.5 to 2.0 feet of drainage material above the liner system as shown in Figure 1. Accordingly, there is at least 15 feet of separation below any of the disposal cells.

The disposal cell construction diagram is found in Figure 1. The saturated zones are the same for all the cells at the site. The saturated conditions are for a silt/sand mixture.

7.5 Human Receptor Parameters

The RESRAD computer model estimates the annual dose by taking into account the occupancy, inhalation and ingestion data. Occupancy includes the time a subject will spend both inside and outside the structure. Food, water and soil are calculated for ingestion. Additionally the inhalation of dust, and radon are accounted for as appropriate. Radon is turned off based upon the exclusion in 40CFR190. The residential scenario in the model continues to calculate risk over 1000 years.

Inhalation rates based upon the level of physical activity and soil ingestion rates were not changed from the RESRAD default values. All details for the RESRAD input were taken from Tables 1 and Table 3 and input values provided preceding each risk assessments in the Previous Risk Assessment file folder on the enclosed CD.

7.6 Resident Parameters

Default residential values were used for the inputs to RESRAD. The default parameters include the following:

- 30 year duration
- 52 weeks per year
- 7 days per week
- 12 hours per day inside
- 4 hours per day outside

Default values were used for inhalation, soil ingestion, drinking water rates, and foods consumed. The home was assumed to be slab on grade and not penetrate the ground surface. Radon in the house was not accounted for based upon the exclusion in 40CFR190.

7.7 RESRAD Resident Farmer Results

RESRAD output results for each of the disposal cells that <u>have</u> received industrial waste with small amounts of NORM/TENORM is shown in Table 4. Small amounts of additional NORM/TENORM waste have been received with the concentration of radionuclides lower that those modeled for in this study. The additional wastes do not change the RESRAD output and are not considered further because they do not significantly impact the source term. The RESRAD output for each individual cell is summed to determine the total overall dose from the site. The RESRAD output results for all the cells that have received waste with small amounts of NORM/TENORM are found with complete results on the CD in the folder titled Previous NORM TENORM Waste Disposal.

The RESRAD output results estimate a maximum total dose for the resident farmer up to 1000 years. All the exposure pathways were used for this dose estimate. The total dose is well below the 25-mrem/yr-dose threshold standard.

7.8 *Previous Wastes Disposed Results*

Approximately 30,000 cubic yards of industrial waste with small amounts of NORM/TENORM was disposed of at the facility previously. Each industrial waste disposal project included a risk assessment specific to the materials received. The risk assessments were done using different risk models and software editions based upon the specific project. A summary of the previous risk assessments and the results of the new risk assessments are found in Table 5. Output files from RESRAD runs are found in the file folder titled Previously Disposed of Waste on the enclosed CD.

Table 4

Summary of Previous Waste Received Total Dose Per Disposal Cell

Cell Number Waste Name	Dose at 1000 years Dose Summed over All Pathways (mrem/yr)
2 (Shattuck)	4.240E-11
19/20	8.4561E-21
CSMRI	0.00E+0
Molycorp Process Residue	1.459E-21
Molycorp Soils	5.245E-21
Molycorp Lining Mtls.	6.581E-22
Molycorp Rare Earth	1.094E-21
Total	4.240E-11

7.9 *Comparison of Case-by-case Models and RESRAD Model*

Industrial wastes with small amounts of NORM/TENORM disposed of previously were approved based upon risk assessment models submitted at that time. All of the models showed that the exposures were very low. The risk assessment models are summarized in Table 6.

Table 5
Summary of Waste Received and Comparison of Previous Modeling

Cell #	Waste Name	Volume in cubic yards	Volume in cubic meters	Molen/REM Dose from RESRAD (mrem/yr)	ISHOLD II Exposure by Duggan (mrem/yr)	COMPLY Exposure by REM (mrem/yr)	RESRAD Exposure by HLA (mrem/yr)	Cover depth in meters	Cover depth in feet
2	Shattuck	3402	2601	4.24E-11	15.84			3.44	11.29
19/20	Other small volumes*								
19/20	CSMRI	21870	16721	0.00E+00		33.3		14.33	47.01
19/20	Molycorp Process Residue	3155	2412	1.46E-21			6.13	5.03	16.50
19/20	Molycorp Soils	667	510	5.25E-21			9.68	5.03	16.50
19/20	Molycorp Lining Mtls.	241	184	6.58E-22			2.19	5.03	16.50
19/20	Molycorp Rare Earth	105	80	1.09E-21			2.44	5.03	16.50

* Volumes include firebrick, Kaiser Hill drinking waste residuals, Shattuck RR ballast, Suncor pipe scale, others not covered.

COMPLY and the HLA RESRAD exposure models included radon the Molen/REM RESRAD did not include radon.

8.0 FUTURE INDUSTRIAL WASTE DISPOSAL

The assessment of concentrations of radionuclides that may be acceptable at the facility was performed and is described in this section. A previous study performed for the National Petroleum Technology Office and US DOE indicates that NORM waste with average concentrations between 0-50 pCi/g of Ra-226 should be acceptable at non-hazardous waste landfills (NPTO-DOE 1999). Industrial wastes with small amounts of NORM/TENORM that have been previously disposed of at the CSI facility have had Ra-226 concentrations in the range of 0-50 pCi/g. Other wastes considered for a case-by-case acceptance at the facility have typically had Ra-226 concentrations within this range.

The concentration of Ra-226 has the most significant contribution to the exposure scenarios from the external radiation. The other radionuclides commonly associated with NORM/TENORM type waste were also considered in the RESRAD models however their contribution to external exposures are one-third that of radium. When radon is considered, Th-230 is an additional significant contributor to the exposure scenario.

8.1 Exposure Pathways

The following exposure scenarios were evaluated.

- External gamma and beta radiation from radionuclides has the largest influence for external exposure and is considered in this scenario.

- Inhalation dose from contaminated dust. In the initial January 2005 submittal radon gas was not considered as an exposure pathway because the site has institutional controls established in the Colorado Solid Waste Regulations. Institutional controls should be considered in evaluation of exposure risk because they become a part of the historic land record. A notation is placed on the deed of the property stating that the property was used as an industrial waste landfill. Structures built on the property are not allowed to penetrate the cover and therefore cannot include basements. Without basements, radon gas accumulation is very limited and considered insignificant. The institutional controls should not fail, however for precautionary purposes, modeling was completed and assumed the maximum dose from inhalation or radon in a home built on the facility with a basement. Inhalation of dust was considered for this scenario.

- Soil ingestion is considered for all pathways because hand to mouth activities such as smoking, chewing tobacco, eating or unconsciously touching hands to face could result in ingestion of contaminated soil.

- Plant ingestion is considered as a pathway due to the close proximity of the crops grown and the contaminated zone and the potential uptake of minerals from the contaminated residuals.

- Meat, milk, and aquatic food ingestion is considered as a pathway due to the close proximity of the contaminated zone. A theoretical resident farmer can potentially raise livestock for food and milk and construct a pond that contains fish that are used for food.

- Drinking water is considered a pathway when water is drawn from a pond or groundwater well for drinking water purposes. Drinking water is assumed to come from the shallowest groundwater found at the site.

8.2 Waste Activity and Concentration

Predicting the concentrations of radionuclides in the industrial wastes received in the future is problematic and impracticable. Each generator of waste will have a differing concentration of radionuclides. The concentration of Ra-226 has the most significant contribution to the exposure scenarios from the external radiation. The other radionuclides commonly associated with NORM/TENORM type waste were also considered in the RESRAD models however their contribution to external exposure is one-third that of radium. The concentration of Ra-226 has the most significant contribution to the external radiation exposure scenario.

A previous study performed for the National Petroleum Technology Office and US DOE indicates that NORM waste with average concentrations between 0-50 pCi/g of Ra-226 should be acceptable at non-hazardous waste landfills (NPTO-DOE 1999). Industrial waste with small amounts of NORM/TENORM that have been previously disposed of at the facility had Ra-226 concentrations in the range of 0-50 pCi/g. Other wastes considered on a case-by-case acceptance at the facility have typically had Ra-226 concentrations in this range.

The average maximum concentrations are the standards for all waste with small amounts of NORM/TENORM approval activities at the site and are incorporated into the Updated Plan for Conservation Services, Inc. submitted separately. Acceptable industrial waste with small amounts of NORM/TENORM will not be allowed to have average concentrations exceeding those listed in Table 6.

Table 6

Maximum Radionuclide Concentrations

Radionuclide	Maximum Concentration
Radium 226	50 pCi/g
Radium 228	12.5 pCi/g
Thorium 228	150 pCi/g
Thorium 230	150 pCi/g
Thorium 232	55 pCi/g
Lead 210	150 pCi/g
Uranium 234	300 pCi/g
Uranium 238	150 pCi/g
Uranium - nat	300 pCi/g
No waste streams will exceed the regulatory definition of source material. Source material is defined as 0.05 percent by weight of uranium and thorium.	

RESRAD computer modeling for the future industrial waste with small amounts of NORM/TENORM at the site used the above concentrations.

8.3 *Sensitivity Analysis*

The RESRAD model was evaluated to determine which NORM/TENORM radionuclides were the most sensitive to the output results in 1000 years. Cell 18/21/22/23 was used with the area, thickness and cover depth remaining constant. The concentrations of the NORM/TENORM radionuclides were held constant using the concentrations listed in Table 6 while one radionuclide was varied. The RESRAD results show that when they are varied, the concentrations of Ra-226 and Th-232 have the largest impact on the dose when radon is not considered.

Contaminated zone parameters were evaluated for sensitivity to thickness of subsurface conditions and the liner. The results indicate that the RESRAD dose output is not significantly impacted by changes in the contaminated zone (area, thickness). The thicknesses of the saturated and unsaturated zones do not significantly impact the RESRAD output results. The RESRAD model was run without a liner system under disposal cell and the dose output results were not significantly different than when a clay liner thickness of 2.61 meters was used. The liner and subsurface conditions do not have a significant impact on the RESRAD output results in this application when radon is not considered.

The parameter that is most sensitive to changes is the cover thickness above the NORM/TENORM waste. Cover thickness less than 1.75 meters thick show a dramatic increase in doses of all components and all pathways at t=1000. Doses of all components and all pathways with a thickness of 1.6 meters thick is equal to 252 mrem/year compared to a dose rate of 0.021 mrem/yr for a thickness of 1.75 meters.

Based upon the significance of the cover thickness to the overall dose rate the thickness value was doubled to provide a more conservative approach to protection from future disposal of waste with small amounts of NORM/TENORM. A thickness of 3.5 meters is used in all of the RESRAD dose and risk calculations and is a standard for waste with small amounts of NORM/TENORM received at CSI in the future.

