ATTACHMENT A

CLEAN HARBORS DEER TRAIL
NORM/TENORM RADIATION PROTECTION PLAN AND
NORM/TENORM STANDARD OPERATING PROCEDURES

INTRODUCTION/APPROVAL

The purpose of the Naturally Occurring Radioactive Material (NORM)/Technologically Enhanced Naturally Occurring Radioactive Material (TENORM) Radiation Protection Program at the Clean Harbors Deer Trail, LLC, Resource Conservation and Recovery Act (RCRA) Subtitle C landfill is to protect employees, the public, and the environment from harmful effects of exposure to ionizing radiation from NORM and TENORM disposed of in accordance with permit limits. Clean Harbors is committed to meeting all applicable regulatory requirements imposed by the State of Colorado and the U.S. Government and to keeping doses from NORM/ TENORM waste As Low As Reasonably Achievable (ALARA) - social, technological and economic factors taken into account.

As part of Clean Harbor's NORM/TENORM Radiation Protection Program, the Company provides:

- Personal instruction in radiation safety from safety staff and field supervisors,
- Relevant manuals, installation and test instructions, and Standard Operating Procedures (SOPs) for equipment and activities at the Deer Trail landfill,
- Radiation safety seminars,
- A personal monitoring system, as required (thermoluminescent dosimeters[TLDs]),
- Gate monitors, radiation monitors, air sampling, and portable radiation survey meters when required, and
- This NORM/TENORM Radiation Protection Plan

This Plan has been approved by the Clean Harbors Deer Trail, LLC corporate staff and the Deer Trail Landfill Radiation Safety Officer (RSO).

Corporate Officer (Title/Name)	Signature	Date
Radiation Safety Officer (Name)	Signature	Date

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REFERENCED STANDARD OPERATING PROCEDURES

Standard Operating Procedure on Individual and Area Dosimetry
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Standard Operating Procedure on Radiation Surveys
Standard Operating Procedure on Use of the Gate Monitoring System
Standard Operating Procedure on Radiation Safety Training
Standard Operating Procedure on Radiation Records

The SOPs referenced in this Plan require approval by the Colorado Department of Public Health and Environment (CDPHE) prior to use or change.

1.0 PURPOSE AND SCOPE

The purpose of this NORM/TENORM Radiation Protection Plan is to establish necessary precautions, procedures, and plans to be observed when working directly with NORM/TENORM waste during disposal operations. Every designated employee who works with and around ionizing radiation from NORM/TENORM waste must read and adhere to this plan and the supporting policies and SOPS. It is the responsibility of the Deer Trail RSO to ensure that all employees have read, understand, and comply with the procedures and conditions defined in this plan. Deer Trail employees may not work unsupervised with NORM/TENORM waste until they complete appropriate radiation safety training (Section 6). The RSO or his designees will maintain a file containing signature sheets acknowledging that all new employees receive appropriate radiation safety training within 10 days of employment. The landfill will accept no other types or forms of radioactive material for disposal beyond NORM/TENORM waste and other radioactive materials that have been exempted, excluded, or cleared for unrestricted use by the public by Federal or State agencies.

For exposure to NORM/TENORM waste, Deer Trail workers will be considered members of the public and radiation exposures will be limited to 100 mrem/yr, plus ALARA, with a goal of 25 mrem/yr or less. If worker dosimetry results indicate that selected worker doses could exceed 25 mrem/yr, an assessment the potential for other manmade exposures for these workers will occur to ensure that maximum individual doses from manmade sources will not exceed 100 mrem/yr. This assessment will consider real individuals working at Deer Trail, not hypothetical members of the public.

As stated in the Deer Trail RCRA permit, the waste acceptance criterion is set at 400 pCi/g of ^{226}Ra, measured on a per shipment basis. If applied as a peak value for purposes of setting the gate monitor alarms, the average concentrations received will be less (probably about 10% of the peak concentration), and therefore average doses to workers will be also be less (probably about 10 mrem/yr), consistent with ALARA. This limit is equated to a gate monitor alarm setpoint of 100 µR/hr above background. Given that background is about 16 µR/hr, the alarm setpoint is 116 µR/hr. This setpoint is about 7 times the background level. Finally, the total activity of NORM/TENORM waste, including alpha- and beta-emitting radionuclides in the uranium and thorium decay chains, will be enforced to the limit of 0.002 µCi/g (2,000 pCi/g) used to define radioactive waste in Colorado, as long as the radium concentration limit of 400 pCi/g per shipment is also maintained.

2.0 ORGANIZATION AND RESPONSIBILITIES

The responsibilities for maintaining radiation safety at the Deer Trail landfill are assigned to: (1) the Deer Trail RSO and his designees, and (2) Deer Trail employees. The duties and responsibilities of these individuals are described below.

Radiation Safety Officer

The Deer Trail RSO is charged by Clean Harbors Deer Trail, LLC, to direct the facility NORM/ TENORM Radiation Protection Program. The RSO will designate staff to assist in administering the program. Specifically, the Deer Trail RSO or his designees shall:

1. Direct the operations of the staff;
2. Be empowered to impose conditions of work, restrictions on work, and termination of work involving NORM/TENORM waste as necessary to protect Company personnel, the public, and the environment or to ensure regulatory compliance;
3. Review the NORM/TENORM Radiation Protection Program at least annually;
4. Serve as the Company's point of contact with State and Federal regulatory agencies on all matters related to radiation safety;
5. Maintain a personnel dosimetry program, including evaluation of the need for issuance of dosimetry, maintain a contract for commercial dosimetry services, maintain dose records, and provide reports to individuals consistent with Colorado Regulations 6 CCR 1007-1, § 4.56 (Reports of Individual Monitoring);
6. Maintain radiation protection records including approved procedures, amendments, revisions and renewals consistent with Colorado Regulations 6 CCR 1007-1, § 4.40, 4.41, 4.42, 4.44, 4.47, and 4.50;
7. Provide radiation safety training for Company personnel;
8. Provide information and consultation on matters related to radiation safety.

Deer Trail Employees

Each Clean Harbors Deer Trail, LLC employee who works with NORM/TENORM waste as outlined in this plan must take responsibility for his or her own protection and for reporting any condition that, in the individual's opinion, constitutes unsafe or improper working conditions. Each individual is responsible for:

1. Maintaining their own exposures to radiation from NORM/TENORM waste ALARA;
2. Following procedures and accepted safe work practices so as not to endanger himself or herself, the public, or the environment;
3. Reporting unsafe working conditions, violations of the rules prescribed in this document, or violations of applicable regulations of the State to their supervisor and/or to the Deer Trail RSO and;
4. When serving as visitor escorts, pointing out a hazardous area that a visitor might be entering and ensuring that visitors observe all Company radiation safety rules and precautions.

3.0 CONTROL AND LIMITATION OF RADIATION EXPOSURES

State and Federal regulations establish a system of radiation dose justification, limitation, and optimization. Individual doses are limited to ensure that deterministic effects (such as radiation burns, or skin *erythema*) are avoided and that total lifetime risks of stochastic effects (such as cancer and hereditary effects) do not exceed overall health risks for persons working in safe industries. However, the regulations require that licensees further optimize radiation doses to individuals and to groups of individuals to the extent practical, social, economic and technological factors taken into account. This concept or philosophy is given the special name ALARA, which is an acronym for As Low As is Reasonably Achievable.

Radiation Dose Limits For exposure to NORM/TENORM waste, Deer Trail workers will be considered members of the public, and radiation exposures will be limited to 100 mrem/yr, plus ALARA, with a goal of 25 mrem/yr or less. If worker dosimetry results indicate that selected worker doses could exceed 25 mrem/yr, an assessment of the potential for other manmade exposures for those workers will occur to ensure that maximum individual doses from manmade sources will not exceed 100 mrem/yr. This assessment will consider real workers at Deer Trail, not hypothetical members of the public.

Routes of Exposure Exposures from NORM/TENORM waste could be received from radiation fields that are external to the body (external exposure) or from radioactive materials that are inside the body (internal exposure following inhalation) or both. Inhalation of dust particles is one of the primary routes of internal exposure.

Means of Exposure Control Common external exposure controls include the use of time, distance, and shielding to minimize radiation doses. Deer Trail radiation safety training courses present these concepts thoroughly, and field personnel should reinforce them continually through daily or weekly radiation safety briefings. Common control measures to reduce inhalation exposures include the use of protective equipment and engineering controls. Protective equipment includes full-face masks that filter airborne particulate materials. The Deer Trail Health and Safety Plan requires these masks for in-cell disposal operations, waste sampling operations, and all operations in the treatment building. These masks, which are required for the non-NORM/TENORM waste currently handled at the facility, are effective for removal of NORM/TENORM particulate matter. Disposable coveralls, gloves, and boot covers provide protection against skin contamination. The Deer Trail Facility Health and Safety Plan describes required protective equipment. Engineering controls used to control exposure include dust control measures in the landfill cell and the air filtration system in the treatment building.

Minors Minor visitors to the Deer Trail facility must be escorted at the site and will not be allowed in restricted areas. The facility does not employ minors.

4.0 RADIATION DOSIMETRY

The purpose of the radiation dosimetry program is to measure radiation dose equivalent received by Deer Trail employees during the handling and disposal of NORM/TENORM waste. The results serve to verify and document compliance with applicable dose limits (see Section 3) and to identify problems and monitor the effectiveness of radiation safety controls.

Radiation doses can be received in two ways: (1) from radioactive materials external to the body (external dose) or (2) from radioactive materials that are inside the body (internal dose). These doses shall be monitored when required by regulation as described below:

External Radiation Dosimetry

1. The Deer Trail RSO or his designee shall issue radiation dosimeters to individual workers who routinely come into contact or are in the proximity of NORM/ TENORM waste being disposed of, consistent with the Deer Trail **Standard Operating Procedure on Individual Dosimetry**.

2. Any Deer Trail employee shall immediately notify the Deer Trail RSO of changes in radiation fields from NORM/TENORM waste that could significantly increase or decrease radiation doses to personnel or that could otherwise affect the need for external dosimetry.

3. Personal radiation dosimeters shall not be issued for greater than 3 months.

4. Radiation dosimeters shall not be deceptively exposed.

    a. Dosimeters are issued to only one person. Dosimeters shall not be shared.

    b. Dosimeters in storage and not being worn shall not be stored near sources of radiation.

    c. Dosimeters should not be exposed to high heat, chemical or physical insults, or washed in a washing machine.

    d. No person shall wear dosimeters issued by the Deer Trail RSO while working for another (non-Deer Trail) employer or institution. Employees shall notify the Deer Trail RSO if they are concurrently working for another employer and working with manmade sources of ionizing radiation.

    e. Dosimeters shall not be worn during medical or dental x-ray examinations.

    f. Dosimeters shall not be worn after medical administration of radioactive materials (thyroid ablation therapy, cardiac stress tests, diagnostic nuclear medicine tests, etc.) until approved by the Deer Trail RSO.

    g. Employees shall notify the Deer Trail RSO immediately on learning of possible deceptive exposures of dosimeters.

    h. Intentional deceptive exposures of dosimeters are forbidden and could result in reprimands or termination of employment.

5. Lost or damaged dosimeters shall be reported to the Deer Trail RSO as soon as possible.

6. Persons who have lost or damaged their dosimeters shall be required to provide documentation of work activities and radioactive material uses as necessary for the Deer Trail RSO to assess doses.

7. Individual dosimeters shall be worn at the location on the body likely to receive the highest dose, consistent with manufacturer specifications.

8. Employees shall return used dosimeters to the Deer Trail RSO promptly after receiving replacement dosimeters at the beginning of a new wear period.

9. Any person who handles or disposes of NORM/TENORM waste on behalf of Deer Trail may request a copy of their dosimetry records at any time. These records are maintained by and are available from the Deer Trail RSO on written request. All contact with the radiation badge service company is to be made through the Deer Trail RSO or his designee.

10. After termination of employment, a dose report (termination report) shall be provided to all persons who received doses exceeding 10% of the public radiation dose limit in the applicable reporting period.

Internal Radiation Dose Assessment

Consistent with Colorado Regulations 6 CCR 1007-1, § 4.9 (Determination of Internal Exposure), for purposes of assessing internal radiation doses from the inhalation of airborne NORM/TENORM waste, suitable and timely measurements of concentrations of airborne materials in workplace air will be made and recorded. Airborne concentrations will be estimated consistent with the **Standard Operating Procedure on Air Sampling**. These concentrations, in combination with estimates of the duration of exposure and the impact of respiratory controls (as appropriate), with assumptions about the physical and chemical nature of the airborne NORM/TENORM waste, will be used to assess internal dose to workers from inhalation, in accordance with the **Standard Operating Procedure on Estimating Inhalation Doses**.

Records

All records of exposure, internal and external, are legal and personal and must be controlled to preclude release of personnel information to unauthorized personnel. All radiation protection records including individual worker records, approved procedures, amendments, revisions, and renewals will be maintained consistent with the Colorado Regulations 6 CCR 1007-1, § 4.40, 4.41, 4.42, 4.44, 4.47, and 4.50.

5.0 RADIATION SURVEYS AND INSTRUMENTATION

Radiation surveys identify and quantify radiological hazards and document regulatory compliance. The Deer Trail RSO and all field personnel must work together to ensure safety in the workplace and to protect the public and the environment from harmful effects of radiation.

Types of Surveys

1. Radiation surveys - may be performed to measure exposure or dose rates from NORM/TENORM waste received for disposal and to record ambient background

levels of radiation. Surveys shall be conducted as necessary to prevent exposures from exceeding limits outlined in Section 3, consistent with the Deer Trail **Standard Operating Procedure on Radiation Surveys**.

2. Exposure and dose rate calculations may be substituted for actual radiation surveys if based on reliable scientific, peer-reviewed assumptions/historical data.

3. Surveys of each waste shipment will be conducted and recorded using monitors positioned at the gate of the facility prior to the weight station, consistent with the Deer Trail **Standard Operating Procedure on Use of the Gate Monitor System**. The gate monitors consist of two Ludlum Model 3502 Gate Monitors; one positioned about 0.76 m (2.5 feet) from each side of the truck. Each monitor consists of a 5 × 5 cm (2 × 2 inch) sodium iodide crystal scintillation detector, with readout provided in the waste receipt/weight station. This limit is equated to a gate monitor alarm setpoint of 100 µR/hr above background based on the waste acceptance criteria for ^{226}Ra of 400 pCi/g. Given that background is about 16 µR/hr; the alarm setpoint is 116 µR/hr. This setpoint, which is about 7 times the background level, will still permit the detection of lost radiation sources in a waste shipment. As an alternative, hand-held survey equipment will be used for this purpose.

4. Surveys will be conducted on all vehicles leaving contaminated areas such as the landfill cells or the treatment building to ensure that no NORM/TENORM waste leaves the facility. Release criteria for vehicles will depend on whether the vehicle is in exclusive or nonexclusive use for the transport of NORM/TENORM waste.

Requirements on Maintaining Radiation Detection Instrumentation

1. The Deer Trail RSO or his designee must possess radiation detection equipment that is appropriate for detecting the types of radiations emitted by NORM/ TENORM waste received for disposal.

2. Portable radiation detectors and the gate monitor shall be calibrated or response-checked, as appropriate for the use of the instrument, at least annually or after repair of the instrument to the manufacturer's specifications. Battery replacement is not cause for performing a calibration. The Deer Trail RSO or his designee will perform such routine calibrations and response checks at the request of any Deer Trail employee.

6.0 TRAINING

All Deer Trail employees who work with or near NORM/TENORM waste must complete radiation safety training, as described in the **Standard Operating Procedure on Radiation Safety Training**. The depth of the training must be commensurate with the level of hazard to which the individual is exposed. **All training must be documented.** No individual shall be allowed to work unsupervised until that person completes appropriate NORM/TENORM radiation safety training.

Basic Radiation Safety Training

1. All individuals who work with NORM/TENORM waste must satisfactorily complete appropriate radiation safety training courses offered by or at the direction of the Deer Trail RSO or demonstrate competence on that subject matter by scoring at least 70% on a test administered or directed by the Deer Trail RSO.

2. This training shall address, as applicable for NORM/TENORM waste:

   a. Special operating schedules and techniques that will minimize exposures when receiving and disposing NORM/TENORM waste,

   b. Availability of protective equipment and clothing,

   c. Biological Effects of ionizing radiation,

   d. Concepts and philosophy of ALARA,

   e. Methods to maintain doses ALARA. and

   f. Types and uses of radiation detection equipment.

3. Deer Trail RSO-provided refresher training shall be conducted at least once each year for all individuals who work with NORM/TENORM waste.

4. All training shall be documented and maintained on file by the Deer Trail RSO or his designee. Training documentation shall include

   a. Content of the training (outline, course description, etc.),
   b. Instructor name,
   c. Date and duration of training,
   d. Printed name of trainee(s), and
   e. Signature or initials of trainee(s).

5. Copies of individual employee training records are available from the Deer Trail RSO.

6. Visitors who work with NORM/TENORM waste will be required to complete training similar to that of employees. Visitors who will not be working with NORM/TENORM waste but who will enter restricted areas will be required to undergo basic training commensurate with the level of exposure they will experience.

Hazard Communication Program

1. The Deer Trail facility has a hazard communication program as part of the Facility Health and Safety Plan. This program uses waste profiles, Material Safety Data Sheets, labels, and formal training to inform employees of any hazards of the waste materials with which they will be working. The program will convey information on specific hazards of NORM/TENORM waste handled at the facility.

7.0 INCIDENTS AND EMERGENCIES

The Deer Trail RCRA Permit Attachment 4, "Contingency Plan," describes general procedures for dealing with emergency situations such as spills or accidents. The Plan contains procedures for spill cleanup, notification of authorities, and other responses. In addition, it describes equipment and staff available to deal with such situations. In the event of a radiological incident, such as a spill of NORM/TENORM waste or other emergency potentially involving NORM/TENORM waste, the Deer Trail RSO must be notified immediately. If there is doubt about whether such notification is necessary, contact should be made to enable the Deer Trail RSO to assess the situation and initiate the appropriate response. If appropriate, the measures described in the Contingency Plan will be implemented.

What Constitutes an Incident or Emergency?

1. Loss, theft, or misuse of NORM/TENORM waste.
2. High or potentially high radiation exposure to an individual or a member of the public (for example, greater than 10 mrem to an offsite member of the public).
3. Intake or potential intake of radioactive materials by inhalation, ingestion, or injection through skin or wound.
4. Deceptive or potentially deceptive exposure of a dosimeter.
5. Personnel contamination that cannot be completely removed after two washes with only soap and water.
6. Personnel injuries that could involve radioactive contamination or radiation exposure.

8.0 RECORDKEEPING

Recordkeeping requirements vary and are maintained along with actual records by the Deer Trail RSO consistent with Colorado Regulations 6 CCR 1007-1, § 4.40, 4.41, 4.42, 4.44, 4.47, and 4.50. Recordkeeping requirements are provided in the **Standard Operating Procedure on Radiation Records.**

General Record-Keeping Requirements

1. The Deer Trail RSO shall maintain the following records in a clear, concise and orderly format. Retention periods are included in parentheses.
   a. Radiation surveys, as required (3 years)
      i. Radiation field surveys in areas in proximity to NORM/TENORM waste for disposal, and
      ii. Ambient radiation field surveys in unaffected areas.
   b. Survey instrument calibrations, as required by the manufacturer (3 years)

c. Personnel records (1 year)

i. Worker/user lists, and

ii. Training records

d. Operating and emergency procedures (current)

e. Procedure manuals from Deer Trail RSO (current)

2. In addition to maintaining duplicates of all records in step 1, the Deer Trail RSO shall maintain the following records, which are available for review during normal office hours.

a. Copies of current State regulations related to NORM/TENORM waste,

b. Inspection reports and copies of all "Notices of Violation" issued by State regulatory agencies and the Deer Trail responses to those notices,

c. Current versions of all policy manuals and SOP manuals,

d. Dosimetry records, and

e. Survey instrument calibration records.

Information Required on Specific Records

1. Radiation surveys

a. Records shall be in units of dpm, Ci, μCi, mR/hr, mrem/hr, etc., as appropriate. Units of "cpm" or "counts" are not acceptable for quantitative surveys records,

b. Records shall uniquely identify the source of the radiation,

c. Records shall clearly indicate the areas surveyed,

d. Records shall indicate the person performing the survey and date of survey, and

e. Records shall uniquely identify the survey instrument used (i.e., serial number or other unique description).

2. Training records are specified in Section 6.

9.0 GLOSSARY OF TERMS

"Absorbed dose" means the energy imparted by ionizing radiation per unit mass of irradiated material. The unit of absorbed dose is the rad.

"Activity" means the rate of disintegration or transformation or decay of radioactive material. The units of activity are "disintegrations per second (or minute)" (dps or dpm) and curie (Ci). 1 Ci = 37,000,000,000 dps (3.7×10^{10} dps)
1 Ci = 2,220,000,000,000 dpm (2.22×10^{12} dpm)

"Agreement State" means a state that has executed an agreement with the U.S. Nuclear Regulatory Commission transferring to the state the responsibility for regulating uses of certain radioactive materials within its borders. Colorado is an agreement state.

"Airborne radioactive material" means any radioactive material dispersed in the air in the form of dusts, fumes, particles, mists, vapors, or gases.

"As low as is reasonably achievable (ALARA)" means making every reasonable effort to maintain exposures to radiation as far below regulatory dose limits as practical, consistent with the purpose for which the licensed or registered activity is undertaken, taking into account the state of technology, the economics of improvements in relation to benefits to public health and safety, and other societal and socioeconomic considerations, and in relation to utilization of ionizing radiation and licensed sources of radiation in the public interest.

"Background radiation" means radiation from cosmic sources; nontechnologically enhanced naturally occurring radioactive material, including radon, except as a decay product of source or special nuclear material, and including global fallout as it exists in the environment from the testing of nuclear explosive devices. "Background radiation" does not include sources of radiation from radioactive materials regulated by the State of Colorado.

"Committed dose equivalent ($H_{T,50}$ or CDE)" means the dose equivalent to organs or tissues of reference (T) that will be received from an intake of radioactive material by an individual during the 50-year period following the intake.

"Committed effective dose equivalent ($H_{E,50}$ or CEDE)" means the sum of the products of the weighting factors applicable to each body organ or tissue irradiated and the committed dose equivalent to each of these organs or tissues ($H_{E,50} = \Sigma W_T H_{T,50}$).

"Curie (Ci)" means a unit of measurement of activity. One curie (Ci) is that quantity of radioactive material that decays at the rate of 3.7×10^{10} disintegrations per second (dps). Commonly used submultiples of the curie are the millicurie and the microcurie. One millicurie (mCi) = 1×10^{-3} curie = 3.7×10^{7} dps. One microcurie (μCi.) = 1×10^{-6} curie = 3.7×10^{4} dps. One nanocurie (nCi) = 1×10^{-9} curie = 3.7×10^{1} dps. One picocurie (pCi) = 1×10^{-12} curie = 3.7×10^{-2} dps.

"Dose" is a generic term that means absorbed dose, dose equivalent, effective dose equivalent, committed dose equivalent, committed effective dose equivalent, total organ dose equivalent, or total effective dose equivalent.

"Dose equivalent (H_T)" means the product of the absorbed dose in tissue, quality factor, and all other necessary modifying factors at the location of interest. The units of dose equivalent are rem or mrem.

"Dosimeter" means a device designed to be worn by a single individual for the assessment of dose equivalent. Examples of individual monitoring devices are film badges, thermoluminescent dosimeters (TLDs), and pocket ionization chambers.

"Effective dose equivalent (H_E)" means the sum of the products of the dose equivalent to each organ or tissue (H_T) and the weighting factor (W_T) applicable to each body organ or tissue irradiated ($H_E = \Sigma W_T H_T$).

"Exposure rate" means the exposure per unit of time, typically milliroentgen per hour (mR/hr) or microroentgen per hour (µR/hr).

"External dose" means that portion of the dose equivalent received from any source of radiation outside the body.

"Internal dose" means that portion of the dose equivalent received from radioactive material taken into the body.

"Ionizing radiation" means any electromagnetic or particulate radiation capable of producing ions, directly or indirectly, in its passage through matter. Ionizing radiation includes gamma rays and x-rays, alpha and beta particles, high-speed electrons, neutrons, and other nuclear particles.

"Lost or missing source of radiation" means a source of radiation whose location is unknown. This definition includes licensed material that has been shipped but has not reached its planned destination and whose location cannot be readily traced in the transportation system, and sources that might be detected and recovered by the Deer Trail gate monitors.

"Natural radioactivity" means radioactivity of naturally occurring nuclides whose location and chemical and physical form have not been altered by man.

"Quality factor (Q)" means the modifying factor that is used to derive dose equivalent from absorbed dose.

Radiation	Quality Factor
beta	1
gamma	1
x-ray	1
alpha	20
neutron	varies from 3 - 10

"Rad" means the special unit of absorbed dose. One rad is equal to an absorbed dose of 100 ergs per gram.

"Radiation" means one or more of the following:

(1) Gamma and x-rays; alpha and beta particles, and other atomic or nuclear particles or rays; or

(2) stimulated emission of radiation from any electronic device to such energy density levels as to reasonably cause bodily harm.

"Radiation Safety Officer (RSO)" is an individual, designated by the Company, who has the required training, knowledge, and authority and responsibility to apply appropriate NORM/TENORM radiation protection rules standards, and practices.

"Rem" means the special unit of any the quantities expressed as dose equivalent. The dose equivalent in rem is equal to the absorbed dose in rad multiplied by the quality factor.

"Roentgen (R)" means the special unit of exposure. One roentgen (R) equals 2.58×10^{-4} coulombs/kilogram of air.

"Sealed source" means radioactive material that is permanently bonded or fixed in a capsule or matrix designed to prevent release and dispersal of the radioactive material under the most severe conditions that are likely to be encountered in normal use and handling.

"Survey" means an evaluation of the radiological conditions and potential hazards incident to the production, use, transfer, release, disposal, or presence of sources of radiation. When appropriate, such evaluations include, but are not limited to, tests, physical examination of location of materials and equipment, and measurements of levels of radiation or concentration of radioactive material present.

"Technologically Enhanced Naturally Occurring Radioactive Material (TENORM)" means naturally occurring radioactive material whose radionuclide concentrations are increased by or as a result of past or present human practices. TENORM does not include:

(a) Background radiation or the natural radioactivity of rocks or soils;

(b) "Byproduct material" or "source material," as defined by Colorado statute or rule; or

(c) Enriched or depleted uranium as defined by Colorado or Federal statute or rule

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

TEDE = DDE + CEDE

"Whole body" means, for purposes of external exposure, head, trunk (including male gonads), arms above the elbow, or legs above the knees.

CLEAN HARBORS DEER TRAIL LLC
STANDARD OPERATING PROCEDURE ON
INDIVIDUAL AND AREA DOSIMETRY

Approved by:

_____ Corporate Official

_____ Radiation Safety Officer

Date:

Effective Date:

1.0 OBJECTIVE: To define general and specific methods and procedures for conducting individual and area dosimetry for Deer Trail.

2.0 SCOPE: Individual dosimetry for Deer Trail workers who may be exposed to radiation from NORM/TENORM waste and for identified areas within and in the immediate area around the Deer Trail landfill shall be performed:

- To determine individual worker radiation doses from external radiation, and
- To determine background and ambient radiation levels.

3.0 POLICY: Individual and area dosimetry shall be performed to verify that radiation doses to Deer Trail workers and members of the public are maintained at levels of 100 mrem/y, plus ALARA. The standard issue Deer Trail dosimeter shall be a thermoluminescent dosimeter in a plastic case, consistent with the manufacturer's specifications and requirements.

4.0 INDIVIDUAL DOSIMETER PROGRAM:

4.1 Dosimeter Issue: All Deer Trail workers who are in the proximity of radiation from NORM/TENORM waste as part of their routine employment shall be issued and wear an individual dosimeter. The individual dosimeters shall be worn at the location on the body likely to receive the highest dose, consistent with manufacturer specifications; typically on the chest area, or between the waist and the neck. Lost or damaged dosimeters shall be reported to the Deer Trail Radiation Safety Officer (RSO) as soon as possible. Persons who have lost or damaged their dosimeters shall be required to provide documentation of work activities and NORM/TENORM exposures as necessary for the Deer Trail RSO to assess doses. Individual dosimeters shall be issued only to personnel formally instructed in their use, and shall be worn only by those to whom the dosimeters were issued. In addition, Deer Trail dosimeters shall not be:

- Deceptively exposed,
  - Employees shall notify the Deer Trail RSO immediately upon learning of possible deceptive exposures of dosimeters.
  - Intentional deceptive exposures of dosimeters are forbidden and may result in reprimands or termination of employment.
- Stored near sources of radiation,

- Exposed to high heat, chemical or physical insults, or washed in a washing machine,
- Worn while working for another employer or institution (employees shall notify the Deer Trail RSO if they are concurrently working for another employer and working with man-made sources of ionizing radiation),
- Worn during medical or dental x-ray examinations,
- Worn after medical administration of radioactive materials (thyroid ablation therapy, cardiac stress tests, diagnostic nuclear medicine tests, etc.) until approved by the Deer Trail RSO.

4.2 Changes in Worker Exposure: If the potential for a worker's exposure changes, the Deer Trail RSO or his designee shall:

- Remove the employee from the individual dosimeter program if the employee has terminated employment or if the employee's job has changed such that they are no longer in the proximity of radiation from NORM/ TENORM waste.
- Add an employee to the individual dosimeter program if their job has changed such that they will now be working in the proximity of radiation from NORM/TENORM waste.

4.3 Non-Occupational Radiation Doses: Dosimeter users:

- Are responsible for ensuring dosimeters are not exposed to non-occupational sources of radiation (e.g., medical or security x-ray devices, therapeutic medical sources, or radiation from medical radionuclides injected into the body).
- Shall notify the Deer Trail RSO or his designee prior to receiving medical injections of radionuclides.
- Shall notify the Deer Trail RSO or his designee if their dosimeter is exposed to non-occupational radiation sources.

The Deer Trail RSO or his designee shall:

- Determine a course of action that will prevent exposure of an individual dosimeter and problems with personnel surveys for employees who report receiving medical injections of radionuclides.
- Will investigate the cause of the exposure from non-occupational sources and determine the corrections that are necessary for recording the employee's radiation dose.
- Perform a dosimetry investigation if a workers dosimeter cannot be read, is lost, has an anomalous result, or equals or exceeds an administrative control level of 25 mrem in any quarter.
- Re-assign the work duties for individual workers whose quarterly radiation dose equals or exceeds 25 mrem in any two consecutive quarters to reduce their exposure to radiation from NORM/TENORM waste.

4.4 Exchanging Dosimeters: Employees shall return used dosimeters to the Deer Trail RSO or his designee promptly after receiving replacement dosimeters at the beginning of a new wear period. The Deer Trail RSO or his designee shall:

- Be responsible for establishing a program for dosimeter exchange, processing (consistent with the manufacturer's specifications), and recording, and reporting the results.

- Assure dosimeters are exchanged on a quarterly basis, unless the Deer Trail RSO or his designee determines a change in exchange frequency is warranted to assure radiation doses to workers and the public are maintained at levels of 100 mrem/y plus ALARA.
- Verify all dosimeters are exchanged and note the dosimeters are in good condition (or note the damage, if they are not).
- Note the actual date of dosimeter exchange.
- Verify all dosimeter results are recorded in a spreadsheet.
- Modify the quarterly doses to include potential inhalation doses, as estimated using the Deer Trail NORM/TENORM SOP on *Standard Operating Procedure on Estimating Inhalation Doses.*
- Develop and report all dose results to the employees on an annual basis.
- Serve as the Deer Trail point of contact for individual dosimetry issues.
- Assure that individual worker doses are recorded, by quarter and annually, using the form in Attachment 1 and maintained in their personnel file.
- Assure that a corporate record of worker doses, by quarter and annually, is developed using the form in Attachment 2 consistent with the Deer Trail NORM/TENORM SOP on *Records Management.*

4.5 Records Requests: Any person who handles or disposes of NORM/TENORM waste on behalf of Deer Trail may request a copy of their dosimetry records at any time. These records are maintained by and are available from the Deer Trail RSO upon written request. All contact with the radiation badge service company is to be made through the Deer Trail RSO or his designee.

4.6 Employment Termination Dose Report: After termination of employment, a dose report (termination report) shall be provided to all persons who received doses exceeding 10% of the public radiation dose limit in the applicable reporting period. This report will be provided using the latest copy of Attachment 1 found in the employees personnel file, updated to show doses through the date of employment termination.

5.0 AREA DOSIMETRY PROGRAM:

5.1 Program Requirements: Quarterly dose rates shall be measured using special issue individual dosimeters in locations:

- Where workers are routinely in the proximity of NORM/ TENORM waste such as the weight station and disposal cell,
- Where it is unlikely that NORM/TENORM waste would be present such as the change room, lunch room, and maintenance areas to confirm contamination control, and
- Remote from NORM/TENORM waste that will record the ambient background.

5.2 Responsibilities: The Deer Trail RSO or his designee shall:

- Determine the number and location of the area dosimeters in and around the Deer Trail landfill and provide a facility map indicating the location of each area dosimeter.
- Ensure that each identified location has at least one area dosimeter.
- Maintain a map of the location of each dosimeter.
- Ensure that area dosimeters are placed 1 to 1.5 m (40 to 60 inches) above the ground or floor level.
- Provide protection for area dosimeters against heat, moisture, and direct sunlight.

- Exchange the dosimeters, consistent with the exchange procedures for employees, on a quarterly basis or other basis, as determined.
- Maintain records for each area dosimeter location in a dosimetry spreadsheet.
- Note any special conditions including tampering, damage, or loss of dosimeter, in the records.
- Investigate any missing or damaged dosimeters.
- Resolve anomalous data, and track and trend data for routine annual and other special reports, as required.
- Serve as the point of contact for area dosimetry issues. Assure that area radiation doses are recorded, by quarter and annually, using the form in Attachment 3 and maintained in their personnel file.
- Assure that a corporate record of area radiation doses, by quarter and annually, is developed using the form in Attachment 4 and maintained as a log consistent with the Deer Trail NORM/TENORM SOP on *Records Management.*

ATTACHMENT 1 – ANNUAL NORM/TENORM INDIVIDUAL DOSIMETRY RECORD

Clean Harbors Deer Trail LLC
ANNUAL NORM/TENORM INDIVIDUAL DOSIMETRY RECORD

Individual ____________________ Payroll No. ____________________

Exchange Dates for Calendar Year _____ (a)	Deployed: Recovered:	Deployed: Recovered:	Deployed: Recovered:	Deployed: Recovered:	
Individual/ (Dosimeter No.)	1st Quarter Dose Rate (mrem)	2nd Quarter Dose Rate (mrem)	3rd Quarter Dose Rate (mrem)	4th Quarter Dose Rate (mrem)	Annual Total Dose Rate (mrem/y)
Exchange Dates for Calendar Year _____ (a)	Deployed: Recovered:	Deployed: Recovered:	Deployed: Recovered:	Deployed: Recovered:	
Individual/ (Dosimeter No.)	1st Quarter Dose Rate (mrem)	2nd Quarter Dose Rate (mrem)	3rd Quarter Dose Rate (mrem)	4th Quarter Dose Rate (mrem)	Annual Total Dose Rate (mrem/y)
Exchange Dates for Calendar Year _____ (a)	Deployed: Recovered:	Deployed: Recovered:	Deployed: Recovered:	Deployed: Recovered:	
Individual/ (Dosimeter No.)	1st Quarter Dose Rate (mrem)	2nd Quarter Dose Rate (mrem)	3rd Quarter Dose Rate (mrem)	4th Quarter Dose Rate (mrem)	Annual Total Dose Rate (mrem/y)

(a) Enter year of employment and provide exact dates for those employees whose deployment and exchange dates differ from the company standard.

Comments: (add additional pages, if necessary)

Annual Log Completed By:	Annual Log Reviewed By:
Name (Print) ____________________	Name (Print) ____________________
Signature ____________________	Signature ____________________

ATTACHMENT 2 – ANNUAL NORM/TENORM INDIVIDUAL DOSIMETRY LOG

Clean Harbors Deer Trail LLC
ANNUAL NORM/TENORM INDIVIDUAL DOSIMETRY LOG

Exchange Dates[a]	Deployed: Recovered:	Deployed: Recovered:	Deployed: Recovered:	Deployed: Recovered:	
Individual Name/ (Dosimeter No.)	1st Quarter Dose Rate (mrem)	2nd Quarter Dose Rate (mrem)	3rd Quarter Dose Rate (mrem)	4th Quarter Dose Rate (mrem)	Annual Total Dose Rate (mrem/y)

(a) Provide exact dates for those employees whose deployment and exchange dates differ from the company standard.

Comments: (add additional pages, if necessary)

Annual Log Completed By:	Annual Log Reviewed By:
Name (Print) _____	Name (Print) _____
Signature _____	Signature _____

ATTACHMENT 3 – NORM/TENORM AREA DOSIMETRY LOG

Clean Harbors Deer Trail LLC
NORM/TENORM AREA DOSIMETRY REPORT

Location

Location Description

Instrument/Probe Model	Pancake GM Survey Meter	Dose Rate Meter	Instrument Comments
Serial No.			
Efficiency			
Correction Factor			
Background Reading	dpm	μR/h	

Date/Time	Description	Distance	NET DOSE RATES	NET CONTAMINATION LEVELS	
			β-γ (μR/h)	Total β-γ (dpm/100 cm²)	Removable β-γ (dpm/100 cm²)

Comments: (add additional pages, if necessary)

Smear samples counted for _____ minutes to determine removable contamination levels.

Survey Conducted By:	Annual Survey Log Reviewed By:
Name (Print) _____	Name (Print) _____
Signature _____	Signature _____

ATTACHMENT 4 – ANNUAL NORM/TENORM AREA DOSIMETRY LOG

Clean Harbors Deer Trail LLC
ANNUAL NORM/TENORM AREA DOSIMETRY LOG

Exchange Dates:	Deployed: Recovered:	Deployed: Recovered:	Deployed: Recovered:	Deployed: Recovered:	
Location	1st Quarter Dose Rate (mrem)	2nd Quarter Dose Rate (mrem)	3rd Quarter Dose Rate (mrem)	4th Quarter Dose Rate (mrem)	Annual Total Dose Rate (mrem/y)

Comments: (add additional pages, if necessary)

Annual Log Completed By:	Annual Log Reviewed By:
Name (Print)	Name (Print) _____
Signature	Signature _____

- A list of and facility map showing actual locations of airborne monitoring equipment (the locations should include areas where NORM/TENORM waste is sampled, treated, and disposed, as well as ambient locations such as the change room or lunch room, site boundary, and location for determining background levels),
- Calibration and performance testing procedures, consistent with the manufacturer's requirements,
- Calibration records and maintenance requirements, and
- Any deviations from this procedure.

- Assure that air monitoring samples are evaluated and documented on a quarterly basis, or more frequently for dusty locations, as necessary,
- Provide revised documentation and equipment locations when facility or operational changes occur that could affect airborne concentrations of NORM/TENORM waste, and
- Oversee the use of the airborne monitoring results in the quarterly estimation of radiation doses to Deer Trail workers.

4.2 Performing Airborne Monitoring: Monitoring of airborne concentrations of NORM/TENORM waste shall be conducted using air monitors (CAMs) with the following considerations:

- Determination and documentation of the elapsed filter exposure time prior to replacement of each air filter,
- Estimates of occupancy time involving potential exposures to airborne NORM/TENORM waste shall be made for each filter exchange, for each monitoring location, by the Deer Trail RSO or his designee,
- Maintaining flow rates consistent with the manufacturer's recommendations so that sample volumes can be accurately estimated, and
- Maintaining calibration and testing according to the manufacturer's recommendations.

4.3 Preliminary Assessment: Upon removal of the air filter, a preliminary assessment shall be conducted using field instruments to determine gross contamination levels. If background levels of radon or thoron progeny interfere, prompt field assessments may not be possible; however, the intent of this preliminary assessment is to assure that the contamination levels present are consistent with the sample receipt criteria for the analytical laboratory.

4.5 Analytical Results: The recovered filter media shall be sent to a qualified analytical laboratory for evaluation. The data and information for each recovered filter shall be recorded using the form shown in Attachment 1. The information shall include: specific sample location, model number or identifier for the sampler, name of analytical laboratory, instrument sensitivity, collection efficiency, flow rate, filter medium, correction factors applied, exchange dates and times, sampling duration, exposure duration, and analytical results including gross sample activity, background activity, net activity, net activity, and estimated error, by radionuclide.

4.4 Trending: Airborne monitoring results shall be plotted on a quarterly basis for purposes of trending airborne concentrations. Such trending will:

- Provide indication of the continued effectiveness of the existing exposure controls,
- Warn of localized deterioration of control equipment or operating procedures,
- Identify long-term variations in airborne radioactivity levels.

5.0 DETERMINATION OF INHALATION RADIATION DOSES FROM NORM/TENORM WASTE: Radiation doses to Deer Trail workers from inhalation of airborne NORM/TENORM

waste shall be evaluated on a quarterly basis, as described in the SOP on *Estimating Inhalation Doses* and the SOP on *Individual Dosimetry*. The procedure on individual dosimetry relies on a determination of the corrected airborne concentration of each radionuclide, in units of pCi/g, using the information recorded on the form in Attachment 1.

6.0 RECORDS: The Deer Trail RSO or his designee shall Maintain records of the workplace airborne monitoring results for each monitoring location and record the information, quarterly and annually, on the form provided in Attachment 1.

ATTACHMENT 1 – NORM/TENORM AIRBORNE MONITORING RECORD

Clean Harbors Deer Trail LLC
NORM/TENORM AIRBORNE MONITORING RECORD

Sample Location: _____ Sampler Model No. _____

Analytical Laboratory: _____ Sensitivity (Estimated Error): _____

Collection Efficiency: _____ Flow Rate: _____

Filter Medium: _____ Correction Factors: _____

Exchange Dates for Calendar Year[a]	Date & Time Deployed: / Recovered:	Date & Time Deployed: / Recovered:	Date & Time Deployed: / Recovered:	Date & Time Deployed: / Recovered:
Sampling Duration	h	h	h	h
Occupancy Time	h	h	h	h
Gross Activity	pCi	pCi	pCi	pCi
Background Activity	pCi	pCi	pCi	pCi
Net Activity	pCi	pCi	pCi	pCi
Radionuclide Net Activity	pCi	pCi	pCi	pCi
	pCi	pCi	pCi	pCi
	pCi	pCi	pCi	pCi
	pCi	pCi	pCi	pCi
	pCi	pCi	pCi	pCi
	pCi	pCi	pCi	pCi
	pCi	pCi	pCi	pCi
	pCi	pCi	pCi	pCi
	pCi	pCi	pCi	pCi
	pCi	pCi	pCi	pCi
	pCi	pCi	pCi	pCi

(a) For filters exchanged more often than once a quarter, note the frequency in the comment section and use additional forms, as required.

Comments: (add additional pages, if necessary)

Annual Record Completed By:

Name (Print) _____

Signature _____

Annual Record Reviewed By:

Name (Print) _____

Signature _____

CLEAN HARBORS DEER TRAIL LLC
STANDARD OPERATING PROCEDURE ON
ESTIMATING INHALATION DOSES

Approved by:

_____ Corporate Official

_____ Radiation Safety Officer

Date:

Effective Date:

1.0 OBJECTIVE: To define specific methods and procedures for estimating NORM/TENORM waste inhalation doses to Deer Trail workers.

2.0 SCOPE: Inhalation radiation doses for workers exposed to airborne concentrations of NORM/TENORM waste shall be performed:

- To determine the potential internal dose to Deer Trail landfill workers.
- To be included and reported as part of the annual total committed effective dose equivalent to Deer Trail workers.

3.0 POLICY: Estimates of inhalation dose to Deer Trail landfill workers shall be conducted to verify that annual total committed effective dose equivalents to Deer Trail workers are maintained less than 100 mrem/y, with doses being maintained ALARA.

4.0 GENERAL PROCEDURE FOR ESTIMATING RADIONUCLIDE INTAKE:

Airborne concentrations and NORM/TENORM waste radionuclide distributions will be established, on a quarterly basis, from the air sampling program, consistent with the Standard Operating Procedure (SOP) on *Air Sampling*. The quarterly data will be specific to work location and will include background ambient concentrations so that localized net airborne concentrations of NORM/TENORM waste (i.e., background corrected concentrations) can be determined.

Since laboratory analysis of air sampler filters provide the total activity on a sample (in pCi) by radionuclide, the average background corrected air concentration is found by dividing the net activity on the sample by the volume of air passing through the sampler, to produce the average pCi/m^3 in air. The volume of air passing through the sampler is the product of the rate of airflow (m^3/h) times the number of hours the sampler is in operation. It is recognized that this average value may underestimate the work place concentrations during receipt and disposal of NORM/TENORM waste since it includes lower air concentrations during time periods when RCRA waste (i.e. non NORM/ TENORM waste) is disposed, time periods when the daily cover is in place and there is

no possibility for airborne NORM/TENORM waste, and off hours time periods when no workers are present.

To correct for this potential underestimate of air concentration, the Deer Trail Radiation Safety Officer (RSO) or his designee will make an estimate of the potential number of hours during the quarter that may pose an airborne hazard for NORM/TENORM waste. The airborne concentration during waste disposal operations is then found by dividing the sample activity for each radionuclide by the volume of air passing through the sampler for the estimated number of hours of airborne NORM/TENORM hazard. This is expressed by the following equation.

$$C_{a,i} = [S_{a,i}]/[V_{a,T} \times T]$$

Where: $C_{a,i}$ = Corrected Airborne Concentration of Radionuclide i (pCi/m^3),
$S_{a,i}$ = Sample Activity for Radionuclide (pCi),
$V_{a,T}$ = Volume Airflow Rate for the Sampler (m^3/h), and
T = Duration of Airborne NORM/TENORM Hazard (h).

Once the estimated radionuclide mixtures and airborne contamination levels are established, individual worker intake by inhalation of can be estimated. The intake by inhalation of a radionuclide i (I_i) is estimated using:

$$I_i = [T_w] \times [\text{Ventilation Rate}] \times [C_{a,i}]$$

For each worker who is potentially exposed to airborne NORM/TENORM waste, an estimate will be made of the amount of time they spend in a specific work location (T_w). This estimate will account for time spend away from potential airborne NORM/TENORM waste, for example time conducting routine maintenance in unaffected areas, time in training, or time conducting offsite activities. For cases where an individual worker may have onsite exposures at many airborne NORM/TENORM waste locations of different concentrations, the highest measured airborne NORM/TENORM waste concentration will be used in estimating individual radionuclide intakes. Based on information provided by the International Commission on Radiation Protection (ICRP) in Publication 66, the adult male ventilation rate during light exercise is 1.5 m^3/h.

5.0 GENERAL PROCEDURE FOR ESTIMATING INHALATION DOSE:

Quarterly radiation doses to workers (committed effective dose equivalents) shall be estimated using the following equation:

$$H_{E,50} = \Sigma_i \Sigma w_T H_{T,50,i}$$

Where: $H_{E,50}$ = the sum of the products of the weighting factors applicable to each of the body organs or tissues that are irradiated and the committed dose equivalent to each of these organs or tissues,
W_T = weighting factors for each specific bodily tissue or organ, and

$H_{T,50,i}$ = committed effective dose equivalent for radionuclide i (mrem).

The committed effective dose equivalent for radionuclide i ($H_{T,50,i}$) is found by multiplying the intake of each radionuclide (I_i) by the unit intake committed dose conversion factor for each radionuclide and tissue or organ ($DCF_{T,i}$) as shown in the following equation:

$$H_{T,50,i} = (I_i) \times (DCF_{T,i})$$

To streamline the process, and for consistency with the doses recorded by the external dosimetry program, unit intake effective dose coefficients ($DCF_{E,i}$ - i.e., $\Sigma_T DCF_{T,i}$) have been tabulated by the U.S. Environmental Protection Agency (EPA). Modifying the above equations to account for the use of unit intake effective dose coefficients is shown in the following equation.

$$H_{E,50} = ([T_w] \times [\text{Ventilation Rate}]) \Sigma_i ([C_{a,i}] \times (DCF_{E,i})$$

The unit intake effective dose coefficients, taken from Federal Guidance Report No. 11 (Eckerman et al. 1988) are provided in Attachment 1 for the NORM/TENORM waste radionuclides of concern. These values are the most conservative (highest) across all solubility classes considered by the EPA.

6.0 RESPIRATORY PROTECTION:

The Deer Trail RCRA permit requires the use of respiratory protection for all activities when workers are in close proximity to the waste. These activities include sampling, treatment (when required), and in cell disposal. Full face piece air-purifying respirators are used by Deer Trail workers for these activities. Consistent with 6 CCR 1007-1, § 4.24 and Part 4 - Appendix A, a respiratory protection factor of 50 will be applied to all appropriate work when the use of respirators is mandatory.

7.0 INHALATION DOSE WORKSHEET:

A worksheet for calculating inhalation committed effective dose equivalents is provided in Attachment 2. The sum of the inhalation doses for each quarter is used to produce the annual inhalation dose estimate for each worker. This value is then added to the annual external dose for each worker to produce the estimated annual total effective dose equivalent.

REFERENCES

Eckerman, K. F., A. B. Wolbarst, and A. C. B. Richardson. 1988. *Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion.* Federal Guidance Report No. 11, EPA-520/1-88-020, U.S. Environmental Protection Agency, Washington, D.C.

International Commission on Radiation Protection (ICRP). 1993. *Human Respiratory Tract Model for Radiological Protection.* ICRP Publication 66, Annals of the ICRP, Vol. 23, Nos. 1-3.

ATTACHMENT 1 – UNIT INTAKE EFFECTIVE DOSE EQUIVALENT COEFFICIENTS

Radionuclides	$DCF_{E,I}$[a] (Sv/Bq inhaled)	$DCF_{E,I}$[b] (mrem/pCi inhaled)
Uranium Series		
^{238}U	3.2E-5	1.2E-1
^{234}Th	9.5E-9	3.5E-5
^{234}U	3.6E-5	1.3E-1
^{230}Th	8.8E-5	3.3E-1
^{226}Ra	2.3E-6	8.5E-3
^{214}Pb	2.1E-9	7.8E-6
^{214}Bi	1.8E-9	6.7E-6
^{210}Pb	3.7E-6	1.4E-2
^{210}Bi	5.3E-8	2.0E-4
^{210}Po	2.5E-6	9.3E-3
Actinium Series		
^{235}U	3.3E-5	1.2E-1
^{231}Th	2.4E-10	8.9E-7
^{231}Pa	3.5E-4	1.3E+0
^{227}Ac	3.5E-4	1.3E+0
^{227}Th	4.4E-6	1.6E-2
^{223}Ra	2.1E-6	7.8E-3
^{211}Pb	2.4E-9	8.9E-6
Thorium Series		
^{232}Th	4.4E-4	1.6E+0
^{228}Ra	1.3E-6	4.8E-3
^{228}Ac	8.3E-8	3.1E-4
^{228}Th	9.2E-5	3.4E-1
^{224}Ra	8.5E-7	3.1E-3
^{212}Pb	4.6E-8	1.7E-4
^{212}Bi	5.8E-9	2.1E-5

(a) Based on data from Federal Guidance Report No. 11 (Eckerman et al. 1988).
(b) Converted from units of Sv/Bq to units of mrem/pCi by multiplying by a conversion factor of 3.700.

ATTACHMENT 2 - *DEER TRAIL NORM/TENORM INHALATION WORKSHEET*

December 15, 2004

Employee Name: _____ Payroll Number: _____ Reporting Period: _____ Date: _____

Sampler Air Flow Rate[1] _____ (m^3/h)
Estimated Duration of Airborne NORM/TENORM Hazard[2] _____ (h)
Estimated Inhalation Exposure Duration for This Worker During the Reporting Period _____ (h)
Respiratory Protection Used? _____ (Y/N)

Inhalation Dose Calculations:	Identified Radionuclides[3]	Column 1 Background Corrected Radionuclide Concentrations[4] (pCi)	Column 2 Estimated Airborne Concentration by Radionuclide[5] (pCi/m^3)	Column 3 Estimated Intake by Radionuclide[6] (pCi)	Column 4 Unit Intake Inhalation Dose Conversion Factors[7] (mrem/pCi)	Estimated Committed Effective Dose Equivalent[8] (mrem)
					Total:	

Prepared by: _____ (Signature)

[1] Insert the air flow rate for the air sampler with the highest reported activity to which this worker was exposed, in units of (m^3/h).
[2] Insert the estimated hours of airborne NORM/TENORM hazard during the reporting period, in units of hours.
[3] List the radionuclides reported by the analytical laboratory for the air sample with the highest reported activity to which this worker was exposed.
[4] List the background corrected radionuclide concentrations reported by the analytical laboratory for this sample.
[5] Divide the entries in **Column 1** (by radionuclide) by the air sampler flow rate and by the estimated duration of airborne NORM/TENORM hazard.
[6] Multiply the entries in **Column 2** by a ventilation rate of 1.5 (m^3/h) and the duration of exposure for this worker.
[7] Insert the unit intake inhalation dose conversion factors from Attachment 1 to SOP Number XXX.x, in units of mrem/pCi inhaled.
[8] Multiply the entries in **Column 3** by the entries in **Column 4**, and divide by 50 if this worker used respiratory protection during the exposure. Total the entries in this column at the bottom of the column.

CLEAN HARBORS DEER TRAIL LLC
STANDARD OPERATING PROCEDURE ON
NORM/TENORM WASTE RADIATION SURVEYS

Approved by:

_____ Corporate Official

_____ Radiation Safety Officer

Date:

Effective Date:

1.0 OBJECTIVE: To define general and specific methods and procedures for conducting NORM/TENORM waste radiation surveys.

2.0 SCOPE: Radiation surveys for NORM/TENORM waste shall be performed:

- To determine ambient radiation and contamination levels in locations around and within the Deer Trail landfill.
- As part of waste receipt to verify radiation levels.
- To assure that workers are free of NORM/TENORM waste contamination when leaving the waste disposal cells or areas where NORM/TENORM waste is temporarily stored.
- To support any spill cleanup procedures that may be required.
- To support personnel decontamination.
- To support equipment or area decontamination.

3.0 POLICY: Radiation surveys shall be conducted to verify waste concentrations and to limit the exposure of Deer Trail workers and to assure that radiation doses to Deer Trail workers are maintained at levels of 100 mrem/y, plus ALARA.

4.0 GENERAL SURVEY METHODS:

4.1 Count Rate Meter Instrument Check List: Prior to use of the Ludlum Model 3 Survey Meter or equivalent, the operation of the GM probe or Gamma Scintillator used will checked using the following procedure:

- Check Batteries
  - Turn the switch to "BAT" or flip the "BAT" switch to "ON."
  - The needle on the meter face should move to a position within or beyond the indicated area on the meter scale.
  - Replace batteries if needed before use.
- Check Count Rate Meter Speaker
  - Turn the audio switch, if present, to "ON."
  - Set the Fast-Slow toggle switch to "f" or "s" depending on type of survey.
  - Set the count rate meter scale to "X1."
  - The rate meter should "chirp" or "click."

- If the speaker does not function, the survey meter can be used, but the surveyor will need to check the meter reading or display frequently.

- Check Background
  - Go to an area removed from the NORM/TENORM waste.
  - Note the count rate when the count rate meter is set to the "X1" scale (this rate may vary from about 10 to 100 counts per minute).
  - Do not use the meter if it does not register a background reading.
- Check Count Rate Meter Probe
  - Hold the supplied check source up to the probe window.
  - Note the count rate.
  - Do not use the survey meter if the counts per minute registered do not fall within ± 20% of the expected reading for the source.

4.2 Dose Rate Meter Check List: Prior to use of the Ludlum Model 19 Micro R Meter, or equivalent, the instrument shall be checked using the following procedure:

- Check Batteries
  - Turn the meter on and check the battery using the battery test button.
  - The meter reading should be within the "BAT TEST" range on the meter display.
  - Replace batteries if needed before use (two standard D cell batteries are required).
- Check Background
  - Turn the meter on and set the black range selector switch to the 0-25 range.
  - Set the Fast-Slow toggle switch to "f" or "s" depending on type of survey
  - The reading should be about 16 µR/h, ± about 10 µR/h.
  - Do not use the meter if a background reading is not recorded.

4.3 Ambient Work Area Radiation Levels: Dose rate surveys shall be performed in locations where workers could receive a total effective dose equivalent of 100 mrem/y (1mSv/y), or where the dose rate from external NORM/TENORM waste sources could exceed 2 mrem/h (0.02 mSv/h). Dose rate surveys shall be performed in a manner and frequency that is representative of the receipt and disposal of NORM/TENORM waste. At a minimum, these surveys should be performed daily when NORM/TENORM waste is received or where workers could be reasonably exposed (i.e., in the waste cells) and recorded on the ambient work area radiation survey form shown in Attachment 1.

4.4 Ambient Non-Work Area Radiation Levels: For purposes of contamination control, ambient radiation levels will be recorded on a monthly basis in areas remote from daily operations involving NORM/TENORM waste. These areas may include the change room, lunch room, administrative offices, and other areas that are identified as part of the Area Dosimetry program (see Standard Operating Procedure [SOP] on *Individual and Area Dosimetry*). The results of these monthly surveys shall be recorded on the non-work area radiation survey form shown in Attachment 2 and maintained in a log book controlled by the Deer Trail Radiation Safety Officer (RSO) or his designee.

4.5 Contamination Surveys: Contamination surveys shall be sufficient to identify areas of NORM/TENORM waste that might result in unacceptable levels of exposure to Deer Trail workers or members of the public, or might indicate the loss of control of

NORM/TENORM waste. Combined fixed (or bulk) and removable surface contamination (when appropriate) should be surveyed using the count rate meter. Contamination surveys will include surveys of equipment and workers or their clothes or possessions for purposes of offsite release. Total or bulk contamination should be measured directly at the surface of the contamination with the count rate meter held at close proximity to the surface, without direct contact with the probe. For solid surfaces, removable contamination can be detected and measured by using a two inch diameter filter paper to wipe the surface. The filter paper will then be held in close proximity of the count rate meter probe to determine the presence of elevated levels of NORM/ TENORM waste contamination. The results of these surveys shall be recorded using the form provided in ambient work area survey form shown in Attachment 1. Contamination surveys shall also be performed to evaluate NORM/TENORM waste contamination that could be present in areas not intended for disposal or storage (for purposes of contamination control), and on building surfaces including floors, walls, furniture as part of the ambient survey program. The information will be recorded on the non-work area radiation survey form shown in Attachment 2 and maintained in a log book controlled by the Deer Trail RSO or his designee.

4.6 Airborne Concentrations: Airborne concentrations of NORM/TENORM waste shall be made at representative locations. These locations include ambient levels remote from NORM/TENORM waste receipt and disposal (i.e. background levels), areas near or within the waste cells, and areas at down wind locations near the facility boundary (to estimate potential offsite exposures). The procedures for obtaining measurements of airborne NORM/TENORM waste are provided in SOP on *NORM/TENORM Airborne Monitoring*.

5.0 WASTE RECEIPT SURVEY METHODS: Radiation surveys shall be conducted for each waste shipment to verify that the external radiation dose rates are within the Deer Trail waste acceptance criteria and to verify that samples taken for offsite analysis will pose no radiation hazard to laboratory and support staff. The dose rate surveys shall be conducted using the following general procedure:

- Turn on the Ludlum Model 19 and perform the checklist for the dose rate meter (Section 4.2 above).
- Collect a representative composite sample from the waste
- Remove the sample to the laboratory hood.
- Scan the sample with the range selector set at the 250 setting by holding the "dimple" at the front of the meter within 1 cm of the sample. Allow the meter to stabilize for several seconds. If the sample reading exceeds 116 µR/h or if it registers off scale (>250 µR/h), replace the sample's lid, close the hood, and notify the Deer Trail RSO immediately.
- Record the result on the appropriate laboratory bench sheet.

More detailed procedures are listed in SOP Screening Waste Samples for Radioactivity in the Laboratory.

6.0 PERSONNEL SURVEYS: Personnel surveys shall be conducted to verify that Deer Trail employees are free of radioactive contamination following activities involving close proximity or contact with NORM/TENORM waste. Personnel surveys shall be conducted using the count rate meter and the following procedure:

- Turn on the meter and perform the checklist for the count rate meter (Section 4.1 above).
- The survey limits should be the detection of radiation levels above background.
- Hold the probe 1 cm from the body surface being surveyed and move the probe slowly over the surface, approximately 2 inches per second.
- If the count rate increases, pause for 5 to 10 seconds over the area to provide for adequate time for instrument response.
- If count rates in excess of background are detected, the area on the individual or the individual's clothing shall be decontaminated and surveyed again.
- The survey order will be from head to foot, as follows:
    - Frisk the hands before picking up the probe (while the probe is still in the meter holder).
    - Head – pause at the mouth and nose for five seconds
    - Neck
    - Arms
    - Chest and abdomen
    - Back, hips, and seat of pants
    - Legs – pause at the knees and cuffs for five seconds
    - Tops of shoes
    - Bottom of shoes
    - Personal items – hats, gloves, notebooks, equipment, etc.

7.0 SURVEYS FOLLOWING SPILLS: As part of cleanup of spills, radiation surveys shall be conducted using the count rate meter using the following procedure:

- Turn on the meter and perform the checklist for the count rate meter (Section 4.1 above).
- The survey limits should be the detection of radiation levels above background.
- Hold the probe 1 cm from the surface being surveyed and move the probe slowly over the surface, approximately 2 inches per second.
- If the count rate increases, pause for 5 to 10 seconds over the area to provide for adequate time for instrument response.
- If count rates in excess of background are detected, the area shall be decontaminated and surveyed again.
- The initial and final results of the survey shall be recorded on the form shown in Attachment 1 to verify and document the effectiveness of spill recovery methods.

8.0 PERSONNEL DECONTAMINATION: NORM/TENORM waste on personnel shall be decontaminated and re-surveyed using the following decontamination procedures:

- Skin contamination may be removed by washing the area with lukewarm water and mild soap. If contamination cannot be removed, contact the Deer Trail RSO.
- Personnel may flush ears/eyes/nose with cool, clear water to decontaminate those areas. If flushing is not successful, qualified medical personnel shall direct additional decontamination efforts.
- Clothing and shoes may be brushed clean. If clothing will not decontaminate, it shall be removed and exchanged with supplied coveralls or protective clothing.
- Contaminated clothing can be hand washed, rinsed, and dried onsite prior to re-surveying. When the clothing is free of detectable contamination, it can be released. Collected wash and rinse water shall be managed as part of the leachate recovery system.
- The initial and final results of the survey shall be recorded on the form shown in Attachment 1 to verify and document the effectiveness of personnel decontamination.

9.0 EQUIPMENT AND AREA DECONTAMINATION: When performed, decontamination will be done to meet the levels in ANSI/HPS N13.12-1999, "Surface and Volume Radioactivity Standards for Clearance." These values are summarized in Table 1 for NORM/TENORM radionuclides or radionuclide mixtures. When necessary, radiation surveys shall be conducted on equipment or areas using the count rate meter using the procedure in Section 4.5 above. The initial and final results of the survey shall be recorded on the form shown in Attachment 1 to verify and document the effectiveness of personnel decontamination.

Table 1. Screening Levels for Clearance from ANSI/HPS N13.12 (1999)

Radionuclide Group	Screening Levels (S.I. Units)	Surface Screening Levels (Conventional Units)	Volume Screening Levels (Conventional Units)
	(Bq/cm^2 or Bq/g)	(dpm/100 cm^2)[a]	(pCi/g)[a]
Group 1 Radium and Thorium: ^{210}Po, ^{210}Pb, ^{226}Ra, ^{228}Ra, ^{228}Th, ^{230}Th, ^{232}Th, and associated decay chains[b]	0.1	600	3
Group 2 Uranium: ^{234}U, ^{235}U, ^{238}U, Natural Uranium[c] and associated decay chains	1	6,000	30

(a) Rounded to one significant figure.
(b) For decay chains, the screening levels represent the total activity (i.e., the activity of the parent plus the activity of all progeny) present.
(c) Where the Natural Uranium activity equals 48.9% from ^{238}U, plus 48.9% from ^{234}U, plus 2.25% from ^{235}U.

10.0 REFERENCES

ANSI/HPS N13.12-1999 "Surface and Volume Radioactivity Standards for Clearance"

Instruction Manual Model 3 Survey Meter, Ludlum Measurements, Inc.

Instruction Manual Model 19 Micro R Meter, Ludlum Measurements, Inc.

ATTACHMENT 1 – NORM/TENORM AMBIENT WORK AREA SURVEY FORM

Clean Harbors Deer Trail LLC **NORM/TENORM SURVEY REPORT**		**Survey No.**
Date	Time	Location
Job Description		Purpose of Survey (check appropriate box[es]) ☐ Routine Area Survey ☐ Material Release ☐ Truck/Container Release ☐ Exposure Incident Contamination Incident: ☐ Skin ☐ Clothing ☐ Spill ☐ Other (Provide Description)

Instrument/Probe Model	Pancake GM Survey Meter	Dose Rate Meter	Instrument Comments
Serial No.			
Efficiency			
Correction Factor			
Background Reading	dpm	μR/h	

No.	Description	Distance	DOSE RATES	CONTAMINATION LEVELS	
			β-γ (μR/h)	Total β-γ (dpm/100 cm²)	Removable β-γ (dpm/100 cm²)

Comments: (add additional pages, if necessary)

Smear samples counted for _____ minutes to determine removable contamination levels.

Survey Conducted By:	Survey Report Reviewed By:
Name (Print) _____	Name (Print) _____
Signature _____	Signature _____

ATTACHMENT 2 – NORM/TENORM AMBIENT NON-WORK AREA SURVEY LOG

Clean Harbors Deer Trail LLC
NORM/TENORM SURVEY REPORT

Location

Location Description

Instrument/Probe Model	Pancake GM Survey Meter	Dose Rate Meter	Instrument Comments
Serial No.			
Efficiency			
Correction Factor			
Background Reading	dpm	μR/h	

Date/Time	Description	Distance	NET DOSE RATES	NET CONTAMINATION LEVELS	
			β-γ (μR/h)	Total β-γ (dpm/100 cm²)	Removable β-γ (+dpm/100 cm²)

Comments: (add additional pages, if necessary)

Smear samples counted for _____ minutes to determine removable contamination levels.

Survey Conducted By:	Annual Survey Log Reviewed By:
Name (Print) _____	Name (Print) _____
Signature _____	Signature _____

CLEAN HARBORS DEER TRAIL LLC
STANDARD OPERATING PROCEDURE ON
USE OF THE GATE MONITORING SYSTEM

Approved by:

_____ Corporate Officer

_____ Radiation Safety Officer

Date:

Effective Date:

1.0 OBJECTIVE: To define general and specific methods and procedures for conducting monitoring of incoming shipments of waste using the Deer Trail gate monitoring system.

2.0 SCOPE: The Deer Trail gate monitoring system will be used:

- To determine that shipments of NORM/TENORM waste have concentrations within the waste acceptance criteria,
- Non-NORM/TENORM waste shipments do not contain man-made radioactive materials or waste not acceptable for disposal at Deer Trail, and
- To screen against the disposal of lost, sealed sources of radioactive material.

3.0 POLICY: Consistent with the Deer Trail Radioactive Materials License, it is Deer Trail's policy to receive only NORM/TENORM waste with a total activity of less than 2,000 pCi/g (natural uranium and thorium decay chain products only), and with a maximum ^{226}Ra concentration less than 400 pCi/g. All other types of licensed radioactive waste in the broader definition of low-level radioactive waste, including other licensed forms of man-made radioactive materials, are prohibited.

4.0 PROCEDURES FOR USING THE DEER TRAIL GATE MONITOR:

4.1 Radiation Screening: The Deer Trail facility will operate scintillation-type radiation monitoring equipment that conforms with the specifications described in Appendix A of this procedure. The equipment will be used to screen all incoming waste material for radiation. Any deviation from either of these two specifications must receive prior approval from the Deer Trail Radiation Safety Officer (RSO).

4.2 NORM-TENORM Waste: For NORM/TENORM waste, the Deer Trail Gate Monitor will be operated in a manner to alarm at 100 µR/h above background. For an average background reading of 16 µR/h, this equates to a total dose rate of 116 µR/h. Each shipment must come to a compete stop with the load between the detectors, and remain stationary for a minimum of 10 seconds. During this time, the radiation monitoring equipment will survey the truck for radiation to determine if it exceeds the alarm point for NORM/TENORM waste.

4.2.1 Waste Passing the Screening: For waste that passes the screening (i.e., within the alarm limits), the recorded dose rates, time and date of receipt, and other required information will be recorded on the manifest consistent with the Records Management and Reporting requirements

set forth in the Deer Trail Radioactive Materials License, and the waste will be cleared for disposal.

4.2.2 Waste Failing the Screening: If an alarm condition results during a scan of an incoming vehicle, then the waste shall be rejected consistent with the Enforcement Policy in Section 5.0 (below).

4.3 Non-NORM/TENORM Waste Gate Monitor Set Point: For non-NORM/TENORM waste, the Deer Trail Gate Monitor will be operated in the manner described in Appendix C to alarm at an average background reading of 16 µR/h. All vehicles entering Deer Trail for disposal of non-NORM/TENORM waste (i.e., hazardous waste) must drive through the gate monitor to confirm that the waste does not contain radioactive materials or lost sealed sources of radiation. Each shipment must come to a compete stop with the load between the detectors, and remain stationary for a minimum of 10 seconds. During this time, the radiation monitoring equipment will survey the truck for radiation to determine if it exceeds the alarm point for non-NORM/TENORM waste.

4.3.1 Waste Passing the Screening: For non-NORM/TENORM waste that passes the screening (i.e., within the alarm limits), the recorded dose rates, time and date of receipt, and other information shall be recorded on the manifest consistent with the Records Management and Reporting requirements set forth in the Deer Trail RCRA Permit, and the waste will be cleared for disposal.

4.3.2 Waste Failing the Screening: If an alarm condition results during a scan of an incoming vehicle, then the waste shall be rejected consistent with the Enforcement Policy in Section 5.0 (below).

5.0 ENFORCEMENT POLICY: If an alarm condition results during a scan of an incoming vehicle, then the waste shall be rejected consistent with the following policy:

5.1 Radiation Alarm - General Level (dose rates greater than 116 µR/h above background for NORM/TENORM Waste or 16 µR/h above background for non-NORM/TENORM Waste):

Step 1 - Record the radiation monitor reading on a Clean Harbors Waste Discrepancy Report along with the hauler's identity and truck number. If possible, also obtain the generator's identity and record this information as well.

Step 2 - Inform the hauler that the load he is hauling exceeds Clean Harbor Deer Trail's policy limits for radioactive materials and that the load is being rejected.

Step 3 - Record the date and time that the hauler leaves with the rejected load.

Step 4 - File all discrepancy reports for radioactivity in a designated file for future reference.

5.2 Post Alarm Follow-Up: It is reasonable to believe that very few incoming waste streams will fail to meet the Deer Trail waste acceptance criteria for NORM/TENORM material. In the event that this limit is exceeded and the load is rejected, follow-up action on the part of the landfill or hauler is advisable to prevent a reoccurrence of this problem. The following conditions and guidelines will be implemented if a load is rejected due to radioactivity:

Condition 1 - Outside Waste; Upon rejection of a load from an outside company for exceeding Clean Harbors Deer Trail radioactive limit, the RSO shall contact the hauling company as soon as possible and give date, time, and the reason for rejected load. A follow-up letter to the hauling company should then be sent confirming the telephone conversation and Clean Harbors Deer Trail policy on radioactive materials.

Condition 2 - Clean Harbors Deer Trail-Hauled Waste; If the rejected load is hauled by a Clean Harbors-Owned District, the preferred approach is for the RSO to direct the District Manager or District Sales Manager to contact the generator by telephone as soon as possible after the time of load rejection. If necessary, a personal visit to the generator may be advisable to help the customer resolve the problem and prevent future loads from containing radioactive materials.

Condition 3 - Notification of Customers; For the Landfill & District - It is recommended that 45 days prior to initiating the radiation screening process, that the landfill and district notify their respective customers of Clean Harbors Deer Trail's policy regarding radioactive materials, the specific date on which radioactivity screening will begin, and the enforcement policy that will be implemented if the limits are exceeded.

ATTACHMENT A – GATE MONITOR SPECIFICATIONS

MECHANICAL/ENVIRONMENTAL

Size: Less than 12" x 12" x 12" (Readout Unit)
Less than 6: dia. x 12" (Detector Unit with Shield)

Operating Temperatures:

At least 40 degrees F - 90 degrees F (Readout Unit)
At least -30 degrees F - 120 degrees F (Detector Unit)

Radiological Shielding:

At least 1" lead in approximately 3n directions behind and around active detector area.

Weight:

Less than 10 lbs. (Readout Unit)
Less than 75 lbs. (Detector Unit with Shield)

Environmental:

Detector, Cable, and Connector shall be water resistant in the installed configuration.

Cables: 20' Coaxial Cable with Connectors between Detector Unit and Readout Unit. A.C. Power Cord.

ELECTRICAL/ELECTRONIC:

Power: 115 VAC (nominal) less than 2 ampers current with internal 12-hour battery reserve. (Readout Unit)
Detector Unit power supplied from Readout Unit.

Meter: Counts per minute display. May be digital or analog. Range at least 10 to 100,000 CPM. If analog, should be logarithmic.

Alarm: Tone Alarm, non-latching, adjustable over full range of meter scale above a minimum set point of not more than 250 CPM. Set must be displayed or displayable on the meter scale.

Accuracy: Displayed value must be accurate to with +5% of a constant input signal over the entire range of the display.

Display/Alarm Time Constant:

If analog, should be approximately 2-20 seconds with at least one intermediate point. May be continuously adjustable between limits. If digital, display should update at least every 6 seconds. Update times may be adjustable above or below 6 seconds.

High Voltage: Adjustable to supply Detector Unit.

Detector Failure Indicator: Readout Unit shall have a visible indicator other than the display which actuates it when the detector has not produced a signal for more than 15 seconds.

Analog Output: Readout Unit shall have a Connector which supplies a 4-20 mA or 0-100 mV signal for powering an external recorder.

Discriminator: Readout Unit shall be able to discriminate against gamma energies below 200 keV in an adjustable manner. If a fixed threshold is used in conjunction with an adjustable High Voltage Power Supply, please state so on your response. Readout Unit shall have a speaker with an adjustable volume which sounds with each incoming detector pulse.

RADIOLOGICAL

Detector Type: 1" x 1" NaI(T1).

Minimum Sensitivity: Must be photon (gamma and x-ray) sensitive. Must alarm on a 100 uCi Cs-137 source at 10 feet within 15 seconds in a constant background field of 10 uR/h of Ra-226 in equilibrium with progeny.

False Alarms: When set for the minimum sensitivity condition above, false alarms to normal background shall be less than once every three months.

CLEAN HARBORS DEER TRAIL LLC
STANDARD OPERATING PROCEDURE ON
NORM/TENORM SAFETY TRAINING

Approved by:

_____ Corporate Official

_____ Radiation Safety Officer

Date:

Effective Date:

1.0 OBJECTIVE: To define general and specific NORM/TENORM waste radiation safety training requirements for Deer Trail general employees to ensure that workers can safely perform assigned duties.

2.0 SCOPE: This procedure applies to all Deer Trail workers who may be exposed to radiation from NORM/TENORM waste. Additional radiation safety training beyond the scope of this procedure may be prescribed for the Deer Trail Radiation Safety Officer (RSO) and/or his designee.

3.0 POLICY: All Deer Trail workers who may potentially be exposed to radiation from the treatment and disposal of NORM/TENORM waste shall attend an initial General Employee NORM/TENORM Radiological Control Training course and refresher training on two-year intervals.

4.0 NORM/TENORM SAFETY TRAINING PROCEDURE:

4.1 Criteria for Determining NORM/TENORM Safety Training Requirements: Training requirements are based on job descriptions and types of areas that workers are required to access to perform their assigned duties. Training may be adjusted to be commensurate with the individual's job category, assigned duties, and previous training and experience. All Deer Trail workers who are in the proximity of radiation from NORM/TENORM waste as part of their routine employment shall be part of the General Employee NORM/TENORM Radiological Control Training program. The following factors shall be considered to determine the appropriate level of knowledge and training for individual Deer Trail workers:

- The individual's job assignment (i.e., activities in or near the weight station, waste sampling and analysis operations, waste treatment facility when NORM/TENORM waste may be present, and disposal cell operations),
- The nature of the NORM/TENORM hazards that may be present (dependent on waste form, type of treatment if any, and disposal configuration), and
- The type and complexity of any protective actions that the individual might be expected to execute (i.e., the need to limit the duration of an activity, provide temporary shielding, wear respiratory equipment, or observe special procedures for some types of NORM/TENORM waste).

4.2 Training Requirements for NORM/TENORM Workers: General employees whose job assignment indicates the potential for exposure to NORM/TENORM waste shall receive General Employee NORM/TENORM Radiological Control Training prior to conducting those assignments. The Deer Trail RSO or his designee is responsible for ensuring that all workers receive the appropriate training before conducting their assigned duties.

4.3 Evaluating the Adequacy of Individual Deer Trail Workers Current Training: The Deer Trail RSO or his designee shall:

- Ensure that all new hires who will work in the proximity to NORM/TENORM waste receive General Worker NORM/TENORM Radiological Control Training.
- Periodically check the training records and determine individual workers current level of NORM/TENORM Radiological Control Training and the expiration date of the training to ensure that workers are adequately trained.
- Compare the individual's current training to the required training, especially in cases where workers change job assignments.
- Ensure that special periodic retraining occurs in the event of changes to Deer Trail polices, procedures, and practices that affect NORM/TENORM waste disposal.

4.4 Training Records: Records certifying completion of required training shall be maintained as part of the Deer Trail records retention program within each individual worker's employment file.

5.0 TRAINING SYLLABUS:

The Deer Trail General Employee NORM/TENORM Radiological Control Training program shall cover the following topics:

- Radioactivity and Radioactive Decay
  - Alpha Emission
  - Beta Emission
  - Gamma-Rays
  - X-Rays
  - Half-Life
  - Units of Radioactivity
- Naturally Occurring Radioactivity
  - Cosmic Radiation
  - Cosmogenic Radioactivity
  - Radionuclides in the Earth
  - Summary of Natural Background Radiation
- Naturally Occurring Radioactive Material (NORM) and Technologically Enhanced Naturally Occurring Radioactive Material (TENORM)
  - Decay Chains and Radionuclides
  - Sources
  - Waste Forms
- Biological Effects of Radiation
  - Acute Effects
  - Chronic Effects
  - Dose Equivalent: The rem
- Basic Radiation Safety Criteria
  - Time, Distance, Shielding for External Radiation

- Inhalation Protection
- Radiation Protection Guidelines and Standards
  - Philosophy of Radiation Protection
  - Deer Trail Regulations and Permit Conditions
  - Deer Trail Waste Acceptance Criteria
- Deer Trail Instrumentation
  - General Radiation Survey Equipment
  - Dose Rate Meters
  - GM Survey Equipment
  - Airborne Sampling
- Deer Trail Individual Dosimetry Program
- Radiation Records
- Quiz

CLEAN HARBORS DEER TRAIL LLC
STANDARD OPERATING PROCEDURE ON
NORM/TENORM WORKER PROTECTION RECORDS

Approved by:

_____ Corporate Official

_____ Radiation Safety Officer

Date:

Effective Date:

1.0 OBJECTIVE: To define general and specific NORM/TENORM worker protection records that shall be generated and maintained for Deer Trail general employees who may be exposed to radiation from NORM/TENORM waste.

2.0 SCOPE: This procedure applies to all NORM/TENORM worker protection records generated for workers at the Deer Trail landfill. These records include:

- NORM/TENORM Protection Policy Statements,
- NORM/TENORM Protection Plan,
- Personnel training (course records and individual records),
- Standard Operating Procedures covering NORM/TENORM waste, including:
  - Standard Operating Procedure on Individual and Area Dosimetry
  - Standard Operating Procedure on NORM/TENORM Airborne Monitoring
  - Standard Operating Procedure on Estimating Inhalation Doses
  - Standard Operating Procedure on Radiation Surveys
  - Standard Operating Procedure on Use of the Gate Monitor
  - Standard Operating Procedure on NORM/TENORM Safety Training
  - Standard Operating Procedure on NORM/TENORM Worker Protection Records
- Radiological survey results,
- Individual and area dosimetery results, and
- Individual Radiation Doses.

3.0 POLICY: All records pertaining to Deer Trail worker activities associated with the receipt, treatment, and disposal of NORM/TENORM waste shall be maintained in their personnel files. All records of exposure, internal and external, are legal and personal and must be controlled to preclude release of personnel information to non-authorized personnel. All radiation protection records including individual worker records, approved procedures, amendments, revisions and renewals will be maintained consistent with the Colorado Regulations 6 CCR 1007-1, § 4.40, 4.41, 4.42, 4.44, 4.47, and 4.50.

4.0 NORM/TENORM WORKER PROTECTION RECORDS PROCEDURE:

4.1 Training: The Deer Trail Radiation Safety Officer (RSO) or his designee shall ensure that all staff training records are dispositioned, controlled, and maintained as described in this procedure:

- Upon completion of the training form (Attachment 1), it shall be checked for completeness, accuracy, and legibility before disposition:
  - Ensure the form has been signed and dated,
  - Ensure that changes to the document are legible, with a simple line through deletions, and clearly printed inserts. All deletions and insertions will include the initials of the individual making the changes.

- Training forms will be filed as part of the Deer Trail Administrative filing system and will include:
  - Course Title, name of instructor, and date(s) of training,
  - Course completion rosters,
  - Course Syllabus or Content Outline,
  - Test scores for each class member, and
  - Documentation of any waivers, exceptions, or extensions.

4.2 Radiological Survey Results: The Deer Trail RSO or his designee shall ensure that all NORM/TENORM radiation survey results obtained using Standard Operating Procedure (SOP) on *Radiation Surveys*, are recorded and filed in the Deer Trail Administrative filing system.

4.3 Individual and Area Dosimetry Results: The Deer Trail RSO or his designee shall ensure that all NORM/TENORM individual worker and Area dosimetry results obtained using SOP on *Individual and Area Dosimetry*, are recorded and filled in the Deer Trail Administrative filing system:

- Individual dosimetry results shall be filed in each worker's personnel file, and in a separate administrative file showing quarterly data for all monitored staff, and
- Area dosimetry results shall be filed in a separate administrative file so that trending analyses over time can be performed.

4.4 Individual Radiation Doses: The Deer Trail RSO or his designee shall ensure that all NORM/TENORM individual worker quarterly and annual radiation doses obtained using the SOP on *Individual and Area Dosimetry*, and the SOP on *Estimating Inhalation Doses*, are recorded on the appropriate forms and filled in the Deer Trail Administrative filing system. Individual radiation dose results shall be filed in each worker's personnel file, and in a separate administrative file showing quarterly data and annual doses for all monitored staff.

ATTACHMENT B

DEVELOPMENT OF WASTE ACCEPTANCE CRITERIA FOR THE DISPOSAL OF NORM/TENORM WASTE AT THE DEER TRAIL, RCRA SUBTITLE C LANDFILL

DMA-TR-11, REV. 1

DEVELOPMENT OF WASTE ACCEPTANCE CRITERIA FOR THE DISPOSAL OF NORM/TENORM WASTE AT THE DEER TRAIL, RCRA SUBTITLE C LANDFILL

W. E. Kennedy, Jr.

August 17, 2004

Prepared on behalf of Clean Harbors

Dade Moeller & Associates, Inc.

LIMITATIONS

Dade Moeller & Associates prepared this evaluation of NORM/TENORM waste acceptance criteria for the Deer Trail RCRA Subtitle C landfill at the direction of Clean Harbors, consistent with currently available information.

EXECUTIVE SUMMARY

Dade Moeller & Associates was asked by Clean Harbors to evaluate the potential disposal of naturally occurring radioactive material (NORM) and technologically enhanced radioactive material (TENORM) at Clean Harbor's Deer Trail RCRA Subtitle C facility, located 70 miles east of Denver, Colorado. The waste acceptance criteria analysis and recommendations provided in this report apply to a wide variety of TENORM wastes with similar radionuclide content. This analysis is conducted using various computer models for the identified conditions with representative scenarios, and measured operational data obtained from thermoluminescent dosimeters (TLDs) from the Clean Harbors Buttonwillow RCRA Subtitle C landfill in near Bakersfield, California. The Buttonwillow operational data are relevant since this landfill has been permitted to receive TENORM waste from geothermal and oil and gas production for several years.

In summary, the following recommendations are developed in this report:

- For exposure to TENORM waste, Deer Trail worker's will be considered as members of the public and radiation exposures will be limited to 100 mrem/y, plus ALARA, with a goal of 25 mrem/y or less. If it is determined from worker dosimetry results that selected worker doses could exceed 25 mrem/y, an assessment will be conducted of the potential for other man-made exposures for Deer Trail workers to assure that maximum individual doses from man-made sources will not exceed 100 mrem/y. This assessment will consider real individuals working at Deer Trail, not hypothetical members of the public.
- Based on the scenario analysis it is determined that long-term post disposal conditions and the resulting public radiation doses for the site are not limiting in determining waste acceptance criteria.
- Based on the calculations in this report, the waste acceptance criteria could be between about 400 to 800 pCi/g of ^{226}Ra. Considering the experience at the Buttonwillow landfill, receipt of waste at an average concentration level of 400 pCi/g of ^{226}Ra, measured on a per shipment basis, is recommended. If applied as a peak value for purposes of setting the gate monitor alarms, it is recognized that the average concentrations received will be less (likely about 10% of the peak concentration), and therefore the average doses to workers will be also be less (likely about 10 mrem/y), consistent with ALARA.
- This proposed limit will equate to an alarm set point of 100 μR/h above background. If background is 16 μR/h, the alarm set point should be 116 μR/h. This new alarm set point would be about seven times the background level, and would still permit the detection of lost radiation sources in a waste shipment.
- It is recommended that the total activity of NORM/TENORM waste, including the alpha and beta emitting radionuclides, be enforced to the limit of 0.002 μCi/g (2,000 pCi/g) used to define radioactive waste in Colorado, as long as the radium concentration limit of 400 pCi/g per shipment is also maintained.