Radon is not evaluated in the RESRAD models as previously noted, however with radon turned on and the cover thickness evaluated, the RESRAD results show that a 7-meter thick cover has a dose of less than 25 mrem/yr. A cover thickness of 7 meters significantly impacts the volume and management of industrial waste with small amounts of NORM/TENORM when the average depth of a disposal cell in Table 1 is 12.79 meters. A bounding scenario of one half the 7 meter thick cover provides a protection for radon of approximately 100 mrem/year in t=1000 years.

Sensitivity of the RESRAD computer model was evaluated with the results demonstrating that the significant parameter is cover thickness. All other parameters do not significantly impact the RESRAD model results. Both Ra-226 and Th-232 are the primary constituents of concern for this RESRAD risk assessment with Th-230 a concern when radon is considered. As a bounding scenario in the sensitivity analysis this scenario is maximum worst case. All disposal cells are expected to contain a considerable amount of industrial waste that does not have radioactivity concerns. A typical worst case scenario would be approximately 30% of the cell volume being from NORM/TENORM waste lowering the overall doses considerably from the theoretical values as shown in Table 10 and the bounding scenarios in the file folder titled Future Waste Disposal Risk Assessments on the enclosed CD. A 3.5-meter cover thickness is considered conservative and is used in all the future disposal scenarios.

Table 7

Sensitivity Analysis on Radionuclide

Radionuclide	Concentration	Dose
Radium 226	50 pCi/g	1.994E-11
	100 pCi/g	2.010E-11
	150 pCi/g	2.026E-11
	1000 pCi/g	2.301E-11
Radium 228	12.5 pCi/g	
Thorium 228	150 pCi/g	
Thorium 230	150 pCi/g	
Thorium 232	150 pCi/g	
Lead 210	150 pCi/g	
Uranium 234	150 pCi/g	
Uranium 238	150 pCi/g	

Radionuclide	Concentration	Dose
Thorium 230	50 pCi/g	1.977E-11
	100 pCi/g	1.985E-11
	150 pCi/g	1.994E-11
	1000 pCi/g	2.143E-11
Radium 226	50 pCi/g	
Radium 228	12.5 pCi/g	
Thorium 228	150 pCi/g	
Thorium 232	150 pCi/g	
Lead 210	150 pCi/g	
Uranium 234	150 pCi/g	
Uranium 238	150 pCi/g	

Radionuclide	Concentration	Dose
Thorium 232	50 pCi/g	6.931E-12
	100 pCi/g	1.344E-11
	150 pCi/g	1.994E-11
	1000 pCi/g	1.305E-10
Radium 226	50 pCi/g	
Radium 228	12.5 pCi/g	
Thorium 228	150 pCi/g	
Thorium 230	150 pCi/g	
Lead 210	150 pCi/g	
Uranium 234	150 pCi/g	
Uranium 238	150 pCi/g	

Radionuclide	Concentration	Dose
Uranium 238	50 pCi/g	1.994E-11
	1000 pCi/g	1.994E-11
Radium 226	50 pCi/g	
Radium 228	12.5 pCi/g	
Thorium 228	150 pCi/g	
Thorium 230	150 pCi/g	
Lead 210	150 pCi/g	
Thorium 232	150 pCi/g	
Uranium 234	150 pCi/g	

Radionuclide	Concentration	Dose
Uranium 234	50 pCi/g	1.994E-11
	1000 pCi/g	1.995E-11
Radium 226	50 pCi/g	
Radium 228	12.5 pCi/g	
Thorium 228	150 pCi/g	
Thorium 230	150 pCi/g	
Lead 210	150 pCi/g	
Thorium 232	150 pCi/g	
Uranium 238	150 pCi/g	

Radionuclide	Concentration	Dose
Lead 210	50 pCi/g	1.994E-11
	1000 pCi/g	1.994E-11
Radium 226	50 pCi/g	
Radium 228	12.5 pCi/g	
Thorium 228	150 pCi/g	
Thorium 230	150 pCi/g	
Uranium 234	150 pCi/g	
Thorium 232	150 pCi/g	
Uranium 238	150 pCi/g	

Radionuclide	Concentration	Dose
Thorium 228	50 pCi/g	1.994E-11
	1000 pCi/g	1.994E-11
Radium 226	50 pCi/g	
Radium 228	12.5 pCi/g	
Lead 210	150 pCi/g	
Thorium 230	150 pCi/g	
Uranium 234	150 pCi/g	
Thorium 232	150 pCi/g	
Uranium 238	150 pCi/g	

8.4 *Contaminated Zone Parameters*

The size of the contaminated zone is input as a cubic rectangle. The dimensions of the rectangle are approximately equivalent to the maximum area of the disposal cell. The thickness of the cubic rectangle is dependent on the total volume of airspace in each disposal cell. A map showing the boundaries of each of the disposal cells is in Future Waste Disposal Cells on the CD corresponding to the disposal cell number. The dimensions of each disposal cell are converted into meters and the values entered into Table 1.

Using disposal cell 24 as an example, the length of north south boundaries of the cell is approximately 366 meters (1200 ft) and the width of the east west boundaries is approximately 152 meters (500 ft). Using an average depth of 12.38 meters the total volume of the cubic rectangle is approximately equal to the total volume of airspace (366m x 152m x 12.36m =688,724m^3) or 900,900 cubic yards. These values have been computed in a spreadsheet with information from Table 6-1 and Table 6.2 in the D&O Plan.

Each cell is calculated similarly and cubic rectangles formed in each RESRAD computer model. The site-specific data (i.e., density, porosity, etc) was determined and is shown in tables preceding each RESRAD output in the appendices corresponding to each disposal cell.

8.5 *Unsaturated and Saturated Zone Hydrologic Parameters*

The site-specific data used is the same for all the risk assessments. Three unsaturated zones are used, one for each of the following layers.

- Zone 1 – Non-hazardous waste layer: Non-hazardous waste in the disposal cell below the industrial waste with small amounts of NORM/TENORM. This zone has been used in many of the RESRAD runs, however it is input with a thickness of zero to make the model more conservative.

- Zone 2 –Liner system: The entire liner system including the synthetic liner and cohesive soil liner is represented. Two meters of clay represent the synthetic liner. This is a conservative value base on one-third the predicted thickness of clay that would represent a synthetic liner permeability of 1 x 10^{-12} cm per second. The risk assessment completed for MolyCorp, Inc. and previously approved by CDPHE are included in this value.

- Zone 3 – Unsaturated subsurface soil layer: The conservative values of the sub-surface characteristics under Cell #25 are used for this layer. A minimum of 15 feet separation from the waste to the first water bearing zone is specified in the D&O Plan, which makes this layer 12 feet (3.65 meters) thick. Using 12 feet for this layer is conservative because there is three feet of clay liner in the sump, the lowest point of any one disposal cell, and an additional 0.5 to 2.0 feet of drainage material above the liner system as shown in Figure 1. Accordingly, there is at least 15 feet of separation below any of the disposal cells.

The disposal cell construction diagram is shown in Figure 1. The saturated zones are the same for all the cells at the site. The saturated conditions are for a silt/sand mixture.

8.6 Human Receptor Parameters

The RESRAD computer model estimates the cumulative effective dose for any year by taking into account the occupancy, inhalation and ingestion data. Occupancy includes the time a subject will spend both inside and outside the structure. Food, water and soil are calculated for ingestion. Additionally the inhalation of dust, and radon are accounted for as appropriate. In the initial January 2005 submittal radon was turned off based upon the exclusion in 40CFR190. To satisfy CDPHE an unrealistic scenario of a resident farmer with a basement on top of the disposal cell was evaluated. This is unrealistic because there are institutional controls that would prohibit both the building of the structure and the penetration of the cover for a basement. For the residential scenario, the model continues to calculate over 1000 years.

Inhalation rates based upon the level of physical activity and soil ingestion rates were not changed from the RESRAD default values. All details for the RESRAD input values are found in Table 1,2,3 and 7.

8.7 Resident Parameters

Default residential values were used for the inputs to RESRAD. The default parameters include the following:

- 30 year duration
- 52 weeks per year
- 7 days per week
- 12 hours per day inside
- 4 hours per day outside

Default values were used for inhalation, soil ingestion, drinking water rates, and foods consumed. The home was assumed to be slab on grade and not penetrate the ground surface. Radon in the house was not accounted for based upon the exclusion in 40CFR190.

8.8 RESRAD Resident Farmer Results

RESRAD output results for each disposal cell that would receive waste with NORM/TENORM in the future is shown in Table 8. The RESRAD output for each individual cell is summed to determine the total overall dose from the site. When radon is considered Cell 13-17 was modeled by RESRAD with a resident farmer on top with a basement that extends one meter below the ground surface. This would represent a maximally exposed individual and is considered unrealistic as described in Section 8.9. The overall dose when radon is on and volumes of waste with small amounts of NORM/TENORM are varied is summarized in Table 11. Summarized RESRAD results indicate that radon has a significant impact on dose when a resident farmer has a basement. To have a dose exposure limit below 25 mrem/yr for the resident farmer with a basement the volume of waste with small amounts of NORM/TENORM that can be received would have to be less than 3% of the total volume of waste in Cell 13-17. A cover of 3.5 meters is used in the resident farmer in a basement scenario.

Table 8

Summary of Total Dose Per Disposal Cell

Cell Number	Dose Summed over All Pathways (mrem/yr) t=1000 years	Excess Cancer Risk over all Pathways t= 1000 years
2	4.240E-11	
19/20	8.4561E-21	
4/5/08	2.113E-11	4.9E-16
6/7/09	2.112E-11	4.9E-16
10/11/12	2.112E-11	4.9E-16
13-17	2.113E-11	4.9E-16
18/24/22/23	2.113E-11	4.9E-16
24	2.112E-11	4.9E-16
25	2.113E-11	4.9E-16
Total	1.48E-10	3.43E-15

The RESRAD results estimate a maximum total dose for the resident farmer for any number of years up to 1000 years. Without radon the dose for the first 500 years was estimated to be zero mrem/yr as seen in the chart at the end of each RESRAD output results. All the exposure pathways were included in this dose estimate. The total dose is well beneath the 25-mrem/yr-dose threshold limit when radon is excluded.

As mentioned above, the most significant contribution to external exposure is Ra-226 and is shown as a comparison to other radionuclides in Table 9. RESRAD separates the dose contributions based upon the individual radionuclides. The dose from each of the individual radionuclides is shown in Table 9.

The assessment determined that the dose risk standard of 25 mrem/yr (excluding radon) is not exceeded when a disposal cell is filled primarily with industrial waste with small amounts of NORM/TENORM having a maximum concentration of radionuclides found in Table 6. The risk assessment is based upon the concentrations in Table 6 and does not account for radon.