The disposal of NORM/TENORM materials at the Clean Harbors Deer Trail facility may be adequately regulated pursuant to the omnibus authority of the Resource Conservation and Recovery Act ("RCRA"), 42 U.S.C. § 6901 et seq. Clean Harbors is in the process of amending its RCRA Part B permit to effectuate this change. In addition to applicable standards prescribed

by the RCRA program, the amended permit shall incorporate standards defining a radiation protection program for Deer Trail workers equivalent to those provided at 6 CCR 1007-1 sections:

- 4.5, Radiation Protection Programs,
- 4.14, Dose Limits for Individual Members of the Public,
- 4.15, Compliance with Dose Limits for Individual Members of the Public,
- 4.17, Surveys and Monitoring, General,
- 4.18, Conditions Requiring Individual Monitoring of External and Internal Occupational Dose,
- 4.40, Records – General Provisions,
- 4.41, Records of Radiation Protection Programs,
- 4.42, Records of Surveys,
- 4.44, Records of Individual Monitoring Results,
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1.0 INTRODUCTION

In a meeting on March 24, 2004, between representatives of Clean Harbors Deer Trail, LLC ("Clean Harbors") and the Colorado Department of Public Health and Environment ("CDPHE"), the topic of regulation and disposal of TENORM was introduced. Following the meeting, Clean Harbors began investigating the feasibility of modification of its Deer Trail facility permits to provide for the receipt and disposal of certain NORM/TENORM wastes. CDPHE recognizes the limited existing disposal options for NORM/TENORM materials including the residues generated by the treatment of public drinking water supplies for radioactivity pursuant to new regulations mandating such treatment. Consequently, Dade Moeller & Associates was asked by Clean Harbors to evaluate the potential disposal of naturally occurring radioactive material (NORM) and technologically enhanced radioactive material (TENORM) at Clean Harbor's Deer Trail RCRA Subtitle C facility, located 70 miles east of Denver, Colorado. The analysis and recommendations provided in this report apply to a wide variety of TENORM wastes with similar radionuclide content, ranging from those dominated by natural uranium and its decay chain, to those dominated by radium and its decay chain. By way of examples, this report specifically considers the properties and nature of material recovered from the Denver Radium Site (Operable Unit 07), oilfield and geothermal waste, and public drinking water treatment TENORM waste. This analysis is conducted using various computer models for the identified conditions with representative scenarios, and measured operational data obtained from thermoluminescent dosimeters (TLDs) from the Clean Harbors Buttonwillow RCRA Subtitle C landfill in near Bakersfield, California. The Buttonwillow operational data are relevant since this landfill has been permitted to receive TENORM waste from geothermal and oil and gas production for several years. Considering the results of various models and operational data when evaluating potential radiation doses is consistent with the process of following "multiple lines of reasoning" as recommended by the U.S. Nuclear Regulatory Commission (NRC) when conducting performance assessments for low-level radioactive waste disposal (Kozak, et al. 1990).

By way of introduction, the following Colorado regulatory definitions are required:

Radioactive: means emitting alpha rays, beta rays, gamma rays, high-energy neutrons or protons, or other high-level radioactive particles. The term "radioactive" does not include material in which the estimated specific activity is not greater than .002 microcuries per gram of material, and in which the radioactivity is essentially uniformly distributed (C.R.S. § 25-11-201).

Radioactive Waste: means all radioactive materials which have no useful purpose and are to be discarded... (C.R.S. § 25-11-201).

Technologically Enhanced Naturally Occurring Radioactive Material (or TENORM): means naturally occurring radioactive whose radionuclide concentrations are increased by or as a result of past or present human practices. "TENORM" does not include:
(a) Background radiation or the natural radioactivity of rocks or soils;
(b) "Byproduct material" or "source material," as defined by Colorado statute or rule; or
(c) Enriched or depleted uranium as defined by Colorado or federal statute or rule (C.R.S. § 25-11-201).

2.0 TENORM WASTE MATERIALS

Although there a wide variety of TENORM waste materials, mostly associated with mineral and resource recovery, three types of waste are identified for this analysis: 1) the Denver Radium Site waste, 2) oilfield and geothermal wastes, and 3) public drinking water treatment waste. The following sections discuss these types of TENORM waste.

2.1 DENVER RADIUM SITE WASTE

Because of regional mineral ores containing uranium and radium, in the early 1900s Denver had a radium extraction and processing industry. The extracted radium was sent to the east coast of the U.S. for refinement, while the waste materials, or ore tailings, remained locally. Some of the discarded tailings were used for road bases/foundations and in asphalt to pave streets in Denver. In the 1980s, the U.S. Environmental Protection Agency (EPA) identified 11 operable units, known as the Denver Radium Site, which were impacted by the radium tailings and residual materials. These materials contain naturally occurring radionuclides that are mostly isotopes of heavy metals, which are called primordial radionuclides associated with the uranium-238 (^{238}U) radioactive decay series. The radium ores and materials are TENORM and contain radioisotopes of uranium, thorium, radium, and associated decay progeny. Because of the radiation emitted by the radium tailings materials, they pose a potential threat to human health and environment. During the early phases, some of the material was remediated and disposed out of state. Some portions were left and managed under institutional controls. During the five-year review process under CERCLA, the City negotiated further remediation as the more appropriate remedy since maintaining the institutional controls was difficult, particularly with respect to utility work. As part of the remediation of the 11 operable units, the City and County of Denver has begun a long-term program to reconstruct these streets by removing the radium-contaminated materials in the road beds for offsite disposal. Removal of the material will mitigate any long-term human health and environmental risks. The road reconstruction efforts will also improve storm water drainage, allow utility maintenance, and reduce maintenance requirements for the roads.

In 2003, Parsons Engineering Science, Inc. was contracted to demolish and reconstruct a section of the Denver Radium Streets (Parsons 2003). Because the radionuclide content of the radium materials was below the concentrations used by the state of Colorado for defining radioactive waste, it was disposed of at a RCRA Subtitle C facility in Idaho specifically permitted to receive TENORM, similar to the Buttonwillow facility in California. Further, because of the low concentrations of radionuclides in the waste, the work conducted during 2003 did not require license from the State of Colorado for possessing or handling radioactive materials. In addition to the initial sampling and characterization data, Parsons conducted sampling and surveying during demolition to assure that the project was in compliance with applicable regulations and requirements (e.g., health and safety of the workers and the public). The samples and surveys during the demolition were to assure that the radionuclide concentrations were below the requirements for radioactive waste, to demonstrate compliance with U.S. Department of Transportation (DOT) shipping requirements for radioactive materials, and to demonstrate final compliance with mandated cleanup levels.

It is anticipated that the radium material characteristic data collected in 2003 by Parsons will be similar to the characteristics associated with future Denver Radium Site materials since they were of similar origin and processing. A summary of those data indicate;

- The minimum, maximum, and average contact radiation exposure rates for each disposal bag of material were 30, 230, and 96 µR/h (Parsons 2003): well within the DOT contact dose rate limit for packages of 200 mrem/h (49 CFR 173.441) used as the basis of the 2003 cleanup.
- Based on information in the 1986 Record of Decision (ROD) for these operable units, the maximum concentration of radium observed in the Denver Radium Site waste was 79 pCi/g, with a peak observed dose rate of 57 µR/h. Since the recovered material will be a mix of clean and contaminated asphalt, the average concentration per truck or container shipped will be less than the peak concentration recorded.
- Following demolition of the streets, as part of the 2003 cleanup effort, radiation surveys were performed by Parsons to confirm that the cleanup goal of 5 pCi/g of ^{226}Ra above a background level of 2 pCi/g had been reached. These surveys used an instrument dose rate criterion of 30 µR/h, measured at the road bed surface. This criterion was determined as the dose rate in air related to a total soil concentration of 7 pCi/g of ^{226}Ra.

2.2 OILFIELD AND GEOTHERMAL TENORM WASTE

Waste from geothermal operations or from oil exploration, production, and refinery often contain NORM radionuclides above background levels. The nature and content of the material depends on the host geology and the amount of brine water present in the oil bearing formation. In the form of TENORM, these radionuclides are not found in the same isotopic ratios found in undisturbed nature and demonstrate elevated concentrated levels of ^{226}Ra and ^{228}Ra compared to the other radionuclides in the ^{238}U and ^{232}Th decay series (NCRP 1987). The selective concentration of ^{226}Ra and ^{228}Ra in these TENORM wastes occurs when radium becomes mobilized in the presence of chloride ions, such as found in brine solutions encountered during geothermal operations or during oil production. With changes in chemistry, the radium and other dissolved minerals will plate out as scale in pipes or in sludge. The concentration of ^{226}Ra in TENORM waste can range from undetectable to as much as several thousand pCi/g (Wilson 1994). For comparison, soils in the U.S. range from less than 1.0 to slightly more than 4.0 pCi/g of ^{226}Ra. In the Denver Colorado area, the concentrations are typically about 2 pCi/g of ^{226}Ra. It is noted that not all of the geothermal or petroleum industry waste is contaminated with TENORM. Based on information from the literature (Wilson 1994, Table 6-1), it is evident that petroleum and geothermal wastes are similar in both radium content and measured dose rate.

Information provided by the Clean Harbors Buttonwillow facility indicates that data from the U.S. EPA provide the ratio of activity of ^{226}Ra in representative oilfield wastes to the total TENORM activity present is about 0.27; or about 27% of the TENORM activity in oilfield waste is caused by ^{226}Ra. As shown in Table 2.1, the U.S. EPA estimates that uranium and thorium largely remain in place because they are relatively insoluble in the brine solutions, while radium and its associated decay products concentrate in the sludge and scale.

The Buttonwillow license permits receipt of concentrations of TENORM wastes up to 2,000 pCi/g. As an upper bound, assuming the radionuclide distribution defined in Table 2.1 for oilfield wastes, the maximum radionuclide concentrations for oilfield wastes are shown in Table 2.2.

Table 2.1. Radionuclides in Oil and Gas Production Waste

Radionuclide	Average Sludge Concentration (pCi/g)	Fractional Contribution in Sludge	Average Scale Concentration (pCi/g)	Fractional Contribution in Scale
^{210}Po (Polonium-210)	56	0.27	360	0.27
^{210}Pb (Lead-210)	56	0.27	360	0.27
^{226}Ra (Radium-226)	56	0.27	360	0.27
^{228}Th (Thorium-228)	19	0.09	120	0.09
^{228}Ra (Radium-228)	19	0.09	120	0.09
Totals	206	1.0	1,320	1.0

Table 2.2. Maximum Radionuclide Concentrations of Petroleum Industry TENORM Waste

Radionuclide	Maximum Concentration (pCi/g)
^{210}Po (Polonium-210)	545
^{210}Pb (Lead-210)	545
^{226}Ra (Radium-226)	545
^{228}Th (Thorium-228)	182
^{228}Ra (Radium-228)	182
Totals	2,000

2.3 PUBLIC DRINKING WATER TREATMENT TENORM WASTE

Municipal drinking water systems use a variety of methods to meet the EPA Drinking Water Standards for finished water. Some of these methods apply selective-sorbent technologies, such as ion exchange resins or the use of spent Granular Activated Carbon (GAC), others use flocculants such as alum. As a byproduct of these drinking water treatment systems, spent resins, sludge, and collected flocculants are produced that contain elevated levels of NORM radionuclides removed from the water. Radionuclide characterization data are scarce and highly dependent on the specific conditions associated with each treatment facility; however, the radionuclides of concern are typically those of radium, uranium, radon, and their progeny (decay products). Although radionuclides associated with the entire uranium decay chain will be present, because of the potential significance of the gamma rays associated with the short-lived progeny of ^{226}Ra, most of the available characterization information is provided in terms of the ^{226}Ra concentration. The ^{226}Ra concentrations in sludge varies from about 0.5 pCi/l to 25 pCi/l (EPA 1994) with the average concentrations in radium-selective sludge of about 16 pCi/g ^{226}Ra

(Wilson 1994, p. 86). It is noted that the average concentration in waste to be disposed will vary depending on waste treatment (i.e., solidification) and packaging prior to disposal.

3.0 EVALUATION OF CURRENT CONDITIONS AT DEER TRAIL

The current permit issued by Colorado Department of Public Health and Environment (CDPHE) for the Deer Trail landfill sets a limit for receipt of radioactive waste at 16 μR/h, as measured by the monitors positioned at the gate of the facility prior to the weight station. This dose rate condition was established to prevent the landfill from receiving radioactive waste. Inspection of the facility revealed that the gate monitors consist of two Ludlum Model 3502 Gate Monitors; one positioned about 0.76 m (2.5 feet) from each side of the truck. Each monitor consists of a 5 x 5 cm (2 x 2 inch) sodium iodide crystal scintillation detector, with readout provided in the waste receipt/weight station. Dose rate readings are recorded for each shipment of waste received. This system was installed in 1991, and has current calibration records, and is operated using the manufacturer's recommendations.

Further, procedures at the Deer Trail landfill require the collection and analysis of composite samples of each load of waste. Part of the analysis of these samples includes a screening for radiation using a Ludlum Model 19 μR/h survey meter. If excessive radiation levels are encountered for the composite samples (i.e., dose rates in contact with the sample in excess of 25 μR/h), work is halted and further evaluations are conducted.

While these requirements and procedures are adequate for screening for radioactive waste, they are not health risk based and do not reflect the current definitions and usage of radioactive waste or radioactive materials in the State of Colorado. By the definition of radioactive waste in Colorado, it would be possible to establish an upper limit on the concentration of NORM and TENORM to be disposed at the Deer Trail landfill as 0.002 μCi/g (2,000 pCi/g). However, this approach may not be protective of public health and the environment for all situations. It is therefore a preferred alternative to evaluate a radiation risk-basis that would protect the public and environment from NORM/TENORM materials, which also would be consistent with current statutes. From these criteria, secondary criteria such as radiation alarm set points, can be determined. The analysis that follows describes the technical approach used to derive waste acceptance criteria for NORM/TENORM for the Deer Trail landfill.

4.0 RADIATION PROTECTION STANDARDS

In the State of Colorado, the general public radiation dose limit is to protect individuals to 100 mrem/y above background, (RH 4.14, Colorado State Radiation Control Regulations). The As Low As Reasonably Achievable (ALARA) principle is applied to this annual dose limit. In most cases, the State would limit exposures to single sources to a fraction of the total annual dose limit, on the order of 25 mrem/y plus ALARA, to assure that individuals exposed to multiple sources of radiation do not exceed the overall 100 mrem/y dose limit. However, it is noted that NORM and TENORM materials have a rather special relationship to background sources since many of the same radionuclides are involved. The National Council on Radiation Protection and Measurement (NCRP) has paid special attention to the potential problems associated with NORM/TENORM materials, as described in their report No. 116, *Limitation of Exposure to*

Ionizing Radiation (1993). In identifying remedial action levels for exposures to natural radiation sources, the NCRP concluded: *Since the average exposure to individuals in the United States from natural sources, excluding radon, is approximately 1 mSv [100 mrem]annually, **it is recommended that remedial action be undertaken when continuous exposures from natural sources, excluding radon, are expected to exceed five times the average, or 5 mSv [500 mrem] annually.*** (NCRP 1993, p. 50).

Further, Question #1835 submitted to the "Ask the Experts" page of the Health Physics Society on the internet (HPS 2004), generally asked what levels of NORM are not going to be hazardous to the health of submersible pump workers in Canada. The response was prepared by Dr. Tom Gesell (Professor at Idaho State University) and Dr. Andy Karam, CHP (Professor at the University of Rochester). Their response summarized information from *Canadian Guidelines for the Management of Naturally Occurring Radioactive materials (NORM)* (Federal Provincial Territorial Radiation Protection Committee 2000) and indicated that the basic dose limits for NORM materials have been established as 20 mSv/y (2 rem/y) and 100 mSv (10 rem) cumulative over five years for occupationally exposed individuals, and 1 mSv/y (100 mrem/y) and 5 mSv (500 mrem) cumulative over five years for incidentally exposed workers and members of the general public. In all cases, the ALARA concept applies; with the key word being "reasonable." The question response cautioned that, because of the relatively low risks associated with most diffuse TENORM material, unwarranted actions should be avoided.

Based on this discussion, it seems reasonable that an overall annual dose limit to workers at the Deer Trail landfill for disposal of TENORM material should be in the range of 100 to 500 mrem/y since their exposures would be consistent with incidentally exposed workers and members of the public. However, to assure that these workers are protected, it is recommended that their radiation doses be limited to 100 mrem/y plus ALARA, with a goal of 25 mrem/y. Therefore, the analysis that follows is based on an assumed annual dose limit for Deer Trail workers of 100 mrem/y, plus ALARA.

5.0 ANALYSIS

As with any exercise of this nature, the most direct approach is to rely on measured data for radiation doses, since measured data provide the most direct link between the estimated exposure conditions and the actual radiation doses that result. Fortunately, measured dose rate information from the Buttonwillow RCRA Subtitle C facility provides a good source of information about the dose rates that workers may experience when handling TENORM waste. In addition, waste characterization data collected by Parsons for the first year (2003) of demolition of the Denver Radium Site partially allows for the direct approach. However, for comparative purposes, detailed mathematical models and as much site-specific data as can be obtained can be used to derive the relationship between the concentration of radioactive materials and the potential radiation doses that may result. This dual approach of comparing measured data and modeling results was selected to provide an investigation following multiple lines of reasoning to reach conclusions that are supported by many independent points of view. The following sections summarize both the direct measurements that are available, and the results of a detailed modeling analysis to determine acceptable concentrations of TENORM waste for disposal at the Deer Trail landfill.

5.1 MEASURED DOSE RATES FROM THE BUTTONWILLOW FACILITY

The Buttonwillow facility consists of waste management units (WMUs) designed to receive specific types of hazardous waste. As stated in Section 2.2 of this report, the Buttonwillow is limited to receiving waste that is less than 2,000 pCi/g, with an average ^{226}Ra content reported to be around 400 pCi/g. The most significant sources of waste received at the Buttonwillow facility are from geothermal and oilfield operations. Virtually all of the waste from geothermal or oilfield operations contain NORM radionuclides above background levels. Because of an awareness of potential radiation exposure concerns for facility workers, Clean Harbors has established a program to monitor the radiation doses for key areas and workers at the facility. This is a volunteer program, not dictated by any California regulations or statutes. The dosimeters are thermoluminescence dosimeters (TLDs) provided by Landauer® Inc., which are exchanged and read on a monthly basis. Although the Buttonwillow facility estimates that the average waste concentrations are around 400 pCi/g of ^{226}Ra based on their manifest records, the majority of the data collected from January 1999 through March 2003 are at levels that are indistinguishable from background. Even when accounting for the missed dose, which is about 1 mrem per month, the estimated average annual doses to the facility workers, of about 12 mrem/y, are well within the 100 mrem/y limit for members of the public in California.

There are likely several reasons for these small measured doses:

- The manifest values typically conservatively report peak concentrations, not average concentrations across a shipment, so not to underestimate the concentrations encountered.
- There is significant self-shielding provided by the waste since it is handled in bulk form.
- Most operations are of short duration (i.e., weighing and sampling) for bulk operations compared to operations involving drums or other containers.
- Most operations are rather remote from the waste (i.e., outside a dump truck or a roll off container).
- Operations involving heavy equipment provide at least 1 cm of steel shielding, thereby reducing dose rates to operators.
- Clean cover materials of about 10 cm are applied to disposed waste, which provides additional shielding for workers.

These data provide strong evidence that the real radiation doses to workers from bulk material handling tasks at a RCRA Subtitle C facility are well within the regulatory limits and are probably ALARA (i.e., nothing further should be done to reduce the annual doses).

5.2 MODELING ANALYSIS FOR TENORM WASTE

The modeling process used to develop dose based waste acceptance criteria is generally as follows:

- First, a suite of radiation exposure scenarios and conditions, which include several representative radiation exposure pathways and groups of individuals, is defined.

- Second, the resulting radiation doses per unit concentration of radionuclides are calculated in terms of mrem/y per pCi/g of activity disposed by applying appropriate models.
- Third, the inverse of the maximum dose results by radionuclide, in units of pCi/g per mrem/y is determined.
- Fourth, the acceptable waste concentration (pCi/g) is developed by multiplying the pCi/g per mrem/y results by the dose limit, in mrem/y.
- Finally, any administrative or practical conditions are identified and addressed, and secondary limits including radiation alarm set points, are established.

This process will help ensure that the maximum exposed individuals in a critical group have been identified and reasonably conservative results have been obtained. Because the majority of the candidate NORM/TENORM wastes typically do not require a license or require any special transportation labels, the waste acceptance criteria should therefore be based on protecting the public (including landfill workers and nearby residents), and the environment. Previous analyses (for example, ANSI/HPS N13.12, 1999) have established that the individuals in contact with or in the closest proximity to radioactive materials are typically exposed to the greatest number of exposure pathways and typically receive the highest radiation doses. These individuals then become the critical group (or groups).

For this analysis, the goal is to limit the potential radiation exposure to members of the public and Deer Trail workers to less than the public dose limits of 100 mrem/y above background. As a simple analysis, for a landfill worker exposed to external radiation for an entire work year (i.e., 2,000 h) this would equate to a maximum hourly external dose rate of 0.05 mrem/h (i.e., 100 mrem/y divided by 2,000 h/y) above background. Note that 0.05 mrem/h is equal to 50 µrem/h. For employees exposed half of a work year to a radiation source, the maximum hourly dose rate would be 0.1 mrem/h (i.e., 100 mrem/y divided by 1,000 h/y) above background. Again note that 0.1 mrem/h would be 100 µrem/h. It is noted that this simple analysis does not include the potential for internal dose caused by inhalation of airborne material. The potential effects of inhalation are considered as part of the modeling analysis to follow.

Three critical groups are identified: 1) truck drivers hauling waste, 2) workers at the Deer Trail landfill, and 3) nearby future residents who may reside near or on the site after closure. The analysis that follows discusses the potential radiation exposure scenarios for each identified group, the selection of alternative models for conducting the analysis, and the conditions that are used to develop waste acceptance criteria for NORM/TENORM wastes for the Deer Trail landfill.

5.2.1 Truck Drivers Hauling Waste

For this analysis, the TENORM waste is assumed to be hauled to the Deer Trail facility in standard roll off boxes, with dimensions 1.8 x 2.4 x 6.5 m (5'10" x 8' x 21'3"). The waste is assumed to have a density of 1.4 g/cm^3, largely reflecting random loading of the roll off boxes with consideration of void spaces. The TSD-Dose (Pfingston, et al., 1998) computer program was used to evaluate doses to truck drivers hauling waste. The TSD-Dose computer code was developed to estimate potential radiation doses to on-site workers and the off-site public from

waste handling operations at a RCRA treatment, storage, and disposal (TSD) facility. The code is based on detailed assessments and assumptions regarding the potential operations and activities at a TSD facility. The user input parameters used to model this scenario are provided in Table 5.1. As shown in this table, the driver is assumed to be located near the waste during the following operations: loading and securing the bulk shipment, driving to the landfill, resting during transit, and truck maintenance during transit. For this analysis, loading, resting, and truck maintenance are assumed to occur at a rate of 5 minute (each) per hour of drive time. The general shielding properties of the roll off box and truck are assumed to be consistent with 12 gauge steel construction, or 0.32 cm (1/8") of steel. The input to TSD-Dose requires the user to define the total activity per container for shipment. For this scenario, unit dose conversion factors were developed assuming 1 h of drive time at 1 Ci per roll off box each of ^{226}Ra plus decay chain progeny and ^{238}U plus decay chain progeny, which equates to an average waste concentration of 5.1E+4 pCi/g of total activity. Modifications to the unit dose conversion factors will allow consideration of variable total drive time per year, independent of the distance hauled. The resulting dose factor per each hour of driving (plus 5 minutes each of loading, resting, and truck maintenance) is 6 mrem/h.

Table 5.1. TSD-Dose Input Parameters for the Truck Driver and Receipt/Sampling Scenarios

Parameter/Scenario	Value	Comment
Truck Driver Scenario		
Roll Off Box Dimensions	1.8 x 2.4 x 6.5 m (5'10" x 8' x 21'3")	Dimensions of a standard 19 m^3 (25 yd^3) roll off box.
Waste Density	1.4 g/cm^3	Solid bulk waste density.
Load Bulk Waste Duration	0.082 hr (5 minutes)	Average time to load roll off box with driver present.
Driver Distance During Loading	1.5 m (5 ')	Average driver proximity to roll off box.
Driver Shielding During Loading	0.32 cm (1/8")	Assumed 12 gauge steel roll off box.
Normalized Drive Time	1 h	To produce unit duration dose factors
Driver Distance From Waste	2.1 m (7')	From cab to roll off box.
Driver Shielding	0.63 cm (1/4")	Combined roll off box and cab.
Driver Rest Duration	5 minutes	Assumed 5 minutes of rest per hour of driving.
Driver Rest Location	0.61 m (2')	Assumed close proximity to roll off box.
Driver Rest Shielding	0.32 cm (1/8")	Assumed 12 gauge steel roll off box.
Driver – Maintenance Duration	5 minutes	Assumed 5 minutes maintenance per hour of driving.
Driver – Maintenance Location	0.91 m (3')	Assumed close proximity to waste
Driver Rest Shielding	0.32 cm (1/8")	Assumed 12 gauge steel roll off box.
Receipt/Sampling Scenario		
Weigh Truck: Average Distance	3.6 m (12')	The worker is in the weigh station to record readings.
Weigh Truck: Duration	10 minutes	Estimated time to inspect the manifest and record the weight.
Inspect/Sample Waste: Average Distance	0.3 m (12")	Sampling near contact with the waste roll off box.
Inspect/Sample Waste: Time per Drum	11.4 seconds	Assigned duration per drum to equal a total of 15 minutes per truck (80 drums).
Airborne Dust Concentration	10 mg/m^3	TSD-Dose default value.
Respiratory Protection Factor	1	No credit for the protection provided by dust masks.

Dividing this value by the waste concentration yields a unit concentration dose conversion factor of 1.2E-4 mrem/h per pCi/g. If it is assumed that a driver could be hauling TENORM waste 1,000 h/y (with an empty truck the remaining 1,000 of the work year), the resulting dose per hour of driving would be 0.12 mrem/y per pCi/g. The inverse of this factor is about 8.4 pCi/g per mrem/y. Finally, multiplying this value by the annual dose limit, 100 mrem/y, gives an acceptable waste concentration of 840 pCi/g, or about 800 pCi/g to one significant figure. This value is probably a conservative estimate for at least two reasons. First, not all of the waste received in a year at the Deer Trail facility would be TENORM waste at an average concentration; thus, the actual doses to the individual driver would be less than 100 mrem/y. Second, 5 minutes each of loading, resting, and truck maintenance, in closer proximity to the waste than inside the cab, per hour of driving is likely an overestimate of the actual time and location of the driver during these activities. The TSD-Dose input/output is provided in Appendix A.

5.2.2 Deer Trail Landfill Workers

To estimate the potential exposure conditions and radiation doses to landfill workers, three scenarios are considered: 1) exposure of workers during waste receipt and sampling, 2) exposure of workers in the waste cell, and 3) the accumulated exposure of workers to trucks or containers of waste at the site. The following paragraphs describe the analyses of each of these scenarios.

Workers Exposed During Receipt and Sampling

The TSD-Dose (Pfingston, et al., 1998) computer program was considered to evaluate doses to workers exposed during waste receipt and sampling operations. Although the code is intended to represent a broad range of activities, it is largely based on handling drums of waste, not bulk waste as is the case for Deer Trail. As a result, the activities associated with waste receipt and sampling for bulk wastes are not very well represented. The relevant portion of the TSD-Dose code is "Operation 2 – Receiving and Sampling," and the relevant aspects of Operation 2 include weighing the vehicle, inspecting the manifest, unloading drums of waste, and inspecting and sampling the drums. However, the default times and exposure geometries are those associated with drums, not bulk waste. For example, the code asks for the user to input the sampling time per drum, for a total time of up to 5 hours per truck to sample the waste. For bulk waste, composite samples are collected for each shipment, with a total exposure duration of between 10 to 15 minutes per truckload. The code assumes 80 drums per truck, thus the sampling time per drum needs to be 0.19 minutes to give 15 minutes per shipment sampling time for the bulk load. The detailed input parameters and assumptions for TSD-Dose are provided in Table 5.1. Consistent with the driver scenario, this scenario was run assuming 1 Ci per roll off box each of ^{226}Ra plus decay chain progeny and ^{238}U plus decay chain progeny, which equates to an average waste concentration of 5.1E+4 pCi/g. The resulting dose, at this input waste concentration, per shipment is 3.9 mrem. This dose is dominated by the external exposure pathway, with about 13% of the total dose from inhalation. Dividing this value by the waste concentration yields a unit concentration dose conversion factor of 7.7E-5 mrem per pCi/g per shipment. At full capacity, the Deer Trail facility could handle about 2,500 shipments per year. If all of these shipments were assumed to be TENORM waste, and if a worker were exposed to all of the shipments, the annual unit concentration dose conversion factor would be 0.19 mrem/y per pCi/g. The inverse

of this factor is 5.2 pCi/g per mrem/y. Finally, multiplying this value by the annual dose limit, 100 mrem/y, gives an acceptable waste concentration of 520 pCi/g, or about 500 pCi/g to one significant figure. It is noted that this value is probably a conservative estimate since not all of the waste received in a year at the Deer Trail facility would be TENORM waste at an average concentration, and since one worker may not be exposed to all shipments; thus, the actual doses to the individual during waste receipt/sampling would be less than 100 mrem/y. The TSD-Dose input/output is provided in Appendix A.

Workers Exposed to Waste in the Disposal Cell

Although there are several job descriptions associated with operations at the Deer Trail facility, those that would result in the highest potential radiation doses would be associated with work in the disposal cells. These individuals would have the closest proximity to the waste for the longest duration. Most of the activities are associated with positioning the waste in the cell and applying daily cover materials using heavy equipment. Because of the presence of hazardous materials, these workers must wear protective clothing to reduce skin contact, and dust masks to reduce inhalation hazards.

The TSD-Dose (Pfingston, et al., 1998) computer program was first considered to evaluate doses to in-cell workers for this scenario. Although the code is intended to represent a broad range of activities, it is largely based on handling drums of waste, not bulk waste as is the case for Deer Trail. The best representation for workers in a disposal cell within TSD-Dose is for "Operation 5 – Onsite Landfill." However, upon closer inspection, these activities in TSD-Dose only account for unloading waste in a mixing pit, adding stabilizers (i.e., fly ash), and trucking the processed waste into the cell. The user's manual indicates that: *The actual burial of the waste at the landfill is not included because of the amount of shielding (i.e., bulldozer and 8 in. of soil) between the worker and the source.* (Pfingston, et al., p. 9). This means that it is not possible to accurately model this scenario with TSD-Dose.

This RESRAD (Yu, et al. 2001) computer program was also considered for this scenario for the external and inhalation pathways only. The default parameter values in RESRAD are designed to be consistent with those recommended by the U.S. EPA in their *Exposure Factor Handbook* (1997) for conducting environmental risk assessments. The RESRAD (Yu, et al. 2001) computer program was developed by the U.S. DOE to support the evaluation of radiation doses and risks from **RES**idual **RA**Dioactive materials in soil at sites undergoing remediation. The computer program has undergone extensive review, benchmarking, verification, and validation. The computer program has been widely used by the U.S. Nuclear Regulatory Commission (NRC), U.S. EPA, U.S. Army Corps of Engineers, industrial firms, universities, and foreign government agencies and institutions.

For this scenario, two RESRAD computer runs were performed and the results were summed. The first was an analysis of external exposure, and the second was an analysis of inhalation exposure. For the external exposure analysis, as a bounding case it was assumed that the worker would be in the cell for 2,000 h/y, ignoring other job activities, time spent hauling clean cover material, and time to change into and out of the protective clothing. To account for shielding provided by the heavy equipment and the daily cover of soil, it is further assumed that the waste

would be covered by an average equivalent of 18 cm (7 inches) of clean soil. This assumption is reasonable since it accounts for an equivalent thickness of steel from the heavy equipment of about 1 cm, with an additional margin of about 2 cm for the daily soil cover. It is further assumed that source geometry has a surface area of 500 m^2 to a depth of 1.5 m (i.e., infinite slab source geometry). In a separate RESRAD analysis, an air concentration of 0.01 mg/m^3 of air at the default inhalation rate are used, without correction for respiratory protection or particle size. This second analysis was required since the 18 cm soil cover assumed in the external exposure analysis effectively covered the waste resulting in no airborne material, thus no inhalation dose. This is a conservative approach to inhalation dose since the workers wear dust masks or are in air-conditioned cabs that would limit the potential for inhalation and since TENORM material may be associated with large particle sized material, which would reduce the inhalation hazard. Dose times of 0, 1, and 1000 years after disposal of the waste were assumed for both cases considered to determine if the buildup of radioactive decay chain progeny would affect the results. Finally, unit concentrations of 1 pCi/g of the following radionuclides were used: ^{238}U + decay chain progeny, ^{234}U, ^{234}Th, ^{226}Ra + decay chain progeny, and ^{210}Po + decay chain progeny. These radionuclides and decay chains provide dose contributions for both the inhalation and external radiation exposure pathways.

The input/output from the RESRAD computer program for the cases considered in this scenario is provided in Appendix B. Note that it is not necessary to modify the default parameters for the pathways that were not considered since they do not contribute to the external or inhalation doses. The maximum individual radiation dose results were dominated by external exposure from ^{226}Ra plus its progeny, with less than about 2% of the total dose from inhalation of all of the radionuclides, including uranium. The dose results were about 0.25 mrem/y per pCi/g of ^{226}Ra. The inverse of this value is about 3.9 pCi/g per mrem/y. Assuming 100 mrem/y of exposure, the derived concentration limit is about 390 pCi/g (or 400 pCi/g to one significant figure) of ^{226}Ra. Note that this may be a conservative estimate based on modeling assumptions; the best way to relate waste concentration to worker dose is through personal dosimetry and workplace monitoring, as previously discussed for the data from the Buttonwillow landfill. Other factors, such as the presence of non NORM/TENORM waste, and fewer hours per year spent in the waste cell, would also increase the potential concentration limit.

Workers Exposed to Trucks or Waste Containers

As a check of the RESRAD analysis for a worker in the waste cell, a simple, yet conservative, scenario is evaluated for a hypothetical landfill worker exposed to trucks or containers of waste at the landfill. It is conservatively assumed that an individual could be located 1 m from a truck or container of waste for the entire work year (2,000 h). External exposure to penetrating radiation (photons and x-rays) from the waste material would be the only exposure pathway for this scenario since the workers would not come into direct contact with the waste. Although it is not anticipated that this scenario could really happen, exposure for an entire work year would bound the exposure situations for workers in the nearby proximity to the trucks or waste containers. Dose rates from the waste container are modeled using the MicroShield® (Grove Engineering 1998) computer code. The MicroShield® code is an industry-accepted computer code that estimates radiation doses for various source/shield/receptor geometries. For this analysis, the waste truck or container is assumed to have dimensions of 2.2 x 5.6 x 1 m

(7.2 x 18.4 x 3.3 feet). The analysis considered 0.32 cm (1/8 inch) of steel shielding to account for the side of the truck or waste container. The waste density was set at 1.4 g/cm^3, or the approximate density of soil. The analysis was conducted for ^{226}Ra and four shorter lived, photon emitting progeny: ^{214}Pb, ^{210}Pb, ^{214}Bi, and ^{210}Bi. As shown in Appendix C, the modeling results are 2.76E-04 mR/h (or 0.276 µR/h) per pCi/g of ^{226}Ra in the waste. The inverse of this unit concentration dose is found as 3.6 pCi/g of ^{226}Ra per µR/h. The derived concentration limit for ^{226}Ra for this scenario for 2,000 h/y of exposure is found by multiplying 3.62 pCi/g of ^{226}Ra in the waste by the dose rate limit (50 µrem/h), or about 180 pCi/g (or 200 pCi/g to one significant figure). As a more realistic case, the derived concentration for a worker near a truck or container for half work year is twice this value, or 360 pCi/g (or 400 pCi/g to one significant figure). Again note that this is a conservative analysis since it is unrealistic to assume an individual would spend a large fraction of their work-year in close proximity to a waste truck or container.

5.2.3 Long-Term Public Exposures

The Deer Trail landfill consists of waste management units designed to receive specific types of RCRA waste. The engineered containment system is consistent with the regulations for RCRA Subtitle C facilities and includes liner systems that have been designed and to prevent migration of waste out of the landfill into the underlying soils, ground water, or surface water. The liner systems are constructed of materials capable of resisting chemical degradation, static loading (weight), and dynamic loading (earthquake forces), and cover the side slopes and the bottom of each waste cell. The liner systems generally consist of two, three foot thick, compacted clay liners. These liners are compacted to a permeability of 1 x 10^{-7} cm/s or less. The secondary compacted clay liner is supported on a compacted sub-grade. Above these liners is a primary leachate collection and removal system, consisting of a minimum of 1.5 feet of soil over a geocomposite/HDPE layer. Upon closure, a cap consisting of another liner system will be applied to the top of the landfill. The closure cap will consist of a vegetative cover and a layered system of at least 1 m (4 feet) of compacted clay and soil. The cap is designed to prevent any rainfall from reaching the waste in the landfill.

Two potential long-term public scenarios have been identified and evaluated here: doses from ingestion of drinking water, and doses to nearby future residents. These scenarios are discussed in the following sections.

Drinking Water Scenario

During the site evaluation phase for the Deer Trail landfill, the hydrogeologic analysis demonstrated over 10,000 years of containment for all of the waste. Geotechnical evaluations have found that the site is underlain by no aquifers, apart from unusable, ancient groundwater perched at a depth 4,000 feet. The site is underlain with Pierre Shale with a natural permeability of 1 x 10^{-7} (Colorado GeoLogic, Inc. 1986). It can therefore be concluded that there will be no future ground water protection issues associated with disposal of NORM/TENORM materials at the Deer Trail landfill. This conclusion is consistent with previous analyses used in the initial permit process for Deer Trail.

In support of the May 2001 rulemaking, "Storage, Treatment, Transportation, and Disposal of Mixed Wastes" (FR 66, pp. 27218 – 27266), the U.S. EPA contracted with the Research Triangle Institute to report on the containment effectiveness of low-level radioactive waste disposal facilities regulated under 10 CFR 61 as compared with Subtitle C RCRA facilities regulated under 40 CFR 260-299 (U.S. EPA 2001). In summary, the report concluded that Subtitle C RCRA disposal facilities provide similar ground water protection as NRC-regulated low-level radioactive waste disposal facilities and would be protective of long-term human health and the environment. Conversely the report concluded that NRC-regulated low-level radioactive waste disposal facilities would be protective of human health and the environment for the disposal of RCRA hazardous wastes following the prescribed Land Disposal Restrictions (LDR) treatment for containerized waste. Although there may be some issues regarding bulk waste disposal and closure conditions, the general conclusions were based on the similarities of the overall facility designs and estimates of long-term performance regarding ground water protection. This overall position by the U.S. EPA is consistent with the findings of this analysis.

Nearby Residents

The relevant regulation for closure and post-closure of the Deer Trail is found in 40 CFR Part 264.117 (2002), *Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities,* Subpart G – *Closure and Post-Closure.* This regulation is included in the Colorado Code of Regulations, 1007-3, Section 264.117. Specifically, in §264.117(c) and 6CCR 1007-3 §264.11:

> *Post-closure use of property on or in which hazardous wastes remain after partial or final closure must never be allowed to disturb the integrity of the final cover, liner(s), or any other components of the containment system, or the function of the facility's monitoring systems ...*

Although the regulations prohibit trespass on the site and human intrusion into the waste, the site resident scenario, an individual who constructs a house on top of the closure cap, is defined to serve as a bounding estimate of future doses and risks to nearby residents. This group of individuals may be those who would be potentially the most exposed to radioactive material following closure of the Deer Trail facility. This group is termed the "critical group" of individuals for expected post-closure performance. The site resident scenario is designed to consider individuals who may reside directly over the buried waste, without disturbing the disposal system. Although this scenario could occur at any time, this analysis is conducted 100 years in the future. The analysis time of 100 years was selected to provide a conservative basis for the undisturbed performance evaluation since the attenuating effects of radioactive decay and migration of radionuclides deeper within the waste management unit from the surface should be minimal. To provide a conservative estimate of the potential radiation doses, the entire waste cell is assumed to be filled with a unit concentration of each of the radionuclides in the NORM/TENORM waste. This scenario considers the lifestyle and potential radiation exposure pathways associated with residential farming activities. The exposure pathways considered for this scenario include direct exposure to external radiation, inhalation, ingestion of soil, and ingestion of plant and animal food products assumed to be raised onsite. As a conservative overestimate, it is assumed that the entire diet of fruit, vegetables, and animal products (milk, meat, and eggs) is raised by the intruder. No access to well water for household

uses or irrigation is assumed since the drilling of a well would require intrusion into the waste. This scenario was evaluated using the RESRAD (Yu, et al. 2001) computer program with default parameters and assumptions. The default parameter values are designed to be consistent with those recommended by the U.S. EPA in their *Exposure Factor Handbook* (1997) for conducting environmental risk assessments. A summary of the RESRAD exposure pathway parameters considered for this scenario is shown in Table 5.2.

The only pathway contributing to the total radiation dose was external exposure to penetrating radiation. However, because of the presence of the layered closure system with roughly a 1 m (4 foot) layer of compacted clay and surface soil, the resulting radiation doses are quite small: 2.3E-5 mrem/y per pCi/g. If we assume that the landfill is filled with waste at the definition of

Table 5.2. Exposure Pathway Parameters Considered for the Site Resident Scenario

Pathway/Parameter	Factor/Units
General – All Pathways	
Cover Depth	1.0 m
Area of Contaminated Zone	330,000 m^2
Depth of Contaminated Zone	10 m
Food Product Ingestion:	
Plant Foods – Fruits, Vegetables, and Grain	160 kg/y
Plant Foods – Leafy Vegetables	14 kg/y
Meat and Poultry	63 kg/y
Milk	92 L/yr
Soil Ingestion	
Soil Ingestion Rate	36 g/y
Inhalation	
Airborne Dust Concentration (Mass Loading Factor)	1.0×10^{-4} g/m^3
Inhalation Rate	$8.4 \times 10^{+3}$ m^3/y
Shielding Factor (Indoor)	0.4
External	
Shielding Factor (Indoor)	0.7
Fraction of Time Spent Indoors	0.5
Fraction of Time Spent Outdoors	0.25
Fraction of Time Offsite	0.25

radioactive waste, 0.002 µCi/g, the individual dose is still small: 4.6E-2 mrem/y. It is noted that because the doses are small, the lifetime risks are at the lower end of the risk range considered by the U.S. EPA for CERCLA cleanup (i.e., an individual lifetime cancer mortality risk of one in a million). The RESRAD input/output is provided in Appendix D.

6.0 PARAMETER SENSITIVITY AND MODELING UNCERTAINTY

Although the subjects of parameter sensitivity and modeling uncertainty have been extensively studied, in the context of evaluating waste acceptance criteria they must be used cautiously. This is because of the lack of data for most situations and the amount of judgment required in selecting parameters and models relevant to the type of waste, environmental setting, and conditions being modeled. In a regulatory setting, the general rule of thumb is to select simple, conservative models, with minimal data requirements to assure that the results will not under predict the doses or risks that could result. This approach, by necessity, will bias the results towards a conservative outcome. The true uncertainty in this situation is the uncertainty in the decisions that are made, not necessarily the numerical modeling output. However, it is still important to attempt to understand the relationship between model input and output to maintain confidence that decisions that are made are defensible.

Evaluation of the scenario results must consider both the sensitivity of the results to the parameter input selections, as well as the potential uncertainty of the overall results. The overall uncertainty considers both the uncertainty in the conceptual model (i.e., do the scenarios selected represent reality), and the uncertainty introduced through assumptions and data selection. For this evaluation, the approach used was to follow multiple lines of reasoning. This meant using different conceptual models, exposure scenarios, parameter selections, and computer approaches for developing a range of potential waste acceptance criteria, then using judgment to select the final waste acceptance criteria. Although it may be impossible to quantify the mathematical uncertainty for a given situation, it is possible to determine if independent modeling approaches produce similar results, thereby giving confidence in the results and the decisions that are made. Therefore, the focus here is not on the numerical differences that could be produced using alternative parameters and assumptions, but rather on convergence of the results using different scenarios, models, and assumptions.

For the truck driver and the deer trail landfill worker scenarios considered in this analysis, the dominant exposure pathway was external exposure to penetrating radiation (i.e., photons from ^{226}Ra plus its decay chain progeny). This was because most of the individuals were not exposed to other pathways (i.e., inhalation) to any significant degree since most of them do not come into direct contact with the waste. For external exposure, only a few parameters are important in the dose assessment. These are: source concentration (defined for the specific type of TENORM waste), exposure geometry, exposure duration, and shielding conditions. A summary of the potential sensitivity across the identified parameters indicates:

- Source Concentration. Although this could vary from 0 – 2,000 pCi/g, this was used as the model output instead of an input condition.
- Exposure Geometry. For the potential conditions encountered for TENORM waste, the exposure geometries varied from a single waste container, to a large volume source representing waste in the landfill. The worker proximity to the waste varied from a fraction of a meter, to several meters depending on the scenario. For a unit concentration, the exposure rates from the different geometries considered varied over about one order of magnitude.

- Exposure Duration. The exposure durations considered for this study were based on conditions representing work conditions for the various job categories identified, with a maximum of 2,000 h/y. For the scenarios considered in this study, the exposure durations varied by about a factor of three.
- Shielding Conditions. The shielding conditions considered in this study varied from no shielding, to a fraction of a centimeter of steel representing waste containers and truck frames. The shielding conditions accounted for a variation of dose rate over about one order of magnitude.

To apply multiple lines of reasoning, three different modeling approaches were used: TSD-Dose, RESRAD, and MicroShield®. The model results for waste acceptance criteria based on ^{226}Ra plus its decay chain progeny are summarized across all scenarios and models in Table 6.1. As shown in this table, there is excellent agreement across the scenarios and models, within a factor of two. Agreement across several scenarios and models for photon emitters reflects the

Table 6.1. Summary of Estimated Waste Acceptance Criteria for ^{226}Ra Plus its Progeny

Scenario	Model	Result (pCi/g ^{226}Ra)
Truck Driver	TSD-Dose	800
Receipt and Sampling Workers	TSD-Dose	500
Workers in the Disposal Cell	RESRAD	400
Workers Exposed to Containers	MicroShield®	400

simplicity of modeling the external exposure pathway, where source geometry and exposure duration are the dominant assumptions that control the resulting doses and screening levels. This agreement also provides confidence in the selection of waste acceptance criteria within the range identified by the modeling results.

7.0 RECOMMENDATIONS

Based on the preceding analysis, several conclusions and recommendations can be reached regarding NORM/TENORM waste acceptance criteria at the Deer Trail landfill:

- For exposure to TENORM waste, Deer Trail worker's will be considered as members of the public and radiation exposures will be limited to 100 mrem/y, plus ALARA, with a goal of 25 mrem/y or less. If it is determined from worker dosimetry results that selected worker doses could exceed 25 mrem/y, an assessment will be conducted of the potential for other man-made exposures for Deer Trail workers to assure that maximum individual doses from man-made sources will not exceed 100 mrem/y. This assessment will consider real individuals working at Deer Trail, not hypothetical members of the public.
- Long-term post disposal conditions and the resulting public radiation doses for the site are not limiting in determining waste acceptance criteria; the site could receive enough NORM/TENORM waste to fill the entire landfill, at the limit defined as radioactive waste (0.002 µCi/g), without creating significant public radiation doses, and without contaminating the ground water.

- Based on the calculations in this report, the waste acceptance criteria could be between about 400 to 800 pCi/g of ^{226}Ra. Considering the experience at the Buttonwillow landfill, receipt of waste at an average concentration level of 400 pCi/g of ^{226}Ra, measured on a per shipment basis, is recommended. If applied as a peak value for purposes of setting the gate monitor alarms, it is recognized that the average concentrations received will be less (likely about 10% of the peak concentration), and therefore the average doses to workers will be also be less (likely about 10 mrem/y), consistent with ALARA.
- This proposed limit will equate to an alarm set point of 100 µR/h above background. If background is 16 µR/h, the alarm set point should be 116 µR/h. This new alarm set point would be about seven times the background level, and would still permit the detection of lost radiation sources in a waste shipment.
- It is noted that the proposed limit is for ^{226}Ra and its short-lived progeny that emit photons (important for external exposure), and that this limit is translated into the alarm set point for waste receipt based on the photon only sensitivity of the gate monitor. It is therefore recommended that the total activity of NORM/TENORM waste, including the alpha and beta emitting radionuclides, be enforced to the limit of 0.002 µCi/g used to define radioactive waste, as long as the radium concentration limit of 400 pCi/g per shipment is also maintained.

Based on the previously discussed Parsons data from the first year of cleanup of the Denver Radium Site, where the maximum concentration of ^{226}Ra observed was 79 pCi/g, these wastes would fall well within the recommended criteria and be acceptable for disposal at the Deer Trail facility. In addition, most of the oilfield/geothermal and drinking water treatment wastes would fall well within the proposed TENORM waste acceptance criteria. A summary of these comparisons is graphically shown in Figure 7.1.

In addition, it is recommended that the current worker protection program at the Deer Trail landfill be modified with the following considerations:

- All current procedures associated with monitoring for radioactive materials be modified based on the new waste acceptance criteria.
- Clean Harbors Deer Trail, LLC should institute a dosimetry program that will quantify background radiation exposures, radiation exposures associated with various locations within the landfill operation (including the waste receipt/weighing station, sample analysis hood, and locations in and around the waste cells), and for individual workers who come into close proximity to the NORM/TENORM waste. Although this program is not required by regulations, it will provide data to confirm that worker radiation doses are less than 100 mrem/y plus ALARA.

The disposal of NORM/TENORM at the Clean Harbors Deer Trail facility may be adequately regulated pursuant to the omnibus authority of the Resource Conservation and Recovery Act ("RCRA"), 42 U.S.C. § 6901 et seq. Clean Harbors is in the process of amending its RCRA Part B permit to effectuate this change. In addition to applicable standards prescribed by the RCRA

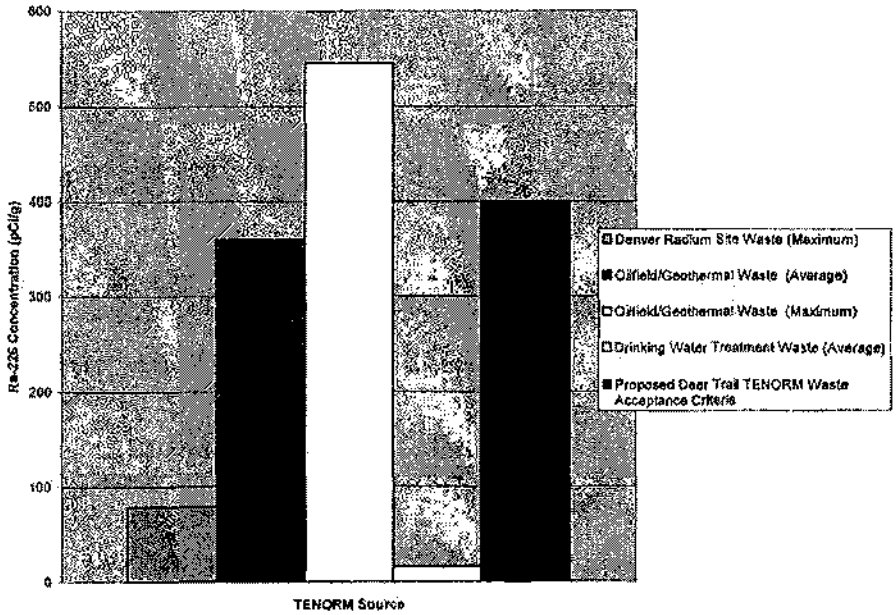

Figure 7.1. Comparison of Proposed Deer Trail TENORM Waste Acceptance Criteria and ^{226}Ra Concentrations from Various TENORM Sources

program, the amended permit will incorporate standards tailored for NORM/TENORM materials equivalent to those provided at 6 CCR 1007-1 sections:

- 4.5, Radiation Protection Programs,
- 4.14, Dose Limits for Individual Members of the Public,
- 4.15, Compliance with Dose Limits for Individual Members of the Public,
- 4.17, Surveys and Monitoring, General,
- 4.18, Conditions Requiring Individual Monitoring of External and Internal Occupational Dose,
- 4.40, Records – General Provisions,
- 4.41, Records of Radiation Protection Programs,
- 4.42, Records of Surveys,
- 4.44, Records of Individual Monitoring Results,
- 4.47, Records of Dose to Individual Members of the Public,
- 4.50, Form of Records,
- 4.56, Reports of Individual Monitoring, and
- 4.57, Notifications and Reports to Individuals.

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APPENDIX A – TSD-Dose INPUT/OUTPUT

TRUCK DRIVER SCENARIO
WEIGHING/SAMPLING SCENARIO

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

Version 2.22 - September 1998

Site: TSD-Denver Driver
Shipment: Radium Waste
User: Kennedy
Title: Denver

	TOTAL	EXTERNAL	INTERNAL
Dose to:			
Driver:	6.0E+00 mrem	6.0E+00 mrem	0.0E+00 mrem
Receiving worker:	not applicable	not applicable	not applicable
Incineration worker:	not applicable	not applicable	not applicable
Landfill worker:	not applicable	not applicable	not applicable
Offsite individual:	not applicable	not applicable	not applicable
Offsite population:	not applicable	not applicable	not applicable
Worker Population:	6.0E-03 p-rem	6.0E-03 p-rem	0.0E+00 p-rem
Dose from:			
Transport to TSD facility:	6.0E+00 mrem	6.0E+00 mrem	not applicable
Receiving and sampling waste:	not applicable	not applicable	not applicable
Storage before processing:	not applicable	not applicable	not applicable
Incineration of waste:	not applicable	not applicable	not applicable
Burial at onsite landfill:	not applicable	not applicable	not applicable
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	U238+D
Activity	1.0E+00 Ci	1.0E+00 Ci
Release Fraction	5.00E-04	5.00E-04
Driver	5.9 E+00	6.2 E-02
Receiving worker	not applicable	
Incineration worker	not applicable	
Landfill worker	not applicable	
Offsite individual	not applicable	
Offsite population	not applicable	
Worker population	5.9 E-03	6.2 E-05

Site Description

Operations Included:

Transport to TSD facility

Operations excluded:

Receiving and sampling waste
Storage before processing
Incineration of waste
Burial at onsite landfill
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 = 1.4 E+00 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: 2.13E+01 feet
width: 8.00E+00 feet
height: 5.83E+00 feet

Step A: Load and secure shipment
average distance: 5.00E+00 feet
duration: 8.30E-02 hours
shielding thickness: 1.25E-01 inches

Step B: Drive
average distance: 7.00E+00 feet (D)
duration: 1.00E+00 hours
shielding thickness: 2.50E-01 inches

Step C: Rest
average distance: 2.00E+00 feet (D)
duration: 8.30E-02 hours
shielding thickness: 1.25E-01 inches (D)

Step D: Maintenance in transit
average distance: 3.00E+00 feet (D)
duration: 8.30E-02 hours
shielding thickness: 6.25E-02 inches (D)

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

Version 2.22 - September 1998

Site: TSD-Denver Receipt/Sampling
Shipment: Radium Waste
User: Kennedy
Title: Denver

	TOTAL	EXTERNAL	INTERNAL
Dose to:			
Driver:	not applicable	not applicable	not applicable
Receiving worker:	3.9E+00 mrem	3.4E+00 mrem	5.2E-01 mrem
Incineration worker:	not applicable	not applicable	not applicable
Landfill worker:	not applicable	not applicable	not applicable
Offsite individual:	not applicable	not applicable	not applicable
Offsite population:	not applicable	not applicable	not applicable
Worker Population:	7.8E-03 p-rem	6.7E-03 p-rem	1.0E-03 p-rem
Dose from:			
Transport to TSD facility:	not applicable	not applicable	not applicable
Receiving and sampling waste:	3.9E+00 mrem	3.4E+00 mrem	5.2E-01 mrem
Storage before processing:	not applicable	not applicable	not applicable
Incineration of waste:	not applicable	not applicable	not applicable
Burial at onsite landfill:	not applicable	not applicable	not applicable
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	U238+D
Activity	1.0E+00 Ci	1.0E+00 Ci
Release Fraction	5.00E-04	5.00E-04
Driver	not applicable	
Receiving worker	3.4 E+00	5.3 E-01
Incineration worker	not applicable	
Landfill worker	not applicable	
Offsite Individual	not applicable	
Offsite population	not applicable	
Worker population	6.7 E-03	1.1 E-03

Site Description

Operations included:

Receiving and sampling waste

Operations excluded:

Transport to TSD facility
Storage before processing
Incineration of waste
Burial at onsite landfill
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 = 1.4 E+00 g/cc
Post-processed waste density = 1.4 E+00 g/cc

Receiving and sampling waste (5 steps)
Number of Workers: 2.0E+00 (D)

Step A: Weight truck, inspect manifest
average distance: 1.20E+01 feet
duration: 1.70E-01 hours

Step B: Unload drums
average distance: 3.00E+00 feet (D)
time per drum or pallet: 0.00E+00 hours

Step C: Inspect and sample drums
average distance: 1.00E+00 feet
time per drum: 3.00E-03 hours
airborne respirable dust concentration: 1.0E+01 mg/m3 (D)
respiratory protection factor: 1.0E+00

Step D: Transfer solids to storage
average distance: 3.00E+00 feet (D)
time per drum or pallet: 0.00E+00 hours

Step E: Pump drummed oil to storage tank
average distance: 6.00E-01 feet (D)
time per drum: 0.00E+00 hours

APPENDIX B - RESRAD INPUT/OUTPUT

WORKERS EXPOSED TO WASTE IN THE DISPOSAL CELL

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Dose Conversion Factor (and Related) Parameter Summary
File: ICRP 13 Morbidity

Menu	Parameter	Current Value	Default	Parameter Name
S-1	Dose conversion factors for inhalation, mrem/pCi:			
S-1	Pb-210+D	2.320E-02	2.320E-02	INCF(1,1)
S-1	Ra-226+D	8.460E-03	8.460E-03	INCF(2,1)
S-1	Th-230	3.260E-01	3.260E-01	INCF(3,1)
S-1	U-234	1.320E-01	1.320E-01	INCF(4,1)
S-1	U-238+D	1.180E-01	1.180E-01	INCF(5,1)
S-2	Dose conversion factors for ingestion, mrem/pCi:			
S-2	Pb-210+D	7.270E-03	7.270E-03	DCF2(1)
S-2	Ra-226+D	1.330E-03	1.330E-03	DCF2(2)
S-2	Th-230	5.460E-04	5.460E-04	DCF2(3)
S-2	U-234	2.830E-04	2.830E-04	DCF2(4)
S-2	U-238+D	2.690E-04	2.690E-04	DCF2(5)
S-34	Food transfer factors:			
S-34	Pb-210+D, plant/soil concentration ratio, dimensionless	1.000E-02	1.000E-02	RTF(1,1)
S-34	Pb-210+D, beef/livestock-intake ratio, (pCi/kg)/(pCi/d)	8.000E-04	8.000E-04	RTF(1,2)
S-34	Pb-210+D, milk/livestock-intake ratio, (pCi/L)/(pCi/d)	5.000E-04	5.000E-04	RTF(1,3)
S-34				
S-34	Ra-226+D, plant/soil concentration ratio, dimensionless	4.000E-02	4.000E-02	RTF(2,1)
S-34	Ra-226+D, beef/livestock-intake ratio, (pCi/kg)/(pCi/d)	1.000E-03	1.000E-03	RTF(2,2)
S-34	Ra-226+D, milk/livestock-intake ratio, (pCi/L)/(pCi/d)	1.000E-03	1.000E-03	RTF(2,3)
S-34				
S-34	Th-230, plant/soil concentration ratio, dimensionless	1.000E-03	1.000E-03	RTF(3,1)
S-34	Th-230, beef/livestock-intake ratio, (pCi/kg)/(pCi/d)	1.000E-04	1.000E-04	RTF(3,2)
S-34	Th-230, milk/livestock-intake ratio, (pCi/L)/(pCi/d)	5.000E-06	5.000E-06	RTF(3,3)
S-34				
S-34	U-234, plant/soil concentration ratio, dimensionless	2.500E-03	2.500E-03	RTF(4,1)
S-34	U-234, beef/livestock-intake ratio, (pCi/kg)/(pCi/d)	3.400E-04	3.400E-04	RTF(4,2)
S-34	U-234, milk/livestock-intake ratio, (pCi/L)/(pCi/d)	6.000E-04	6.000E-04	RTF(4,3)
S-34				
S-34	U-238+D, plant/soil concentration ratio, dimensionless	2.500E-03	2.500E-03	RTF(5,1)
S-34	U-238+D, beef/livestock-intake ratio, (pCi/kg)/(pCi/d)	3.400E-04	3.400E-04	RTF(5,2)
S-34	U-238+D, milk/livestock-intake ratio, (pCi/L)/(pCi/d)	6.000E-04	6.000E-04	RTF(5,3)
S-34				
D-5	Bioaccumulation factors, fresh water, L/kg:			
D-5	Pb-210+D, fish	3.000E+02	3.000E+02	BIOFAC(1,1)
D-5	Pb-210+D, crustacea and mollusks	1.000E+02	1.000E+02	BIOFAC(1,2)
D-5				
D-5	Ra-226+D, fish	5.000E+01	5.000E+01	BIOFAC(2,1)
D-5	Ra-226+D, crustacea and mollusks	2.500E+02	2.500E+02	BIOFAC(2,2)
D-5				
D-5	Th-230, fish	1.000E+02	1.000E+02	BIOFAC(3,1)
D-5	Th-230, crustacea and mollusks	5.000E+02	5.000E+02	BIOFAC(3,2)
D-5				
D-5	U-238, fish	1.000E+01	1.000E+01	BIOFAC(4,1)
D-5	U-238, crustacea and mollusks	6.000E+01	6.000E+01	BIOFAC(4,2)
D-5				
D-5	D-238+D, fish	1.000E+01	1.000E+01	BIOFAC(5,1)
D-5	D-238+D, crustacea and mollusks	6.000E+01	6.000E+01	BIOFAC(5,2)

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Site-Specific Parameter Summary

Num	Parameter	User Input	Default	Used by RESRAD (If different from user input)	Parameter Name
R011	Area of contaminated zone (m**2)	5.000E+02	1.000E+04		AREA
R011	Thickness of contaminated zone (m)	1.500E+00	2.000E+00		THICK0
R011	Length parallel to aquifer flow (m)	not used	1.000E+02		LCZPAQ
R011	Basic radiation dose limit (mrem/yr)	2.500E+01	2.500E+01		BRDL
R011	Time since placement of material (yr)	0.000E+00	0.000E+00		TI
R011	Times for calculations (yr)	1.000E+00	1.000E+00		T(1)
R012	Times for calculations (yr)	3.000E+00	3.000E+00		T(2)
R011	Times for calculations (yr)	not used	1.000E+01		T(3)
R011	Times for calculations (yr)	not used	3.000E+01		T(4)
R011	Times for calculations (yr)	not used	1.000E+02		T(5)
R011	Times for calculations (yr)	not used	3.000E+02		T(6)
R011	Times for calculations (yr)	not used	1.000E+03		T(7)
R011	Times for calculations (yr)	not used	0.000E+00		T(8)
R011	Times for calculations (yr)	not used	0.000E+00		T(9)
R011	Times for calculations (yr)	not used	0.000E+00		T(10)
R022	Initial principal radionuclide (pCi/g):	Pb-210	0.000E+00		S1(1,1)
R012	Initial principal radionuclide (pCi/g):	Ra-226	1.000E+00		S1(1,2)
R012	Initial principal radionuclide (pCi/g):	Th-230	0.000E+00		S1(1,3)
R012	Initial principal radionuclide (pCi/g):	U-234	1.000E+00		S1(1,4)
R012	Initial principal radionuclide (pCi/g):	U-238	1.000E+00		S1(1,5)
R012	Concentration in groundwater (pCi/l):	Pb-210	not used		W1(1,1)
R012	Concentration in groundwater (pCi/l):	Ra-226	not used		W1(1,2)
R012	Concentration in groundwater (pCi/l):	Th-230	not used		W1(1,3)
R012	Concentration in groundwater (pCi/l):	U-234	not used		W1(1,4)
R012	Concentration in groundwater (pCi/l):	U-238	not used		W1(1,5)
R013	Cover depth (m)	1.800E-01	0.000E+00		COVER0
R013	Density of cover material (g/cm**3)	1.500E+00	1.500E+00		DENSCV
R013	Cover depth erosion rate (m/yr)	9.000E-05	1.000E-03		VCV
R013	Density of contaminated zone (g/cm**3)	1.500E+00	1.500E+00		DENSCZ
R013	Contaminated zone erosion rate (m/yr)	1.000E-03	1.000E-03		VCZ
R013	Contaminated zone total porosity	4.000E-01	4.000E-01		TPCZ
R013	Contaminated zone field capacity	2.000E-01	2.000E-01		FCCZ
R013	Contaminated zone hydraulic conductivity (m/yr)	1.000E+01	1.000E+01		HCCZ
R013	Contaminated zone b parameter	5.300E+00	5.300E+00		BCZ
R013	Average annual wind speed (m/sec)	2.000E+00	2.000E+00		WINDSP
R013	Humidity in air (g/m**3)	not used	8.000E-00		HUMID
R013	Evapotranspiration coefficient	5.000E-01	5.000E-01		EVAPCZR
R013	Precipitation (m/yr)	1.000E+00	1.000E+00		PRECIP
R013	Irrigation (m/yr)	2.000E-01	2.000E-01		RI
R013	Irrigation mode	overhead	overhead		IDITCH
R013	Runoff coefficient	2.000E-01	2.000E-01		RUNOFF
R013	Watershed area for nearby stream or pond (m**2)	not used	1.000E+06		WAREA
R013	Accuracy for water/soil computations	not used	1.000E-03		ERW
R052	Density of saturated zone (g/cm**3)	not used	1.500E+00		DENSAZ
R054	Saturated zone total porosity	not used	4.000E-01		TPSZ
R054	Saturated zone effective porosity	not used	2.000E-01		EPSZ
R054	Saturated zone field capacity	not used	2.000E-01		FCSZ
R054	Saturated zone hydraulic conductivity (m/yr)	not used	1.000E+02		HCSZ
R054	Saturated zone hydraulic gradient	not used	2.000E-02		HGSZ

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Site-Specific Parameter Summary (continued)

Menu	Parameter	User Input	Default	Used by RESRAD (If different from user input)	Parameter Name
R014	Saturated zone b parameter	not used	5.300E+00	---	HS2
R014	Water table drop rate (m/yr)	not used	1.000E-03	---	VWT
R014	Well pump intake depth (m below water table)	not used	1.000E+01	---	DWIBWT
R014	Model: Nondispersion (ND) or Mass-Balance (MB)	not used	ND	---	MODEL
R014	Well pumping rate (m**3/yr)	not used	2.500E+02	---	UW
R015	Number of unsaturated zone strata	not used	1	---	NS
R015	Unsat. zone 1, thickness (m)	not used	4.000E+00	---	H(1)
R015	Unsat. zone 1, soil density (g/cm**3)	not used	1.500E+00	---	DENSUZ(1)
R015	Unsat. zone 1, total porosity	not used	4.000E-01	---	TPUZ(1)
R015	Unsat. zone 1, effective porosity	not used	2.000E-01	---	EPUZ(1)
R015	Unsat. zone 1, field capacity	not used	2.000E-01	---	FCUZ(1)
R015	Unsat. zone 1, soil-specific b parameter	not used	5.300E+00	---	BUZ(1)
R015	Unsat. zone 1, hydraulic conductivity (m/yr)	not used	1.000E+01	---	HCUZ(1)
R016	Distribution coefficients for Pb-210				
R016	Contaminated zone (cm**3/g)	1.000E+02	1.000E+02	---	DCNUCC(1)
R016	Unsaturated zone 1 (cm**3/g)	not used	1.000E+02	---	DCNUCU(1,1)
R016	Saturated zone (cm**3/g)	not used	1.000E+02	---	DCNUCS(1)
R016	Leach rate (/yr)	0.000E+00	0.000E+00	2.217E-03	ALEACH(1)
R016	Solubility constant	0.000E+00	0.000E+00	not used	SOLUBK(1)
R016	Distribution coefficients for Ra-226				
R016	Contaminated zone (cm**3/g)	7.000E+01	7.000E+01	---	DCNUCC(2)
R016	Unsaturated zone 1 (cm**3/g)	not used	7.000E+01	---	DCNUCU(2,1)
R016	Saturated zone (cm**3/g)	not used	7.000E+01	---	DCNUCS(2)
R016	Leach rate (/yr)	0.000E+00	0.000E+00	3.165E-03	ALEACH(2)
R016	Solubility constant	0.000E+00	0.000E+00	not used	SOLUBK(2)
R016	Distribution coefficients for Th-230				
R016	Contaminated zone (cm**3/g)	6.000E+04	6.000E+04	---	DCNUCC(3)
R016	Unsaturated zone 1 (cm**3/g)	not used	6.000E+04	---	DCNUCU(3,1)
R016	Saturated zone (cm**3/g)	not used	6.000E+04	---	DCNUCS(3)
R016	Leach rate (/yr)	0.000E+00	0.000E+00	3.704E-06	ALEACH(3)
R016	Solubility constant	0.000E+00	0.000E+00	not used	SOLUBK(3)
R016	Distribution coefficients for U-234				
R016	Contaminated zone (cm**3/g)	5.000E+01	5.000E+01	---	DCNUCC(4)
R016	Unsaturated zone 1 (cm**3/g)	not used	5.000E+01	---	DCNUCU(4,1)
R016	Saturated zone (cm**3/g)	not used	5.000E+01	---	DCNUCS(4)
R016	Leach rate (/yr)	0.000E+00	0.000E+00	4.426E-03	ALEACH(4)
R016	Solubility constant	0.000E+00	0.000E+00	not used	SOLUBK(4)
R016	Distribution coefficients for U-238				
R016	Contaminated zone (cm**3/g)	5.000E+01	5.000E+01	---	DCNUCC(5)
R016	Unsaturated zone 1 (cm**3/g)	not used	5.000E+01	---	DCNUCU(5,1)
R016	Saturated zone (cm**3/g)	not used	5.000E+01	---	DCNUCS(5)
R016	Leach rate (/yr)	0.000E+00	0.000E+00	4.426E-03	ALEACH(5)
R016	Solubility constant	0.000E+00	0.000E+00	not used	SOLUBK(5)
R017	Inhalation rate (m**3/yr)	1.916E+03	8.400E+03	---	INHALR

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Menu	Parameter	User Input	Default	Used by RESRAD (If different from user input)	Parameter Name
R017	Mass loading for inhalation (g/m**3)	2.000E-04	1.000E-04	---	MLINH
R017	Exposure duration	3.000E+01	3.000E+01	---	ED
R017	Shielding factor, inhalation	4.000E-01	4.000E-01	---	SHF3
R017	Shielding factor, external gamma	7.000E-01	7.000E-01	---	SHF1
R017	Fraction of time spent indoors	0.000E+00	5.000E-01	---	FIND
R017	Fraction of time spent outdoors (on site)	2.280E-01	2.500E-01	---	FOTD
R017	Shape factor flag, external gamma	1.000E+00	1.000E+00	>0 shows circular AREA.	FS
R017	Radii of shape factor array (used if FS = -1):				
R017	Outer annular radius (m), ring 1:	not used	5.000E+01	---	RAD_SHAPE(1)
R017	Outer annular radius (m), ring 2:	not used	7.071E+01	---	RAD_SHAPE(2)
R017	Outer annular radius (m), ring 3:	not used	0.000E+00	---	RAD_SHAPE(3)
R017	Outer annular radius (m), ring 4:	not used	0.000E+00	---	RAD_SHAPE(4)
R017	Outer annular radius (m), ring 5:	not used	0.000E+00	---	RAD_SHAPE(5)
R017	Outer annular radius (m), ring 6:	not used	0.000E+00	---	RAD_SHAPE(6)
R017	Outer annular radius (m), ring 7:	not used	0.000E+00	---	RAD_SHAPE(7)
R017	Outer annular radius (m), ring 8:	not used	0.000E+00	---	RAD_SHAPE(8)
R017	Outer annular radius (m), ring 9:	not used	0.000E+00	---	RAD_SHAPE(9)
R017	Outer annular radius (m), ring 10:	not used	0.000E+00	---	RAD_SHAPE(10)
R017	Outer annular radius (m), ring 11:	not used	0.000E+00	---	RAD_SHAPE(11)
R017	Outer annular radius (m), ring 12:	not used	0.000E+00	---	RAD_SHAPE(12)
R017	Fractions of annular areas within AREA:				
R017	Ring 1	not used	1.000E+00	---	FRACA(1)
R017	Ring 2	not used	2.732E-01	---	FRACA(2)
R017	Ring 3	not used	0.000E+00	---	FRACA(3)
R017	Ring 4	not used	0.000E+00	---	FRACA(4)
R017	Ring 5	not used	0.000E+00	---	FRACA(5)
R017	Ring 6	not used	0.000E+00	---	FRACA(6)
R017	Ring 7	not used	0.000E+00	---	FRACA(7)
R017	Ring 8	not used	0.000E+00	---	FRACA(8)
R017	Ring 9	not used	0.000E+00	---	FRACA(9)
R017	Ring 10	not used	0.000E+00	---	FRACA(10)
R017	Ring 11	not used	0.000E+00	---	FRACA(11)
R017	Ring 12	not used	0.000E+00	---	FRACA(12)
R018	Fruits, vegetables and grain consumption (kg/yr)	not used	1.600E+02	---	DIET(1)
R018	Leafy vegetable consumption (kg/yr)	not used	1.400E+01	---	DIET(2)
R018	Milk consumption (L/yr)	not used	9.200E+01	---	DIET(3)
R018	Meat and poultry consumption (kg/yr)	not used	6.300E+01	---	DIET(4)
R018	Fish consumption (kg/yr)	not used	5.400E+00	---	DIET(5)
R018	Other seafood consumption (kg/yr)	not used	9.000E-01	---	DIET(6)
R018	Soil ingestion rate (g/yr)	not used	3.650E+01	---	SOIL
R018	Drinking water intake (L/yr)	not used	5.100E+02	---	DWI
R018	Contamination fraction of drinking water	not used	1.000E+00	---	FDW
R018	Contamination fraction of household water	not used	1.000E+00	---	FHHW
R018	Contamination fraction of livestock water	not used	1.000E+00	---	FLW
R018	Contamination fraction of irrigation water	not used	1.000E+00	---	FIRW
R018	Contamination fraction of aquatic food	not used	5.000E-01	---	FR9
R018	Contamination fraction of plant food	not used	-1	---	FPLANT
R018	Contamination fraction of meat	not used	-1	---	FMEAT
R018	Contamination fraction of milk	not used	-1	---	FMILK

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Menu	Parameter	User Input	Default	Used by RESRAD (If different from user input)	Parameter Name
R019	Livestock fodder intake for meat (kg/day)	not used	6.800E+01	---	LFI5
R019	Livestock fodder intake for milk (kg/day)	not used	5.500E+01	---	LFI6
R019	Livestock water intake for meat (L/day)	not used	5.000E+01	---	LWI5
R019	Livestock water intake for milk (L/day)	not used	1.600E+02	---	LWI6
R019	Livestock soil intake (kg/day)	not used	5.000E-01	---	LSI
R019	Mass loading for foliar deposition (g/m**3)	not used	1.000E-04	---	MLFD
R019	Depth of soil mixing layer (m)	1.500E-01	1.500E-01	---	DM
R019	Depth of roots (m)	not used	9.000E-01	---	DROOT
R019	Drinking water fraction from ground water	not used	1.000E+00	---	FGWDW
R019	Household water fraction from ground water	not used	1.000E+00	---	FGWHH
R019	Livestock water fraction from ground water	not used	1.000E+00	---	FGWLW
R019	Irrigation fraction from ground water	not used	1.000E+00	---	FGWIR
R19B	Wet weight crop yield for Non-Leafy (kg/m**2)	not used	7.000E-01	---	YV(1)
R19B	Wet weight crop yield for Leafy (kg/m**2)	not used	1.500E+00	---	YV(2)
R19B	Wet weight crop yield for Fodder (kg/m**2)	not used	1.100E+00	---	YV(3)
R19B	Growing Season for Non-Leafy (years)	not used	1.700E-01	---	TE(1)
R19B	Growing Season for Leafy (years)	not used	2.500E-01	---	TE(2)
R19B	Growing Season for Fodder (years)	not used	8.000E-02	---	TE(3)
R19B	Translocation Factor for Non-Leafy	not used	1.000E-01	---	TIV(1)
R19B	Translocation Factor for Leafy	not used	1.000E+00	---	TIV(2)
R19B	Translocation Factor for Fodder	not used	1.000E+00	---	TIV(3)
R19B	Dry Foliar Interception Fraction for Non-Leafy	not used	2.500E-01	---	RDRY(1)
R19B	Dry Foliar Interception Fraction for Leafy	not used	2.500E-01	---	RDRY(2)
R19B	Dry Foliar Interception Fraction for Fodder	not used	2.500E-01	---	RDRY(3)
R19B	Wet Foliar Interception Fraction for Non-Leafy	not used	2.500E-01	---	RWET(1)
R19B	Wet Foliar Interception Fraction for Leafy	not used	2.500E-01	---	RWET(2)
R19B	Wet Foliar Interception Fraction for Fodder	not used	2.500E-01	---	RWET(3)
R19B	Weathering Removal Constant for Vegetation	not used	2.000E+01	---	WLAM
C14	C-12 concentration in water (g/cm**3)	not used	2.000E-05	---	C12WTR
C14	C-12 concentration in contaminated soil (g/g)	not used	3.000E-02	---	C12CZ
C14	Fraction of vegetation carbon from soil	not used	2.000E-02	---	CSOIL
C14	Fraction of vegetation carbon from air	not used	9.800E-01	---	CAIR
C14	C-14 evasion layer thickness in soil (m)	not used	3.000E-01	---	DMC
C14	C-14 evasion flux rate from soil (1/sec)	not used	7.000E-07	---	EVSN
C14	C-12 evasion flux rate from soil (1/sec)	not used	1.000E-10	---	REVSN
C14	Fraction of grain in beef cattle feed	not used	8.000E-01	---	AVFG4
C14	Fraction of grain in milk cow feed	not used	2.000E-01	---	AVFG5
C14	DCF correction factor for gaseous forms of C14	not used	8.894E+01	---	CO2F
STOR	Storage times of contaminated foodstuffs (days):				
STOR	Fruits, non-leafy vegetables, and grain	1.400E+01	1.400E+01	---	STOR_T(1)
STOR	Leafy vegetables	1.000E+00	1.000E+00	---	STOR_T(2)
STOR	Milk	1.000E+00	1.000E+00	---	STOR_T(3)
STOR	Meat and poultry	2.000E+01	2.000E+01	---	STOR_T(4)
STOR	Fish	7.000E+00	7.000E+00	---	STOR_T(5)
STOR	Crustacea and mollusks	7.000E+00	7.000E+00	---	STOR_T(6)
STOR	Well water	1.000E+00	1.000E+00	---	STOR_T(7)
STOR	Surface water	1.000E+00	1.000E+00	---	STOR_T(8)
STOR	Livestock fodder	4.500E+01	4.500E+01	---	STOR_T(9)

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Site-Specific Parameter Summary (continued)

Menu	Parameter	User Input	Default	Used by RESRAD (If different from user input)	Parameter Name
R021	Thickness of building foundation (m)	not used	1.500E-01	---	FLOOR1
R021	Bulk density of building foundation (g/cm**3)	not used	2.400E+00	---	DENSFL
R021	Total porosity of the cover material	not used	4.000E-01	---	TPCV
R021	Total porosity of the building foundation	not used	1.000E-01	---	TPFL
R021	Volumetric water content of the cover material	not used	5.000E-02	---	PH2OCV
R021	Volumetric water content of the foundation	not used	3.000E-02	---	PH2OFL
R021	Diffusion coefficient for radon gas (m/sec):				
R021	in cover material	not used	2.000E-06	---	DIFCV
R021	in foundation material	not used	3.000E-07	---	DIFFL
R021	in contaminated zone soil	not used	2.000E-06	---	DIFCZ
R021	Radon vertical dimension of mixing (m)	not used	2.000E+00	---	HMIX
R021	Average building air exchange rate (1/hr)	not used	5.000E-01	---	REXG
R021	Height of the building (room) (m)	not used	2.500E+00	---	HRM
R021	Building interior area factor	not used	0.000E+00	---	FAI
R021	Building depth below ground surface (m)	not used	-1.000E+00	---	DMFL
R021	Emanating power of Rn-222 gas	not used	2.500E-01	---	EMANA(1)
R021	Emanating power of Rn-220 gas	not used	1.500E-01	---	EMANA(2)
TITL	Number of graphical time points	32	---	---	NPTS
TITL	Maximum number of integration points for dose	17	---	---	LYMAX
TITL	Maximum number of integration points for risk	257	---	---	KYMAX

Summary of Pathway Selections

Pathway	User Selection
1 -- external gamma	active
2 -- inhalation (w/o radon)	active
3 -- plant ingestion	suppressed
4 -- meat ingestion	suppressed
5 -- milk ingestion	suppressed
6 -- aquatic foods	suppressed
7 -- drinking water	suppressed
8 -- soil ingestion	suppressed
9 -- radon	suppressed
Find peak pathway doses	active

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Summary : Deaver Radium - In Cell External            File: Deaver Radium - In Cell External.RAD

     Contaminated Zone Dimensions           Initial Soil Concentrations, pCi/g

        Area:    500.00 square meters               Pb-210      1.000E+00
   Thickness:      1.50 meters                      Ra-226      1.000E+00
 Cover Depth:      0.18 meters                      Th-230      1.000E+00
                                                    U-234       1.000E+00
                                                    U-238       1.560E+00