Table 9

Dose Contribution from Individual Radionuclides
t=1000 years

Radionuclide	Individual Dose Summed over All Pathways (mrem/yr)
Lead 210	0.000E+00
Radium 226	9.91937E-13
Radium 228	0.000E+00
Thorium 228	0.000E+00
Thorium 230	1.64466E-12
Thorium 232	1.24145E-10
Uranium 234	7.83308E-15
Uranium 238	1.38206E-15
Total	1.26791E-10

When radon is included in the assessment the dose risks increases significantly. Addressing the increase dose as it relates to the volume of industrial waste with small amounts of NORM/TENORM and the concentrations of radionuclides can be done be using fractions of the amounts of waste and radionuclides. A summary of RESRAD output results are listed in Table 10 showing the percent of waste with small amounts of NORM/TENORM and their predicted dose exposures in mrem/yr. The 100 mrem/yr threshold is exceeded at approximately 13% of industrial waste with small amounts of NORM/TENORM. At approximately 3% of industrial waste with small amounts of NORM/TENORM the 25 mrem/yr standard is met. All these results consider a cover depth of 3.5 meters. RESRAD output results also show that the most significant radionuclides effecting radon are Ra-226 and Th-230.

Table 10

NORM/TENORM Dose as a Percentage of Waste	
Percentage of NORM / TENORM in Cell 13-17	Dose to a Maximally Exposed Individual
30	233.6
25	194.6
20	155.7
15	116.8
13	101.2
12	93.43
10	77.86
3	27.83
2	20.09
1	12.35

Based upon RESRAD models shown in the file folder titled Maximally Exposed Individual on the enclosed CD

The RESRAD computer model was completed on worst-case scenarios where all the disposal cells were filled to capacity, with industrial waste with small amounts of NORM/TENORM. Excluding radon the dose from this concentration of industrial waste with small amounts of NORM/TENORM is within the current dose standard of 25 mrem/yr as shown in Table 9. The dose to a resident farmer when radon is considered, in a structure without a basement, increases to approximately 85 mrem/yr in 1000 years. When the resident farmer includes a basement and radon (a maximally exposed individual scenario), the dose is as high as 2500 mrem/yr. The reason the dose increases is because the basement provides an area for the radon to accumulate and provide an inhalation hazard to the resident farmer.

When radon in the maximally exposed individual is considered and the dose held below approximately 25 mrem/yr only 3 percent of the industrial waste with small amounts of NORM/TENORM may be received. The results listed in Table 10 shows how the doses change based upon the percentage of waste with small amounts of NORM/TENORM. Three percent of the total volume of Cell 13-17 is approximately 80,644 cubic yards as shown in Table 11.

Table 11

WM/CSI Disposal Cell Volumes

Cell Number	Volume in Meters	Volume in Cubic Yards (CY)	12% of Waste in CY as NORM / TENORM	3% of Waste as NORM / TENORM
1	Full			
2	Full	Full		
3	Full			
4/5/8	538510	704350	84522	21130
6/7/9	410219	536550	64386	16096
10/11/12	515612	674400	80928	20232
13-17	2055225	2688150	322578	80644
18/21/22/23	1305393	1707400	204888	51222
19/20	Full	Full		
24	688783	588040	108108	27027
25	1247249	900900	195762	48940
Totals	6760992	8843100	1061172	265293

8.9 Volume Monitoring for Radon

CDPHE asked that radon gas be considered in the exposure scenario and a constraint of 25 mrem/yr to a member of the general public, a resident farmer on top of the landfill 1000 years in the future. This is an unrealistic scenario and the results should not be used to constrain disposal activities at the facility and instead be used as a bounding scenario indicating the absolute worst case. The resident farmer with radon in a basement is a maximally exposed individual. The risk assessment should be held to a standard of the dose to an average member of a critical group not the maximally exposed individual. The argument for not using a maximally exposed individual is described in the Consolidated

NMSS Decommissioning Guidance, Updated to Implement the License termination Rule Analysis[4] as follows:

> "As required by 10CFR 20.1402, expected doses are evaluated for the average member of the critical group, which is not necessarily the same as the maximally exposed individual. This is not a reduction in the level of protection provided to the public but is an attempt to emphasize the uncertainty and assumptions needed in calculating potential future doses while limiting boundless speculation on possible future exposure scenarios. While it is possible to actually identify, with confidence, the most exposed member of the public in some operational situations (through monitoring, time-studies, distanced from the facility, etc.), identification of the specific individual who should receive the highest dose some time (up to 1000 years) in the future is impractical, if not impossible. Speculation on his or her habits, characteristics, age, or metabolism could be endless. The use of the "average member of the critical group" acknowledges that any hypothetical "individual" used in the performance assessment is based, in some manner, on the statistical results from data sets (i.e., the breathing rate is based on the range of possible breathing rates) gathered from groups of individuals. While bounding assumptions could be used to select values for each of the parameters (e.g., the maximum amount of meat, milk, vegetables, possible exposure time), the result could be an extremely conservative calculation of an unrealistic scenario and may lead to excessively low allowable residual radioactivity levels."

Holding CSI to the standard of the maximally exposed individual when his/her exposure to radon is the only factor contributing to the high dose is unrealistic and unwarranted. CSI chose to use a reasonable average member of the critical group as a standard. This average member of the critical group would be on top of the landfill for their entire life (a conservative assumption) in an area without a basement and would not be held to the standards for radon. When that scenario is considered the dose risk is very low as shown in Table 9.

The information to calculate the maximally exposed individual scenario will be available in the operating record at CSI. CSI should be able to receive as much waste with small amounts of NORM/TENORM as is allowed based upon the size of disposal cells and cover requirements. When the volume of waste with NORM/TENORM approaches the 3% volume ranges as shown in Table 11, one of the following actions will be considered:

1. a radon gas survey be conducted to collect actual onsite date and using models to predict the concentrations of radon gas in a basement on the closed disposal cell
2. a physical barrier armoring the cover will be placed on the top of the closed disposal cell such that excavation into the disposal cell would be adequately prevented

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[4] U.S. Nuclear Regulatory Commission, *Consolidated NMSS Decommissioning Guidance – Updates to Implement the License Termination Rule Analysis – Draft NUREG – 1757, Supp. 1*, page IV-9, September 2005

3. additional cover (one meter) will be placed on top of the closed disposal cell to compensate for the radon exposure potential in a basement
4. other methods determined to be acceptable at the time of cell closure.

By taking this approach, CSI will not be limited in the concentrations and amounts of wastes with small amounts of NORM/TENORM, above those listed in Table 6.

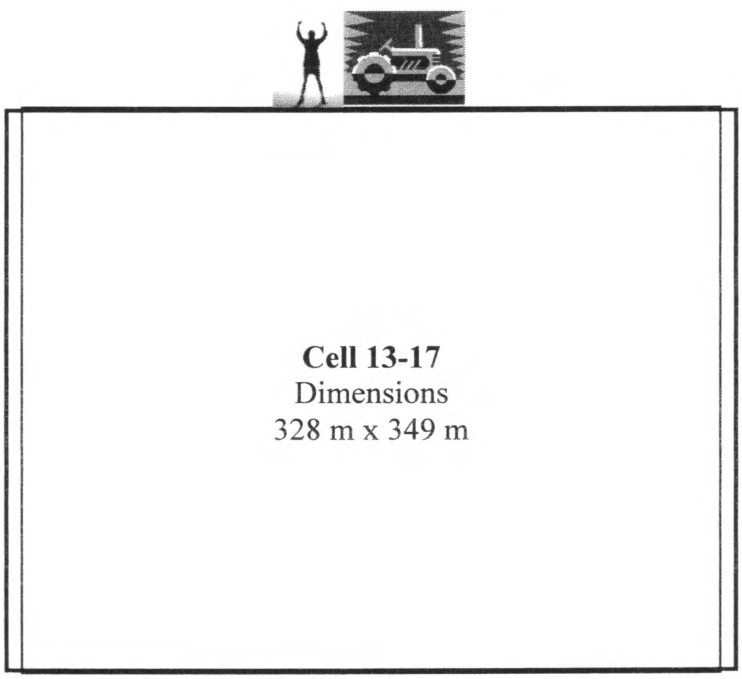
9.0 WORKER SCENARIO

This worker scenario is designed to evaluate the effects of working at the landfill and the potential contact with contaminants in the industrial waste with small amounts of NORM/TENORM delivered to the facility. The initial January 2005 submittal did not include the workers exposure to radon. This worker scenario is designed to assess the external radiation exposure and exposure to radon.

A worker may contact the contaminated material while operating heavy equipment and managing the industrial waste with small amounts of NORM/TENORM during disposal activities. The physical exposure to the material would be brief. Workers are trained in radiation basics and understand how to minimize risk and practice ALARA. The term ALARA (As Low As Reasonably Achievable) is used extensively in reference to practices and procedures dealing with radiation, and all workers are trained in practicing ALARA.

The worker scenario assumes that the largest disposal cell (Cell 13-17) is filled to capacity with industrial waste with small amounts of NORM/TENORM. The RESRAD occupancy area is input as a square with the worker located at the boundary as shown in Figure 3. This is a realistic scenario in that the worker does not spend their entire work day on top of the disposal cell. Locating the worker immediately adjacent to the landfill provides a conservative scenario without overestimating exposure.

Figure 3
WM/CSI Worker Scenario
RESRAD Model Configuration



To demonstrate an ongoing commitment to the safety of CSI workers, an annual review of the waste received and the handling procedures will be done in the first five years of operation. The results will be summarized in a report demonstrating the exposure scenarios.

9.1 Input Parameters

9.1.1 Exposure Pathways

Exposure pathways applicable for this scenario are:

- External exposure to gamma radiation when in close proximity to materials
- Inhalation of dusts in the air with suspended materials
- Incidental ingestion of materials
- Radon turned "ON"
- The foundation depth below ground surface is set at zero
- The occupancy outdoor occupancy time fraction is set to 1
- The indoor occupancy time fraction is set to zero

The settings account for the worker to be at grade and outdoors only and are reasonable and conservative because the worker will typically be in a cab of heavy equipment that has air filtration. The worker will not be in a contained area inside where radon could accumulate.

Two water wells are installed at the facility for non-potable uses, construction water and dust suppression. The water is not used for drinking purposes. The two water wells tap the lower Denver aquifer at 310 feet (95 meters) and the upper Arapahoe aquifer at 580 (177 meters) feet below ground surface. For the waste materials to reach this aquifer a breech of the liner systems would need to occur and the contaminants would need to travel vertically a significant distance through layers of perched water and several feet of unsaturated claystone. Intake of water was not considered in the exposure scenario because the water used on site is not used for drinking or bathing.

9.2 Soil Activity & Concentrations

The maximum concentrations used to set up acceptance criteria at the facility were used to run the RESRAD computer model. The concentrations of the radionuclides used are found in Table 6.