                  Total Dose TDOSE(t), mrem/yr
              Basic Radiation Dose Limit = 2.500E+01 mrem/yr
Total Mixture Sum M(t) = Fraction of Basic Dose Limit Received at Time (t)

   t (years):  0.000E+00  1.000E+00  1.000E+03
    TDOSE(t):  2.539E-01  2.530E-01  3.617E-02
        M(t):  1.015E-02  1.012E-02  1.447E-03
0Maximum TDOSE(t):  2.539E-01 mrem/yr   at t = 0.000E+00 years
```

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Summary : Denver Radium - In Cell External File: Denver Radium - In Cell External.RAD

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 0.000E+00 years
Water Independent Pathways (Inhalation excludes radon)

Radio-Nuclide	Ground mrem/yr	Ground fract.	Inhalation mrem/yr	Inhalation fract.	Radon mrem/yr	Radon fract.	Plant mrem/yr	Plant fract.	Meat mrem/yr	Meat fract.	Milk mrem/yr	Milk fract.	Soil mrem/yr	Soil fract.
Pb-210	9.131E-06	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Ra-226	2.513E-01	0.9900	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Th-230	5.599E-05	0.0002	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
U-234	3.513E-07	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
U-238	2.484E-03	0.0098	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Total	2.539E-01	1.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 0.000E+00 years
Water Dependent Pathways

Radio-Nuclide	Water mrem/yr	Water fract.	Fish mrem/yr	Fish fract.	Radon mrem/yr	Radon fract.	Plant mrem/yr	Plant fract.	Meat mrem/yr	Meat fract.	Milk mrem/yr	Milk fract.	All Pathways* mrem/yr	All Pathways* fract.
Pb-210	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	9.131E-06	0.0000
Ra-226	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.513E-01	0.9900
Th-230	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	5.599E-05	0.0002
U-234	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	3.513E-07	0.0000
U-238	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.484E-03	0.0098
Total	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.539E-01	1.0000

*Sum of all water independent and dependent pathways.

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Total Dose Contributions TDOSR(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 1.000E+00 years
Water Independent Pathways (Plants excludes radon)

Radio-Nuclide	Ground mrem/yr	Ground fract.	Inhalation mrem/yr	Inhalation fract.	Radon mrem/yr	Radon fract.	Plant mrem/yr	Plant fract.	Meat mrem/yr	Meat fract.	Milk mrem/yr	Milk fract.	Soil mrem/yr	Soil fract.
Pb-210	8.8012E-06	3.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000
Ra-226	2.3045E-01	0.9825	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000
Th-230	1.6417E-04	0.0007	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000
U-234	3.3018E-07	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000
U-238	2.4732E-07	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000
Total	2.3523E-01	1.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 1.000E+00 years
Water Dependent Pathways

Radio-Nuclide	Water mrem/yr	Water fract.	Fish mrem/yr	Fish fract.	Radon mrem/yr	Radon fract.	Plant mrem/yr	Plant fract.	Meat mrem/yr	Meat fract.	Milk mrem/yr	Milk fract.	All Pathways* mrem/yr	All Pathways* fract.
Pb-210	0.0000E+00	0.0000	6.0003E-02	6.0003	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	8.8315E-06	0.0000
Ra-226	0.0000E+00	0.0000	1.0005E-03	0.0010	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	2.3045E-01	0.9825
Th-230	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	1.6417E-04	0.0007
U-234	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	3.3018E-07	0.0000
U-238	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	2.4732E-07	0.0000
Total	0.0000E+00	0.0000	6.0004E-02	0.2550	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	2.3523E-01	1.0000

*Sum of all water independent and dependent pathways.

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Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 1.000E+03 years
Water Independent Pathways (Inhalation excludes radon)

Radio-	Ground		Inhalation		Radon		Plant		Meat		Milk		Soil	
Nuclide	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.
Pb-210	3.156E-20	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Ra-226	6.882E-03	0.1902	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Th-230	2.921E-02	0.8074	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
U-234	5.542E-05	0.0015	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
U-238	2.976E-05	0.0008	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Total	3.617E-02	1.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 1.000E+03 years
Water Dependent Pathways

Radio-	Water		Fish		Radon		Plant		Meat		Milk		All Pathways*	
Nuclide	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.
Pb-210	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	3.156E-20	0.0000
Ra-226	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	6.882E-03	0.1902
Th-230	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.921E-02	0.8074
U-234	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	5.542E-05	0.0015
U-238	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.976E-05	0.0008
Total	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	3.617E-02	1.0000

*Sum of all water independent and dependent pathways.

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Dose/Source Ratios Summed Over All Pathways
Parent and Progeny Principal Radionuclide Contributions Indicated

Parent (i)	Product (j)	Branch Fraction*	DSR(j,t) (mrem/yr)/(pCi/g) t= 0.000E+00	1.000E+00	1.000E+03
Pb-210	Pb-210	1.000E+00	9.231E-06	8.831E-06	3.150E-20
Ra-226	Ra-226	1.000E+00	2.513E-01	2.504E-01	6.875E-03
Ra-226	Pb-210	1.000E+00	1.425E-07	4.256E-07	2.655E-07
Ra-226	∑DSR(j)		2.513E-01	2.504E-01	6.890E-03
Th-230	Th-230	1.000E+00	1.527E-06	1.527E-06	1.508E-06
Th-230	Ra-226	1.000E+00	5.447E-05	1.631E-04	2.920E-02
Th-230	Pb-210	1.000E+00	2.564E-11	1.430E-10	3.002E-06
Th-230	∑DSR(j)		5.599E-05	1.647E-04	2.921E-02
U-234	U-234	1.000E+00	3.512E-07	3.496E-07	4.191E-09
U-234	Th-230	1.000E+00	6.865E-12	2.055E-11	3.038E-09
U-234	Ra-226	1.000E+00	1.633E-10	1.141E-09	5.541E-05
U-234	Pb-210	1.000E+00	4.556E-17	6.914E-16	1.987E-09
U-234	∑DSR(j)		3.513E-07	3.508E-07	5.542E-05
U-238	U-238	1.000E+00	2.484E-03	2.473E-03	2.973E-05
U-238	U-234	1.000E+00	4.974E-13	1.486E-12	1.190E-11
U-238	Th-230	1.000E+00	6.483E-18	4.926E-17	1.846E-12
U-238	Ra-226	1.000E+00	1.157E-16	2.731E-15	3.053E-08
U-238	Pb-210	1.000E+00	2.639E-23	8.113E-22	1.027E-12
U-238	∑DSR(j)		2.484E-03	2.473E-03	2.976E-05

*Branch Fraction is the cumulative factor for the j't principal radionuclide daughter: CUMBRF(j) = BRF(1)*BRF(2)* ... BRF(j).
The DSR includes contributions from associated (half-life ≤ 0.5 yr) daughters.

Single Radionuclide Soil Guidelines G(i,t) in pCi/g
Basic Radiation Dose Limit = 2.500E+01 mrem/yr

Nuclide (i)	t= 0.000E+00	1.000E+00	1.000E+03
Pb-210	2.739E+06	2.831E+06	*7.631E+13
Ra-226	9.948E+01	9.984E+01	3.634E+03
Th-230	4.465E+05	1.518E+05	8.560E+02
U-234	7.118E+07	7.127E+07	4.511E+05
U-238	1.006E+04	1.011E+04	*3.360E+05

*At specific activity limit

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          Summed Dose/Source Ratios DSR(i,t) in (mrem/yr)/(pCi/g)
          and Single Radionuclide Soil Guidelines G(i,t) in pCi/g
        at tmin = time of minimum single radionuclide soil guideline
     and at tmax = time of maximum total dose = 0.000E+00 years
Nuclide  Initial        tmin       DSR(i,tmin) G(i,tmin) DSR(i,tmax) G(i,tmax)
  (i)    (pCi/g)       (years)                  (pCi/g)               (pCi/g)

Pb-210  1.000E+00    0.000E+00     9.131E-06  2.738E+06  9.131E-06  2.738E+06
Ra-226  1.000E+00    0.000E+00     2.513E-01  9.948E+01  2.513E-01  9.948E+01
Th-230  1.000E+00    1.000E+03     2.921E-02  8.560E+02  5.599E-05  4.465E+05
U-234   1.000E+00    1.000E+03     5.542E-03  4.511E+05  3.513E-07  7.116E+07
U-238   1.000E+00    0.000E+00     2.484E-03  1.006E+04  2.484E-03  1.006E+04
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Individual Nuclide Dose Summed Over All Pathways
Parent Nuclide and Branch Fraction Indicated

Nuclide (j)	Parent (i)	BRF(i)	DOSE(j,t), mrem/yr t= 0.000E+00	1.000E+00	1.000E+03
Pb-210	Pb-210	1.000E+00	9.131E-06	8.931E-06	3.150E-20
Pb-210	Ra-226	1.000E+00	1.425E-07	4.206E-07	2.655E-07
Pb-210	Th-230	1.000E+00	2.064E-11	1.430E-10	1.002E-06
Pb-210	U-234	1.000E+00	4.650E-17	6.916E-16	1.887E-09
Pb-210	U-238	1.000E+00	2.639E-23	8.115E-22	1.027E-12
Pb-210	ΣDOSE(j)		9.273E-06	9.252E-06	1.269E-06
Ra-226	Ra-226	1.000E+00	2.513E-01	2.504E-01	6.879E-03
Ra-226	Th-230	1.000E+00	5.447E-05	1.651E-04	2.920E-02
Ra-226	U-234	1.000E+00	1.633E-10	1.141E-09	5.541E-05
Ra-226	U-238	1.000E+00	1.157E-16	1.731E-15	3.053E-08
Ra-226	ΣDOSE(j)		2.514E-01	2.506E-01	3.614E-02
Th-230	Th-230	1.000E+00	1.527E-06	1.527E-06	1.508E-06
Th-230	U-234	1.000E+00	6.865E-12	2.055E-11	3.035E-09
Th-230	U-238	1.000E+00	6.493E-18	4.526E-17	1.846E-12
Th-230	ΣDOSE(j)		1.527E-06	1.527E-06	1.511E-06
U-234	U-234	1.000E+00	3.512E-07	3.496E-07	4.191E-09
U-234	U-238	1.000E+00	4.974E-13	1.426E-12	3.390E-11
U-234	ΣDOSE(j)		3.512E-07	3.496E-07	4.203E-09
U-238	U-238	1.000E+00	2.484E-03	2.473E-03	2.973E-05

BRF(i) is the branch fraction of the parent nuclide.

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          Individual Nuclide Soil Concentration
       Parent Nuclide and Branch Fraction Indicated
Nuclide Parent   BRF(i)              S(j,t), pCi/g
  (j)     (i)              t= 0.000E+00 1.000E+00 1.000E+03

Pb-210  Pb-210  1.000E+00    1.000E+00 9.672E-01 3.450E-15
Pb-210  Ra-226  1.000E+00    0.000E+00 3.252E-02 2.865E-02
Pb-210  Th-230  1.000E+00    0.000E+00 6.651E-06 1.075E-01
Pb-210  U-234   1.000E+00    0.000E+00 2.000E-12 2.632E-04
Pb-210  U-238   1.000E+00    0.000E+00 1.419E-17 1.106E-07
Pb-210  ∑S(j):               1.000E+00 [illegible] 1.369E-01
Ra-226  Ra-226  1.000E+00    1.000E+00 9.964E-01 2.737E-02
Ra-226  Th-230  1.000E+00    0.000E+00 4.724E-04 1.160E-01
Ra-226  U-234   1.000E+00    0.000E+00 1.945E-09 2.280E-04
Ra-226  U-238   1.000E+00    0.000E+00 1.837E-15 1.272E-07
Ra-226  ∑S(j):               1.000E+00 9.969E-01 1.436E-01
Th-230  Th-230  1.000E+00    1.000E+00 1.000E+00 9.874E-01
Th-230  U-234   1.000E+00    0.000E+00 9.982E-06 1.889E-03
Th-230  U-238   1.000E+00    0.000E+00 1.272E-11 1.208E-06
Th-230  ∑S(j):               1.000E+00 1.000E+00 9.894E-01
U-234   U-234   1.000E+00    1.000E+00 9.956E-01 1.193E-02
U-234   U-238   1.000E+00    0.000E+00 2.322E-06 3.389E-05
U-234   ∑S(j):               1.000E+00 9.956E-01 1.197E-02
U-238   U-238   1.000E+00    1.000E+00 9.956E-01 1.197E-02

BRF(i) is the branch fraction of the parent nuclide.
RESCALC.EXE execution time =    0.92 seconds
```

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File : Denver Radium - In Cell Remediated.RAD

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Part I: Mixture Sums and Single Radionuclide Guidelines

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Summary : Denver Radium - In Cell Inhalation1
File    : Denver Radium - In Cell Inhalation1.RAD
```

Dose Conversion Factor (and Related) Parameter Summary
File: FGR 13 Morbidity

Menu	Parameter	Current Value	Default	Parameter Name
B-1	Dose conversion factors for inhalation, mrem/pCi:			
B-1	Pb-210+D	2.320E-02	2.320E-02	DCF2(1)
B-1	Ra-226+D	8.600E-03	8.600E-03	DCF2(2)
B-1	Th-230	3.260E-01	3.260E-01	DCF2(3)
B-1	U-234	1.320E-01	1.320E-01	DCF2(4)
B-1	U-238+D	1.180E-01	1.180E-01	DCF2(5)
D-1	Dose conversion factors for ingestion, mrem/pCi:			
D-1	Pb-210+D	7.270E-03	7.270E-03	DCF3(1)
D-1	Ra-226+D	1.330E-03	1.330E-03	DCF3(2)
D-1	Th-230	5.480E-04	5.480E-04	DCF3(3)
D-1	U-234	2.830E-04	2.830E-04	DCF3(4)
D-1	U-238+D	2.690E-04	2.690E-04	DCF3(5)
D-34	Food transfer factors:			
D-34	Pb-210+D , plant/soil concentration ratio, dimensionless	1.000E-02	1.000E-02	RTF(1,1)
D-34	Pb-210+D , beef/livestock-intake ratio, (pCi/kg)/(pCi/d)	8.000E-04	8.000E-04	RTF(1,2)
D-34	Pb-210+D , milk/livestock-intake ratio, (pCi/L)/(pCi/d)	3.000E-04	3.000E-04	RTF(1,3)
D-34				
D-34	Ra-226+D , plant/soil concentration ratio, dimensionless	4.000E-02	4.000E-02	RTF(2,1)
D-34	Ra-226+D , beef/livestock-intake ratio, (pCi/kg)/(pCi/d)	1.000E-03	1.000E-03	RTF(2,2)
D-34	Ra-226+D , milk/livestock-intake ratio, (pCi/L)/(pCi/d)	1.000E-03	1.000E-03	RTF(2,3)
D-34				
D-34	Th-230 , plant/soil concentration ratio, dimensionless	1.000E-03	1.000E-03	RTF(3,1)
D-34	Th-230 , beef/livestock-intake ratio, (pCi/kg)/(pCi/d)	1.000E-04	1.000E-04	RTF(3,2)
D-34	Th-230 , milk/livestock-intake ratio, (pCi/L)/(pCi/d)	5.000E-06	5.000E-06	RTF(3,3)
D-34				
D-34	U-234 , plant/soil concentration ratio, dimensionless	2.500E-03	2.500E-03	RTF(4,1)
D-34	U-234 , beef/livestock-intake ratio, (pCi/kg)/(pCi/d)	3.400E-04	3.400E-04	RTF(4,2)
D-34	U-234 , milk/livestock-intake ratio, (pCi/L)/(pCi/d)	6.000E-04	6.000E-04	RTF(4,3)
D-34				
D-34	U-238+D , plant/soil concentration ratio, dimensionless	2.500E-03	2.500E-03	RTF(5,1)
D-34	U-238+D , beef/livestock-intake ratio, (pCi/kg)/(pCi/d)	3.400E-04	3.400E-04	RTF(5,2)
D-34	U-238+D , milk/livestock-intake ratio, (pCi/L)/(pCi/d)	6.000E-04	6.000E-04	RTF(5,3)
D-5	Bioaccumulation factors, fresh water, L/kg:			
D-5	Pb-210+D , fish	3.000E+02	3.000E+02	BIOFAC(1,1)
D-5	Pb-210+D , crustacea and mollusks	1.000E+02	1.000E+02	BIOFAC(1,2)
D-5				
D-5	Ra-226+D , fish	5.000E+01	5.000E+01	BIOFAC(2,1)
D-5	Ra-226+D , crustacea and mollusks	2.500E+02	2.500E+02	BIOFAC(2,2)
D-5				
D-5	Th-230 , fish	1.000E+02	1.000E+02	BIOFAC(3,1)
D-5	Th-230 , crustacea and mollusks	5.000E+02	5.000E+02	BIOFAC(3,2)
D-5				
D-5	U-234 , fish	1.000E+01	1.000E+01	BIOFAC(4,1)
D-5	U-234 , crustacea and mollusks	6.000E+01	6.000E+01	BIOFAC(4,2)
D-5				

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Summary : Denver Radium - In Cell Inhalation1
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                 Dose Conversion Factor (and Related) Parameter Summary (continued)
                                   File: FGR 13 Morbidity
      *                                                 * Current  *            * Parameter
Menu  *                    Parameter                    *  Value   *  Default   *   Name

D-5   * U-238+D  , fish                                 * 1.000E+01 * 1.000E+01 * BIOFAC( 5,1)
D-5   * U-238+D  , crustacea and mollusks               * 6.000E+01 * 6.000E+01 * BIOFAC( 5,2)
```

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                              Site-Specific Parameter Summary
     *                                                   *   User    *           *      Used by RESRAD            * Parameter
Menu *                   Parameter                       *   Input   *  Default  * (If different from user input) *   Name

R011 * Area of contaminated zone (m**2)                  * 5.000E+02 * 1.000E+04 *              ---               * AREA
R011 * Thickness of contaminated zone (m)                * 1.500E+00 * 2.000E+00 *              ---               * THICK0
R011 * Length parallel to aquifer flow (m)               * not used  * 1.000E+02 *              ---               * LCZPAQ
R011 * Basic radiation dose limit (mrem/yr)              * 2.500E+01 * 2.500E+01 *              ---               * BRDL
R011 * Time since placement of material (yr)             * 0.000E+00 * 0.000E+00 *              ---               * TI
R011 * Times for calculations (yr)                       * 1.000E+00 * 1.000E+00 *              ---               * T( 2)
R011 * Times for calculations (yr)                       * 1.000E+03 * 3.000E+00 *              ---               * T( 3)
R011 * Times for calculations (yr)                       * not used  * 1.000E+01 *              ---               * T( 4)
R011 * Times for calculations (yr)                       * not used  * 3.000E+01 *              ---               * T( 5)
R011 * Times for calculations (yr)                       * not used  * 1.000E+02 *              ---               * T( 6)
R011 * Times for calculations (yr)                       * not used  * 3.000E+02 *              ---               * T( 7)
R011 * Times for calculations (yr)                       * not used  * 1.000E+03 *              ---               * T( 8)
R011 * Times for calculations (yr)                       * not used  * 0.000E+00 *              ---               * T( 9)
R011 * Times for calculations (yr)                       * not used  * 0.000E+00 *              ---               * T(10)
     *                                                   *           *           *                                *
R012 * Initial principal radionuclide (pCi/g):   Pb-210  * 1.000E+00 * 0.000E+00 *              ---               * S1( 1)
R012 * Initial principal radionuclide (pCi/g):   Ra-226  * 1.000E+00 * 0.000E+00 *              ---               * S1( 2)
R012 * Initial principal radionuclide (pCi/g):   Th-230  * 1.000E+00 * 0.000E+00 *              ---               * S1( 3)
R012 * Initial principal radionuclide (pCi/g):   U-234   * 1.000E+00 * 0.000E+00 *              ---               * S1( 4)
R012 * Initial principal radionuclide (pCi/g):   U-238   * 1.000E+00 * 0.000E+00 *              ---               * S1( 5)
R012 * Concentration in groundwater   (pCi/L):   Pb-210  * not used  * 0.000E+00 *              ---               * W1( 1)
R012 * Concentration in groundwater   (pCi/L):   Ra-226  * not used  * 0.000E+00 *              ---               * W1( 2)
R012 * Concentration in groundwater   (pCi/L):   Th-230  * not used  * 0.000E+00 *              ---               * W1( 3)
R012 * Concentration in groundwater   (pCi/L):   U-234   * not used  * 0.000E+00 *              ---               * W1( 4)
R012 * Concentration in groundwater   (pCi/L):   U-238   * not used  * 0.000E+00 *              ---               * W1( 5)
     *                                                   *           *           *                                *
R013 * Cover depth (m)                                   * 0.000E+00 * 0.000E+00 *              ---               * COVER0
R013 * Density of cover material (g/cm**3)               * not used  * 1.500E+00 *              ---               * DENSCV
R013 * Cover depth erosion rate (m/yr)                   * not used  * 1.000E-03 *              ---               * VCV
R013 * Density of contaminated zone (g/cm**3)            * 1.500E+00 * 1.500E+00 *              ---               * DENSCZ
R013 * Contaminated zone erosion rate (m/yr)             * 1.000E-03 * 1.000E-03 *              ---               * VCZ
R013 * Contaminated zone total porosity                  * 4.000E-01 * 4.000E-01 *              ---               * TPCZ
R013 * Contaminated zone field capacity                  * 2.000E-01 * 2.000E-01 *              ---               * FCCZ
R013 * Contaminated zone hydraulic conductivity (m/yr)   * 1.000E+01 * 1.000E+01 *              ---               * HCCZ
R013 * Contaminated zone b parameter                     * 5.300E+00 * 5.300E+00 *              ---               * BCZ
R013 * Average annual wind speed (m/sec)                 * 2.000E+00 * 2.000E+00 *              ---               * WIND
R013 * Humidity in air (g/m**3)                          * not used  * 8.000E+00 *              ---               * HUMID
R013 * Evapotranspiration coefficient                    * 5.000E-01 * 5.000E-01 *              ---               * EVAPTR
R013 * Precipitation (m/yr)                              * 1.000E+00 * 1.000E+00 *              ---               * PRECIP
R013 * Irrigation (m/yr)                                 * 2.000E-01 * 2.000E-01 *              ---               * RI
R013 * Irrigation mode                                   * overhead  * overhead  *              ---               * IDITCH
R013 * Runoff coefficient                                * 2.000E-01 * 2.000E-01 *              ---               * RUNOFF
R013 * Watershed area for nearby stream or pond (m**2)   * not used  * 1.000E+06 *              ---               * WAREA
R013 * Accuracy for water/soil computations              * not used  * 1.000E-03 *              ---               * EPS
     *                                                   *           *           *                                *
R014 * Density of saturated zone (g/cm**3)               * not used  * 1.500E+00 *              ---               * DENSAQ
R014 * Saturated zone total porosity                     * not used  * 4.000E-01 *              ---               * TPSZ
R014 * Saturated zone effective porosity                 * not used  * 2.000E-01 *              ---               * EPSZ
R014 * Saturated zone field capacity                     * not used  * 2.000E-01 *              ---               * FCSZ
R014 * Saturated zone hydraulic conductivity (m/yr)      * not used  * 1.000E+02 *              ---               * HCSZ
```

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Site-Specific Parameter Summary (continued)

Menu	Parameter	User Input	Default	Used by RESRAD (If different from user input)	Parameter Name
R014	Saturated zone hydraulic gradient	not used	2.000E-02	---	HGWT
R014	Saturated zone b parameter	not used	5.300E+00	---	BS
R014	Water table drop rate (m/yr)	not used	1.000E-03	---	VWT
R014	Well pump intake depth (m below water table)	not used	1.000E+01	---	DWIBWT
R014	Model: Nondispersion (ND) or Mass-Balance (MB)	not used	ND	---	MODEL
R014	Well pumping rate (m**3/yr)	not used	2.500E+02	---	UW
R015	Number of unsaturated zone strata	not used	1	---	NS
R015	Unsat. zone 1, thickness (m)	not used	4.000E+00	---	H(1)
R015	Unsat. zone 1, soil density (g/cm**3)	not used	1.500E+00	---	DENSUZ(1)
R015	Unsat. zone 1, total porosity	not used	4.000E-01	---	TPUZ(1)
R015	Unsat. zone 1, effective porosity	not used	2.000E-01	---	EPUZ(1)
R015	Unsat. zone 1, field capacity	not used	2.000E-01	---	FCUZ(1)
R015	Unsat. zone 1, soil-specific b parameter	not used	5.300E+00	---	BUZ(1)
R015	Unsat. zone 1, hydraulic conductivity (m/yr)	not used	1.000E+01	---	HCUZ(1)
R016	Distribution coefficients for Pb-210				
R016	Contaminated zone (cm**3/g)	1.000E+02	1.000E+02	---	DCNUCC(1)
R016	Unsaturated zone 1 (cm**3/g)	not used	1.000E+02	---	DCNUCU(1,1)
R016	Saturated zone (cm**3/g)	not used	1.000E+02	---	DCNUCS(1)
R016	Leach rate (/yr)	0.000E+00	0.000E+00	2.217E-03	ALEACH(1)
R016	Solubility constant	0.000E+00	0.000E+00	not used	SOLUBK(1)
R016	Distribution coefficients for Ra-226				
R016	Contaminated zone (cm**3/g)	7.000E+01	7.000E+01	---	DCNUCC(2)
R016	Unsaturated zone 1 (cm**3/g)	not used	7.000E+01	---	DCNUCU(2,1)
R016	Saturated zone (cm**3/g)	not used	7.000E+01	---	DCNUCS(2)
R016	Leach rate (/yr)	0.000E+00	0.000E+00	3.165E-03	ALEACH(2)
R016	Solubility constant	0.000E+00	0.000E+00	not used	SOLUBK(2)
R016	Distribution coefficients for Th-230				
R016	Contaminated zone (cm**3/g)	6.000E+04	6.000E+04	---	DCNUCC(3)
R016	Unsaturated zone 1 (cm**3/g)	not used	6.000E+04	---	DCNUCU(3,1)
R016	Saturated zone (cm**3/g)	not used	6.000E+04	---	DCNUCS(3)
R016	Leach rate (/yr)	0.000E+00	0.000E+00	3.704E-06	ALEACH(3)
R016	Solubility constant	0.000E+00	0.000E+00	not used	SOLUBK(3)
R016	Distribution coefficients for U-234				
R016	Contaminated zone (cm**3/g)	5.000E+01	5.000E+01	---	DCNUCC(4)
R016	Unsaturated zone 1 (cm**3/g)	not used	5.000E+01	---	DCNUCU(4,1)
R016	Saturated zone (cm**3/g)	not used	5.000E+01	---	DCNUCS(4)
R016	Leach rate (/yr)	0.000E+00	0.000E+00	4.426E-03	ALEACH(4)
R016	Solubility constant	0.000E+00	0.000E+00	not used	SOLUBK(4)
R016	Distribution coefficients for U-238				
R016	Contaminated zone (cm**3/g)	5.000E+01	5.000E+01	---	DCNUCC(5)
R016	Unsaturated zone 1 (cm**3/g)	not used	5.000E+01	---	DCNUCU(5,1)
R016	Saturated zone (cm**3/g)	not used	5.000E+01	---	DCNUCS(5)
R016	Leach rate (/yr)	0.000E+00	0.000E+00	4.426E-03	ALEACH(5)
R016	Solubility constant	0.000E+00	0.000E+00	not used	SOLUBK(5)

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Site-Specific Parameter Summary (continued)

Menu	Parameter	User Input	Default	Used by RESRAD (If different from user input)	Parameter Name
R017	Inhalation rate (m**3/yr)	1.916E+03	8.400E+03	---	INHALR
R017	Mass loading for inhalation (g/m**3)	1.000E-05	1.000E-04	---	MLINH
R017	Exposure duration	3.000E+01	3.000E+01	---	ED
R017	Shielding factor, inhalation	4.000E-01	4.000E-01	---	SHF3
R017	Shielding factor, external gamma	not used	7.000E-01	---	SHF1
R017	Fraction of time spent indoors	0.000E+00	5.000E-01	---	FIND
R017	Fraction of time spent outdoors (on site)	2.280E-01	2.500E-01	---	FOTD
R017	Shape factor flag, external gamma	not used	1.000E+00	>0 shows circular AREA.	FS
R017	Radii of shape factor array (used if FS = -1):				
R017	Outer annular radius (m), ring 1:	not used	5.000E+01	---	RAD_SHAPE(1)
R017	Outer annular radius (m), ring 2:	not used	7.071E+01	---	RAD_SHAPE(2)
R017	Outer annular radius (m), ring 3:	not used	0.000E+00	---	RAD_SHAPE(3)
R017	Outer annular radius (m), ring 4:	not used	0.000E+00	---	RAD_SHAPE(4)
R017	Outer annular radius (m), ring 5:	not used	0.000E+00	---	RAD_SHAPE(5)
R017	Outer annular radius (m), ring 6:	not used	0.000E+00	---	RAD_SHAPE(6)
R017	Outer annular radius (m), ring 7:	not used	0.000E+00	---	RAD_SHAPE(7)
R017	Outer annular radius (m), ring 8:	not used	0.000E+00	---	RAD_SHAPE(8)
R017	Outer annular radius (m), ring 9:	not used	0.000E+00	---	RAD_SHAPE(9)
R017	Outer annular radius (m), ring 10:	not used	0.000E+00	---	RAD_SHAPE(10)
R017	Outer annular radius (m), ring 11:	not used	0.000E+00	---	RAD_SHAPE(11)
R017	Outer annular radius (m), ring 12:	not used	0.000E+00	---	RAD_SHAPE(12)
R017	Fractions of annular areas within AREA:				
R017	Ring 1	not used	1.000E+00	---	FRACA(1)
R017	Ring 2	not used	2.732E-01	---	FRACA(2)
R017	Ring 3	not used	0.000E+00	---	FRACA(3)
R017	Ring 4	not used	0.000E+00	---	FRACA(4)
R017	Ring 5	not used	0.000E+00	---	FRACA(5)
R017	Ring 6	not used	0.000E+00	---	FRACA(6)
R017	Ring 7	not used	0.000E+00	---	FRACA(7)
R017	Ring 8	not used	0.000E+00	---	FRACA(8)
R017	Ring 9	not used	0.000E+00	---	FRACA(9)
R017	Ring 10	not used	0.000E+00	---	FRACA(10)
R017	Ring 11	not used	0.000E+00	---	FRACA(11)
R017	Ring 12	not used	0.000E+00	---	FRACA(12)
R018	Fruits, vegetables and grain consumption (kg/yr)	not used	1.600E+02	---	DIET(1)
R018	Leafy vegetable consumption (kg/yr)	not used	1.400E+01	---	DIET(2)
R018	Milk consumption (L/yr)	not used	9.200E+01	---	DIET(3)
R018	Meat and poultry consumption (kg/yr)	not used	6.300E+01	---	DIET(4)
R018	Fish consumption (kg/yr)	not used	5.400E+00	---	DIET(5)
R018	Other seafood consumption (kg/yr)	not used	9.000E-01	---	DIET(6)
R018	Soil ingestion rate (g/yr)	not used	3.650E+01	---	SOIL
R018	Drinking water intake (L/yr)	not used	5.100E+02	---	DWI
R018	Contamination fraction of drinking water	not used	1.000E+00	---	FDW
R018	Contamination fraction of household water	not used	1.000E+00	---	FHHW
R018	Contamination fraction of livestock water	not used	1.000E+00	---	FLW
R018	Contamination fraction of irrigation water	not used	1.000E+00	---	FIRW
R018	Contamination fraction of aquatic food	not used	5.000E-01	---	FR9
R018	Contamination fraction of plant food	not used	-1	---	FPLANT

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Site-Specific Parameter Summary (continued)

Menu	Parameter	User Input	Default	Used by RESRAD (If different from user input)	Parameter Name
R019	Contamination fraction of meat	not used	-1	---	FMEAT
R019	Contamination fraction of milk	not used	-1	---	FMILK
R019	Livestock fodder intake for meat (kg/day)	not used	6.800E+01	---	LFI5
R019	Livestock fodder intake for milk (kg/day)	not used	5.500E+01	---	LFI6
R019	Livestock water intake for meat (L/day)	not used	5.000E+01	---	LWI5
R019	Livestock water intake for milk (L/day)	not used	1.600E+02	---	LWI6
R019	Livestock soil intake (kg/day)	not used	5.000E-01	---	LSI
R019	Mass loading for foliar deposition (g/m**3)	not used	1.000E-04	---	MLFD
R019	Depth of soil mixing layer (m)	1.500E-01	1.500E-01	---	DM
R019	Depth of roots (m)	not used	9.000E-01	---	DROOT
R019	Drinking water fraction from ground water	not used	1.000E+00	---	FGWDW
R019	Household water fraction from ground water	not used	1.000E+00	---	FGWHH
R019	Livestock water fraction from ground water	not used	1.000E+00	---	FGWLW
R019	Irrigation fraction from ground water	not used	1.000E+00	---	FGWIR
R19B	Wet weight crop yield for Non-Leafy (kg/m**2)	not used	7.000E-01	---	YV(1)
R19B	Wet weight crop yield for Leafy (kg/m**2)	not used	1.500E+00	---	YV(2)
R19B	Wet weight crop yield for Fodder (kg/m**2)	not used	1.100E+00	---	YV(3)
R19B	Growing Season for Non-Leafy (years)	not used	1.700E-01	---	TE(1)
R19B	Growing Season for Leafy (years)	not used	2.500E-01	---	TE(2)
R19B	Growing Season for Fodder (years)	not used	8.000E-02	---	TE(3)
R19B	Translocation Factor for Non-Leafy	not used	1.000E-01	---	TIV(1)
R19B	Translocation Factor for Leafy	not used	1.000E+00	---	TIV(2)
R19B	Translocation Factor for Fodder	not used	1.000E+00	---	TIV(3)
R19B	Dry Foliar Interception Fraction for Non-Leafy	not used	2.500E-01	---	RDRY(1)
R19B	Dry Foliar Interception Fraction for Leafy	not used	2.500E-01	---	RDRY(2)
R19B	Dry Foliar Interception Fraction for Fodder	not used	2.500E-01	---	RDRY(3)
R19B	Wet Foliar Interception Fraction for Non-Leafy	not used	2.500E-01	---	RWET(1)
R19B	Wet Foliar Interception Fraction for Leafy	not used	2.500E-01	---	RWET(2)
R19B	Wet Foliar Interception Fraction for Fodder	not used	2.500E-01	---	RWET(3)
R19B	Weathering Removal Constant for Vegetation	not used	2.000E+01	---	WLAM
C14	C-12 concentration in water (g/cm**3)	not used	2.000E-05	---	C12WTR
C14	C-12 concentration in contaminated soil (g/g)	not used	3.000E-02	---	C12CZ
C14	Fraction of vegetation carbon from soil	not used	2.000E-02	---	CSOIL
C14	Fraction of vegetation carbon from air	not used	9.800E-01	---	CAIR
C14	C-14 evasion layer thickness in soil (m)	not used	3.000E-01	---	DMC
C14	C-14 evasion flux rate from soil (1/sec)	not used	7.000E-07	---	EVSN
C14	C-12 evasion flux rate from soil (1/sec)	not used	1.000E-10	---	REVSN
C14	Fraction of grain in beef cattle feed	not used	8.000E-01	---	AVFG4
C14	Fraction of grain in milk cow feed	not used	2.000E-01	---	AVFG5
C14	DCF correction factor for gaseous forms of C14	not used	8.894E+01	---	CO2F
STOR	Storage times of contaminated foodstuffs (days):				
STOR	Fruits, non-leafy vegetables, and grain	1.400E+01	1.400E+01	---	STOR_T(1)
STOR	Leafy vegetables	1.000E+00	1.000E+00	---	STOR_T(2)
STOR	Milk	1.000E+00	1.000E+00	---	STOR_T(3)
STOR	Meat and poultry	2.000E+01	2.000E+01	---	STOR_T(4)
STOR	Fish	7.000E+00	7.000E+00	---	STOR_T(5)

RESRAD, Version 6.21 T½ Limit = 0.5 year 04/07/2004 11:25 Page 3
Summary : Denver Radium - In Cell Inhalation1
File : Denver Radium - In Cell Inhalation1.RAD

Site-Specific Parameter Summary (continued)

Menu	Parameter	User Input	Default	Used by RESRAD (If different from user input)	Parameter Name
STOR	Crustacea and mollusks	7.000E+00	7.000E+00	---	STOR_T(6)
STOR	Well water	1.000E+00	1.000E+00	---	STOR_T(7)
STOR	Surface water	1.000E+00	1.000E+00	---	STOR_T(8)
STOR	Livestock fodder	4.500E+01	4.500E+01	---	STOR_T(9)
R021	Thickness of building foundation (m)	not used	1.500E-01	---	FLOOR1
R021	Bulk density of building foundation (g/cm**3)	not used	2.400E+00	---	DENSFL
R021	Total porosity of the cover material	not used	4.000E-01	---	TPCV
R021	Total porosity of the building foundation	not used	1.500E-01	---	TPFL
R021	Volumetric water content of the cover material	not used	5.000E-02	---	PH2OCV
R021	Volumetric water content of the foundation	not used	3.000E-02	---	PH2OFL
R021	Diffusion coefficient for radon gas (m/sec):				
R021	in cover material	not used	2.000E-06	---	DIFCV
R021	in foundation material	not used	3.000E-07	---	DIFFL
R021	in contaminated zone soil	not used	2.000E-06	---	DIFCZ
R021	Radon vertical dimension of mixing (m)	not used	2.000E+00	---	HMIX
R021	Average building air exchange rate (1/hr)	not used	5.000E-01	---	REXG
R021	Height of the building (room) (m)	not used	2.500E+00	---	HRM
R021	Building interior area factor	not used	0.000E+00	---	FAI
R021	Building depth below ground surface (m)	not used	-1.000E+00	---	DMFL
R021	Emanating power of Rn-222 gas	not used	2.500E-01	---	EMANA(1)
R021	Emanating power of Rn-220 gas	not used	1.500E-01	---	EMANA(2)
TITL	Number of graphical time points	32	---	---	NPTS
TITL	Maximum number of integration points for dose	17	---	---	LYMAX
TITL	Maximum number of integration points for risk	257	---	---	KYMAX

Summary of Pathway Selections

Pathway	User Selection
1 -- external gamma	suppressed
2 -- inhalation (w/o radon)	active
3 -- plant ingestion	suppressed
4 -- meat ingestion	suppressed
5 -- milk ingestion	suppressed
6 -- aquatic foods	suppressed
7 -- drinking water	suppressed
8 -- soil ingestion	suppressed
9 -- radon	suppressed
Find peak pathway doses	active

```
RESRAD, Version 6.21     T½ Limit = 0.5 year        04/07/2004  11:25  Page   9
Summary : Denver Radium - In Cell Inhalation1
File    : Denver Radium - In Cell Inhalation1.RAD

     Contaminated Zone Dimensions           Initial Soil Concentrations, pCi/g

       Area:    500.00 square meters                 Pb-210     1.000E+00
  Thickness:      1.50 meters                        Ra-226     1.000E+00
Cover Depth:      0.00 meters                        Th-230     1.000E+00
                                                     U-234      1.000E+00
                                                     U-238      1.000E+00

                       Total Dose TDOSE(t), mrem/yr
                 Basic Radiation Dose Limit = 2.500E+01 mrem/yr
Total Mixture Sum M(t) = Fraction of Basic Dose Limit Received at Time (t)

    t (years):  0.000E+00  1.000E+00  1.000E+03
     TDOSE(t):  3.288E-04  3.282E-04  1.787E-04
         M(t):  1.315E-05  1.313E-05  7.147E-06
0Maximum TDOSE(t):  3.288E-04 mrem/yr   at t = 0.000E+00 years
```

```
RESRAD, Version 6.21     T½ Limit = 0.5 year        04/07/2004  11:29  Page  10
Summary : Denver Radium - In Cell Inhalation2
File    : Denver Radium - In Cell Inhalation2.RAD

                 Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
                                  As mrem/yr and Fraction of Total Dose At t = 0.000E+00 years
                                   Water Independent Pathways (Inhalation excludes radon)
             Ground                 Inhalation           Radon              Plant              Meat               Milk               Soil
Radio-   Nuclide  mrem/yr  fract.   mrem/yr  fract.   mrem/yr  fract.   mrem/yr  fract.   mrem/yr  fract.   mrem/yr  fract.   mrem/yr  fract.

Pb-210  0.000E+00 0.0000  1.236E-05 0.0376  0.000E+00 0.0000  0.000E+00 0.0000  0.000E+00 0.0000  0.000E+00 0.0000  0.000E+00 0.0000
Ra-226  0.000E+00 0.0000  4.842E-06 0.0147  0.000E+00 0.0000  0.000E+00 0.0000  0.000E+00 0.0000  0.000E+00 0.0000  0.000E+00 0.0000
Th-230  0.000E+00 0.0000  1.765E-04 0.5369  0.000E+00 0.0000  0.000E+00 0.0000  0.000E+00 0.0000  0.000E+00 0.0000  0.000E+00 0.0000
U-234   0.000E+00 0.0000  7.132E-05 0.2169  0.000E+00 0.0000  0.000E+00 0.0000  0.000E+00 0.0000  0.000E+00 0.0000  0.000E+00 0.0000
U-238   0.000E+00 0.0000  6.376E-05 0.1939  0.000E+00 0.0000  0.000E+00 0.0000  0.000E+00 0.0000  0.000E+00 0.0000  0.000E+00 0.0000

Total   0.000E+00 0.0000  3.288E-04 1.0000  0.000E+00 0.0000  0.000E+00 0.0000  0.000E+00 0.0000  0.000E+00 0.0000  0.000E+00 0.0000

                 Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
                                  As mrem/yr and Fraction of Total Dose At t = 0.000E+00 years
                                                 Water Dependent Pathways
             Water                  Fish                 Radon              Plant              Meat               Milk            All Pathways*
Radio-   Nuclide  mrem/yr  fract.   mrem/yr  fract.   mrem/yr  fract.   mrem/yr  fract.   mrem/yr  fract.   mrem/yr  fract.   mrem/yr  fract.

Pb-210  0.000E+00 0.0000  0.000E+00 0.0000  0.000E+00 0.0000  0.000E+00 0.0000  0.000E+00 0.0000  0.000E+00 0.0000  1.236E-05 0.0376
Ra-226  0.000E+00 0.0000  0.000E+00 0.0000  0.000E+00 0.0000  0.000E+00 0.0000  0.000E+00 0.0000  0.000E+00 0.0000  4.842E-06 0.0147
Th-230  0.000E+00 0.0000  0.000E+00 0.0000  0.000E+00 0.0000  0.000E+00 0.0000  0.000E+00 0.0000  0.000E+00 0.0000  1.765E-04 0.5369
U-234   0.000E+00 0.0000  0.000E+00 0.0000  0.000E+00 0.0000  0.000E+00 0.0000  0.000E+00 0.0000  0.000E+00 0.0000  7.132E-05 0.2169
U-238   0.000E+00 0.0000  0.000E+00 0.0000  0.000E+00 0.0000  0.000E+00 0.0000  0.000E+00 0.0000  0.000E+00 0.0000  6.376E-05 0.1939