9.3 Contaminated Zone Parameters

Cell 13-17 was used for the worker scenario because it is the largest cell and represents the maximum external radiation exposure to a worker. The contaminated zone is shaped as a cubic rectangle with the dimensions of the cell taken from Plate 2 and the total area taken from Table 6-1 of the D&O Plan. The thickness of the cubic rectangle is dependent on the total volume of airspace in the disposal cell. The dimensions of the contaminated zone in cell 13-17 are 328 meters north to south and 349 meters east to west. The thickness of the contaminated zone is 17.98 meters based upon the total volume of the cell (328m x 349m x 17.98m = 2,056,049m^3)

The cover thicknesses are varied between zero and 1.22 meters (4 feet) over the contaminated zone. The waste deliveries will normally be covered with new waste in a short period of time. Weather data was obtained from DIA and NOAA and used for the wind speed and precipitation. Water pathways were not considered for this scenario nor were the other ingestion pathways for plants, milk and foods because the materials will not be grown or consumed.

The landfill worker will not spend the entire time of each workday on top of and in the middle of the contaminated zone. Workers must attend to various tasks and activities that take place outside the disposal cell. For this reason the landfill worker was placed at the edge of the contaminated zone for the assessment of external gamma radiation exposure and inhalation of radon.

Sensitivity analysis was done on the cover depth and show that a minimum of 0.1524 meters (0.5 foot) of cover should be placed on the waste with small amounts of NORM/TENORM soon after it is received.

9.4 Landfill Worker Parameters

With the waste received over the course of a year and the various activities that a landfill worker must perform the following time schedules were assumed:

- One hundred percent of an average work week hours (40 hrs/wk)
- Five work days per week, and no other days off in a year (52 wk/yr)

The landfill worker is expected to work a total of 2080 hours in one year processing industrial waste with small amounts of NORM/TENORM. The worker is assumed to spend 100 percent of their time outside when in close proximity to the materials. A landfill worker typically works outdoors in an enclosed cab of heavy equipment or vehicle making this scenario very conservative.

The default inhalation rates for an industrial worker were used for the worker scenario. No changes were made for the time differences making the risk assessment very conservative because a worker spends less than 25% of an entire year of hours at work and only a fraction of that time in the area of the waste.

9.5 *RESRAD Results*

The results of the RESRAD computer model using the above listed exposure pathways and worker scenario estimate that the dose for the landfill worker is approximately 10 mrem/yr with a 0.3048 meter (1 foot) cover over the industrial waste with small amounts of NORM/TENORM. With a cover depth of 0.6096 meter (2 foot) cover over the industrial waste with small amounts of NORM/TENORM, the estimated dose for a landfill worker is 0.69 mrem/yr. The worker predicted dose is estimated to be 50 mrem/yr. when placing six inches (0.5 foot) of cover. An operational cover of six inches (0.5 foot) of cover will be placed over the industrial waste with small amounts of NORM/TENORM soon after delivery. An additional cover of 1 to 2 feet will be placed over the industrial waste with small amounts of NORM/TENORM within one to two weeks from delivery. And within six months the waste will have a total of two to three feet of cover to bring the predicted dose to less than 1 mrem/yr. The RESRAD results are summarized on Table 12 and are found in the file folder titled Worker Risk Assessment on the enclosed CD

Table 12

Worker RESRAD Results

Cover Thickness in Meters	Cover Thickness in Feet	Predicted Dose with Radon ON (mrem/yr)
0	0	317
0.1143	0.375	80
0.1524	0.5	49.8400
0.2286	0.75	22.2400
0.3048	1	10.1400
0.4572	1.5	2.3250
0.6096	2	0.6900
0.9144	3	0.2125
1.2192	4	0.1414

RESRAD model with radon "ON" and no basement occupancy is outdoor only

All radionuclides and exposure pathways are included in this total dose estimate. Industrial wastes with small amounts of NORM/TENORM received in previous years will have been covered and will not be a factor in determining the possible doses. The total dose for a landfill worker is below the dose threshold limit of 25 mrem/yr when at least 0.3048 meters (1 foot) cover is applied.

The updated Plan includes a protocol for managing waste with small amounts of NORM/TENORM and specifies the placement of at least two to three feet of cover over the waste within six month of delivery to ensure the total dose for a landfill worker is well below the dose standard of 25 mrem/yr. This will reduce the radon dose to the worker significantly.

10.0 ADDITIONAL STUDIES

Two additional studies were conducted to assess the impacts of waste with small amounts of NORM/TENORM at the facility. A calculation of the radon emanation was made. Worker exposure was evaluated using the TSD-DOSE model for treatment, storage and disposal facilities.

10.1 Radon Emanation

Radon emanation was calculated using the Uranium Mill Tailings Cover Calculator available at the web site http://www.wise-uranium.org/ctc.html. The calculator is a clone of the Radiation Attenuation Effectiveness and Cover Optimization with Moisture Effects and performs one-dimensional steady-state radon diffusion calculations.

The largest cell 13-17 was used with a total thickness of 18 meters of contaminant zone listed as layer number one. The contaminant zone has a Ra-226 concentration of 50 pCi/g. On top of the contaminant zone is a 2.89 meter, layer two, of non-hazardous industrial waste using the properties found in Table 3. A final cover, layer three, with 0.61 meters of cover materials with properties found in Table 3, completed the input data. Radon effective diffusion coefficient was taken from the default value used in RESRAD.

The output results are summarized in Table 13. The results indicate that radon flux is below 1 pCi/m2s in cases of a 3.5-meter thick cover. When the cover thickness is reduced to 0.61 meters (2 feet) the radon flux is 12. The cover design is consistent with radon flux requirements for uranium cells (20 pCi/m^2s)

A bounding scenario was used where the Ra-226 concentration after in-growth of thorium isotopes over 1000 years was increased to 85 pCi/g. The value of 85 pCi/g was entered into the calculator to determine radon flux at the 1000-year time frame. The results of the scenarios are found in Table 13. The results indicate that the 20 pCi/m^2s is only exceeded by 0.61 pCi/m^2s when the cover is 0.61 meters (2 feet) or less.

Table 13

Radon Flux Calculation Results

Layer Material	Layer Number	Thickness in meters	Exit Flux in pCi/m2s	Exit Concentration pCi/L
Scenario #1-50				
Contaminant zone	1	18	11.93	21111
Non-Haz Cover	2	2.89	0.219	253.6
Final Cap	3	0.61	0.154	0.0
Scenario #2-50				
Contaminant zone	1	18	14.67	40490
Non-Haz Cover	2	2.89	0.261	509.7
Final Cap	3	0.61	0.184	0.0
Scenario #3-50				
Contaminant zone	1	18	17.17	33580
Final Cap	2	0.61	12.12	0.0
Scenario #1-85				
Contaminant zone	1	18	20.29	35890
Non-Haz Cover	2	2.89	0.370	435.4
Final Cap	3	0.61	0.261	0.0
Scenario #2-85				
Contaminant zone	1	18	24.94	68840
Non-Haz Cover	2	2.89	0.443	866.5
Final Cap	3	0.61	0.313	0.0
Scenario #3-85				
Contaminant zone	1	18	29.20	57090
Final Cap	2	0.61	20.61	0.0

Scenario #1-50 is the first scenario using Ra-226 concentration of 50 pCi/g
Scenario #1-85 is the first scenario using Ra-226 concentration of 85 pCi/g
Using the Uranium Mill Tailing Cover Calculator
Results found in Appendix 1

10.2 Worker Exposure using TSD-Dose

An additional study to evaluate worker exposure was conducted using the TSD-DOSE model. The TSD-DOSE model is a radiological dose assessment model for treatment, storage, and disposal facilities typically disposing of hazardous waste. The radionuclide concentrations in Table 6 were entered after conversion into curies. All defaults were utilized. The incineration, transport to offsite landfill, and incinerator maintenance scenarios were excluded because they do not apply to the facility operations. The results are shown in Appendix 2 and show that the dose exposure is less than 1E-6 mrem/yr.

10.3 Results of the National Petroleum Technology Office NORM/TENORM Study

The National Petroleum Technology Office and the US DOE have studied the disposal of NORM/TENORM in non-hazardous waste landfills. This study has determined that states should consider the acceptance of NORM/TENORM with an average Ra-226 concentration of 50 pCi/g or less at certain non-hazardous landfills[5].

10.4 Results of the ISCORS Study on Wastewater Treatment Residuals

The Interagency Steering Committed on Radiation Standards completed an assessment of radioactivity in disposal options for wastewater treatment residuals known as the ISCOR study[6]. ISCORS final report assessed the radioactivity in sewage sludge for several disposal scenarios including landfilling, land application, and incineration. The assessments evaluated a wide variety of publicly owned treatment works (POTW's) sewage sludges and calculated doses for the different scenarios. The basic conclusions are:

- that a widespread threat to public health is not significant,
- localized exposures to very high levels of radioactive materials occurs in some specific cases,
- sampling and transportation of sludges is limited with the predominant concern of radon in enclosed spaces, and
- if land application is carried out for a long time in the future a potential exists for exposure to radon.

The evaluation did not include a resident farmer scenario and instead modeled a landfill neighbor. These results showed very low doses with radon being the most significant factor. A probabilistic approach was used in the modeling rather than the deterministic methods. An interesting result showed that POTW's participating in the survey in the mountains and inter plains regions of the United States have concentration of Ra-226 as high as 47 pCi/g in sewer sludges.

The ISCORS report is a very useful comparison in so far as the study involved a comprehensive peer review and the results considered conservative. The conservative results show that the exposure from a landfill impoundment (most similar to the CSI facility) to a close neighbor had a total effective dose equivalent (TEDE) of 2.9 mrem/yr. for a 95% sample survey (0.47 median value) for the radon component. This demonstrates that according to the ISCORS study, producing conservative results and using some input conditions with higher values than those used in this CSI study, impacts to the neighbors are very minimal.

---

[5] An Assessment of the Disposal of Petroleum Industry NORM in Non-hazardous Landfills, DOE/BC/W-31-109-ENG-38-8, Argonne National Laboratory, October 1999

[6] ISCORS Assessment of Radioactivity in Sewage Sludge: Radiological Survey Results and Analysis, EPA 832-R-03-002, November 2003.

11.0 SUMMARY AND CONCLUSIONS

11.1 Summary

This dose risk assessment evaluated the exposure scenarios for:

- Industrial waste with small amounts of NORM/TENORM previously disposed of at CSI
- Future industrial waste with small amounts of NORM/TENORM to be disposed of at CSI
- A landfill worker at CSI Using the RESRAD computer model to evaluate dose associated with industrial waste with small amounts of NORM/TENORM disposed of at the CSI landfill.
- Radon emanation using flux calculations
- Worker exposure modeling with TSD-DOSE

The doses are summarized below.

11.2 Previously disposed industrial waste with small amounts of NORM/TENORM

RESRAD predicted the estimated dose from all the waste previously disposed of at the CSI facility is 4.47E-15 mrem excluding radon, well below the limit of 25 mrem/yr.

11.3 Future industrial waste disposal with small amounts of NORM/TENORM

RESRAD predicted the estimated dose from the entire capacity of all the industrial waste disposal cells filled with only industrial waste with small amounts of NORM/TENORM is less than 1 mrem/yr (radon excluded), well below the limit of 25 mrem/yr. When radon is included and a maximally exposed individual scenario is evaluated, the RESRAD predicted doses are significantly higher.

Section 8.9 sets up a method to use when volumes of industrial waste with small amounts of NORM/TENORM approach the concentrations that could affect a maximally exposed individual. Considering that volumes of industrial waste with small amounts of NORM/TENORM will be tracked, actions can be taken to reduce or eliminate the exposure to the maximally exposed individual. The landfill cover is considered robust over the 1000-year post closure life.

Industrial waste with small amounts of NORM/TENORM (maximum concentrations listed in Table 6) is acceptable at the facility based upon the risk assessments presented in this report. Future constraints limiting volumes should not apply until such time that the total volumes of waste with small concentrations of NORM/TENORM approach those listed in Table 11. A reasonable approach to apply in the event that the volumes Table 11 are approached is found in Section 8.9.

Radon emanation is shown to be considerably less than 20 pCi/m2s based upon radon flux calculations summarized in Table 13 and shown in Appendix 1.

11.4 Worker Scenario

RESRAD predicted the estimated dose from a maximum exposed worker and waste with small amounts of NORM/TENORM and 0.1524 meter (0.5 feet) cover at the CSI facility to be 50 mrem/yr, half the exposure limit of 100 mrem/yr for a worker. The exposure falls to 10 mrem/yr when 0.3048 meters (1 foot) of cover is placed over the waste with small amounts of NORM/TENORM. Additional RESRAD modeling of bounding scenarios shows that worker exposure to radon is decreased with significantly with 2 to 3 feet of cover is placed on top of the waste with small amounts of NORM/TENORM. The placement of 0.5 foot of an operational layer will cover the waste with small amounts of NORM/TENORM immediately after receipt, and additional 1-2 feet of cover will be placed in 1-2 weeks, and a total of 2 to 3 feet of cover will be placed within 6 months.

The dose risk assessment using the TSD-DOSE model predicts that the dose risk is less than 1E-6 mrem/yr well below any dose limit.

11.5 Conclusions

The dose risk assessments conducted by Molen & Associates and Radiant Energy Management demonstrate that CSI can manage industrial waste with small amounts of NORM/TENORM in a safe and compliant manner. The total dose of all previously disposed industrial waste with small amounts of NORM/TENORM and the future maximum volume of industrial waste with small amounts of NORM/TENORM is less than 1 mrem/yr (excluding radon), which is well below the 25 mrem/yr standard derived from C.C.R. 1007-1 and 4.61.2. Additional studies considering radon were addressed and confirm that even with radon industrial waste with NORM/TENORM can be handled in a safe and compliant manner.

Furthermore the Updated Waste Identification Plan outlines a waste acceptance protocol which eliminates the administrative burden of case-by-case reviews as requested by CDPHE while ensuring compliance with applicable regulatory requirements. The Updated Waste Identification Plan does not change CSI's long-standing practice of accepting industrial waste with small amounts NORM/TENORM. Rather, it is merely formalizing and streamlining the administrative process by which CSI previously accepted this type waste and observe CDPHE's request to reduce the administrative burden on CDPHE and obviate case-by-case determinations for acceptance of with small amounts of NORM/TENORM at CSI.

The landfill covers, (both the currently approved and proposed alternative final cover designs) on the cells will meet post-closure radon emission requirements as shown by bounding studies of radon flux and dose exposure modeling (Table 13 and Appendix 1). The cover is robust at 3.5 meters (11.5 feet) of a combination of industrial waste and prescriptive cover material. Soil erosion calculations indicate that no more than one inch of erosion will occur over a 1400-year period. Exposure scenarios with radon "on" in the RESRAD model are only significant when an entire cell is completely full with waste with small amounts of NORM/TEMORM. A plan of action in the event that the amount of waste with small amounts of NORM/TENORM approach certain volumes assures that the maximally exposed individual will not receive more than 25 mrem/yr from the facility 1000 years in the future.

12.0 REFERENCES

United States Department of Energy, *User's Manual for RESRAD Version 6*. ANL/EAD-4. July 2001

Argonne National Laboratory, An Assessment of the Disposal of Petroleum Industry NORM in Non-hazardous Landfills. DOE/BC/W-31-109-ENG-38-8. October 1999

ISCORS, *Assessment of Radioactivity in Sewage Sludge: Radiological Survey Results and Analysis*. EPA 832-R-03-002. November 2003.

Conservation Services Inc., *Revised Design and Operations Plan*, Adams County CD 86-88 CD (A). February 1996.

Conservation Services Inc., *Construction Quality Assurance and Specifications Plan, Liner, Leachate Collection and Removal and Final Cover System*, prepared by American Environmental Consulting, LLC. May 2003

Conservation Services Inc., *Revisions and Clarification of RESRAD Model Application (dated June 3, 1999) for Disposal of Residual Materials Containing Small Concentrations of Naturally Occurring Radioactive Materials (NORM) at the CSI Industrial Waste Disposal Facility near Bennett, Colorado*, prepared by Harding Lawson Associates for Molycorp. October 18, 1999.

Conversation Services Inc., *Letter to Mr. Greg Brand, Colorado Department of Public Health and Environment, re S.W. Shattuck Chemical Company Waste Disposal at Conservation Services, Additional Information and Clarifications (included ISHOLD model results)*, April 25, 1994.

Conservation Services Inc., *Letter to Wastren Remediation re: CSMRI – Disposal of Contaminated Soils (includes COMPLY model results),* October 3, 1995.

U.S. Nuclear Regulatory Commission, *Consolidated NMSS Decommissioning Guidance – Updates to Implement the License Termination Rule Analysis – Draft NUREG – 1757, Supp. 1*, page IV-9, September 2005.

Appendix 1

Output Results
From
Uranium Mill Tailing
Radon Flux Calculator

Uranium Mill Tailings Cover Calculator

(last updated 2 Jul 2004)
Requires Netscape 3.0, Internet Explorer 3.0 or higher. JavaS
For educational purposes only. No warranty.

Determine the radon flux through a multi-layer soil co optimize the cover for a given flux.

(For calculating radon flux from bare and/or water covered tai Calculator)

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Radon Flux Calculations
Scenario #1 – Largest Cell #13-17
Site specific data for porosity, moisture, and fraction passing #200 Mesh

Layer #1 – NORM/TENORM
Layer #2 – Non Hazardous Industrial Waste
Layer #3 – Cap

Select activity unit first, then enter the parameters and click the "Calculate" button below. HELP
Layer 1 is the tailings layer.
Numbers can be entered in exponential notation: $5 \cdot 10^{-6}$ = 5e-6

Activity unit: (•) pCi ( ) Bq

Sample Data **Input Data**

Layer Data HELP

Layer No.	Thickness [m]	Ra-226 Activity Conc. [pCi/g]	Rn-222 Emanation Fraction	Porosity	Moisture Cont. [dry wt_%]	Fraction Passing #200 Mesh (75 µm) *)	Rn-222 Eff. Diff.Coeff *) [m^2/s]
1	18	50	0.2	0.39	15.3	0.15	1E-6
2	2.89	0	0	0.39	15.3	0.15	1e-6
3	0.61	0	0	0.4	15.0	0.15	1e-6
4							
5							
6							
7							
8							

Options HELP

Entrance Radon flux to Layer 1 [pCi/m^2s] *)

	Surface Radon conc. at top of system [pCi/L] *)
	Layer No. to be optimized *)
	Surface flux constraint for optimization [pCi/m^{2}s] *)
	Surface flux convergence criterion (fraction) *)
391	Annual Precipitation [cm] *)
	Annual Lake Evaporation [cm] *)
3.66	Depth to Water Table [m] *)

*) optional

Calculate | Reset Form | HELP

Results

```
---------------- Input Parameters ----------------

 Number of Layers:  3
 Radon Flux into Layer 1:  0 pCi/m2s
 Surface Radon Concentration:  0 pCi/L
 Bare Source Flux (Jo) from Layer 1:  23.87 pCi/m2s
 Specific Bare Source Flux from Layer 1:  0.477 pCi/m2s per pCi_Ra-226/g

Layer Thickness  Ra-226   Emanat  Porosity  Moisture   Diff Coeff
 No.     [m]     [pCi/g]  Fract             [dry wt_%]  [m2/s]
  1     18        50      0.2       0.39      15.30     1.000E-6
  2     2.89      0       0         0.39      15.30     1.000E-6
  3     0.61      0       0         0.4       15        1.000E-6


-------- Results of Radon Diffusion Calculation --------

Layer  Thickness   Exit Flux  Exit Conc.    MIC
 No.      [m]     [pCi/m2s]   [pCi/L]
  1      18        11.93       21.11E3     0.522
  2      2.89      0.219       253.6E0     0.522
  3      0.61      0.154       0E0         0.550

Total cover radon retention: 99.35%
```

> See also:

- Unit Converter
- Uranium Mill Tailings Radon Flux Calculator
- Uranium Radiation Properties · Uranium Radiation Exposure
- Uranium Decay Calculator
- Radon Individual Dose Calculator
- Uranium in Soil Individual Dose Calculator
- Uranium Mine and Mill Resident Individual Dose Calculator
- Nuclear Fuel Population Health Risk Calculator (collective dose)

Uranium Mill Tailings Cover Calculator

(last updated 2 Jul 2004)
Requires Netscape 3.0, Internet Explorer 3.0 or higher. JavaS
For educational purposes only. No warranty.

Determine the radon flux through a multi-layer soil cov optimize the cover for a given flux.