Total   0.000E+00 0.0000  0.000E+00 0.0000  0.000E+00 0.0000  0.000E+00 0.0000  0.000E+00 0.0000  0.000E+00 0.0000  3.288E-04 1.0000
*Sum of all water independent and dependent pathways.
```

RESRAD, Version 6.21 Tm Limit = 0.5 year 06/07/2004 11:25 Page 11
Summary : Denver Radium - In Cell Inhalation
File : Denver Radium - In Cell Inhalation.RAD

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 1.0000E+00 years
Water Independent Pathways (Inhalation excludes radon)

Radio-	Ground		Inhalation		Radon		Plant		Meat		Milk		Soil	
Nuclide	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.
Pb-210	0.0000E+00	0.0000	1.1958E-05	0.0364	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000
Ra-226	0.0000E+00	0.0000	5.2015E-06	0.0158	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000
Th-230	0.0000E+00	0.0000	1.7658E-04	0.5374	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000
U-234	0.0000E+00	0.0000	7.1018E-05	0.2161	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000
U-238	0.0000E+00	0.0000	6.2485E-05	0.1901	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000
Total	0.0000E+00	0.0000	3.2828E-04	1.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 1.0000E+00 years
Water Dependent Pathways

Radio-	Water		Fish		Radon		Plant		Meat		Milk		All Pathways*	
Nuclide	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.
Pb-210	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	1.1958E-05	0.0364
Ra-226	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	5.2015E-06	0.0158
Th-230	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	1.7658E-04	0.5374
U-234	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	7.1018E-05	0.2161
U-238	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	6.2485E-05	0.1901
Total	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	3.2828E-04	1.0000

*Sum of all water independent and dependent pathways.

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RESRAD, Version 6.21     T½ Limit = 0.5 year        04/07/2004  11:25  Page 12
Summary : Denver Radium - In Cell Inhalation1
File    : Denver Radium - In Cell Inhalation1.RAD
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Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 1.000E+03 years
Water Independent Pathways (Inhalation excludes radon)

Radio-Nuclide	Ground mrem/yr	Ground fract.	Inhalation mrem/yr	Inhalation fract.	Radon mrem/yr	Radon fract.	Plant mrem/yr	Plant fract.	Meat mrem/yr	Meat fract.	Milk mrem/yr	Milk fract.	Soil mrem/yr	Soil fract.
Pb-210	0.000E+00	0.0000	4.263E-20	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Ra-226	0.000E+00	0.0000	4.865E-07	0.0027	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Th-230	0.000E+00	0.0000	1.762E-04	0.9862	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
U-234	0.000E+00	0.0000	1.296E-06	0.0067	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
U-238	0.000E+00	0.0000	7.657E-07	0.0043	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Total	0.000E+00	0.0000	1.787E-04	1.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 1.000E+03 years
Water Dependent Pathways

Radio-Nuclide	Water mrem/yr	Water fract.	Fish mrem/yr	Fish fract.	Radon mrem/yr	Radon fract.	Plant mrem/yr	Plant fract.	Meat mrem/yr	Meat fract.	Milk mrem/yr	Milk fract.	All Pathways* mrem/yr	All Pathways* fract.
Pb-210	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	4.263E-20	0.0000
Ra-226	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	4.865E-07	0.0027
Th-230	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.762E-04	0.9862
U-234	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.296E-06	0.0067
U-238	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	7.657E-07	0.0043
Total	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.787E-04	1.0000

*Sum of all water independent and dependent pathways.

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RESRAD, Version 6.21     T½ Limit = 0.5 year       04/07/2004  11:25   Page  19
Summary : Denver Radium - In Cell Inhalation1
File    : Denver Radium - In Cell Inhalation1.RAD

        Dose/Source Ratios Summed Over All Pathways
Parent and Progeny Principal Radionuclide Contributions Indicated
Parent  Product  Branch        DSR(j,t)  (mrem/yr)/(pCi/g)
 (i)      (j)    Fraction*  t= 0.000E+00 1.000E+00 1.000E+03

Pb-210  Pb-210   1.000E+00     1.238E-05 1.198E-05 4.263E-20
Ra-226  Ra-226   1.000E+00     4.649E-06 4.632E-06 1.273E-07
Ra-226  Pb-210   1.000E+00     1.929E-07 5.653E-07 3.593E-07
Ra-226  ΣDSR(j)                4.842E-06 5.201E-06 4.865E-07
Th-230  Th-230   1.000E+00     1.765E-04 1.765E-04 1.743E-04
Th-230  Ra-226   1.000E+00     1.009E-09 3.013E-09 5.407E-07
Th-230  Pb-210   1.000E+00     2.794E-13 1.925E-10 1.396E-06
Th-230  ΣDSR(j)                1.765E-04 1.765E-04 1.762E-04
U-234   U-234    1.000E+00     7.132E-05 7.101E-05 8.512E-07
U-234   Th-230   1.000E+00     7.934E-10 2.376E-09 3.511E-07
U-234   Ra-226   1.000E+00     3.023E-15 2.110E-14 1.025E-09
U-234   Pb-210   1.000E+00     6.299E-17 5.357E-16 2.554E-09
U-234   ΣDSR(j)                7.132E-05 7.101E-05 1.206E-06
U-238   U-238    1.000E+00     6.376E-05 6.348E-05 7.631E-07
U-238   U-234    1.000E+00     1.010E-10 3.019E-10 2.415E-09
U-238   Th-230   1.000E+00     7.492E-16 5.231E-15 2.134E-10
U-238   Ra-226   1.000E+00     2.140E-21 3.701E-20 5.648E-13
U-238   Pb-210   1.000E+00     3.571E-23 1.090E-21 1.389E-12
U-238   ΣDSR(j)                6.376E-05 6.348E-05 7.657E-07

*Branch Fraction is the cumulative factor for the j't principal radionuclide daughter:  CUMBRF(j) = BRF(1)*BRF(2)* ... BRF(j).
The DSR includes contributions from associated (half-life ≤ 0.5 yr) daughters.

Single Radionuclide Soil Guidelines G(i,t) in pCi/g
   Basic Radiation Dose Limit = 2.500E+01 mrem/yr
Nuclide
  (i)     t= 0.000E+00   1.000E+00   1.000E+03

Pb-210      2.023E+06   2.092E+06  *7.631E+13
Ra-226      5.164E+06   4.806E+06   5.135E+07
Th-230      1.416E+05   1.416E+05   1.419E+05
U-234       3.505E+05   3.521E+05   2.073E+07
U-238      *3.360E+05  *3.360E+05  *3.360E+05

*At specific activity limit
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RESRAD, Version 6.21     T½ Limit = 0.5 year        04/07/2004  11:25  Page  34
Summary : Denver Radium - In Cell Inhalation1
File    : Denver Radium - In Cell Inhalation1.RAD

           Summed Dose/Source Ratios DSR(i,t) in (mrem/yr)/(pCi/g)
           and Single Radionuclide Soil Guidelines G(i,t) in pCi/g
         at tmin = time of minimum single radionuclide soil guideline
     and at tmax = time of maximum total dose = 0.000E+00 years
Nuclide  Initial        tmin       DSR(i,tmin) G(i,tmin) DSR(i,tmax) G(i,tmax)
  (i)    (pCi/g)       (years)                  (pCi/g)               (pCi/g)

Pb-210  1.000E+00    0.000E+00     1.236E-05  2.023E+06  1.236E-05  2.023E+06
Ra-226  1.000E+00    64.2 ± 0.1    1.258E-05  1.987E+06  4.842E-06  5.164E+06
Th-230  1.000E+00   342.6 ± 0.7    1.772E-04  1.411E+05  1.765E-04  1.416E+05
U-234   1.000E+00    0.000E+00     7.132E-05  3.505E+05  7.132E-05  3.505E+05
U-238   1.000E+00    0.000E+00     6.376E-05 *3.360E+05  6.376E-05 *3.360E+05

*At specific activity limit
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RESRAD, Version 6.21     T½ Limit = 0.5 year        04/07/2004  11:25   Page  15
Summary : Denver Radium - In Cell Inhalation1
File    : Denver Radium - In Cell Inhalation1.RAD

     Individual Nuclide Dose Summed Over All Pathways
       Parent Nuclide and Branch Fraction Indicated
Nuclide Parent   BRF(i)            DOSE(j,t), mrem/yr
  (j)     (i)               t= 0.000E+00 1.000E+00 1.000E+03

Pb-210  Pb-210  1.000E+00    1.236E-05 1.193E-05 4.263E-20
Pb-210  Ra-226  1.000E+00    1.929E-07 5.692E-07 3.593E-07
Pb-210  Th-230  1.000E+00    2.794E-11 1.035E-10 1.356E-06
Pb-210  U-234   1.000E+00    6.293E-17 5.357E-16 2.554E-09
Pb-210  U-238   1.000E+00    3.571E-23 1.858E-21 1.399E-12
Pb-210  ΣDOSE(j)             1.255E-05 1.262E-05 1.718E-06
Ra-226  Ra-226  1.000E+00    4.649E-06 4.622E-06 1.273E-07
Ra-226  Th-230  1.000E+00    1.008E-09 3.018E-09 5.402E-07
Ra-226  U-234   1.000E+00    3.021E-15 2.110E-14 1.025E-09
Ra-226  U-238   1.000E+00    2.140E-21 3.201E-20 5.648E-13
Ra-226  ΣDOSE(j)             4.650E-06 4.635E-06 6.685E-07
Th-230  Th-230  1.000E+00    1.765E-04 1.765E-04 1.740E-04
Th-230  U-234   1.000E+00    2.934E-10 2.376E-09 3.511E-07
Th-230  U-238   1.000E+00    7.492E-16 5.231E-15 2.134E-10
Th-230  ΣDOSE(j)             1.765E-04 1.765E-04 1.747E-04
U-234   U-234   1.000E+00    7.132E-05 7.101E-05 8.512E-07
U-234   U-238   1.000E+00    1.010E-10 3.019E-10 2.418E-09
U-234   ΣDOSE(j)             7.132E-05 7.101E-05 8.536E-07
U-238   U-238   1.000E+00    6.376E-05 6.348E-05 7.631E-07

BRF(i) is the branch fraction of the parent nuclide.
```

```
RESRAD, Version 6.22     T½ Limit = 0.5 year        04/07/2004  11:35  Page 16
Summary : Denver Radium - In Cell Inhalation1
File    : Denver Radium - In Cell Inhalation1.RAD

           Individual Nuclide Soil Concentrations
        Parent Nuclide and Branch Fraction Indicated
Nuclide Parent   BRF(i)              S(j,t), pCi/g
  (j)     (i)              t= 0.000E+00 1.000E+00 1.000E+03

Pb-210  Pb-210  1.000E+00    1.000E+00 9.572E-01 3.450E-15
Pb-210  Ra-226  1.000E+00    0.000E+00 3.982E-02 2.865E-02
Pb-210  Th-230  1.000E+00    0.000E+00 6.551E-06 1.079E-01
Pb-210  U-234   1.000E+00    0.000E+00 2.900E-11 2.032E-04
Pb-210  U-238   1.000E+00    0.000E+00 1.419E-17 1.196E-07
Pb-210  ∑S(j):               1.000E+00 9.970E-01 1.368E-01
Ra-226  Ra-226  1.000E+00    1.000E+00 9.564E-01 2.737E-02
Ra-226  Th-230  1.000E+00    0.000E+00 4.324E-04 1.160E-01
Ra-226  U-234   1.000E+00    0.000E+00 1.945E-09 2.300E-04
Ra-226  U-238   1.000E+00    0.000E+00 1.037E-15 1.212E-07
Ra-226  ∑S(j):               1.000E+00 9.568E-01 1.436E-01
Th-230  Th-230  1.000E+00    1.000E+00 1.000E+00 9.974E-01
Th-230  U-234   1.000E+00    0.000E+00 8.983E-06 1.959E-03
Th-230  U-238   1.000E+00    0.000E+00 1.272E-11 1.208E-06
Th-230  ∑S(j):               1.000E+00 1.000E+00 9.994E-01
U-234   U-234   1.000E+00    1.000E+00 9.956E-01 1.193E-02
U-234   U-238   1.000E+00    0.000E+00 2.823E-06 3.388E-05
U-234   ∑S(j):               1.000E+00 9.956E-01 1.197E-02
U-238   U-238   1.000E+00    1.000E+00 9.956E-01 1.197E-02

BRF(i) is the branch fraction of the parent nuclide.
RESCALC.EXE execution time =    0.50 seconds
```

APPENDIX C – MICROSHIELD MODELING RESULTS

WORKERS IN THE PROXIMITY OF A WASTE CONTAINER

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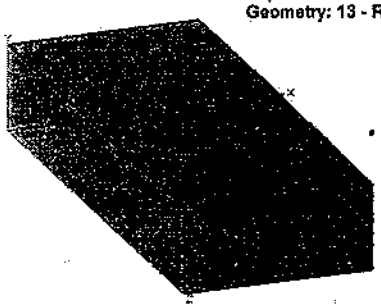
MicroShield v5.05 (5.05-00439)
Dade Moeller & Assoc.

Page : 1
DOS File : RA226SI.MS5
Run Date: March 30, 2004
Run Time: 3:54:16 PM
Duration : 00:00:11

File Ref: _____
Date: 3/30/04
By: TRT
Checked: WEK

Case Title: Truck with Soil
Description: Waste Site with 1 pCi/g Ra-226
Geometry: 13 - Rectangular Volume



Source Dimensions

Length	220.0 cm	7 ft 2.6 in
Width	560.0 cm	18 ft 4.5 in
Height	100.0 cm	3 ft 3.4 in

Dose Points

	X	Y	Z
# 1	320.3175 cm	50 cm	280 cm
	10 ft 6.1 in	1 ft 7.7 in	9 ft 2.2 in
# 2	221.3175 cm	50 cm	280 cm
	7 ft 3.1 in	1 ft 7.7 in	9 ft 2.2 in

Shields

Shield Name	Dimension	Material	Density
Source	1.23e+07 cm³	SiO2	1.4
Shield 1	.318 cm	Iron	7.86
Air Gap		Air	0.00122

Source Input
Grouping Method : Standard Indices
Number of Groups : 25
Lower Energy Cutoff : 0.015
Photons < 0.015 : Excluded
Library : Grove

Nuclide	curies	becquerels	µCi/cm³	Bq/cm³
Bi-210	1.2320e-005	4.5584e+005	1.0000e-006	3.7000e-002
Bi-214	1.2320e-005	4.5584e+005	1.0000e-006	3.7000e-002
Pb-210	1.2320e-005	4.5584e+005	1.0000e-006	3.7000e-002
Pb-214	1.2320e-005	4.5584e+005	1.0000e-006	3.7000e-002
Ra-226	1.2320e-005	4.5584e+005	1.0000e-006	3.7000e-002

Buildup
The material reference is : Shield 1

Integration Parameters

X Direction	10
Y Direction	20
Z Direction	20

Results - Dose Point # 1 - (320.3175,50,280) cm

Page : 2
DOS File : RA226SI.MS5
Run Date: March 30, 2004
Run Time: 3:54:16 PM
Duration : 00:00:11

Energy MeV	Activity photons/sec	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.05	2.350e+04	1.191e-07	1.459e-07	3.173e-10	3.887e-10
0.08	1.051e+05	6.041e-05	8.813e-05	9.560e-08	1.395e-07
0.1	6.187e+02	9.537e-07	1.549e-06	1.459e-09	2.370e-09
0.2	4.910e+04	3.783e-04	8.323e-04	6.677e-07	1.469e-06
0.3	9.407e+04	1.396e-03	3.299e-03	2.642e-06	6.258e-06
0.4	1.744e+05	4.042e-03	9.582e-03	7.876e-06	1.867e-05
0.5	7.797e+03	2.545e-04	5.909e-04	4.996e-07	1.160e-06
0.6	2.198e+05	9.492e-03	2.144e-02	1.853e-05	4.185e-05
0.8	4.303e+04	2.897e-03	6.208e-03	5.510e-06	1.181e-05
1.0	1.427e+05	1.358e-02	2.783e-02	2.606e-05	5.130e-05
1.5	8.678e+04	1.558e-02	2.920e-02	2.821e-05	4.913e-05
2.0	1.220e+05	3.419e-02	6.062e-02	5.267e-05	9.406e-05
TOTALS:	1.069e+06	8.189e-02	1.599e-01	1.400e-04	2.758e-04

Results - Dose Point # 2 - (221.3175,50,280) cm

Energy MeV	Activity photons/sec	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.05	2.350e+04	7.172e-08	8.911e-08	1.911e-10	2.374e-10
0.08	1.051e+05	1.088e-04	1.646e-04	1.722e-07	2.605e-07
0.1	6.187e+02	2.050e-06	3.473e-06	3.137e-09	5.313e-09
0.2	4.910e+04	1.003e-03	2.396e-03	1.771e-06	4.229e-06
0.3	9.407e+04	3.896e-03	1.012e-02	7.391e-06	1.920e-05
0.4	1.744e+05	1.161e-02	3.037e-02	2.261e-05	5.917e-05
0.5	7.797e+03	7.459e-04	1.911e-03	1.464e-06	3.750e-06
0.6	2.198e+05	2.828e-02	7.035e-02	5.520e-05	1.373e-04
0.8	4.303e+04	8.656e-03	2.079e-02	1.684e-05	3.955e-05
1.0	1.427e+05	4.240e-02	9.462e-02	7.816e-05	1.744e-04
1.5	8.678e+04	5.038e-02	1.018e-01	8.476e-05	1.713e-04
2.0	1.220e+05	1.131e-01	2.150e-01	1.749e-04	3.325e-04
TOTALS:	1.069e+06	2.604e-01	5.476e-01	4.433e-04	9.417e-04

APPENDIX D – RESRAD INPUT/OUTPUT

FUTURE RESIDENT SCENARIO

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RESRAD, Version 6.21 TM Limit = 0.5 year 03/31/2004 09:46 Page 1
Summary : Denver Radium Case - Resident
File : Denver Radium Case Resident.RAD

Table of Contents

Part I: Mixture Sums and Single Radionuclide Guidelines

RESRAD, Version 6.21 T½ Limit = 0.5 year 03/31/2004 09:46 Page 2
Summary : Denver Radium Case - Resident
File : Denver Radium Case Resident.RAD

Dose Conversion Factor (and Related) Parameter Summary
File: FGR 13 Morbidity

Menu	Parameter	Current Value	Default	Parameter Name
B-1	Dose conversion factors for inhalation, mrem/pCi:			
B-1	Pb-210+D	2.320E-02	2.320E-02	DCF2(1)
B-1	Ra-226+D	8.600E-03	8.600E-03	DCF2(2)
B-1	Th-230	3.260E-01	3.260E-01	DCF2(3)
B-1	U-234	1.320E-01	1.320E-01	DCF2(4)
B-1	U-238+D	1.180E-01	1.180E-01	DCF2(5)
D-1	Dose conversion factors for ingestion, mrem/pCi:			
D-1	Pb-210+D	7.270E-03	7.270E-03	DCF3(1)
D-1	Ra-226+D	1.330E-03	1.330E-03	DCF3(2)
D-1	Th-230	5.480E-04	5.480E-04	DCF3(3)
D-1	U-234	2.830E-04	2.830E-04	DCF3(4)
D-1	U-238+D	2.690E-04	2.690E-04	DCF3(5)
D-34	Food transfer factors:			
D-34	Pb-210+D , plant/soil concentration ratio, dimensionless	1.000E-02	1.000E-02	RTF(1,1)
D-34	Pb-210+D , beef/livestock-intake ratio, (pCi/kg)/(pCi/d)	8.000E-04	8.000E-04	RTF(1,2)
D-34	Pb-210+D , milk/livestock-intake ratio, (pCi/L)/(pCi/d)	3.000E-04	3.000E-04	RTF(1,3)
D-34				
D-34	Ra-226+D , plant/soil concentration ratio, dimensionless	4.000E-02	4.000E-02	RTF(2,1)
D-34	Ra-226+D , beef/livestock-intake ratio, (pCi/kg)/(pCi/d)	1.000E-03	1.000E-03	RTF(2,2)
D-34	Ra-226+D , milk/livestock-intake ratio, (pCi/L)/(pCi/d)	1.000E-03	1.000E-03	RTF(2,3)
D-34				
D-34	Th-230 , plant/soil concentration ratio, dimensionless	1.000E-03	1.000E-03	RTF(3,1)
D-34	Th-230 , beef/livestock-intake ratio, (pCi/kg)/(pCi/d)	1.000E-04	1.000E-04	RTF(3,2)
D-34	Th-230 , milk/livestock-intake ratio, (pCi/L)/(pCi/d)	5.000E-06	5.000E-06	RTF(3,3)
D-34				
D-34	U-234 , plant/soil concentration ratio, dimensionless	2.500E-03	2.500E-03	RTF(4,1)
D-34	U-234 , beef/livestock-intake ratio, (pCi/kg)/(pCi/d)	3.400E-04	3.400E-04	RTF(4,2)
D-34	U-234 , milk/livestock-intake ratio, (pCi/L)/(pCi/d)	6.000E-04	6.000E-04	RTF(4,3)
D-34				
D-34	U-238+D , plant/soil concentration ratio, dimensionless	2.500E-03	2.500E-03	RTF(5,1)
D-34	U-238+D , beef/livestock-intake ratio, (pCi/kg)/(pCi/d)	3.400E-04	3.400E-04	RTF(5,2)
D-34	U-238+D , milk/livestock-intake ratio, (pCi/L)/(pCi/d)	6.000E-04	6.000E-04	RTF(5,3)
D-5	Bioaccumulation factors, fresh water, L/kg:			
D-5	Pb-210+D , fish	3.000E+02	3.000E+02	BIOFAC(1,1)
D-5	Pb-210+D , crustacea and mollusks	1.000E+02	1.000E+02	BIOFAC(1,2)
D-5				
D-5	Ra-226+D , fish	5.000E+01	5.000E+01	BIOFAC(2,1)
D-5	Ra-226+D , crustacea and mollusks	2.500E+02	2.500E+02	BIOFAC(2,2)
D-5				
D-5	Th-230 , fish	1.000E+02	1.000E+02	BIOFAC(3,1)
D-5	Th-230 , crustacea and mollusks	5.000E+02	5.000E+02	BIOFAC(3,2)
D-5				
D-5	U-234 , fish	1.000E+01	1.000E+01	BIOFAC(4,1)
D-5	U-234 , crustacea and mollusks	6.000E+01	6.000E+01	BIOFAC(4,2)
D-5				

RESRAD, Version 6.21   T½ Limit = 0.5 year   03/31/2004 09:46 Page 3
Summary : Denver Radium Case - Resident
File   : Denver Radium Case Resident.RAD

Dose Conversion Factor (and Related) Parameter Summary (continued)
File: FGR 13 Morbidity

Menu	Parameter	Current Value	Default	Parameter Name
D-5	U-238+D , fish	1.000E+01	1.000E+01	BIOFAC(5,1)
D-5	U-238+D , crustacea and mollusks	6.000E+01	6.000E+01	BIOFAC(5,2)

RESRAD, Version 6.21   T½ Limit = 0.5 year   03/31/2004 09:46 Page 4
Summary : Denver Radium Case - Resident
File   : Denver Radium Case Resident.RAD

Site-Specific Parameter Summary

Menu	Parameter	User Input	Default	Used by RESRAD (If different from user input)	Parameter Name
R011	Area of contaminated zone (m**2)	3.300E+05	1.000E+04	---	AREA
R011	Thickness of contaminated zone (m)	1.000E-01	2.000E+00	---	THICK0
R011	Length parallel to aquifer flow (m)	1.000E+02	1.000E+02	---	LCZPAQ
R011	Basic radiation dose limit (mrem/yr)	2.500E+01	2.500E+01	---	BRDL
R011	Time since placement of material (yr)	0.000E+00	0.000E+00	---	TI
R011	Times for calculations (yr)	1.000E+00	1.000E+00	---	T(2)
R011	Times for calculations (yr)	1.000E+02	3.000E+00	---	T(3)
R011	Times for calculations (yr)	not used	1.000E+01	---	T(4)
R011	Times for calculations (yr)	not used	3.000E+01	---	T(5)
R011	Times for calculations (yr)	not used	1.000E+02	---	T(6)
R011	Times for calculations (yr)	not used	3.000E+02	---	T(7)
R011	Times for calculations (yr)	not used	1.000E+03	---	T(8)
R011	Times for calculations (yr)	not used	0.000E+00	---	T(9)
R011	Times for calculations (yr)	not used	0.000E+00	---	T(10)
R012	Initial principal radionuclide (pCi/g): Pb-210	1.000E+00	0.000E+00	---	S1(1)
R012	Initial principal radionuclide (pCi/g): Ra-226	1.000E+00	0.000E+00	---	S1(2)
R012	Initial principal radionuclide (pCi/g): Th-230	1.000E+00	0.000E+00	---	S1(3)
R012	Initial principal radionuclide (pCi/g): U-234	1.000E+00	0.000E+00	---	S1(4)
R012	Initial principal radionuclide (pCi/g): U-238	1.000E+00	0.000E+00	---	S1(5)
R012	Concentration in groundwater (pCi/L): Pb-210	not used	0.000E+00	---	W1(1)
R012	Concentration in groundwater (pCi/L): Ra-226	not used	0.000E+00	---	W1(2)
R012	Concentration in groundwater (pCi/L): Th-230	not used	0.000E+00	---	W1(3)
R012	Concentration in groundwater (pCi/L): U-234	not used	0.000E+00	---	W1(4)
R012	Concentration in groundwater (pCi/L): U-238	not used	0.000E+00	---	W1(5)
R013	Cover depth (m)	1.000E+00	0.000E+00	---	COVER0
R013	Density of cover material (g/cm**3)	1.500E+00	1.500E+00	---	DENSCV
R013	Cover depth erosion rate (m/yr)	0.000E+00	1.000E-03	---	VCV
R013	Density of contaminated zone (g/cm**3)	1.500E+00	1.500E+00	---	DENSCZ
R013	Contaminated zone erosion rate (m/yr)	0.000E+00	1.000E-03	---	VCZ
R013	Contaminated zone total porosity	4.000E-01	4.000E-01	---	TPCZ
R013	Contaminated zone field capacity	2.000E-01	2.000E-01	---	FCCZ
R013	Contaminated zone hydraulic conductivity (m/yr)	1.000E+01	1.000E+01	---	HCCZ
R013	Contaminated zone b parameter	5.300E+00	5.300E+00	---	BCZ
R013	Average annual wind speed (m/sec)	2.000E+00	2.000E+00	---	WIND
R013	Humidity in air (g/m**3)	not used	8.000E+00	---	HUMID
R013	Evapotranspiration coefficient	5.000E-01	5.000E-01	---	EVAPTR
R013	Precipitation (m/yr)	1.000E+00	1.000E+00	---	PRECIP
R013	Irrigation (m/yr)	2.000E-01	2.000E-01	---	RI
R013	Irrigation mode	overhead	overhead	---	IDITCH
R013	Runoff coefficient	2.000E-01	2.000E-01	---	RUNOFF
R013	Watershed area for nearby stream or pond (m**2)	1.000E+06	1.000E+06	---	WAREA
R013	Accuracy for water/soil computations	1.000E-03	1.000E-03	---	EPS
R014	Density of saturated zone (g/cm**3)	1.500E+00	1.500E+00	---	DENSAQ
R014	Saturated zone total porosity	4.000E-01	4.000E-01	---	TPSZ
R014	Saturated zone effective porosity	2.000E-01	2.000E-01	---	EPSZ
R014	Saturated zone field capacity	2.000E-01	2.000E-01	---	FCSZ
R014	Saturated zone hydraulic conductivity (m/yr)	1.000E+02	1.000E+02	---	HCSZ

RESRAD, Version 6.21 T½ Limit = 0.5 year 03/31/2004 09:46 Page 5
Summary : Denver Radium Case - Resident
File : Denver Radium Case Resident.RAD

Site-Specific Parameter Summary (continued)

Menu	Parameter	User Input	Default	Used by RESRAD (If different from user input)	Parameter Name
R014	Saturated zone hydraulic gradient	2.000E-02	2.000E-02	---	HGWT
R014	Saturated zone b parameter	5.300E+00	5.300E+00	---	BSZ
R014	Water table drop rate (m/yr)	1.000E-03	1.000E-03	---	VWT
R014	Well pump intake depth (m below water table)	1.000E+01	1.000E+01	---	DWIBWT
R014	Model: Nondispersion (ND) or Mass-Balance (MB)	ND	ND	---	MODEL
R014	Well pumping rate (m**3/yr)	2.500E+02	2.500E+02	---	UW
R015	Number of unsaturated zone strata	1	1	---	NS
R015	Unsat. zone 1, thickness (m)	4.000E+00	4.000E+00	---	H(1)
R015	Unsat. zone 1, soil density (g/cm**3)	1.500E+00	1.500E+00	---	DENSUZ(1)
R015	Unsat. zone 1, total porosity	4.000E-01	4.000E-01	---	TPUZ(1)
R015	Unsat. zone 1, effective porosity	2.000E-01	2.000E-01	---	EPUZ(1)
R015	Unsat. zone 1, field capacity	2.000E-01	2.000E-01	---	FCUZ(1)
R015	Unsat. zone 1, soil-specific b parameter	5.300E+00	5.300E+00	---	BUZ(1)
R015	Unsat. zone 1, hydraulic conductivity (m/yr)	1.000E+01	1.000E+01	---	HCUZ(1)
R016	Distribution coefficients for Pb-210				
R016	Contaminated zone (cm**3/g)	1.000E+02	1.000E+02	---	DCNUCC(1)
R016	Unsaturated zone 1 (cm**3/g)	1.000E+02	1.000E+02	---	DCNUCU(1,1)
R016	Saturated zone (cm**3/g)	1.000E+02	1.000E+02	---	DCNUCS(1)
R016	Leach rate (/yr)	0.000E+00	0.000E+00	3.326E-04	ALEACH(1)
R016	Solubility constant	0.000E+00	0.000E+00	not used	SOLUBK(1)
R016	Distribution coefficients for Ra-226				
R016	Contaminated zone (cm**3/g)	7.000E+01	7.000E+01	---	DCNUCC(2)
R016	Unsaturated zone 1 (cm**3/g)	7.000E+01	7.000E+01	---	DCNUCU(2,1)
R016	Saturated zone (cm**3/g)	7.000E+01	7.000E+01	---	DCNUCS(2)
R016	Leach rate (/yr)	0.000E+00	0.000E+00	4.747E-04	ALEACH(2)
R016	Solubility constant	0.000E+00	0.000E+00	not used	SOLUBK(2)
R016	Distribution coefficients for Th-230				
R016	Contaminated zone (cm**3/g)	6.000E+04	6.000E+04	---	DCNUCC(3)
R016	Unsaturated zone 1 (cm**3/g)	6.000E+04	6.000E+04	---	DCNUCU(3,1)
R016	Saturated zone (cm**3/g)	6.000E+04	6.000E+04	---	DCNUCS(3)
R016	Leach rate (/yr)	0.000E+00	0.000E+00	5.556E-07	ALEACH(3)
R016	Solubility constant	0.000E+00	0.000E+00	not used	SOLUBK(3)
R016	Distribution coefficients for U-234				
R016	Contaminated zone (cm**3/g)	5.000E+01	5.000E+01	---	DCNUCC(4)
R016	Unsaturated zone 1 (cm**3/g)	5.000E+01	5.000E+01	---	DCNUCU(4,1)
R016	Saturated zone (cm**3/g)	5.000E+01	5.000E+01	---	DCNUCS(4)
R016	Leach rate (/yr)	0.000E+00	0.000E+00	6.638E-04	ALEACH(4)
R016	Solubility constant	0.000E+00	0.000E+00	not used	SOLUBK(4)
R016	Distribution coefficients for U-238				
R016	Contaminated zone (cm**3/g)	5.000E+01	5.000E+01	---	DCNUCC(5)
R016	Unsaturated zone 1 (cm**3/g)	5.000E+01	5.000E+01	---	DCNUCU(5,1)
R016	Saturated zone (cm**3/g)	5.000E+01	5.000E+01	---	DCNUCS(5)
R016	Leach rate (/yr)	0.000E+00	0.000E+00	6.638E-04	ALEACH(5)
R016	Solubility constant	0.000E+00	0.000E+00	not used	SOLUBK(5)

RESRAD, Version 6.21 Tm Limit = 0.5 year 05/31/2005 09:46 Page 6
Summary : Denver Radium Case - Residents
File : Denver Radium Case Residents.RAD

Site-Specific Parameter Summary (continued)

Menu	Parameter	User Input	Default	Used by RESRAD (if different from user input)	Parameter Name
R017	Inhalation rate (m^3/yr)	8.400E+03	8.400E+03	---	INHALR
R017	Mass loading for inhalation (g/m^3)	1.000E-04	1.000E-04	---	MASSR
R017	Exposure duration	3.000E+01	2.000E+01	---	ED
R017	Shielding factor, inhalation	4.000E-01	4.000E-01	---	SHF3
R017	Shielding factor, external gamma	7.000E-01	7.000E-01	---	SHF1
R017	Fraction of time spent indoors	5.000E-01	5.000E-01	---	FIND
R017	Fraction of time spent outdoors (on site)	2.500E-01	2.500E-01	---	FOTD
R017	Shape factor flag, external gamma	1.000E+00	2.000E+00	>0 shows circular AREA.	SE
R017	Radii of shape factor array (used if FS = -1):				
R019	Outer annular radius (m), ring 1:	not used	9.400E+01	---	RAD_SHAPE(1)
R017	Outer annular radius (m), ring 2:	not used	7.071E+01	---	RAD_SHAPE(2)
R017	Outer annular radius (m), ring 3:	not used	0.000E+00	---	RAD_SHAPE(3)
R017	Outer annular radius (m), ring 4:	not used	0.000E+00	---	RAD_SHAPE(4)
R017	Outer annular radius (m), ring 5:	not used	0.000E+00	---	RAD_SHAPE(5)
R017	Outer annular radius (m), ring 6:	not used	0.000E+00	---	RAD_SHAPE(6)
R017	Outer annular radius (m), ring 7:	not used	0.000E+00	---	RAD_SHAPE(7)
R017	Outer annular radius (m), ring 8:	not used	0.000E+00	---	RAD_SHAPE(8)
R017	Outer annular radius (m), ring 9:	not used	0.000E+00	---	RAD_SHAPE(9)
R017	Outer annular radius (m), ring 10:	not used	0.000E+00	---	RAD_SHAPE(10)
R017	Outer annular radius (m), ring 11:	not used	0.000E+00	---	RAD_SHAPE(11)
R017	Outer annular radius (m), ring 12:	not used	0.000E+00	---	RAD_SHAPE(12)
R017	Fractions of annular areas within AREA:				
R017	Ring 1	not used	1.000E+00	---	FRACA(1)
R017	Ring 2	not used	2.732E-01	---	FRACA(2)
R017	Ring 3	not used	0.000E+00	---	FRACA(3)
R017	Ring 4	not used	0.000E+00	---	FRACA(4)
R017	Ring 5	not used	0.000E+00	---	FRACA(5)
R017	Ring 6	not used	0.000E+00	---	FRACA(6)
R017	Ring 7	not used	0.000E+00	---	FRACA(7)
R017	Ring 8	not used	0.000E+00	---	FRACA(8)
R017	Ring 9	not used	0.000E+00	---	FRACA(9)
R017	Ring 10	not used	0.000E+00	---	FRACA(10)
R017	Ring 11	not used	0.000E+00	---	FRACA(11)
R017	Ring 12	not used	0.000E+00	---	FRACA(12)
R018	Fruits, vegetables and grain consumption (kg/yr)	1.600E+02	1.600E+02	---	DIET(1)
R018	Leafy vegetable consumption (kg/yr)	1.400E+01	1.400E+01	---	DIET(2)
R018	Milk consumption (l/yr)	9.200E+01	9.200E+01	---	DIET(3)
R018	Meat and poultry consumption (kg/yr)	6.300E+01	6.300E+01	---	DIET(4)
R018	Fish consumption (kg/yr)	5.400E+00	5.400E+00	---	DIET(5)
R018	Other seafood consumption (kg/yr)	9.000E-01	9.000E-01	---	DIET(6)
R018	Soil ingestion rate (g/yr)	3.650E+01	3.650E+01	---	SOIL
R018	Drinking water intake (l/yr)	5.100E+02	5.100E+02	---	DWI
R018	Contamination fraction of drinking water	1.000E+00	1.000E+00	---	FDW
R018	Contamination fraction of household water	1.000E+00	1.000E+00	---	FHHW
R018	Contamination fraction of livestock water	1.000E+00	1.000E+00	---	FLW
R018	Contamination fraction of irrigation water	1.000E-02	1.000E+00	---	FIRW
R018	Contamination fraction of aquatic food	not used	5.000E-01	---	FR9
R019	Contamination fraction of plant food	-1	-1	0.500E+00	FPLANT

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Summary : Denver Radium Case - Resident
File : Denver Radium Case Resident.RAD

Site-Specific Parameter Summary (continued)

Menu	Parameter	User Input	Default	Used by RESRAD (If different from user input)	Parameter Name
R018	Contamination fraction of meat	-1	-1	0.100E+01	FMEAT
R018	Contamination fraction of milk	-1	-1	0.100E+01	FMILK
R019	Livestock fodder intake for meat (kg/day)	6.800E+01	6.800E+01	---	LFI5
R019	Livestock fodder intake for milk (kg/day)	5.500E+01	5.500E+01	---	LFI6
R019	Livestock water intake for meat (L/day)	5.000E+01	5.000E+01	---	LWI5
R019	Livestock water intake for milk (L/day)	1.600E+02	1.600E+02	---	LWI6
R019	Livestock soil intake (kg/day)	5.000E-01	5.000E-01	---	LSI
R019	Mass loading for foliar deposition (g/m**3)	1.000E-04	1.000E-04	---	MLFD
R019	Depth of soil mixing layer (m)	1.500E-01	1.500E-01	---	DM
R019	Depth of roots (m)	9.000E-01	9.000E-01	---	DROOT
R019	Drinking water fraction from ground water	not used	1.000E+00	---	FGWDW
R019	Household water fraction from ground water	not used	1.000E+00	---	FGWHH
R019	Livestock water fraction from ground water	1.000E+00	1.000E+00	---	FGWLW
R019	Irrigation fraction from ground water	1.000E+00	1.000E+00	---	FGWIR
R19B	Wet weight crop yield for Non-Leafy (kg/m**2)	7.000E-01	7.000E-01	---	YV(1)
R19B	Wet weight crop yield for Leafy (kg/m**2)	1.500E+00	1.500E+00	---	YV(2)
R19B	Wet weight crop yield for Fodder (kg/m**2)	1.100E+00	1.100E+00	---	YV(3)
R19B	Growing Season for Non-Leafy (years)	1.700E-01	1.700E-01	---	TE(1)
R19B	Growing Season for Leafy (years)	2.500E-01	2.500E-01	---	TE(2)
R19B	Growing Season for Fodder (years)	8.000E-02	8.000E-02	---	TE(3)
R19B	Translocation Factor for Non-Leafy	1.000E-01	1.000E-01	---	TIV(1)
R19B	Translocation Factor for Leafy	1.000E+00	1.000E+00	---	TIV(2)
R19B	Translocation Factor for Fodder	1.000E+00	1.000E+00	---	TIV(3)
R19B	Dry Foliar Interception Fraction for Non-Leafy	2.500E-01	2.500E-01	---	RDRY(1)
R19B	Dry Foliar Interception Fraction for Leafy	2.500E-01	2.500E-01	---	RDRY(2)
R19B	Dry Foliar Interception Fraction for Fodder	2.500E-01	2.500E-01	---	RDRY(3)
R19B	Wet Foliar Interception Fraction for Non-Leafy	2.500E-01	2.500E-01	---	RWET(1)
R19B	Wet Foliar Interception Fraction for Leafy	2.500E-01	2.500E-01	---	RWET(2)
R19B	Wet Foliar Interception Fraction for Fodder	2.500E-01	2.500E-01	---	RWET(3)
R19B	Weathering Removal Constant for Vegetation	2.000E+01	2.000E+01	---	WLAM
C14	C-12 concentration in water (g/cm**3)	not used	2.000E-05	---	C12WTR
C14	C-12 concentration in contaminated soil (g/g)	not used	3.000E-02	---	C12CS
C14	Fraction of vegetation carbon from soil	not used	2.000E-02	---	CSOIL
C14	Fraction of vegetation carbon from air	not used	9.800E-01	---	CAIR
C14	C-14 evasion layer thickness in soil (m)	not used	3.000E-01	---	DMC
C14	C-14 evasion flux rate from soil (1/sec)	not used	7.000E-07	---	EVSN
C14	C-12 evasion flux rate from soil (1/sec)	not used	1.000E-10	---	REVSN
C14	Fraction of grain in beef cattle feed	not used	8.000E-01	---	AVFG4
C14	Fraction of grain in milk cow feed	not used	2.000E-01	---	AVFG5
C14	DCF correction factor for gaseous forms of C14	not used	8.894E+01	---	CO2F
STOR	Storage times of contaminated foodstuffs (days):				
STOR	Fruits, non-leafy vegetables, and grain	1.400E+01	1.400E+01	---	STOR_T(1)
STOR	Leafy vegetables	1.000E+00	1.000E+00	---	STOR_T(2)
STOR	Milk	1.000E+00	1.000E+00	---	STOR_T(3)
STOR	Meat and poultry	2.000E+01	2.000E+01	---	STOR_T(4)
STOR	Fish	7.000E+00	7.000E+00	---	STOR_T(5)

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Summary : Denver Radium Case - Resident
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Site-Specific Parameter Summary (continued)

Menu	Parameter	User Input	Default	Used by RESRAD (If different from user input)	Parameter Name
STOR	Crustacea and mollusks	7.000E+00	7.000E+00	---	STOR_T(6)
STOR	Well water	1.000E+00	1.000E+00	---	STOR_T(7)
STOR	Surface water	1.000E+00	1.000E+00	---	STOR_T(8)
STOR	Livestock fodder	4.500E+01	4.500E+01	---	STOR_T(9)
R021	Thickness of building foundation (m)	not used	1.500E-01	---	FLOOR1
R021	Bulk density of building foundation (g/cm**3)	not used	2.400E+00	---	DENSFL
R021	Total porosity of the cover material	not used	4.000E-01	---	TPCV
R021	Total porosity of the building foundation	not used	1.000E-01	---	TPFL
R021	Volumetric water content of the cover material	not used	5.000E-02	---	PH2OCV
R021	Volumetric water content of the foundation	not used	3.000E-02	---	PH2OFL
R021	Diffusion coefficient for radon gas (m/sec):				
R021	in cover material	not used	2.000E-06	---	DIFCV
R021	in foundation material	not used	3.000E-07	---	DIFFL
R021	in contaminated zone soil	not used	2.000E-06	---	DIFCZ
R021	Radon vertical dimension of mixing (m)	not used	2.000E+00	---	HMIX
R021	Average building air exchange rate (1/hr)	not used	5.000E-01	---	REXG
R021	Height of the building (room) (m)	not used	2.500E+00	---	HRM
R021	Building interior area factor	not used	0.000E+00	---	FAI
R021	Building depth below ground surface (m)	not used	-1.000E+00	---	DMFL
R021	Emanating power of Rn-222 gas	not used	2.500E-01	---	EMANA(1)
R021	Emanating power of Rn-220 gas	not used	1.500E-01	---	EMANA(2)
TITL	Number of graphical time points	32	---	---	NPTS
TITL	Maximum number of integration points for dose	17	---	---	LYMAX
TITL	Maximum number of integration points for risk	257	---	---	KYMAX

Summary of Pathway Selections

Pathway	User Selection
1 -- external gamma	active
2 -- inhalation (w/o radon)	active
3 -- plant ingestion	active
4 -- meat ingestion	active
5 -- milk ingestion	active
6 -- aquatic foods	suppressed
7 -- drinking water	suppressed
8 -- soil ingestion	active
9 -- radon	suppressed
Find peak pathway doses	active

```
RESRAD, Version 6.21     T½ Limit = 0.5 year        03/31/2004  09:46  Page   9
Summary : Denver Radium Case - Resident
File    : Denver Radium Case Resident.RAD

     Contaminated Zone Dimensions           Initial Soil Concentrations, pCi/g

       Area: 330000.00 square meters              Pb-210     1.000E+00
  Thickness:     10.00 meters                     Ra-226     1.000E+00
Cover Depth:      1.00 meters                     Th-230     1.000E+00
                                                  U-234      1.000E+00
                                                  U-238      1.000E+00

                         Total Dose TDOSE(t), mrem/yr
                  Basic Radiation Dose Limit = 2.500E+01 mrem/yr
Total Mixture Sum M(t) = Fraction of Basic Dose Limit Received at Time (t)

   t (years):  0.000E+00  1.000E+00  1.000E+02
    TDOSE(t):  2.448E-05  2.447E-05  2.337E-05
        M(t):  9.792E-07  9.787E-07  9.347E-07
Maximum TDOSE(t):  2.448E-05 mrem/yr   at t = 0.000E+00 years
```

RESRAD, Version 6.21 Tm Limit = 0.5 year 03/31/2004 09:46 Page 10
Summary : Denver Radium Case - Resident
File : Denver Radium Case Resident.RAD

Total Dose Conversions (DOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 0.0000E+00 years
Water Independent Pathways (excludes radon)

Radio-Nuclide	Ground		Inhalation		Radon		Plant		Meat		Milk		Soil	
	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.
Pb-210	1.0798E-14	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000
Ra-226	2.4139E-05	0.9965	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000
Th-230	5.2933E-09	0.0002	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000
U-234	1.1982E-14	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000
U-238	8.9748E-08	0.0033	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000
Total	2.4166E-05	1.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000

Total Dose Conversions (DOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 0.0000E+00 years
Water Dependent Pathways

Radio-Nuclide	Water		Fish		Radon		Plant		Meat		Milk		All Pathways*	
	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.
Pb-210	0.0000E+00	0.0000	0.0035E+00	0.9939	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	1.0798E-14	0.4608
Ra-226	0.0000E+00	0.0000	0.0025E+00	0.0060	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	2.4139E-05	0.9965
Th-230	0.0000E+00	0.0000	0.3672E-03	0.9999	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	5.2933E-09	0.0002
U-234	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	1.1982E-14	0.0000
U-238	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	8.9748E-08	0.0033
Total	0.0000E+00	0.0000	0.0060E+00	0.9939	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	2.4166E-05	1.0000

*Sum of all water independent and dependent pathways.

RESRAD, Version 6.21 Tx Limit = 0.5 year 03/31/2005 09:46 Page 11
Summary : Denver Radium Case - Residents
File : Denver Radium Case Residents.RAD

Total Dose Contributions TDOSE(1,p,t) for Individual Radionuclides (1) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 1.0000E+00 years
Water Independent Pathways (Inhalation excludes radon)

Radio-Nuclide	Ground mrem/yr	Ground fract.	Inhalation mrem/yr	Inhalation fract.	Radon mrem/yr	Radon fract.	Plant mrem/yr	Plant fract.	Meat mrem/yr	Meat fract.	Milk mrem/yr	Milk fract.	Soil mrem/yr	Soil fract.
Pb-210	2.0435E-24	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000
Ra-226	2.4378E-05	0.9961	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000
Th-230	1.3852E-08	0.0006	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000
U-234	1.1105E-13	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000
U-238	8.0698E-09	0.0033	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000
Total	2.4478E-05	1.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000

Total Dose Contributions TWOSE(1,p,t) for Individual Radionuclides (1) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 1.0000E+00 years
Water Dependent Pathways

Radio-Nuclide	Water mrem/yr	Water fract.	Fish mrem/yr	Fish fract.	Radon mrem/yr	Radon fract.	Plant mrem/yr	Plant fract.	Meat mrem/yr	Meat fract.	Milk mrem/yr	Milk fract.	All Pathways* mrem/yr	All Pathways* fract.
Pb-210	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	1.0456E-14	0.0000
Ra-226	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	2.4378E-05	0.9961
Th-230	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	1.5856E-08	0.0006
U-234	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	1.1105E-13	0.0000
U-238	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	8.0698E-09	0.0033
Total	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	2.4478E-05	1.0000

*Sum of all water independent and dependent pathways.

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Summary : Denver Radium Case - Resident
File : Denver Radium Case Residuum.RAD

Total Dose Contributions TDOSE(j,p,t) for Individual Radionuclides (j) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 1.0005E+02 years
Water Independent Pathways (Inhalation excludes radon)

Radio-Nuclide	Ground		Inhalation		Radon		Plant		Meat		Milk		Soil	
	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.
Pb-210	4.6628E-16	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000
Ra-226	2.2295E-05	0.9533	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000
Th-230	1.0156E-06	0.0434	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000
Th-232	4.5596E-10	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000
U-238	7.3568E-08	0.0032	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000
Total	2.3378E-05	1.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000

Total Dose Contributions TDOSE(j,p,t) for Individual Radionuclides (j) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 1.0005E+02 years
Water Dependent Pathways

Radio-Nuclide	Water		Fish		Radon		Plant		Meat		Milk		All Pathways*	
	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.
Pb-210	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	4.6628E-16	0.0000
Ra-226	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	2.2295E-05	0.9533
Th-230	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	1.0156E-06	0.0434
Th-232	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	4.5596E-10	0.0000
U-238	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	7.3568E-08	0.0032
Total	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	2.3378E-05	1.0000

*Sum of all water independent and dependent pathways.

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        Dose/Source Ratios Summed Over All Pathways
Parent and Progeny Principal Radionuclide Contributions Indicated
Parent  Product  Branch        DSR(j,t)  (mrem/yr)/(pCi/g)
 (i)      (j)    Fraction*  t= 0.000E+00 1.000E+00 1.000E+02

Pb-210  Pb-210  1.000E+00     1.079E-14 1.045E-14 4.662E-16
Ra-226  Ra-226  1.000E+00     2.439E-05 2.437E-05 2.228E-05
Ra-226  Pb-210  1.000E+00     1.085E-16 6.983E-16 9.716E-15
Ra-226  ΣDSR(j)               2.439E-05 2.437E-05 2.229E-05
Th-230  Th-230  1.000E+00     4.121E-16 4.121E-16 4.117E-16
Th-230  Ra-226  1.000E+00     5.285E-09 1.585E-08 1.015E-06
Th-230  Pb-210  1.000E+00     2.440E-29 1.692E-19 3.170E-16
Th-230  ΣDSR(j)               5.285E-09 1.585E-08 1.015E-06
U-234   U-234   1.000E+00     4.012E-17 4.010E-17 3.754E-17
U-234   Th-230  1.000E+00     1.954E-21 5.861E-21 3.604E-19
U-234   Ra-226  1.000E+00     1.596E-14 1.209E-13 4.559E-10
U-234   Pb-210  1.000E+00     5.498E-26 8.190E-25 1.141E-19
U-234   ΣDSR(j)               1.590E-14 1.110E-13 4.559E-10
U-238   U-238   1.000E+00     8.074E-08 8.069E-08 7.556E-08
U-238   U-234   1.000E+00     5.687E-23 1.705E-22 1.070E-20
U-238   Th-230  1.000E+00     1.752E-27 1.226E-26 5.078E-23
U-238   Ra-226  1.000E+00     1.124E-20 1.685E-19 4.315E-14
U-238   Pb-210  1.000E+00     3.121E-32 9.619E-31 9.062E-24
U-238   ΣDSR(j)               8.074E-08 8.069E-08 7.556E-08

*Branch Fraction is the cumulative factor for the j't principal radionuclide daughter:  CUMBRF(j) = BRF(1)*BRF(2)* ... BRF(j).
The DSR includes contributions from associated (half-life ≤ 0.5 yr) daughters.

Single Radionuclide Soil Guidelines G(i,t) in pCi/g
   Basic Radiation Dose Limit = 2.500E+01 mrem/yr
Nuclide
  (i)     t= 0.000E+00   1.000E+00   1.000E+02

Pb-210     *7.631E+13  *7.631E+13  *7.631E+13
Ra-226      1.025E+06   1.026E+06   1.122E+06
Th-230      4.731E+09   1.578E+09   2.463E+07
U-234      *6.245E+09  *6.245E+09  *6.245E+09
U-238      *3.360E+05  *3.360E+05  *3.360E+05