(For calculating radon flux from bare and/or water covered ta Calculator)

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Radon Flux Calculations
Scenario #2 – Largest Cell #13-17
High value for porosity, lower for moisture

Layer #1 – NORM/TENORM
Layer #2 – Non Hazardous Industrial Waste
Layer #3 – Cap

Select activity unit first, then enter the parameters and click the "Calculate" button below. HELP
Layer 1 is the tailings layer.
Numbers can be entered in exponential notation: $5 \cdot 10^{-6}$ = 5e-6

Activity unit: (•) pCi ( ) Bq

Sample Data **Input Data**

Layer Data HELP

Layer No.	Thickness [m]	Ra-226 Activity Conc. [pCi/g]	Rn-222 Emanation Fraction	Porosity	Moisture Cont. [dry wt_%]	Fraction Passing #200 Mesh (75 µm) *)	Rn-222 Eff. Diff.Coeff *) [m²/s]
1	18	50	0.2	0.25	7.5	0.15	1E-6
2	2.89	0	0	0.25	7.5	0.15	1e-6
3	0.61	0	0	0.25	7.5	0.15	1e-6
4							
5							
6							
7							
8							

Options HELP

	Entrance Radon flux to Layer 1 [pCi/m^{2}s] *)
	Surface Radon conc. at top of system [pCi/L] *)
	Layer No. to be optimized *)
	Surface flux constraint for optimization [pCi/m^{2}s] *)
	Surface flux convergence criterion (fraction) *)
391	Annual Precipitation [cm] *)
	Annual Lake Evaporation [cm] *)
3.66	Depth to Water Table [m] *)

*) optional

Calculate Reset Form HELP

Results

```
---------------  Input Parameters  ---------------

 Number of Layers:  3
 Radon Flux into Layer 1:  0 pCi/m2s
 Surface Radon Concentration:  0 pCi/L
 Bare Source Flux (Jo) from Layer 1:  29.35 pCi/m2s
 Specific Bare Source Flux from Layer 1:  0.587 pCi/m2s per pCi_Ra-226/g

Layer Thickness  Ra-226   Emanat  Porosity  Moisture   Diff Coeff
 No.     [m]     [pCi/g]  Fract             [dry wt_%]  [m2/s]
  1     18       50       0.2       0.25       7.5       1.000E-6
  2     2.89     0        0         0.25       7.5       1.000E-6
  3     0.61     0        0         0.25       7.5       1.000E-6


-------  Results of Radon Diffusion Calculation  --------

Layer  Thickness   Exit Flux  Exit Conc.    MIC
 No.      [m]     [pCi/m2s]   [pCi/L]
  1      18        14.67       40.49E3     0.550
  2      2.89      0.261       509.7E0     0.550
  3      0.61      0.184       0E0         0.550

Total cover radon retention: 99.37%
```

> See also:

- Unit Converter
- Uranium Mill Tailings Radon Flux Calculator
- Uranium Radiation Properties · Uranium Radiation Exposure
- Uranium Decay Calculator
- Radon Individual Dose Calculator
- Uranium in Soil Individual Dose Calculator
- Uranium Mine and Mill Resident Individual Dose Calculator
- Nuclear Fuel Population Health Risk Calculator (collective dose)

Uranium Mill Tailings Cover Calculator

(last updated 2 Jul 2004)
Requires Netscape 3.0, Internet Explorer 3.0 or higher. Java!
For educational purposes only. No warranty.

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Radon Flux Calculations
Scenario #3 – Largest Cell #13-17
High value for porosity lower for moisture

Layer #1 – Cap (2 foot or 0.61 m)

Determine the radon flux through a multi-layer soil co
optimize the cover for a given flux.

(For calculating radon flux from bare and/or water covered t
Calculator)

Select activity unit first, then enter the parameters and click the "Calculate" button below. HELP
Layer 1 is the tailings layer.
Numbers can be entered in exponential notation: $5 \cdot 10^{-6}$ = 5e-6

Activity unit: (•) pCi ( ) Bq

Input Data

Sample Data

Layer Data HELP

Layer No.	Thickness [m]	Ra-226 Activity Conc. [pCi/g]	Rn-222 Emanation Fraction	Porosity	Moisture Cont. [dry wt_%]	Fraction Passing #200 Mesh (75 µm) *)	Rn-222 Eff. Diff.Coeff *) [m²/s]
1	18	50	0.2	0.25	7.5	0.15	1E-6
2	0.61	0	0	0.25	7.5	0.15	1e-6
3	00	0	0	0.25	7.5	0.15	1e-6
4							
5							
6							
7							
8							

Options HELP

	Entrance Radon flux to Layer 1 [pCi/m^{2}s] *)
	Surface Radon conc. at top of system [pCi/L] *)
	Layer No. to be optimized *)
	Surface flux constraint for optimization [pCi/m^{2}s] *)
	Surface flux convergence criterion (fraction) *)
391	Annual Precipitation [cm] *)
	Annual Lake Evaporation [cm] *)
3.66	Depth to Water Table [m] *)

*) optional

Calculate | Reset Form | HELP

Results

```
---------------  Input Parameters  ---------------

 Number of Layers:  2
 Radon Flux into Layer 1:  0 pCi/m2s
 Surface Radon Concentration:  0 pCi/L
 Bare Source Flux (Jo) from Layer 1:  29.35 pCi/m2s
 Specific Bare Source Flux from Layer 1:  0.587 pCi/m2s per pCi_Ra-226/g

Layer Thickness  Ra-226   Emanat  Porosity  Moisture  Diff Coeff
 No.     [m]     [pCi/g]  Fract            [dry wt_%]  [m2/s]
  1    18        50       0.2       0.25      7.5       1.000E-6
  2    0.61      0        0         0.25      7.5       1.000E-6


-------  Results of Radon Diffusion Calculation  -------

Layer  Thickness   Exit Flux  Exit Conc.     MIC
 No.      [m]      [pCi/m2s]   [pCi/L]
  1      18         17.17      33.58E3      0.550
  2      0.61       12.12      0E0          0.550

Total cover radon retention: 58.69%
```

> See also:

- Unit Converter
- Uranium Mill Tailings Radon Flux Calculator
- Uranium Radiation Properties · Uranium Radiation Exposure
- Uranium Decay Calculator
- Radon Individual Dose Calculator
- Uranium in Soil Individual Dose Calculator
- Uranium Mine and Mill Resident Individual Dose Calculator
- Nuclear Fuel Population Health Risk Calculator (collective dose)

Uranium Mill Tailings Cover Calculator

APPENDIX 1
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Radon Flux Calculation after 1000 years
Ra226 concentration of 85 pCi/g after in-growth
Scenario #1-1000 – Largest Cell #13-17
Site specific data for porosity, moisture, and fraction passing #200 Mesh
Layer #1 – NORM/TENORM
Layer #2 – Non Hazardous Industrial Waste
Layer #3 – Cap

(last updated 2 Jul 2004)
Requires Netscape 3.0, Internet Explorer 3.0 or higher. Java
For educational purposes only. No warranty.

Determine the radon flux through a multi-layer soil co optimize the cover for a given flux.

(For calculating radon flux from bare and/or water covered t Calculator)

Select activity unit first, then enter the parameters and click the "Calculate" button below. HELP
Layer 1 is the tailings layer.
Numbers can be entered in exponential notation: $5 \cdot 10^{-6}$ = 5e-6

Activity unit: (•) pCi ( ) Bq

Input Data

Sample Data

Layer Data HELP

Layer No.	Thickness [m]	Ra-226 Activity Conc. [pCi/g]	Rn-222 Emanation Fraction	Porosity	Moisture Cont. [dry wt_%]	Fraction Passing #200 Mesh (75 µm) *)	Rn-222 Eff. Diff.Coeff *) [m^2/s]
1	18	85	0.2	0.39	15.3	0.15	1e-6
2	2.89	0	0	0.39	15.3	0.15	1e-6
3	0.61	0	0	0.4	15.3	0.15	1e-6
4							
5							
6							
7							
8							

Options HELP

	Entrance Radon flux to Layer 1 [pCi/m^{2}s] *)
	Surface Radon conc. at top of system [pCi/L] *)
	Layer No. to be optimized *)
	Surface flux constraint for optimization [pCi/m^{2}s] *)
	Surface flux convergence criterion (fraction) *)
391	Annual Precipitation [cm] *)
	Annual Lake Evaporation [cm] *)
3.66	Depth to Water Table [m] *)

*) optional

Calculate | Reset Form | HELP

Results

```
---------------- Input Parameters ----------------

 Number of Layers:  3
 Radon Flux into Layer 1:  0 pCi/m2s
 Surface Radon Concentration:  0 pCi/L
 Bare Source Flux (Jo) from Layer 1:  40.57 pCi/m2s
 Specific Bare Source Flux from Layer 1:  0.477 pCi/m2s per pCi_Ra-226/g

Layer Thickness  Ra-226   Emanat  Porosity  Moisture   Diff Coeff
 No.     [m]     [pCi/g]  Fract             [dry wt_%]  [m2/s]
  1     18       85       0.2       0.39      15.30     1.000E-6
  2     2.89     0        0         0.39      15.30     1.000E-6
  3     0.61     0        0         0.4       15.30     1.000E-6


-------  Results of Radon Diffusion Calculation  -------

Layer  Thickness   Exit Flux  Exit Conc.     MIC
 No.      [m]     [pCi/m2s]   [pCi/L]
  1      18        20.29      35.89E3      0.522
  2      2.89      0.370      435.4E0      0.522
  3      0.61      0.261      0E0          0.541

Total cover radon retention: 99.36%
```

> See also:

- Unit Converter
- Uranium Mill Tailings Radon Flux Calculator
- Uranium Radiation Properties · Uranium Radiation Exposure
- Uranium Decay Calculator
- Radon Individual Dose Calculator
- Uranium in Soil Individual Dose Calculator
- Uranium Mine and Mill Resident Individual Dose Calculator
- Nuclear Fuel Population Health Risk Calculator (collective dose)

Uranium Mill Tailings Cover Calculator

APPENDIX 1
CSI Bennett Risk Assessment Report May 2006

Radon Flux Calculations after 1000 years
Ra226 concentration of 85 pCi/g after in-growth
Scenario #2 -1000 – Largest Cell #13-17
High value for porosity, lower for moisture

Layer #1 – NORM/TENORM
Layer #2 – Non Hazardous Industrial Waste
Layer #3 – Cap

(last updated 2 Jul 2004)
Requires Netscape 3.0, Internet Explorer 3.0 or higher. JavaS
For educational purposes only. No warranty.

Determine the radon flux through a multi-layer soil co
optimize the cover for a given flux.

(For calculating radon flux from bare and/or water covered ta
Calculator)

Select activity unit first, then enter the parameters and click the "Calculate" button below. HELP
Layer 1 is the tailings layer.
Numbers can be entered in exponential notation: $5 \cdot 10^{-6}$ = 5e-6

Activity unit: ◉ pCi ○ Bq

Sample Data **Input Data**

Layer Data HELP

Layer No.	Thickness [m]	Ra-226 Activity Conc. [pCi/g]	Rn-222 Emanation Fraction	Porosity	Moisture Cont. [dry wt_%]	Fraction Passing #200 Mesh (75 µm) *)	Rn-222 Eff. Diff.Coeff *) [m^2/s]
1	18	85	0.2	0.25	7.5	0.15	1e-6
2	2.89	0	0	0.25	7.5	0.15	1e-6
3	0.61	0	0	0.25	7.5	0.15	1e-6
4							
5							
6							
7							
8							

Options HELP

	Entrance Radon flux to Layer 1 [pCi/m^{2}s] *)
	Surface Radon conc. at top of system [pCi/L] *)
	Layer No. to be optimized *)
	Surface flux constraint for optimization [pCi/m^{2}s] *)
	Surface flux convergence criterion (fraction) *)
391	Annual Precipitation [cm] *)
	Annual Lake Evaporation [cm] *)
3.66	Depth to Water Table [m] *)

*) optional

Calculate Reset Form HELP

Results

```
--------------- Input Parameters ---------------

 Number of Layers: 3
 Radon Flux into Layer 1: 0 pCi/m2s
 Surface Radon Concentration: 0 pCi/L
 Bare Source Flux (Jo) from Layer 1: 49.89 pCi/m2s
 Specific Bare Source Flux from Layer 1: 0.587 pCi/m2s per pCi_Ra-226/g

Layer Thickness  Ra-226   Emanat  Porosity  Moisture   Diff Coeff
 No.     [m]     [pCi/g]  Fract             [dry wt_%]  [m2/s]
  1     18       85       0.2      0.25       7.5       1.000E-6
  2     2.89     0        0        0.25       7.5       1.000E-6
  3     0.61     0        0        0.25       7.5       1.000E-6


------- Results of Radon Diffusion Calculation -------

Layer  Thickness   Exit Flux  Exit Conc.    MIC
 No.      [m]     [pCi/m2s]   [pCi/L]
  1      18        24.94       68.84E3     0.550
  2      2.89      0.443       866.5E0     0.550
  3      0.61      0.313       0E0         0.550

Total cover radon retention: 99.37%
```

> See also:

- Unit Converter
- Uranium Mill Tailings Radon Flux Calculator
- Uranium Radiation Properties · Uranium Radiation Exposure
- Uranium Decay Calculator
- Radon Individual Dose Calculator
- Uranium in Soil Individual Dose Calculator
- Uranium Mine and Mill Resident Individual Dose Calculator
- Nuclear Fuel Population Health Risk Calculator (collective dose)

Uranium Mill Tailings Cover Calculator

(last updated 2 Jul 2004)
Requires Netscape 3.0, Internet Explorer 3.0 or higher. JavaS
For educational purposes only. No warranty.

Determine the radon flux through a multi-layer soil co
optimize the cover for a given flux.

(For calculating radon flux from bare and/or water covered ta
Calculator)

APPENDIX 1
CSI Bennett Risk Assessment Report May 2006

Radon Flux Calculations after 1000 years
Ra226 concentration of 85 pCi/g after in-growth
Scenario #3 - 1000 – Largest Cell #13-17
High value for porosity lower for moisture

Layer #1 – Cap (2 foot or 0.61 m)

Select activity unit first, then enter the parameters and click the "Calculate" button below. HELP
Layer 1 is the tailings layer.
Numbers can be entered in exponential notation: $5 \cdot 10^{-6} = 5e-6$

Activity unit: (•) pCi ( ) Bq

Input Data

Sample Data

Layer Data HELP

Layer No.	Thickness [m]	Ra-226 Activity Conc. [pCi/g]	Rn-222 Emanation Fraction	Porosity	Moisture Cont. [dry wt_%]	Fraction Passing #200 Mesh (75 µm) *)	Rn-222 Eff. Diff.Coeff *) [m^2/s]
1	18	85	0.2	0.25	7.5	0.15	1e-6
2	0.61	0	0	0.25	7.5	0.15	1e-6
3							
4							
5							
6							
7							
8							

Options HELP

[ ]	Entrance Radon flux to Layer 1 [pCi/m^{2}s] *)
[ ]	Surface Radon conc. at top of system [pCi/L] *)
[ ]	Layer No. to be optimized *)
[ ]	Surface flux constraint for optimization [pCi/m^{2}s] *)
[ ]	Surface flux convergence criterion (fraction) *)
[ ]	Annual Precipitation [cm] *)
[ ]	Annual Lake Evaporation [cm] *)
[ ]	Depth to Water Table [m] *)

*) optional

Calculate | Reset Form | HELP

Results

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---------------- Input Parameters ----------------

 Number of Layers:  2
 Radon Flux into Layer 1:  0 pCi/m2s
 Surface Radon Concentration:  0 pCi/L
 Bare Source Flux (Jo) from Layer 1:  49.89 pCi/m2s
 Specific Bare Source Flux from Layer 1:  0.587 pCi/m2s per pCi_Ra-226/g

Layer Thickness  Ra-226   Emanat  Porosity  Moisture   Diff Coeff
 No.     [m]     [pCi/g]  Fract             [dry wt_%]  [m2/s]
  1     18        85       0.2      0.25      7.5       1.000E-6
  2     0.61      0        0        0.25      7.5       1.000E-6


-------- Results of Radon Diffusion Calculation --------

Layer  Thickness   Exit Flux  Exit Conc.    MIC
 No.      [m]      [pCi/m2s]   [pCi/L]
  1      18          29.20      57.09E3     0.550
  2      0.61        20.61      0E0         0.550

Total cover radon retention: 58.69%
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> See also:

- Unit Converter
- Uranium Mill Tailings Radon Flux Calculator
- Uranium Radiation Properties · Uranium Radiation Exposure
- Uranium Decay Calculator
- Radon Individual Dose Calculator
- Uranium in Soil Individual Dose Calculator
- Uranium Mine and Mill Resident Individual Dose Calculator
- Nuclear Fuel Population Health Risk Calculator (collective dose)

Appendix 2

Worker Risk Assessments
TSD-DOSE Output

TSD-DOSE: A Radiological Dose Assessment Model for Treatment, Storage, and Disposal Facilities

Version 2.22 - September 1998

Site:	WMCSI Bennett Facilty
Shipment:	Maximum concentrations of radionuclides
User:	Mark Molen
Title:	Maximum results for waste received

	TOTAL	EXTERNAL	INTERNAL
Dose to:			
Driver:	1.8E-07 mrem	1.8E-07 mrem	0.0E+00 mrem
Receiving worker:	4.5E-07 mrem	4.5E-07 mrem	5.7E-09 mrem
Incineration worker:	3.9E-07 mrem	3.9E-07 mrem	0.0E+00 mrem
Landfill worker:	8.0E-09 mrem	3.8E-09 mrem	4.2E-09 mrem
Offsite individual:	3.7E-12 mrem		
Offsite population:	1.9E-14 p-rem		
Worker Population:	3.4E-09 p-rem	3.4E-09 p-rem	1.6E-11 p-rem
Dose from:			
Transport to TSD facility:	1.8E-07 mrem	1.8E-07 mrem	not applicable
Receiving and sampling waste:	6.3E-08 mrem	5.8E-08 mrem	5.7E-09 mrem
Storage before processing:	3.9E-07 mrem	3.9E-07 mrem	not applicable
Incineration of waste:	not applicable	not applicable	not applicable
Burial at onsite landfill:	8.0E-09 mrem	3.8E-09 mrem	4.2E-09 mrem
Transport to offsite landfill:	not applicable	not applicable	not applicable
Incinerator maintenance:	not applicable	not applicable	not applicable

Doses due to each isotope (mrem - population dose in p-rem).

Isotope	Ra226+D	Ra228+D	Th228+D	Th230	Th232
Activity	5.0E-11 Ci	1.3E-11 Ci	1.5E-10 Ci	1.5E-10 Ci	5.5E-11 Ci
Release Fraction	5.00E-04	5.00E-04	5.00E-04	5.00E-04	5.00E-04
Driver	4.8 E-08	6.7 E-09	1.3 E-07	9.8 E-12	9.2 E-13
Receiving worker	1.2 E-07	1.7 E-08	3.1 E-07	1.1 E-09	2.1 E-09
Incineration worker	not applicable				
Landfill worker	9.8 E-10	1.4 E-10	3.5 E-09	8.2 E-10	1.5 E-09
Offsite individual	5.8 E-14	2.5 E-15	7.6 E-13	7.2 E-13	1.3 E-12
Offsite population	3.0 E-16	1.3 E-17	3.9 E-15	3.6 E-15	6.7 E-15
Worker population	9.0 E-10	1.3 E-10	2.4 E-09	3.3 E-12	5.7 E-12

Doses due to each isotope (cont'd).

Isotope	U234	U238+D
Activity	3.0E-10 Ci	1.5E-10 Ci
Release Fraction	5.00E-04	5.00E-04
Driver	3.4 E-12	1.6 E-09
Receiving worker	9.2 E-10	4.6 E-09
Incineration worker	not applicable	
Landfill worker	6.6 E-10	3.3 E-10
Offsite individual	5.8 E-13	2.6 E-13
Offsite population	2.9 E-15	1.3 E-15
Worker population	2.6 E-12	3.3 E-11

Site Description

Operations included:

Transport to TSD facility
Receiving and sampling waste
Storage before processing
Burial at onsite landfill

Operations excluded:

Incineration of waste
Transport to offsite landfill
Incinerator maintenance

Parameters

The following are the adjustable parameters used to model each operation.
A (D) after a value indicates the default value was used.

Fraction solid waste = 1.000
Fraction liquid waste = 0.000
Pre-processed waste density = 7.0 E-01 g/cc
Post-processed waste density = 1.4 E+00 g/cc

Transport to TSD facility (4 steps)

Number of Workers: 1.0E+00 (D)
Truck bed dimensions (for all steps)
length: 1.84E+01 feet (D)
width: 7.30E+00 feet (D)
height: 2.80E+00 feet (D)

Step A: Load and secure shipment
average distance: 3.00E+00 feet (D)
duration: 3.00E+00 hours (D)
shielding thickness: 6.25E-02 inches (D)

Step B: Drive
average distance: 7.00E+00 feet (D)
duration: 2.80E+01 hours (D)
shielding thickness: 1.25E-01 inches (D)

Step C: Rest
average distance: 2.00E+00 feet (D)
duration: 1.60E+01 hours (D)
shielding thickness: 1.25E-01 inches (D)

Step D: Maintenance in transit
average distance: 3.00E+00 feet (D)
duration: 2.00E+00 hours (D)
shielding thickness: 6.25E-02 inches (D)

Receiving and sampling waste (5 steps)

Number of Workers: 2.0E+00 (D)

Step A: Weight truck, inspect manifest
average distance: 5.00E+00 feet (D)
duration: 1.00E+00 hours (D)

Receiving and sampling waste (cont'd)

Step B: Unload drums
average distance: 3.00E+00 feet (D)
time per drum or pallet: 8.33E-02 hours (D)

Step C: Inspect and sample drums
average distance: 5.00E-01 feet (D)
time per drum: 8.33E-02 hours (D)
airborne respirable dust concentration: 1.0E+01 mg/m3 (D)
respiratory protection factor: 1.0E+01 (D)

Step D: Transfer solids to storage
average distance: 3.00E+00 feet (D)
time per drum or pallet: 1.67E-01 hours (D)

Step E: Pump drummed oil to storage tank
average distance: 5.00E-01 feet (D)
time per drum: 8.33E-02 hours (D)

Storage before processing (3 steps)

Step A: Workers in solid waste storage area
average distance: 3.00E+00 feet (D)
duration: 6.00E+01 hours (D)

Step B: Transfer solids out
average distance: 3.00E+00 feet (D)
time per drum or pallet: 8.33E-02 hours (D)

Step C: Workers in liquid waste storage area
average distance: 3.00E+00 feet (D)
duration: 6.00E+01 hours (D)
shielding thickness: 1.25E-01 inches (D)
Storage tank dimensions:
length: 7.00E+00 feet (D)
width: 7.00E+00 feet (D)
height: 1.20E+01 feet (D)

Burial at onsite landfill (4 steps)

Number of Workers: 1.0E+00 (D)
Dump truck bed dimensions for steps A, C, and D):
length: 2.50E+01 feet (D)
width: 6.00E+00 feet (D)
height: 3.00E+00 feet (D)

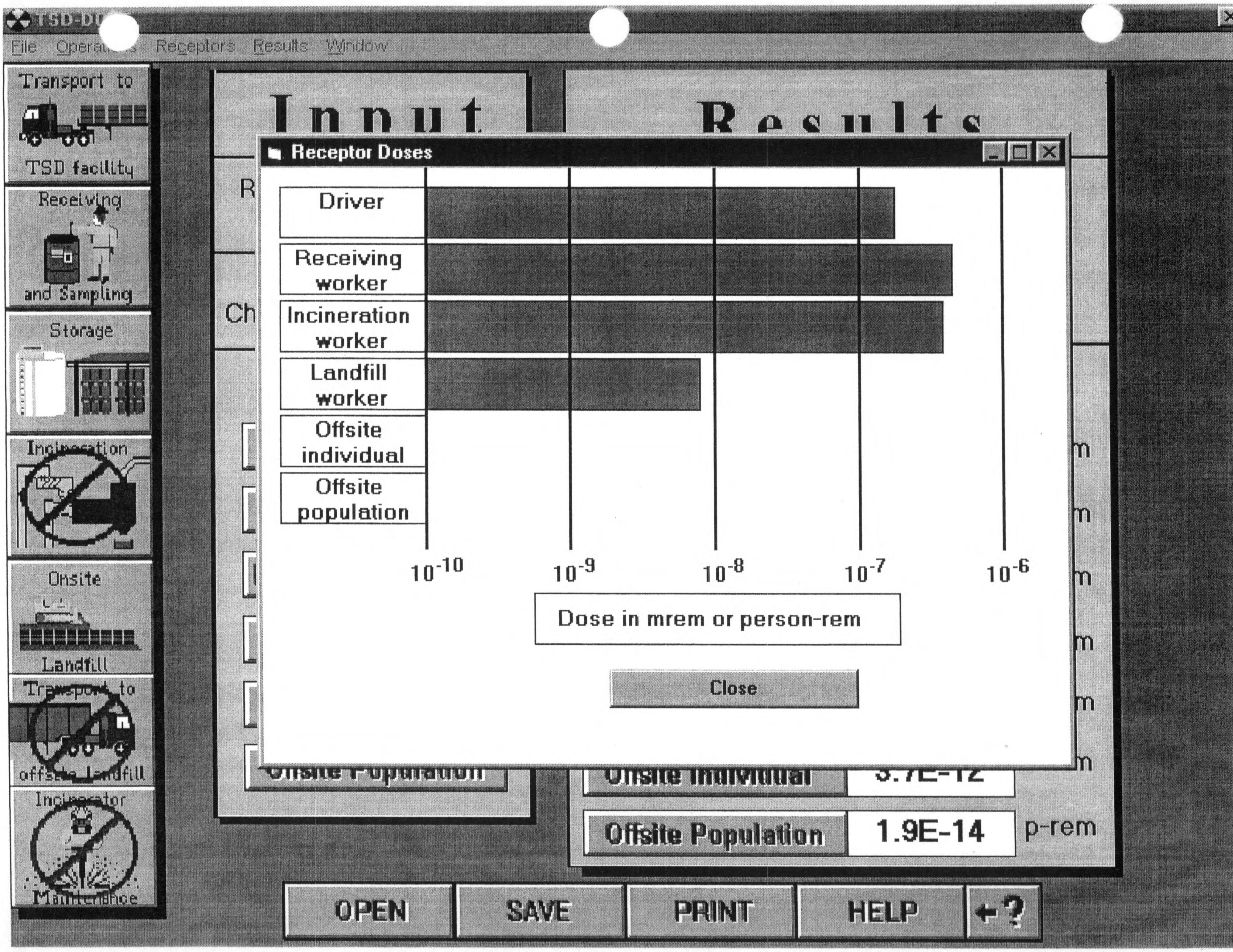
Step A: Unload waste to mixing pit
average distance: 5.00E+00 feet (D)
duration: 2.50E-01 hours (D)
shielding thickness: 1.25E-01 inches (D)
airborne respirable dust concentration: 1.0E+00 mg/m3 (D)
respiratory protection factor: 1.0E+00 (D)

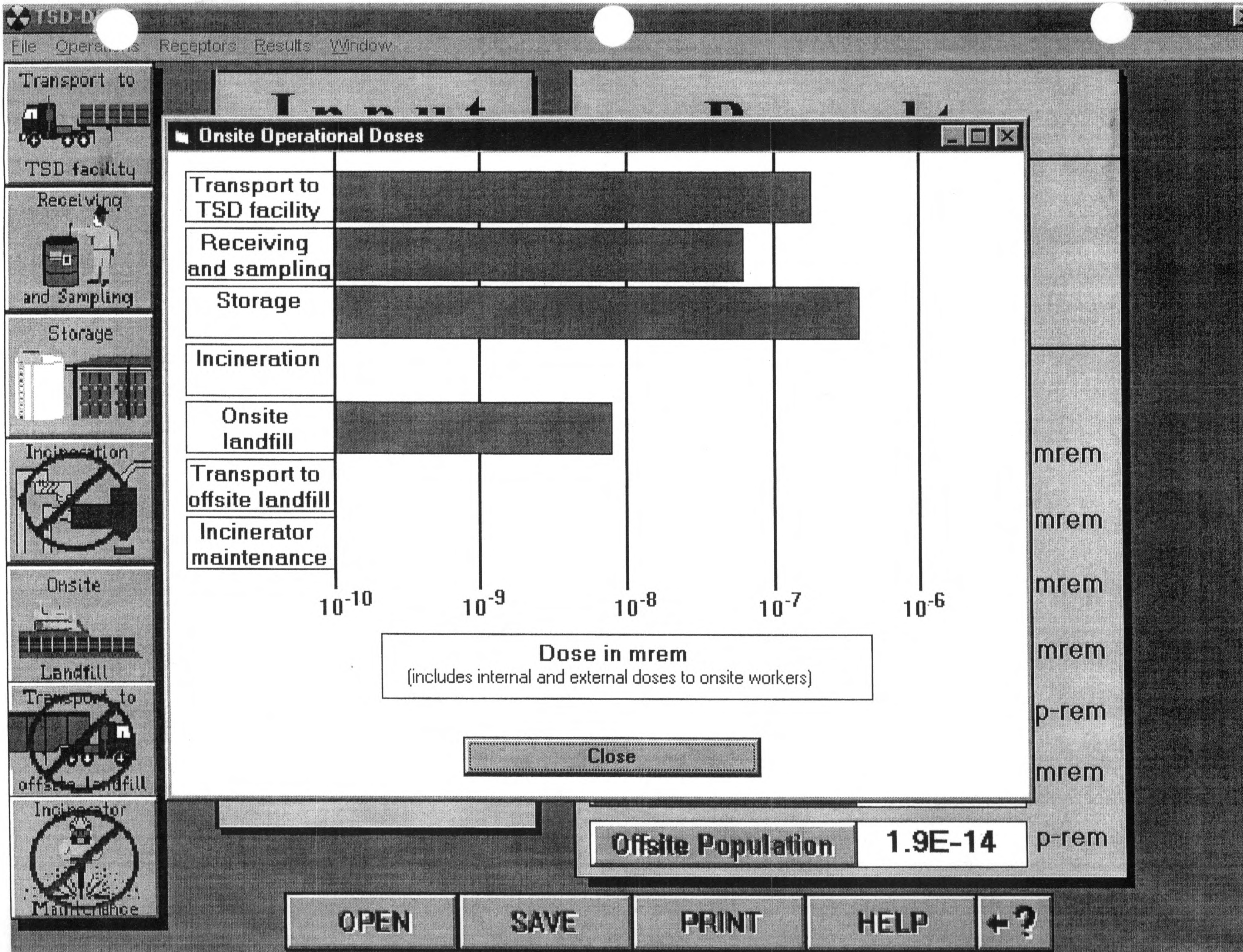
Step B: Mix waste in mixing pit
average distance: 1.00E+01 feet (D)
duration: 5.00E-01 hours (D)
cover thickness: 2.00E+00 inches (D)
Mixing pit dimensions:
length: 1.00E+01 feet (D)
width: 1.00E+01 feet (D)
depth: 1.00E+01 feet (D)
cover thickness: 2.00E+00 inches (D)

Burial at onsite landfill (cont'd)

Step C: Load truck and transport to landfill
average distance: 5.00E+00 feet (D)
duration: 2.50E-01 hours (D)
shielding thickness: 1.25E-01 inches (D)

Step D: Unload truck at landfill
average distance: 5.00E+00 feet (D)
duration: 2.50E-01 hours (D)
shielding thickness: 1.25E-01 inches (D)


File
Receptors
Results
Window
Transport to
TSD facility
Receiving
and Sampling
Storage
Onsite
Landfill
Input
Results
Receptor Doses
Driver
Receiving worker
Incineration worker
Landfill worker
Offsite individual
Offsite population
10^{-10}
10^{-9}
10^{-8}
10^{-7}
10^{-6}
Dose in mrem or person-rem
Close
Offsite Population
1.9E-14
p-rem
OPEN
SAVE
PRINT
HELP


TSD-D
File
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and Sampling
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Landfill
Onsite Operational Doses
Transport to
TSD facility
Receiving
and sampling
Storage
Incineration
Onsite
landfill
Transport to
offsite landfill
Incinerator
maintenance
10-10
10-9
10-8
10-7
10-6
Dose in mrem
(includes internal and external doses to onsite workers)
Close
mrem
mrem
mrem
mrem
p-rem
mrem
Offsite Population
1.9E-14
p-rem
OPEN
SAVE
PRINT
HELP