*At specific activity limit
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            Summed Dose/Source Ratios DSR(i,t) in (mrem/yr)/(pCi/g)
            and Single Radionuclide Soil Guidelines G(i,t) in pCi/g
          at tmin = time of minimum single radionuclide soil guideline
     and at tmax = time of maximum total dose = 0.000E+00 years
```

Nuclide (i)	Initial (pCi/g)	tmin (years)	DSR(i,tmin)	G(i,tmin) (pCi/g)	DSR(i,tmax)	G(i,tmax) (pCi/g)
Pb-210	1.000E+00	0.000E+00	1.079E-14	*7.631E+13	1.079E-14	*7.631E+13
Ra-226	1.023E+00	0.000E+00	2.439E-05	1.025E+06	2.439E-05	1.025E+06
Th-230	1.000E+00	1.000E+02	1.915E-06	2.463E+07	5.285E-09	4.731E+09
U-234	1.000E+00	1.000E+02	4.569E-10	*6.345E+09	1.590E-14	*6.245E+09
U-238	1.000E+00	0.000E+00	8.074E-08	*3.360E+05	8.074E-08	*3.360E+05

*At specific activity limit

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Individual Nuclide Dose Summed Over All Pathways
Parent Nuclide and Branch Fraction Indicated

Nuclide (j)	Parent (i)	BRF(i)	DOSE(j,t), mrem/yr t= 0.000E+00	1.000E+00	1.000E+02
Pb-210	Pb-210	1.000E+00	1.079E-14	1.045E-14	4.662E-16
Pb-210	Ra-226	1.000E+00	1.685E-16	4.983E-16	9.716E-15
Pb-210	Th-230	1.000E+00	2.440E-20	1.692E-19	3.170E-16
Pb-210	U-234	1.000E+00	5.498E-26	8.190E-25	1.141E-19
Pb-210	U-238	1.000E+00	0.000E+00	0.000E+00	9.062E-24
Pb-210	∑DOSE(j)		1.096E-14	1.095E-14	1.053E-14
Ra-226	Ra-226	1.000E+00	2.439E-05	2.437E-05	2.228E-05
Ra-226	Th-230	1.000E+00	5.285E-09	1.585E-08	1.015E-06
Ra-226	U-234	1.000E+00	1.586E-14	1.109E-13	4.559E-10
Ra-226	U-238	1.000E+00	1.124E-20	1.685E-19	4.315E-14
Ra-226	∑DOSE(j)		2.440E-05	2.439E-05	2.329E-05
Th-230	Th-230	1.000E+00	4.121E-16	4.121E-16	4.117E-16
Th-230	U-234	1.000E+00	1.894E-21	5.561E-21	3.604E-19
Th-230	U-238	1.000E+00	1.752E-27	1.226E-26	5.078E-23
Th-230	∑DOSE(j)		4.121E-16	4.121E-16	4.120E-16
U-234	U-234	1.000E+00	4.012E-17	4.010E-17	3.754E-17
U-234	U-238	1.000E+00	6.687E-23	1.705E-22	1.070E-20
U-234	∑DOSE(j)		4.012E-17	4.010E-17	3.755E-17
U-238	U-238	1.000E+00	8.074E-08	8.069E-08	7.556E-08

BRF(i) is the branch fraction of the parent nuclide.

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Individual Nuclide Soil Concentration
Parent Nuclide and Branch Fraction Indicated

Nuclide (j)	Parent (i)	BRF(i)	S(j,t), pCi/g t= 0.000E+00	1.000E+00	1.000E+02
Pb-210	Pb-210	1.000E+00	1.000E+00	9.691E-01	4.322E-02
Pb-210	Ra-226	1.000E+00	0.000E+00	3.059E-02	8.864E-01
Pb-210	Th-230	1.000E+00	0.000E+00	6.661E-06	2.874E-02
Pb-210	U-234	1.000E+00	0.000E+00	2.046E-11	1.029E-05
Pb-210	U-238	1.000E+00	0.000E+00	1.422E-17	8.126E-10
Pb-210	ΣS(j):		1.000E+00	9.997E-01	9.584E-01
Ra-226	Ra-226	1.000E+00	1.000E+00	9.991E-01	9.132E-01
Ra-226	Th-230	1.000E+00	0.000E+00	4.330E-04	4.139E-02
Ra-226	U-234	1.000E+00	0.000E+00	1.949E-09	1.856E-05
Ra-226	U-238	1.000E+00	0.000E+00	1.842E-15	1.742E-09
Ra-226	ΣS(j):		1.000E+00	9.995E-01	9.546E-01
Th-230	Th-230	1.000E+00	1.000E+00	1.000E+00	9.990E-01
Th-230	U-234	1.000E+00	0.000E+00	8.999E-06	8.704E-04
Th-230	U-238	1.000E+00	0.000E+00	1.275E-11	1.220E-07
Th-230	ΣS(j):		1.000E+00	1.000E+00	9.999E-01
U-234	U-234	1.000E+00	1.000E+00	9.993E-01	9.355E-01
U-234	U-238	1.000E+00	0.000E+00	2.833E-06	2.653E-04
U-234	ΣS(j):		1.000E+00	9.993E-01	9.358E-01
U-238	U-238	1.000E+00	1.000E+00	9.993E-01	9.358E-01

BRF(i) is the branch fraction of the parent nuclide.
RESCALC.EXE execution time =   0.68 seconds

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Part III: Intake Quantities and Health Risk Factors

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Cancer Risk Slope Factors Summary Table
Risk Library: PER 73 Morbidity

Menu	Parameter	Current Value	Default	Parameter Name
S6-1	Ground external radiation slope factors, 1/yr per (pCi/g):			
S6-1	Pb-210+D	4.21E-09	4.21E-09	SLEF(1,1)
S6-1	Ra-226+D	8.49E-06	8.49E-06	SLEF(2,1)
S6-1	Th-230	8.18E-10	8.18E-10	SLEF(3,1)
S6-1	U-234	2.52E-10	2.52E-10	SLEF(4,1)
S6-1	U-238+D	6.66E-08	6.96E-08	SLEF(5,1)
S6-2	Inhalation, slope factors, 1/(pCi):			
S6-2	Pb-210+D	3.09E-08	2.08E-08	SLEF(1,2)
S6-2	Ra-226+D	2.92E-08	2.82E-08	SLEF(2,2)
S6-2	Th-230	3.60E-08	3.40E-08	SLEF(3,2)
S6-2	U-234	2.78E-08	2.78E-08	SLEF(4,2)
S6-2	U-238+D	2.36E-08	2.36E-08	SLEF(5,2)
S6-3	Food ingestion, slope factors, 1/(pCi):			
S6-3	Pb-210+D	3.44E-09	3.44E-09	SLEF(1,3)
S6-3	Ra-226+D	5.14E-10	5.14E-10	SLEF(2,3)
S6-3	Th-230	1.19E-10	1.19E-10	SLEF(3,3)
S6-3	U-234	9.55E-11	9.55E-11	SLEF(4,3)
S6-3	U-238+D	1.20E-10	1.20E-10	SLEF(5,3)
S6-4	Water ingestion, slope factors, 1/(pCi):			
S6-4	Pb-210+D	2.66E-09	2.66E-09	SLEF(1,4)
S6-4	Ra-226+D	3.85E-10	2.85E-10	SLEF(2,4)
S6-4	Th-230	8.18E-11	9.10E-11	SLEF(3,4)
S6-4	U-234	7.07E-11	7.07E-11	SLEF(4,4)
S6-4	U-238+D	8.73E-11	8.73E-11	SLEF(5,4)
S6-5	Soil ingestion, slope factors, 1/(pCi):			
S6-5	Pb-210+D	3.44E-09	3.44E-09	SLEF(1,5)
S6-5	Ra-226+D	5.14E-10	5.14E-10	SLEF(2,5)
S6-5	Th-230	1.19E-10	1.19E-10	SLEF(3,5)
S6-5	U-234	9.55E-11	9.55E-11	SLEF(4,5)
S6-5	U-238+D	1.20E-10	1.20E-10	SLEF(5,5)
S6-6	Radon Inhalation slope factors, 1/(pCi):			
S6-6	Rn-222	1.60E-12	1.60E-12	SLEFRN(1,3)
S6-6	Pb-210	2.79E-12	3.70E-12	SLEFRN(2,3)
S6-6	Bi-214	6.20E-12	6.20E-12	SLEFRN(3,3)
S6-6	Po-214	1.50E-11	1.50E-11	SLEFRN(4,3)
S6-7	Radon K factors, (mrem/WLM):			
S6-7	Rn-222 Indoor	7.60E+02	7.60E+02	KFACTR(1,1)
S6-7	Rn-222 Outdoor	5.70E+02	5.70E+02	KFACTR(1,2)

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Amount of Intake Quantities QINT(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As pCi/yr at t= 0.0000E+00 years

Radio-Nuclide	Water Independent Pathways (Inhalation w/o Radon) Inhalation	Plant	Meat	Milk	Soil	Water Dependent Pathways Water	Fish	Plant	Meat	Milk	Total Ingestion*
Pb-210	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Ra-226	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Th-230	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
U-234	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
U-238	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

* Sum of all ingestion pathways, i.e. water independent plant, meat, milk, soil and water-dependent water, fish, plant, meat, milk pathways

Amount of Intake Quantities QINT(i,t) and QINT(i,t) for Inhalation of Radon and its Decay Products as pCi/yr at t= 0.0000E+00 years

Radon Pathway	Radionuclides Rn-222	Rn-218	Po-214	Bi-214	Rn-220	Po-216	Pb-212	Bi-212
Water-ind.	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Water-dep.	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Total	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

Water-ind. = Water-independent Water-dep. = Water-dependent

Excess Cancer Risks CRSK(i,p,t) for Individual Radionuclides (i) and Pathways (p) and Fraction of Total Risk at t= 0.0000E+00 years

Radio-Nuclide	Ground Inhalation risk	frac.	Water Independent Pathways (Inhalation excludes radon) Plant risk	frac.	Meat risk	frac.	Milk risk	frac.	Soil risk	frac.
Pb-210	2.2695E-15	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000
Ra-226	9.5119E-13	0.9979	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000
Th-230	8.3576E-21	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000
U-234	7.4746E-23	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000
U-238	1.3678E-12	0.0021	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000
Total	9.5285E-10	1.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000

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Excess Cancer Risks CNRS(i,p,t) for Individual Radionuclides (i) and Pathways (p)
and Fraction of Total Risk at t= 0.000E+00 years

Water Dependent Pathways

Radio-Nuclide	Water risk	Water fract.	Fish risk	Fish fract.	Plant risk	Plant fract.	Meat risk	Meat fract.	Milk risk	Milk fract.	All Pathways** risk	All Pathways** fract.
Pb-210	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.249E-19	0.0000
Ra-226	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	5.511E-10	0.9975
Th-230	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	8.357E-21	0.0000
U-234	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	7.474E-22	0.0000
U-238	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.367E-12	0.0025
Total	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	5.525E-10	1.0000

** Sum of water independent ground, inhalation, plant, meat, milk, soil
and water dependent water, fish, plant, meat, milk pathways

Excess Cancer Risks CNRSS(irn,i,t) and CNRSW(irn,i,t) for Inhalation of
Radon and its Decay Products at t= 0.000E+00 years

Radon Pathway	Rn-222	Po-218	Pb-214	Bi-214	Rn-220	Po-216	Pb-212	Bi-212
Water-ind.	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Water-dep.	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Total	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00

Water-ind. -- Water-independent Water-dep. -- Water-dependent

Total Excess Cancer Risk CNRSI(i,p,t)*** for Initially Existent Radionuclides (i) and Pathways (p)
and Fraction of Total Risk at t= 0.000E+00 years
Water Independent Pathways (Inhalation excludes radon)

Radio-Nuclide	Ground risk	Ground fract.	Inhalation risk	Inhalation fract.	Radon risk	Radon fract.	Plant risk	Plant fract.	Meat risk	Meat fract.	Milk risk	Milk fract.	Soil risk	Soil fract.
Pb-210	1.464E-15	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Ra-226	5.479E-10	0.9911	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Th-230	3.574E-12	0.0065	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
U-234	3.206E-16	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
U-238	1.367E-12	0.0025	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Total	5.525E-10	1.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000

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Total Excess Cancer Risk CRESI(i,p,t)*** for Initially Existent Radionuclides (i) and Pathways (p)
and Fraction of Total Risk at t= 0.0000E+00 years

Water Dependent Pathways

Radio-nuclide	Water risk	Water fract.	Fish risk	Fish fract.	Radon risk	Radon fract.	Plant risk	Plant fract.	Meat risk	Meat fract.	Milk risk	Milk fract.	All pathways risk	All pathways fract.
Rn-210	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	3.4682-19	0.0000
Ra-226	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	8.4795-18	0.0011
Th-230	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	3.8745-12	0.0485
U-234	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	3.2086-14	0.0004
U-238	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	1.3672-12	0.0025
Total	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	5.5258-10	1.0000

***CRESI(i,p,t) includes contribution from decay daughter radionuclides

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Amount of Intake Quantities QINT(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As pCi/yr at t= 1.000E+00 years

Radio-Nuclide	Water Independent Pathways (Inhalation w/o radon): Inhalation	Plant	Meat	Milk	Soil	Water Dependent Pathways: Water	Fish	Plant	Meat	Milk	Total Ingestion*
Pb-210	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Ra-226	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Th-230	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
U-234	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
U-238	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00

* Sum of all ingestion pathways, i.e. water independent plant, meat, milk, soil and water-dependent water, fish, plant, meat, milk pathways

Amount of Intake Quantities QINT9(irn,i,t) and QINT9W(irn,i,t) for Inhalation of
Radon and its Decay Products as pCi/yr at t= 1.000E+00 years

Radon Pathway	Rn-222	Po-218	Pb-214	Bi-214	Rn-220	Po-216	Pb-212	Bi-212
Water-ind.	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Water-dep.	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Total	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00

Water-ind. == Water-independent Water-dep. == Water-dependent

Excess Cancer Risks CNRS(i,p,t) for Individual Radionuclides (i) and Pathways (p)
and Fraction of Total Risk at t= 1.000E+00 years
Water Independent Pathways (Inhalation excludes radon)

Radio-Nuclide	Ground risk	fract.	Inhalation risk	fract.	Plant risk	fract.	Meat risk	fract.	Milk risk	fract.	Soil risk	fract.
Pb-210	2.248E-19	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Ra-226	5.508E-10	0.9975	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Th-230	8.337E-21	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
U-234	7.469E-22	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
U-238	1.366E-12	0.0025	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Total	5.522E-10	1.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000

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Excess Cancer Risks CNRS(i,p,t) for Individual Radionuclides (i) and Pathways (p)
and Fraction of Total Risk at t= 3.0000E+02 years

Water Dependent Pathways

Radio-	Water		Fish		Plant		Meat		Milk		All Pathways**	
Nuclide	risk	fract.	risk	fract.	risk	fract.	risk	fract.	risk	fract.	risk	fract.
Pb-210	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	2.2485E-19	0.0000
Ra-226	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	5.5085E-10	0.9935
Th-230	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	8.3576E-21	0.0000
U-234	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	7.4636E-22	0.0000
U-238	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	1.3668E-12	0.0025
Total	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	5.5228E-10	0.9960

** Sum of water independent ground, inhalation, plant, meat, milk, soil
and water dependent water, fish, plant, meat, milk pathways

Excess Cancer Risks CNRS(i,,,t) and Child(i,,,t) for Inhalation of
Radon and its Decay Products at t= 1.0000E+00 years
Radionuclides

Radon Pathway	Rn-222	Po-218	Pb-214	Bi-214	Rn-220	Po-216	Pb-212	Bi-212
Water-ind.	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Water-dep.	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Total	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

Water-ind. = Water-independent Water-dep. = Water-dependent

Total Excess Cancer Risk CNRS(i,p,t) for Initially Existent Radionuclides (i) and Pathways (p)
and Fraction of Total Risk at t= 1.0000E+00 years
Water Independent Pathways (Inhalation excludes radon)

Radio-	Ground		Inhalation		Radon		Plant		Meat		Milk		Soil	
Nuclide	risk	fract.	risk	fract.	risk	fract.	risk	fract.	risk	fract.	risk	fract.	risk	fract.
Pb-210	1.4198E-19	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000
Ra-226	5.4785E-10	0.9936	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000
Th-230	8.3218E-21	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000
U-234	7.4358E-22	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000
U-238	1.3668E-12	0.0025	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000
Total	5.5228E-10	1.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000	0.0000E+00	0.0000

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Total Excess Cancer Risk CNRSI(i,p,t)*** for Initially Existent Radionuclides (i) and Pathways (p)
and Fraction of Total Risk at t= 1.000E+00 years

	Water Dependent Pathways													
Radio-	Water		Fish		Radon		Plant		Meat		Milk		All pathways	
Nuclide	risk	fract.	risk	fract.	risk	fract.	risk	fract.	risk	fract.	risk	fract.	risk	fract.
Pb-210	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.419E-19	0.0000
Ra-226	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	5.470E-10	0.9906
Th-230	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	3.811E-12	0.0069
U-234	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	3.538E-16	0.0000
U-238	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.366E-12	0.0025
Total	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	5.522E-10	1.0000

***CNRSI(i,p,t) includes contribution from decay daughter radionuclides

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Amount of Intake Quantities QINT(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As pCi/yr at t= 1.000E+02 years

Radio-	Water Independent Pathways (Inhalation w/o radon)					Water Dependent Pathways					Total
Nuclide	Inhalation	Plant	Meat	Milk	Soil	Water	Fish	Plant	Meat	Milk	Ingestion*
Pb-210	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Ra-226	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Th-230	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
U-234	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
U-238	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00

* Sum of all ingestion pathways, i.e. water independent plant, meat, milk, soil and water-dependent water, fish, plant, meat, milk pathways

Amount of Intake Quantities QIN79(irn,i,t) and QINT9W(irn,i,t) for Inhalation of
Radon and its Decay Products as pCi/yr at t= 1.000E+02 years

Radon	Radionuclides							
Pathway	Rn-222	Po-218	Pb-214	Bi-214	Rn-220	Po-216	Pb-212	Bi-212
Water-ind.	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Water-dep.	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Total	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00

Water-ind. == Water-independent Water-dep. == Water-dependent

Excess Cancer Risks CNRS(i,p,t) for Individual Radionuclides (i) and Pathways (p)
and Fraction of Total Risk at t= 1.000E+02 years
Water Independent Pathways (Inhalation excludes radon)

Radio-	Ground		Inhalation		Plant		Meat		Milk		Soil	
Nuclide	risk	fract.	risk	fract.	risk	fract.	risk	fract.	risk	fract.	risk	fract.
Pb-210	2.152E-13	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Ra-226	5.262E-10	0.9976	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Th-230	8.357E-21	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
U-234	6.994E-22	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
U-238	1.279E-12	0.0024	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Total	5.275E-10	1.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000

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Excess Cancer Risks CNRS(i,p,t) for Individual Radionuclides (i) and Pathways (p)
and Fraction of Total Risk at t= 1.000E+02 years

Water Dependent Pathways

Radio-Nuclide	Water risk	Water fract.	Fish risk	Fish fract.	Plant risk	Plant fract.	Meat risk	Meat fract.	Milk risk	Milk fract.	All Pathways** risk	All Pathways** fract.
Pb-210	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.152E-19	0.0000
Ra-226	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	5.262E-10	0.9976
Th-230	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	8.357E-21	0.0000
U-234	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	6.994E-22	0.0000
U-238	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.279E-12	0.0024
Total	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	5.276E-10	1.0000

** Sum of water independent ground, inhalation, plant, meat, milk, soil
and water dependent water, fish, plant, meat, milk pathways

Excess Cancer Risks CNRS9(irn,i,t) and CNRS9W(irn,i,t) for Inhalation of
Radon and its Decay Products at t= 1.000E+02 years
Radionuclides

Radon Pathway	Rn-222	Po-218	Pb-214	Bi-214	Rn-220	Po-216	Pb-212	Bi-212
Water-ind.	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Water-dep.	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Total	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00

Water-ind. == Water-independent   Water-dep. == Water-dependent

Total Excess Cancer Risk CNRSI(i,p,t)*** for Initially Existent Radionuclides (i) and Pathways (p)
and Fraction of Total Risk at t= 1.000E+02 years
Water Independent Pathways (Inhalation excludes radon)

Radio-Nuclide	Ground risk	Ground fract.	Inhalation risk	Inhalation fract.	Radon risk	Radon fract.	Plant risk	Plant fract.	Meat risk	Meat fract.	Milk risk	Milk fract.	Soil risk	Soil fract.
Pb-210	6.326E-21	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Ra-226	5.000E-10	0.9478	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Th-230	2.623E-11	0.0497	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
U-234	1.354E-14	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
U-238	1.279E-12	0.0024	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Total	5.275E-10	1.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000

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Total Excess Cancer Risk CNRS1(i,p,t)*** for Initially Existent Radionuclides (i) and Pathways (p) and Fraction of Total Risk at t= 1.000E+02 years

Water Dependent Pathways

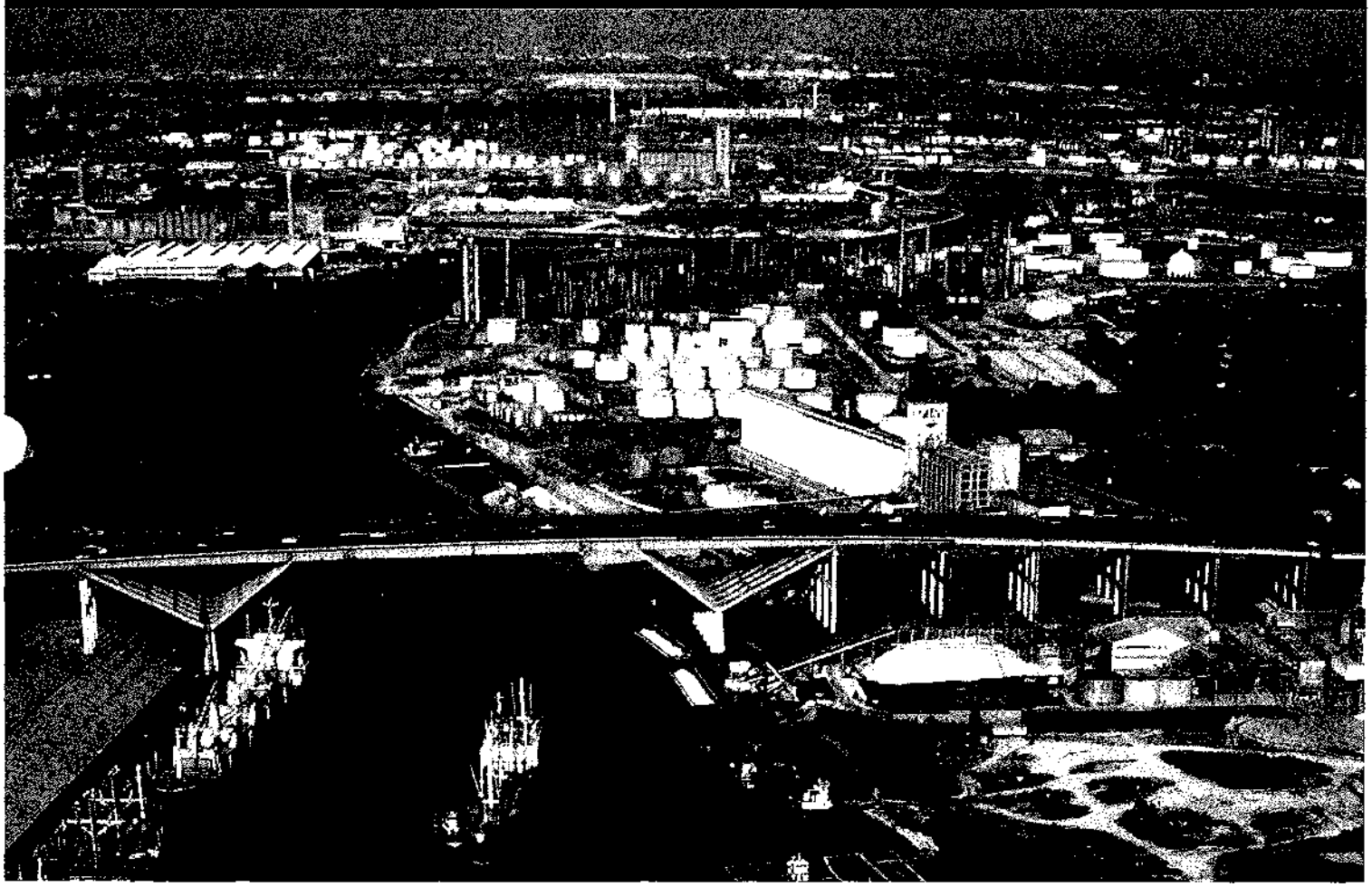
Radio-Nuclide	Water risk	Water fract.	Fish risk	Fish fract.	Radon risk	Radon fract.	Plant risk	Plant fract.	Meat risk	Meat fract.	Milk risk	Milk fract.	All pathways risk	All pathways fract.
Pb-210	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	6.228E-21	0.0000
Ra-226	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	5.000E-10	0.9478
Th-230	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.623E-11	0.0497
U-234	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.354E-14	0.0000
U-238	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.279E-12	0.0024
Total	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	5.275E-10	1.0000

***CNRS1(i,p,t) includes contribution from decay daughter radionuclides

ATTACHMENT C

COMPANY ANNUAL REPORTS FOR 2001, 2002, AND 2003

PROVEN LEADERSHIP FOR A COMPLEX WORLD



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CLEAN HARBORS | ANNUAL REPORT

ABOUT CLEAN HARBORS

Clean Harbors, Inc. is North America's leading provider of environmental and hazardous waste management services. With an unmatched infrastructure of 48 waste management facilities, including nine landfills, five incineration locations and seven wastewater treatment centers, the Company provides essential services to more than 30,000 customers, comprising a majority of the Fortune 500, thousands of smaller private entities and numerous governmental agencies.

Headquartered in Braintree, Massachusetts, Clean Harbors has more than 100 locations strategically positioned throughout North America in 36 U.S. states, six Canadian provinces, Mexico and Puerto Rico.

LETTER FROM THE PRESIDENT

The year 2003 was an eventful one for Clean Harbors. We completed the integration of Safety Kleen's Chemical Services Division (CSD), an organization more than twice our size. We streamlined and refocused our combined operations taking costs out of the business and improving the utilization of our expanded asset infrastructure.

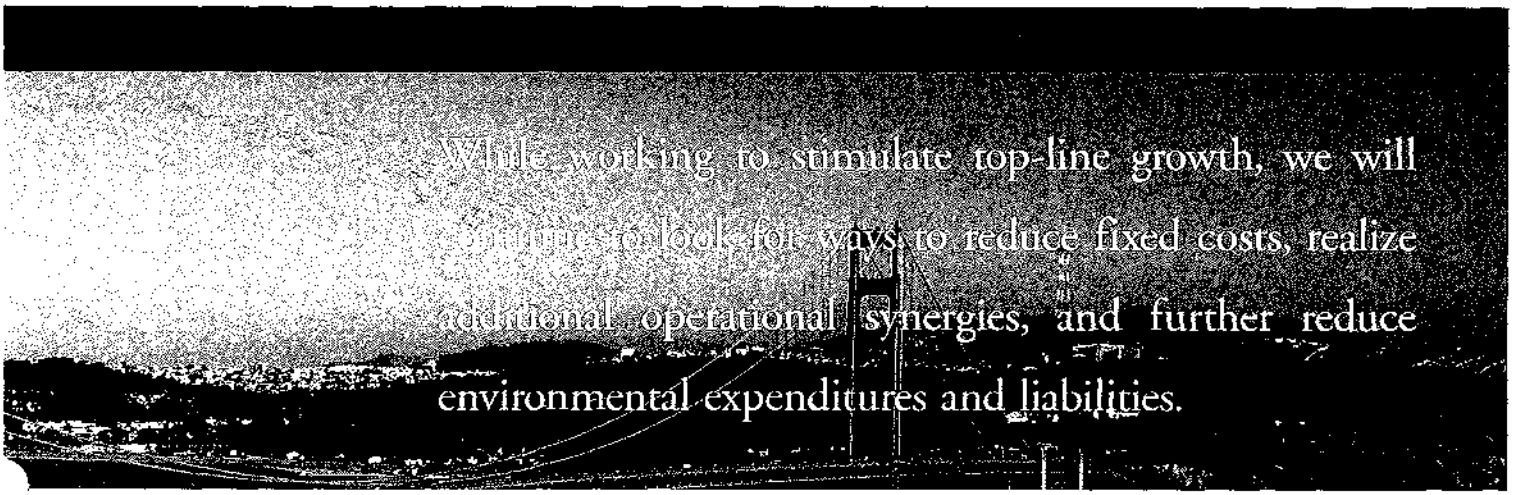
We also conducted the largest emergency response project in Clean Harbors' history, cleaning up a significant oil spill in Buzzards Bay near Cape Cod, Massachusetts. This project involved the efforts of hundreds of Clean Harbors employees over a span of three months. Our outstanding performance earned us recognition that reinforced the Clean Harbors brand and underscored our strength as the industry's premier company for emergency response work.

From an operational perspective, we completed several initiatives in an effort to right-size the company. Our initiatives included a significant reduction in the size of our workforce, innovative health care cost controls, and greater internalization of our waste volumes. We also reduced the Company's assumed environmental liabilities. We implemented a new accounting standard, completed purchase accounting, made decisions to utilize additional landfill airspace, and resolved, managed or deferred certain liabilities. These actions resulted in a $22 million net reduction of our environmental liabilities from $205 million to $183 million.

The progress we made in 2003 required hard work and considerable sacrifice on the part of each and every employee. Furthermore, what we achieved in 2003 was accomplished in a continued weak economic environment. Not only did industries in the United States and Canada generate less waste, they continued to delay their discretionary environmental spending in anticipation of a more favorable business climate. The resulting shortfall impacted Clean Harbors' landfill, wastewater and incinerator volumes, making it difficult to maintain satisfactory utilization rates at these facilities. Our distributor and environmental service providers faced the same pressures.

However, despite the soft economy in 2003, we utilized our resources to position the company for future growth. Our cost reduction efforts and growth initiatives that we undertook created momentum as 2004 began. The network of service locations, facilities and sizeable customer base we acquired in late September 2002 created a broad North American footprint for Clean Harbors. These new assets position us to expand all of our services.

The geographic regions we now serve present us with excellent opportunities to expand our Site Services business. In addition, we have successfully attracted customers for both Site Services and Technical Services in key vertical markets. The centerpiece of this effort is an ongoing initiative to improve the Company's ability to work cross-functionally in sales, marketing and operations within these regions and the industries we serve.



There are several areas where we expect waste volumes to rise in tandem with demand for environmental services as the economy improves. The industry's response to the stricter federal Maximum Achievable Control Technology (MACT) standards has changed the landscape in ways that should be favorable for Clean Harbors. We anticipate that, as the September 2004 deadline for MACT compliance approaches, large waste producers that operate their own incinerators will find outsourcing a more viable option than meeting the new regulatory standards themselves. Clean Harbors will be positioned to capture this outsourcing business because of its commitment to achieve MACT compliance at every Clean Harbors incineration facility, investing more than $20 million in our Deer Park, Texas plant alone.

Another growth opportunity is the pursuit of large site remediation projects. We expect activity in this market to increase in 2004 as site work that was put on budgetary hold for the past two years begins to receive funding.

While working to stimulate top-line growth, we will continue to look for ways to reduce fixed costs, realize additional operational synergies, and further reduce environmental expenditures and liabilities. We will continue working to internalize our waste streams and transportation operations, and investigating opportunities to reduce our capital costs.

After years of industry consolidation and change in the North American hazardous waste and environmental services industry, today only five major companies remain in business. This number is in sharp contrast to the 1990's when there were 23 significant competitors. Our proven leadership in a complex world has resulted in Clean Harbors becoming the largest hazardous waste disposal company in North America.

Clean Harbors begins 2004 in an excellent position to improve its operational and financial performance. As the stronger economy drives growth in demand for hazardous waste industry services, Clean Harbors, with its unmatched capabilities, will answer the call. Clean Harbors intends to capitalize on the unlimited opportunities that exist throughout North America. This is an exciting time for the Company and I'm confident in our ability to take on the challenges for a successful 2004.

On behalf of the entire Clean Harbors team, I would like to thank you for your continued support.

Sincerely,
Alan S. McKim

Chairman, President and Chief Executive Officer
Clean Harbors, Inc.
March 31, 2004

CHEMICAL

UTILITIES

ENVIRONMENTAL SERVICES PROVIDERS

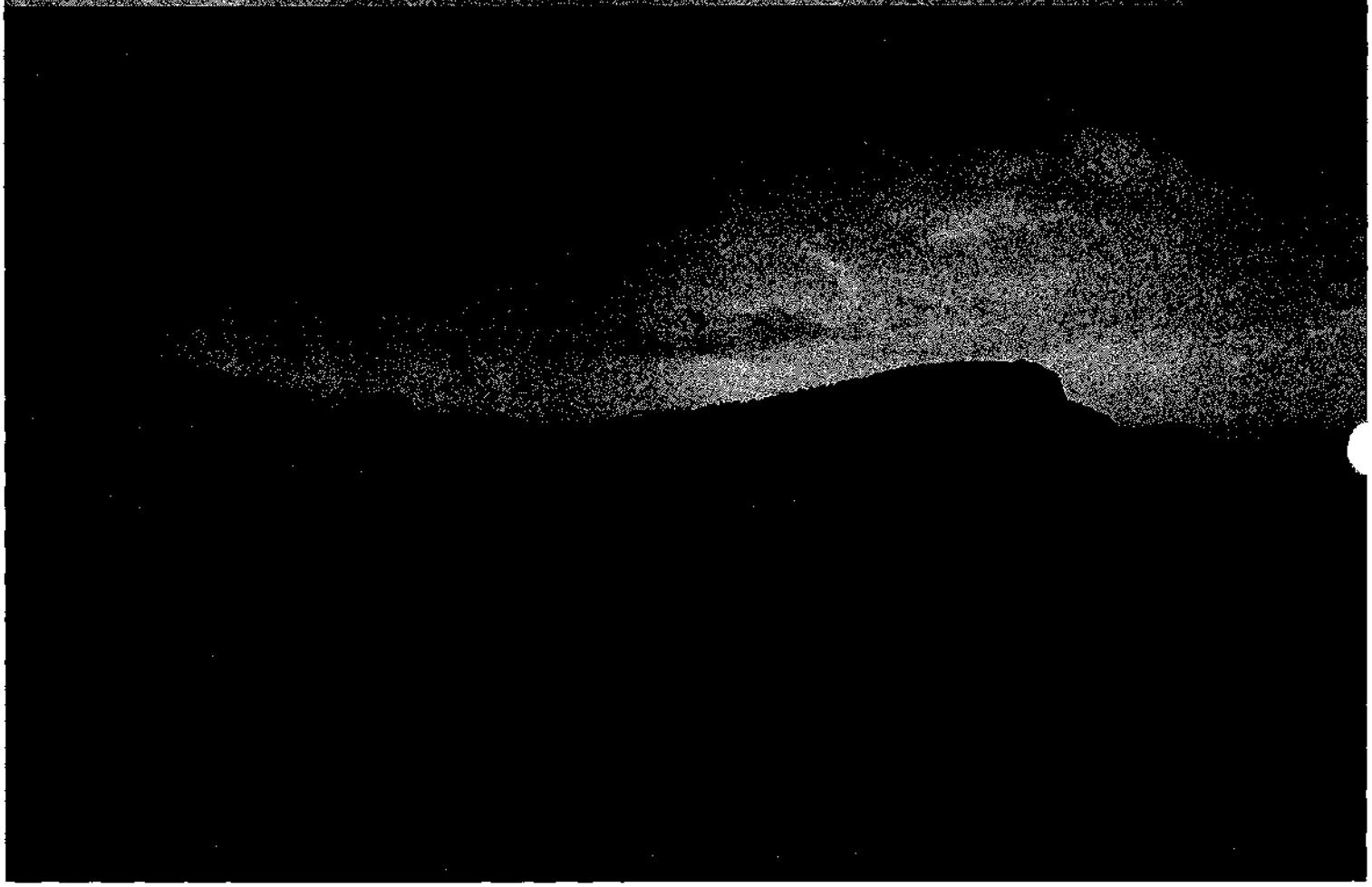
PETROLEUM REFINING

MAKING A DIFFERENCE IN YOUR WORLD.

PHARMACEUTICAL

ELECTRICAL EQUIPMENT

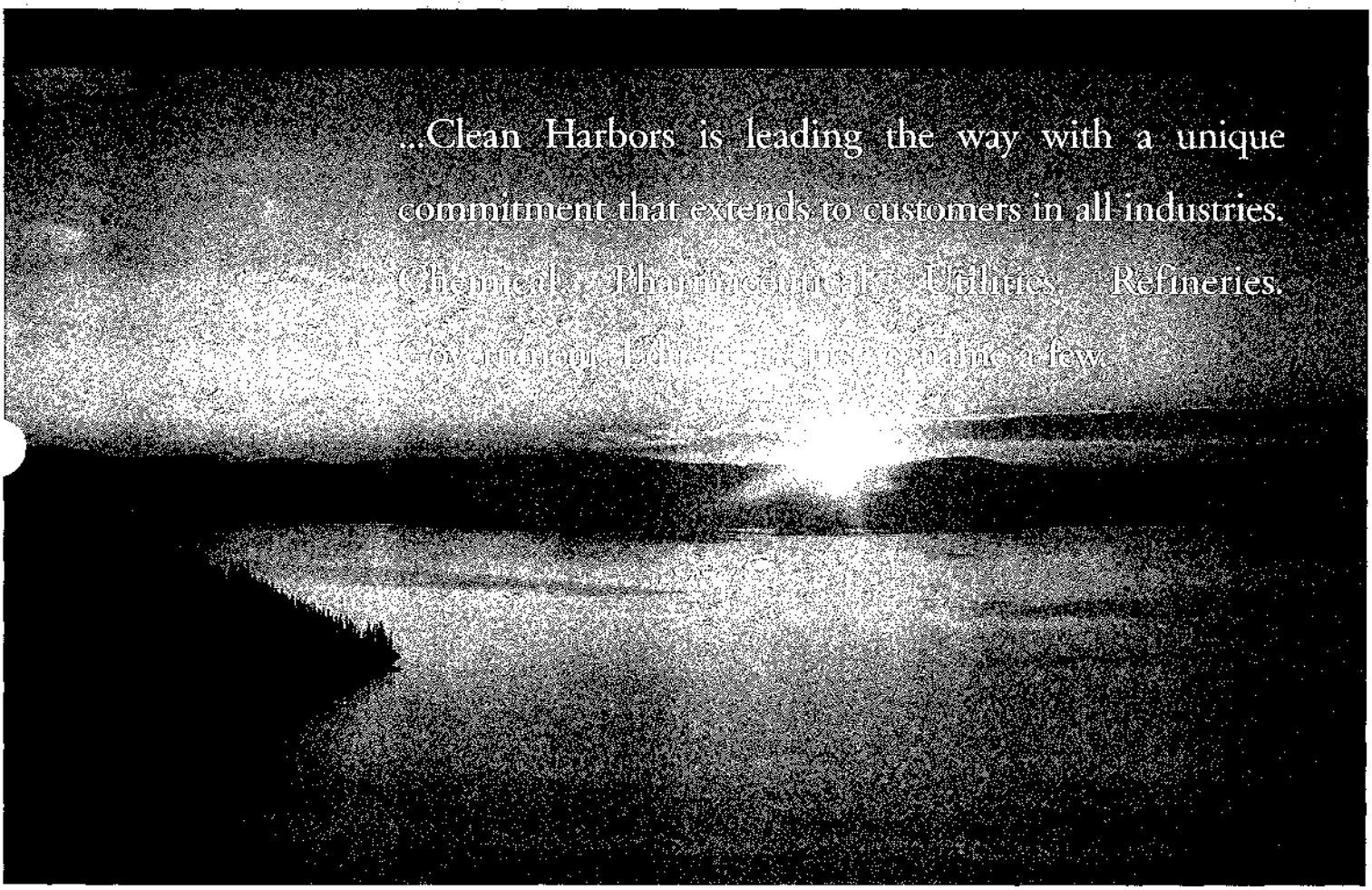
STATE / PROVINCIAL GOVERNMENTS



So, how important is environmental management to you? While most people might consider recycling or the safe handling of hazardous and non-hazardous waste as valuable services, they may not realize the full effect an environmental services company can have on their day-to-day lives.

Especially when it's a company with the experience, expertise, resources and vision of Clean Harbors.

The business of environmental management is evolving... and Clean Harbors is leading the way with a unique commitment that extends to customers in all industries, **Chemical. Pharmaceutical. Utilities. Refineries. Government. Education.** just to name a few.



By developing customer-centric solutions – supported by one of the largest, most trusted service organizations in North America – Clean Harbors not only addresses specific environmental concerns, but works with customers to improve their overall operation. We've been counted on to help reduce liability costs, increase employee productivity and streamline operating expenses.

For more than two decades, Clean Harbors has prided itself on quick response, strict health and safety compliance, and successful results. A renowned reputation for bringing together the best people and technology has enabled Clean Harbors to expand, both internally and through strategic acquisitions.

Today, Clean Harbors is widely recognized as **the premier provider of environmental services and solutions**. We're able to respond to a customer need at a moment's notice, while satisfying all regulatory requirements.

Our focus on delivering comprehensive Technical and Site Services to a full range of fast-growing industries – using the latest technologies and best-practice methods – allows us to meet our customers' needs, and, in many cases, *their* customers' needs as well.

The result is a positive, far-reaching impact that can be felt just about everywhere . . . as you'll see on the following pages.

THROUGHOUT THE HOUSEHOLD, YOU'LL FIND US...

FEDERAL GOVERNMENTS

ENGINEERING AND CONSULTING

AIRCRAFT MFG/ENGINES AND PARTS

EDUCATIONAL SERVICES

HEAVY CONSTRUCTION/EXCAVATION

TRANSPORTATION

MUNICIPALITIES

MACHINERY

FABRICATED METAL PRODUCTS

INSTRUMENTS/PRECISION PRODUCTS

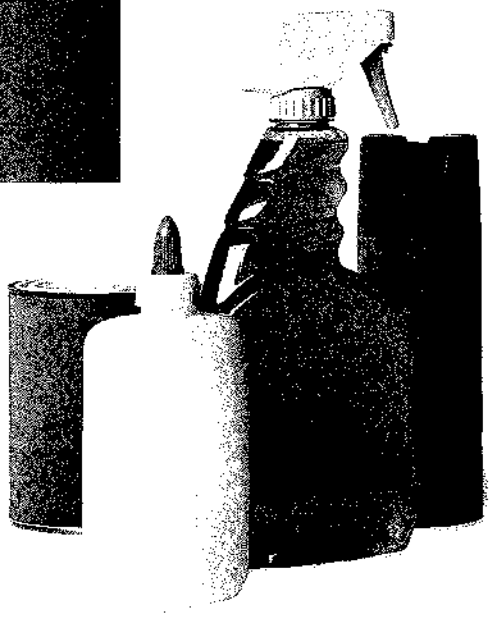
STEEL AND PRIMARY METAL PRODUCTS

AUTOMOTIVE

PAPER, LUMBER AND WOOD

HEALTH SERVICES

Working hand-in-ha
plant's environmental
Clean Harbors Apo
customized waste m
ensuring complete co
cost-effective handlin



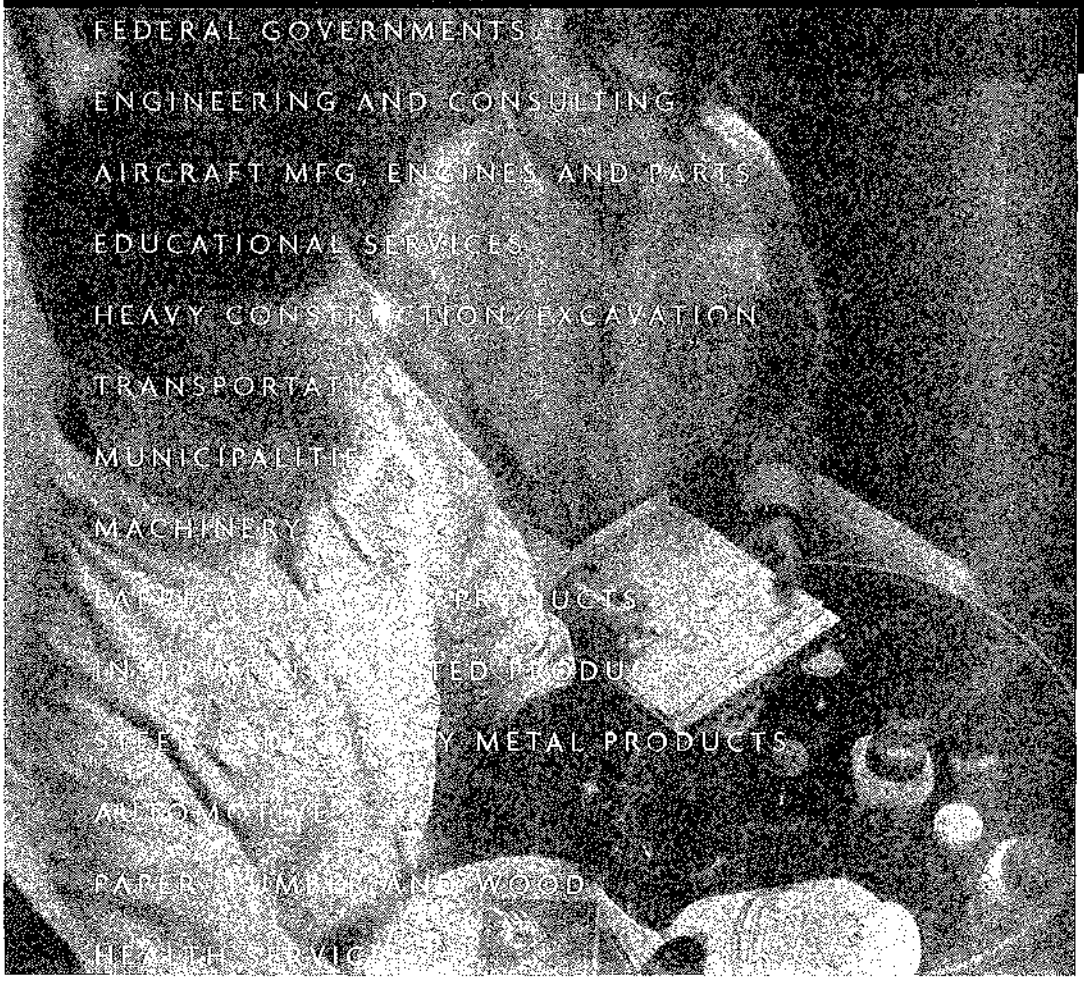
nd with a chemical manager, an on-site llo team provides a anagement program mpliance and the most g of waste for disposal.

the industry. And since Clean Harbors provides a true end-to-end solution where there are no third parties involved, we keep costs and liability down.

Because of our single-source capabilities, many chemical companies turn to us to manage their entire environmental program. Our consultants work in tandem with the customer to not only provide proper transportation and disposal, but also identify ways to improve waste management and further reduce costs.

What does this mean to you? It helps ensure that the household products you rely on were manufactured to the highest quality standards.

IN THE PURSUIT OF A CURE, YOU'LL FIND US...



A pharmaceutical co
of developing a bre
—moves into a new
than expected thank
fast and safe han
between the two sites

mpany—on the brink
akthrough medicine
ıb four weeks earlier
s to Clean Harbors'
dling of chemicals

For a pharmaceutical company's R&D efforts, Clean Harbors plays a most significant role. It's in these labs that a wide range of chemicals must be properly handled for disposal or, in some cases, transported to other laboratories. Time and safety are of the essence and our **CleanPack**™ Service delivers.

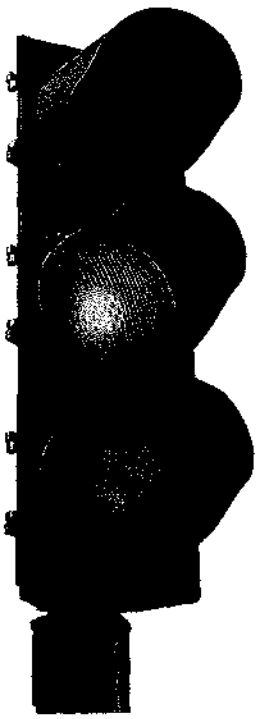
Our highly trained chemists– well-versed in chemical recognition and compatibility– –go right to the lab site where they collect, identify, label and package chemical waste into approved containers. A Clean Harbors vehicle then transports the containers to one of our nearby disposal facilities. Labs can continue their critical work as needed during this service.

Through our CleanPack Service, we move entire chemical inventories in laboratories to new buildings, with minimal disruption to their overall research.

What does this mean to you? With an assist from Clean Harbors, pharmaceutical companies can devote more time to developing the medicines that keep people healthy.

WHERE THE LIGHTS SHINE BRIGHT, YOU'LL FIND US...

A utility company—
hurricane—is able to
in a city due, in part,
field crew that ensure

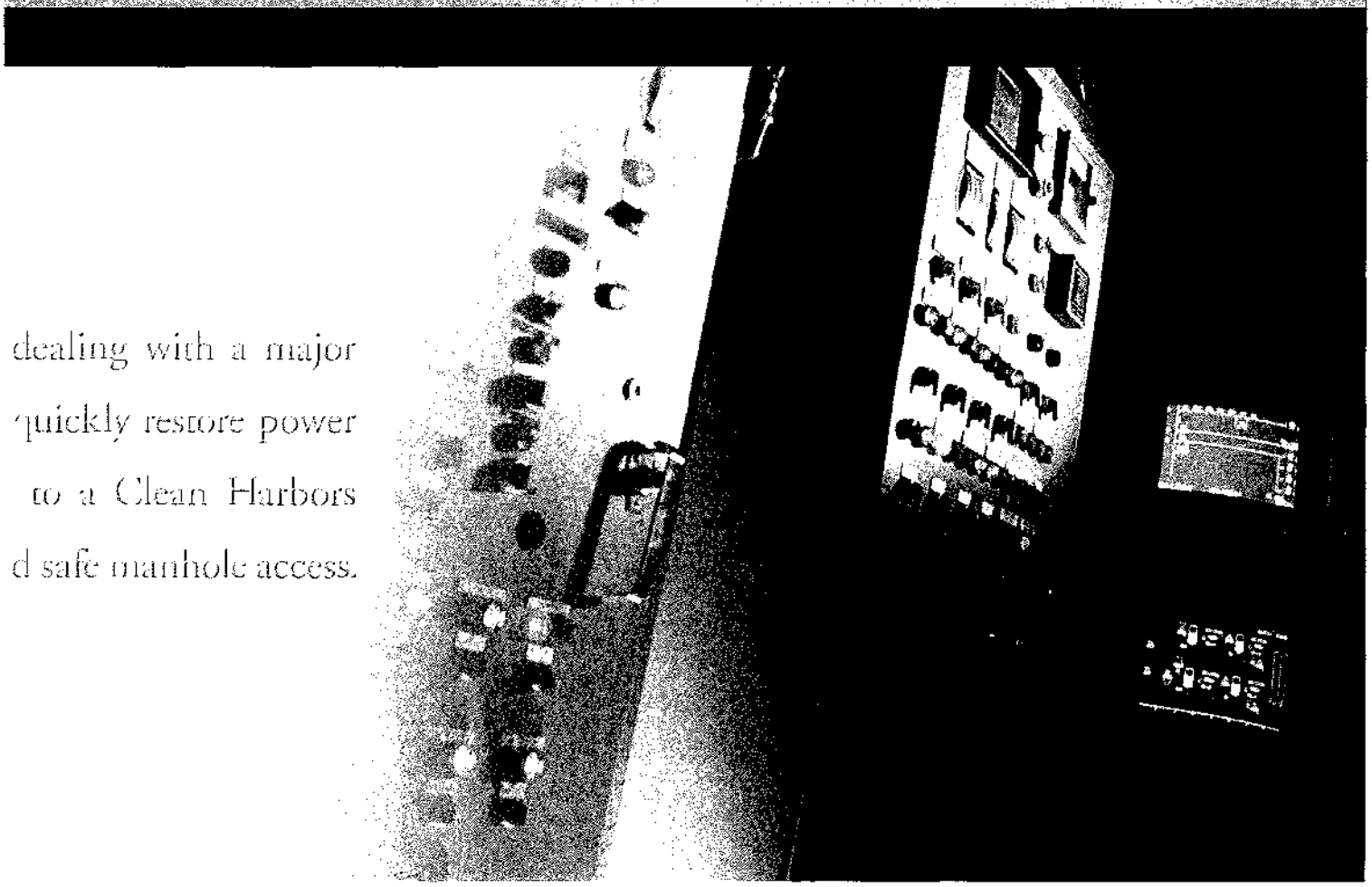


dealing with a major

quickly restore power

to a Clean Harbors

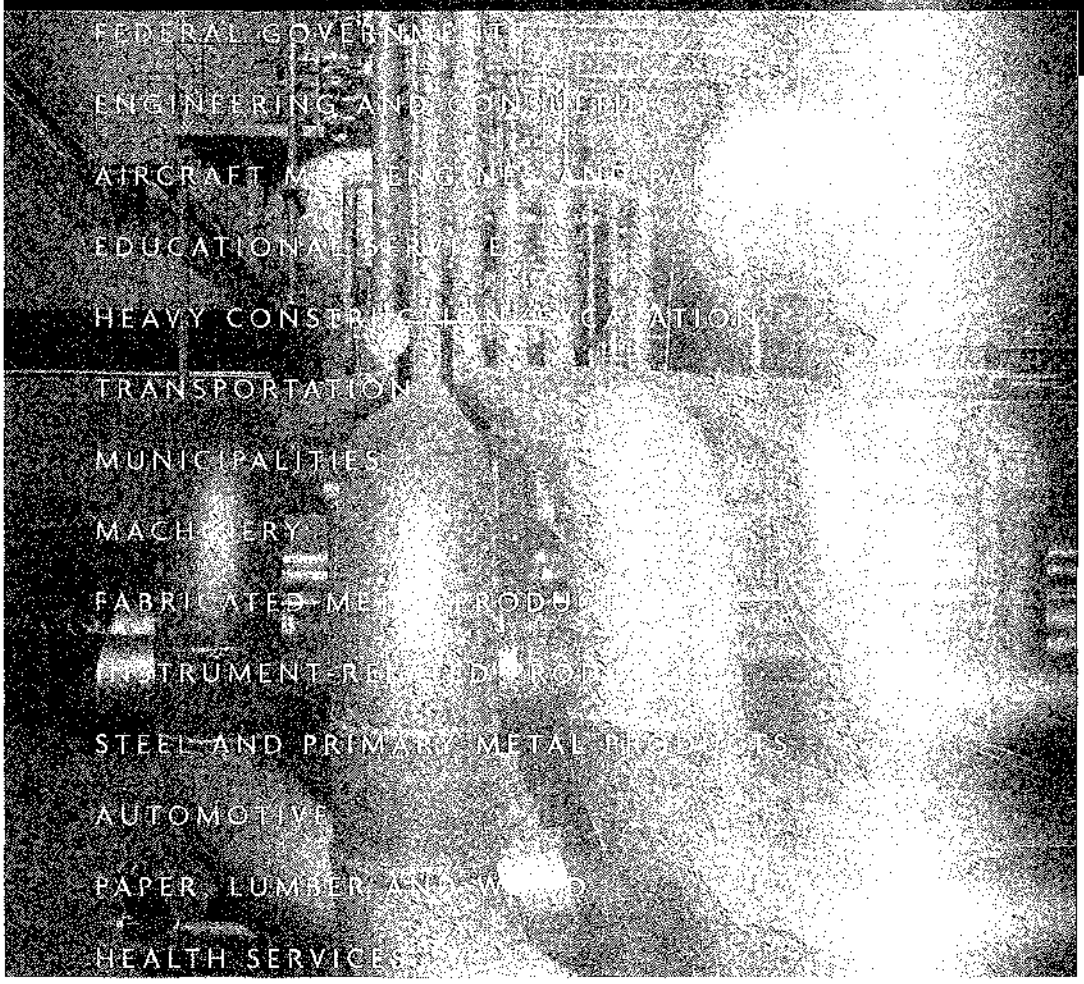
d safe manhole access.



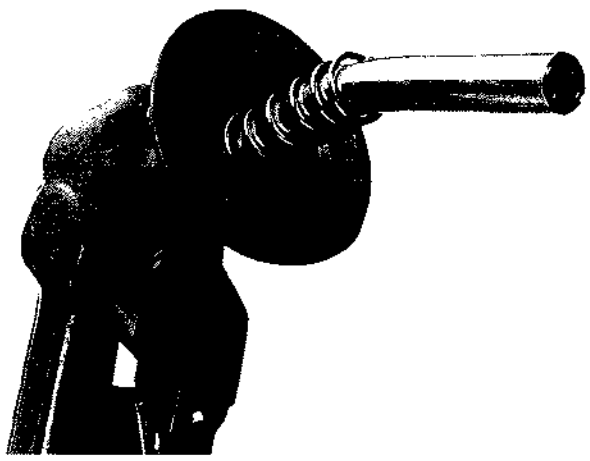
Regardless of location, we can dispatch crews and equipment on a planned or emergency basis to perform services such as confined space entry, site decontamination, large remediation projects, selective demolition, spill clean up, manhole cleanouts and vacuum services. This is particularly valuable when unforeseen weather-related catastrophes arise. When electric and phone service can hang in the balance for millions of people, it's reassuring for utilities to know that Clean Harbors is available at a moment's notice to assist their own crews in restoring power anywhere, under any conditions.

What does it mean to you? By relying on Clean Harbors to provide environmental services, utilities can better focus on the services they provide to the masses.

AT THE HEART OF EVERY PUMP, YOU'LL FIND US...



By using Clean Har
processing during
maintenance, a refin
the volume of waste,
overall efficiency and



bors' on-site material

large-scale tank

ery is able to reduce

greatly improving its

production.

More and more refineries are also heavily relying on Clean Harbors' **Industrial Services** to provide, among other things, hydroblasting and on-site material processing.

Our hydroblasting experts combine optimum pressure and flow rates with specialty tooling to clean any size diameter piping and effectively remove harmful deposits that can impede or clog the system. Again, this kind of outsourced maintenance means the refinery can continue to focus on production.

The same goes for our on-site cleaning of large tanks and surface impoundments. For example, when hazardous sludge needs to be removed from storm water tanks, we deliver a complete solution. Our team will test, remove and dispose of the waste, as well as thoroughly clean and decontaminate the tank and its surrounding area. Advanced equipment like a mobile thermal desorbtion unit as well as specialized dredging and dewatering machines will help process the sludge and reduce the overall volume. This saves the refinery a substantial amount on transportation and disposal costs.

When a refinery is pumping out nearly one million barrels of crude oil a day, such a service is essential to streamlining expenses and maximizing production.

What does this mean to you? It means that refineries can maintain optimum production levels to ensure the flow of heating oil to heat your home, or gasoline to drive your car.

Selected Financial Data

For the Year Ended December 31 (in thousands except per share amounts)

Income Statement Data	2003	2002	2001	2000	1999
Revenues	$ 610,969	$ 350,133	$ 251,601	$ 233,466	$ 202,965
Cost of revenues	453,206	252,213	178,085	166,303	149,637
Selling, general and administrative expenses	108,145	61,518	43,727	41,610	36,661
Accretion of environmental liabilities	11,114	1,199	—	—	—
Depreciation and amortization	26,482	15,508	11,113	10,656	9,501
Restructuring	(124)	750	—	—	—
Other acquisition costs	—	5,406	—	—	—
Income from operations	12,146	13,539	18,676	14,897	7,166
Other income (expense)	(379)	129	—	—	—
Loss on early extinguishment of debt	—	(24,658)	—	—	—
Interest (expense), net	(23,724)	(13,414)	(10,724)	(9,795)	(9,128)
Income (loss) before provision for income taxes and cumulative effect of change in accounting principle	(11,957)	(24,404)	7,952	5,102	(1,962)
Provision for (benefit from) income taxes	5,322	3,787	2,412	(2,016)	282
Income (loss) before cumulative effect of change in accounting principle	(17,279)	(28,191)	5,540	7,118	(2,244)
Cumulative effect of change in accounting principle	66	—	—	—	—
Net income (loss)	(17,345)	(28,191)	5,540	7,118	(2,244)
Dividends and accretion on preferred stock	3,287	1,291	448	448	448
Net income (loss) attributable to common shareholders	$ (20,632)	$ (29,482)	$ 5,092	$ 6,670	$ (2,692)
Basic earnings (loss) per share:					
Income (loss) before cumulative effect of change in accounting principle	$ (1.52)	$ (2.42)	$ 0.45	$ 0.60	$ (0.25)
Cumulative effect of change in accounting principle, net of income taxes	—	—	—	—	—
Net income (loss) attributable to common shareholders	$ (1.52)	$ (2.42)	$ 0.45	$ 0.60	$ (0.25)
Diluted earnings (loss) per share:					
Income (loss) before cumulative effect of change in accounting principle	$ (1.52)	$ (2.42)	$ 0.40	$ 0.59	$ (0.25)
Cumulative effect of change in accounting principle, net of income taxes	—	—	—	—	—
Net income (loss) attributable to common shareholders	$ (1.52)	$ (2.42)	$ 0.40	$ 0.59	$ (0.25)
Weighted average number of common shares outstanding	13,553	12,189	11,404	11,085	10,649
Weighted average common shares outstanding plus potentially dilutive common shares	13,553	12,189	12,676	11,305	10,649
Financial Data:					
Working capital	$ (17,958)	$ 24,899	$ 10,529	$ 16,421	$ 14,565
Goodwill	$ 19,032	$ 19,032	$ 19,032	$ 19,799	$ 20,566
Total assets	$ 540,159	$ 599,690	$ 156,958	$ 149,568	$ 145,247
Long-term obligations, less current portion	$ 150,621	$ 156,245	$ 49,410	$ 65,322	$ 73,497
Redeemable preferred stock	$ 15,631	$ 13,543	$ —	$ —	$ —
Stockholders' equity	$ 9,313	$ 21,782	$ 49,569	$ 41,635	$ 34,171

No cash dividends have been declared on our common stock.

Shareholder Information

Form 10-K
Copies of the Company's Annual Report on Form 10-K for the fiscal year ended December 31, 2003, filed with the Securities and Exchange Commission on March 15, 2004, may be obtained without charge online at www.cleanharbors.com or by writing to the Company at
1501 Washington Street
P.O. Box 859048
Braintree, MA 02185-9048
Attention: Investor Relations
781.849.1800 ext. 4491

Annual Meeting
9:00 a.m. May 14, 2004
Fleet Conference and Training Center, Seventh Floor
The Berkeley Room
One Federal Street
Boston, MA 02110

Auditors
PricewaterhouseCoopers LLP
One International Place
Boston, MA 02110

Clerk of the Corporation
C. Michael Malm, Esq.
Davis, Malm & D'Agostine, P.C.

Corporate Counsel
Davis, Malm & D'Agostine, P.C.
One Boston Place
Boston, MA 02108

Transfer Agent
American Stock Transfer & Trust Company
40 Wall Street
New York, NY 10005
800.937.5449

Corporate Headquarters
Clean Harbors Environmental Services, Inc.
1501 Washington Street
P.O. Box 859048
Braintree, MA 02185-9048
781.849.1800
www.cleanharbors.com

Clean Harbors is an Affirmative Action/Equal Opportunity Employer.

Stock Listing

The Company's common stock began trading publicly in the over-the-counter market on November 24, 1987 and was included in the NASDAQ National Market System effective December 1, 1987. The Company's common stock trades on the NASDAQ Stock Market under the symbol CLHB. The following table sets forth the high and low sales prices of the Company's common stock for the indicated periods as reported by NASDAQ.

On March 4, 2004, there were 585 holders of record of the Company's common stock excluding stockholders whose shares were held in nominee name. The Company estimates that approximately 4,200 additional stockholders held shares in street name on that date.

The Company has never declared nor paid any cash dividends on its common stock and the Company is prohibited under its loan agreements from paying dividends on its common stock.

2003	*High*	*Low*	*2002*	*High*	*Low*
First Quarter	$16.52	$8.94	First Quarter	$11.80	$8.02
Second Quarter	15.03	8.95	Second Quarter	15.66	6.96
Third Quarter	9.88	4.25	Third Quarter	12.35	6.60
Fourth Quarter	9.75	3.25	Fourth Quarter	17.82	7.90

Safe Harbor Statement

Any statements contained herein that are not historical facts are forward-looking statements within the meaning of the Private Securities Litigation Reform Act of 1995 and involve risks and uncertainties. These forward-looking statements are generally identifiable by use of the words "believes," "expects," "intends," "anticipates," "plans to," "estimates," "projects," or similar expressions. These forward-looking statements are subject to certain risks and uncertainties that could cause actual results to differ materially from those reflected in the forward-looking statements. Readers are cautioned not to place undue reliance on these forward-looking statements, which reflect management's opinions only as of the date hereof. The Company undertakes no obligation to revise or publicly release the results of any revision to these forward-looking statements.

A variety of factors beyond the control of the Company affect the Company's performance including, but not limited to:

- The effects of general economic conditions in the United States, Canada and other territories and countries where the Company does business;
- The effect of economic forces and competition in specific marketplaces where the Company competes;
- The possible impact of new regulations or laws pertaining to all activities of the Company's operations;
- The outcome of litigation or threatened litigation or regulatory actions;
- The effect of commodity pricing on overall revenues and profitability;
- The effects of the embedded derivative on the Company's preferred stock on earnings per share;
- Possible fluctuations in quarterly or annual results or adverse impacts on the Company's results caused by the adoption or implementation of new accounting standards or interpretations of regulatory rules and regulations;
- The effect of weather conditions or other aspects of the forces of nature on field or facility operations;
- The effects of industry trends in the environmental services and waste handling marketplaces;
- The effects of conditions in the financial services industry on the availability of capital and financing;
- The Company's ability to successfully complete the integration of the CSD acquisition which became effective in September 2002 and to manage the significant environmental liabilities which it assumed in connection with the acquisition; and
- The availability and costs of liability insurance and financial assurance required by governmental entities relating to our facilities.

Any of the above mentioned and numerous other factors may adversely impact the Company's financial performance. Additional information on the potential factors that could affect the Company's actual results of operations is included in its filings with the Securities and Exchange Commission, including but not limited to its Form 10-Q for the quarter ended September 30, 2003 and its Annual Report on Form 10-K, more specifically and specifically Item 7, for the fiscal year ended December 31, 2003 filed with the SEC on March 15, 2004.

PROVEN LEADERSHIP FOR A COMPLEX WORLD

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Directors

Alan S. McKim
President, Chief Executive Officer and Chairman of the Board, Clean Harbors, Inc.

John D. Barr
President and Chief Executive Officer, Automotive Performance Industries

John P. DeVillars
Director of Business Development, BlueWave Strategies, LLC

Daniel J. McCarthy
Professor of Strategic Management, Northeastern University

John R. Preston
President and Chief Executive Officer, Atomic Ordered Materials

John F. Kaslow
Consultant to the Energy Industry

Thomas J. Shields
President and Managing Director, Shields & Co.

Lorne R. Waxlax
Former Executive Vice President, The Gillette Company

Officers

Alan S. McKim
Chairman, President and Chief Executive Officer*

Eugene A. Cookson
President Site Services**

Mark S. Burgess
Executive Vice President and Chief Financial Officer*

Stephen H. Moynihan
Senior Vice President— Strategy and Development*

William J. Geary, Esq.
Executive Vice President and General Counsel**

David M. Parry
Senior Vice President— Technical Services**

George L. Curtis
Senior Vice President- Pricing and Proposals**

Eric W. Gerstenberg
Senior Vice President- Disposal Services**

Carl D. Paschetag, Jr.
Vice President, Treasurer and Controller*

William F. O'Connor
Senior Vice President Risk Management**

Michael J. Twohig
Senior Vice President and Chief Information Officer**

Guy R. Adam
Vice President— Canadian Operations

Jerry E. Correll
Senior Vice President— Sales and Marketing**

Anthony Pucillo
Executive Vice President Marketing, Sales and Central Services**

Brain P. Weber
Senior Vice President Central Services**

*Clean Harbors, Inc.
**Clean Harbors Environmental Services, Inc.

Corporate Headquarters
Clean Harbors
Environmental Services, Inc.
1501 Washington Street
PO Box 859048
Braintree, MA 02185-9048
781.849.1800
www.cleanharbors.com

CleanHarbors®
ENVIRONMENTAL SERVICES, INC.

CLEAN HARBORS | ANNUAL REPORT

Dear Fellow Shareholder,

For Clean Harbors, 2002 was a year of intense activity and tremendous accomplishment. Tripling the Company's size by acquiring Safety-Kleen's Chemical Services Division (CSD), we established Clean Harbors as one of North America's largest providers of environmental services and the largest operator of hazardous waste management services in North America—reshaping our industry's competitive landscape in the process. We extended Clean Harbors' geographic reach to every corner of the continent. We increased our penetration in virtually every market segment. And we expanded our customer base to over 30,000, including most of the Fortune 500.

We have completed numerous acquisitions since our founding in 1980, but the purchase of CSD was our largest and most strategic. Against a backdrop of recession and faltering economic recovery, coupled with the difficult environment in the capital markets, the CSD acquisition was by far the most complex and challenging as well. Nonetheless, we were able to secure a total of $280 million in financing to close the transaction.

For the full year, which included CSD for approximately four months, we reported record revenues of $350.1 million. In closing the CSD acquisition, we recorded a $28.7 million extraordinary loss for debt retirement costs plus one-time restructuring and other acquisition-related charges of $6.1 million. This resulted in a net loss for the year of $28.2 million and loss per diluted share of ($2.42). Excluding the extraordinary loss and restructuring and other acquisition charges, net income for the year was $2.6 million.

As a result of the acquisition, we begin our first full year as a combined organization with the industry's strongest asset infrastructure—over 100 service locations including more than 50 waste management facilities in the United States, Canada, Mexico and Puerto Rico—and 4,000 talented employees. Having added CSD's four incineration facilities with six incinerators, we are first in North America in waste-incineration volume with seven incinerators and significant market share. The nine landfill facilities we acquired with CSD provide us with a 25% to 30% share of North America's hazardous waste landfill market. And, with the inclusion of six CSD facilities for wastewater treatment, we are the second largest in this market with a 17% share.

In addition to expanding our scale and market position, the CSD acquisition presents us with the potential to realize numerous operational synergies. Early in the integration process, we were pleasantly surprised by the cultural similarities between Clean Harbors and CSD. These similarities have already made it easier than we had anticipated to share information, increasing our confidence in the quality of the human and physical assets we have acquired while speeding the execution of our integration plan.

That plan calls for realizing integration synergies by trimming overhead, as well as by eliminating redundant waste collection sites, closing sales offices and pruning in other areas. We also expect to realize savings from planned sourcing and increased purchasing power. And from a strategic standpoint, we are confident that, by applying Clean Harbors' industry-leading IT systems and business model, we can generate substantial increases in infrastructure utilization across the Company.

We also plan to leverage our expanded infrastructure in order to internalize waste streams that we have historically outsourced. One of the most gratifying realizations of the integration process is that we have the potential to internalize virtually all of the waste streams of the combined Company—and thus generate greater costs savings and competitive advantage for Clean Harbors. All told, we expect our integration synergies to produce a total savings of $50 million in 2003, with the potential for an additional $35 million in 2004.

Over these two upcoming years, we anticipate seeing more of the changes that have been sweeping across the hazardous waste industry since the new millennium began. The 1990s were characterized by excess capacity throughout the industry, especially within the incineration market. In addition, the 1990s were years in which a slowdown in new governmental regulations and lack of forceful industry leadership tended to depress demand for hazardous waste and environmental services.

Looking forward, the introduction of tougher Maximum Achievable Control Technology (MACT) standards and stricter hazardous waste disposal regulations in Canada promise to accelerate the pace of industry change. Along with everyone in the industry, Clean Harbors will be making substantial investments in meeting the MACT standards. Compliance with MACT is likely to require a number of large waste producers to upgrade their aging facilities. We believe that some of these large waste producers will find an upgrade too costly and instead choose to close their facilities and outsource the handling of their waste.

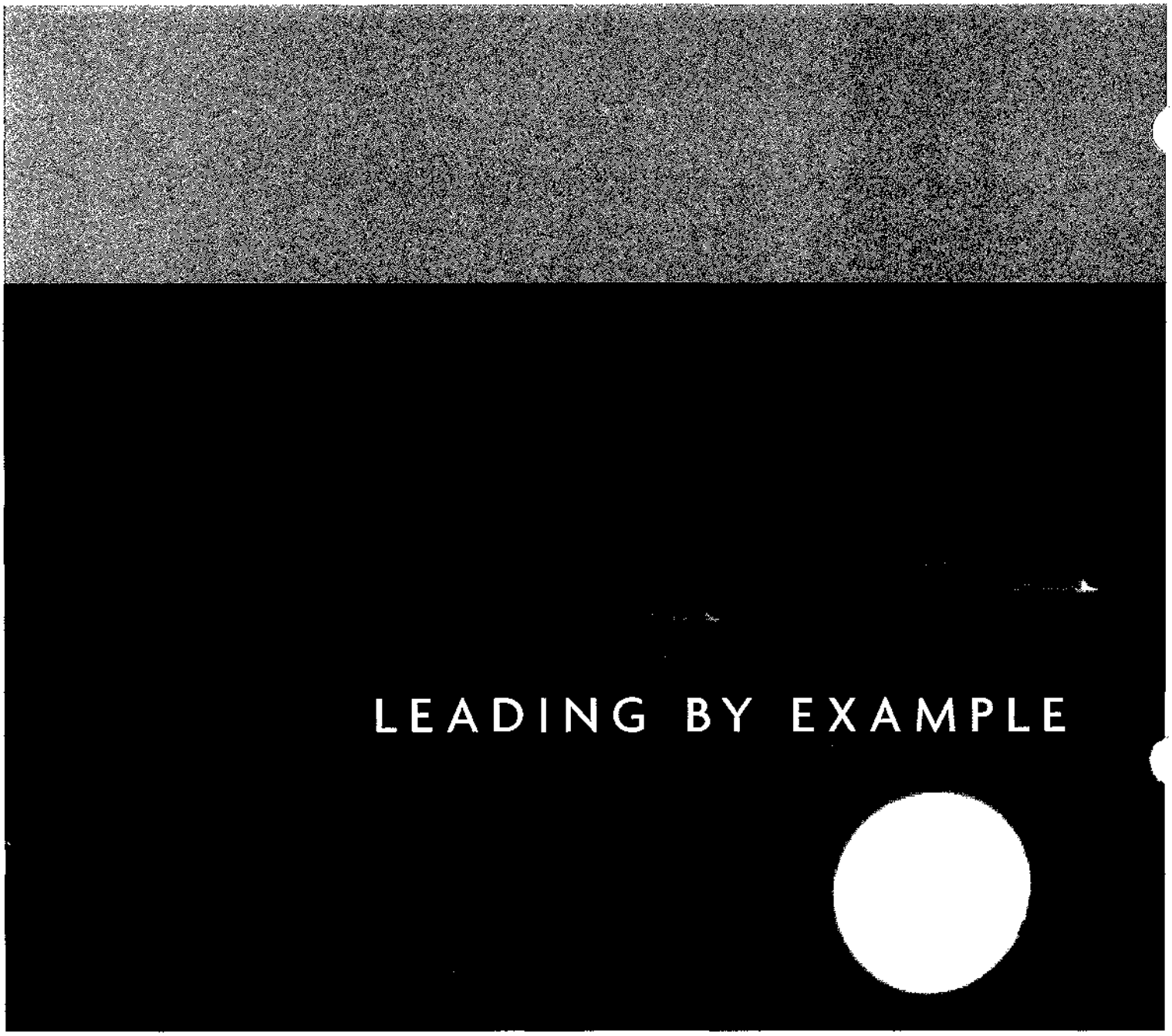
Clean Harbors is in an excellent position to meet this need. We have expanded our infrastructure—and thus, our proximity to customers—at a time when overall capacity has been shrinking. Through the innovative use of our proprietary technology, we have developed an expertise in real-time hazardous waste tracking that truly differentiates our services. For companies that are seeking to manage their environmental responsibilities for greatest security and efficiency, there is no better choice than Clean Harbors.

We will be working to capitalize on our competitive advantages in 2003. Our primary objectives are to expand our Canadian business, rationalize our pricing, and position Clean Harbors to refinance its senior and subordinated debt. We will also continue to enhance our veteran management team—which averages 15 years of industry experience at the senior level—to efficiently manage our much larger Company. At the same time, we expect to achieve growth in all of our service lines while continuing our tradition of excellence in employee health and safety and in regulatory compliance.

Thanks to our customer-oriented culture and the hard work of our combined team of Clean Harbors and CSD employees, we have begun to transform Clean Harbors, as well as the hazardous waste and environmental services industry, for the better. The following pages of this annual report elaborate on our formula for success: strong corporate culture, technology leadership, innovative services and close customer relationships. By continuing to deliver on this formula, we have the potential to further secure the leadership position in our industry and provide our environmental services and solutions to an even stronger and more diverse customer base. With the dedication of our employees, and with your support as shareholders, I am confident that we will accomplish these goals.

Sincerely,
Alan S. McKim

Chairman and Chief Executive Officer
Clean Harbors, Inc.
April 1, 2003



LEADING BY EXAMPLE

At the Forefront in Environmental Management

What makes a leader? In the environmental services industry, true leadership is measured not by revenue or market share, but by the experience, expertise and innovation a company brings to the project. For more than two decades, Clean Harbors has come to embody these attributes, steadily growing in size and reach, yet remaining faithful to its roots of doing whatever is necessary to finish the job right.

In the early '80s, when EPA regulations were forcing chemical manufacturers and petroleum companies to reexamine their business practices, Clean Harbors was able to deliver a powerful combination of responsiveness and government compliance. Over the years, as the focus shifted to offering improved environmental services with an emphasis on cost savings, Clean Harbors again stepped up, embracing the information age and its many possibilities.

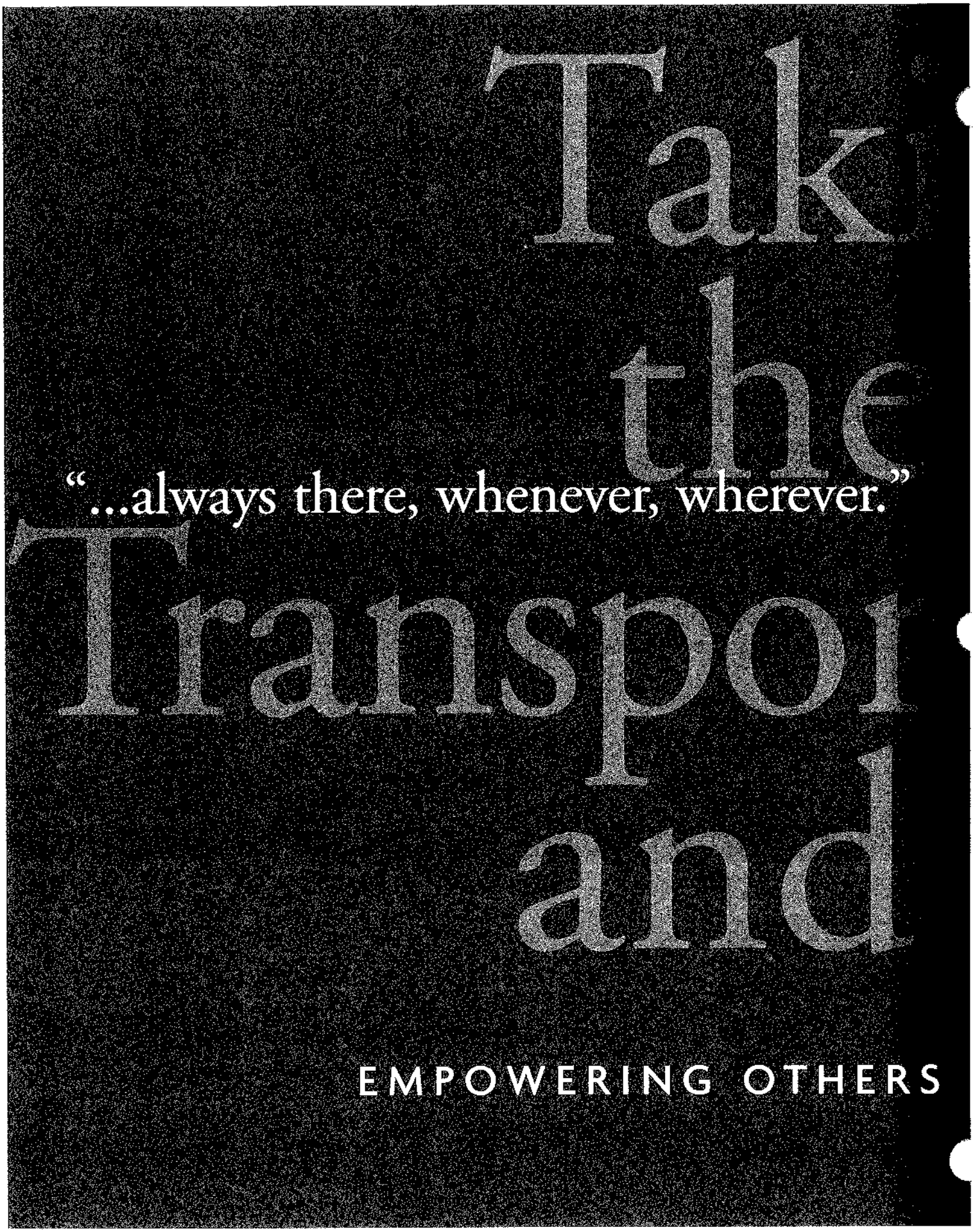
One particular service offering that helps illustrate Clean Harbors' leadership position is its Apollo Program. By bringing technical expertise and resources right to the customer site, Clean Harbors delivers a total waste management solution. Its technicians work in tandem with customers to provide proper waste transportation and disposal, lab chemical packing, industrial cleaning and maintenance, etc. Customers benefit from a safer, more cost-effective and self-sufficient environmental program.

No other company in the industry provides this kind of turnkey solution and it's just one example of Clean Harbors' approach to taking the lead.

Today, Clean Harbors can boast one of the most impressive and expansive operations in North America. Through strategic acquisitions as well as its own in-house advancements in Technical and Site Services, the company has enjoyed considerable success while reshaping the way people think about environmental management.

In an industry not known to produce leaders and visionaries, Clean Harbors certainly has the financial and corporate capabilities to qualify for that role. But, that's not all it takes to be a leader. Talk to any customer or partner who has worked with Clean Harbors and you learn that leadership is defined at a much more personal, much more important level.

The following pages reveal some of their experiences...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TO SUCCEED

EMPOWERING OTHERS TO SUCCEED

"The customer needed a reliable source to handle its complex waste management needs across many locations—while keeping costs and liability in check. Clean Harbors' plan included localized pickup and disposal, plus a single point of contact to always be there, whenever and wherever."

Brenda Roop
Account Manager

TRANSPORTATION AND DISPOSAL

From incineration, waste treatment, recycling and landfill disposal to more specialized services such as fuel blending and explosives management, Clean Harbors provides reliable, cost-effective Transportation and Disposal services to customers across North America.

The Customer: One of the world's leading manufacturers of faucets, cabinets, architectural coatings, locks, and other home improvement and building products.

The Challenge: With several companies located throughout the U.S., the customer needed to consolidate the number of environmental vendors who provided waste transportation and disposal. The ultimate goal was to increase control of the waste stream process, reduce costs and limit liability.

The Solution: Clean Harbors developed a customized waste pickup and disposal program. Leveraging multiple locations in close proximity to the customer's many locations, Clean Harbors was able to cut transportation costs and limit over-the-road liability. The customer's personnel were trained on site, helping it stay in compliance with present and future regulations.

In addition, a single point of contact was assigned to work with the company's environmental manager, providing several services including monthly reports on waste activities for all facilities. Together, they identify ways the customer can improve waste management and further reduce costs.

Clean Harbors' commitment to service was recognized this past year when Clean Harbors won the customer's Supplier Award.

Taking Lead

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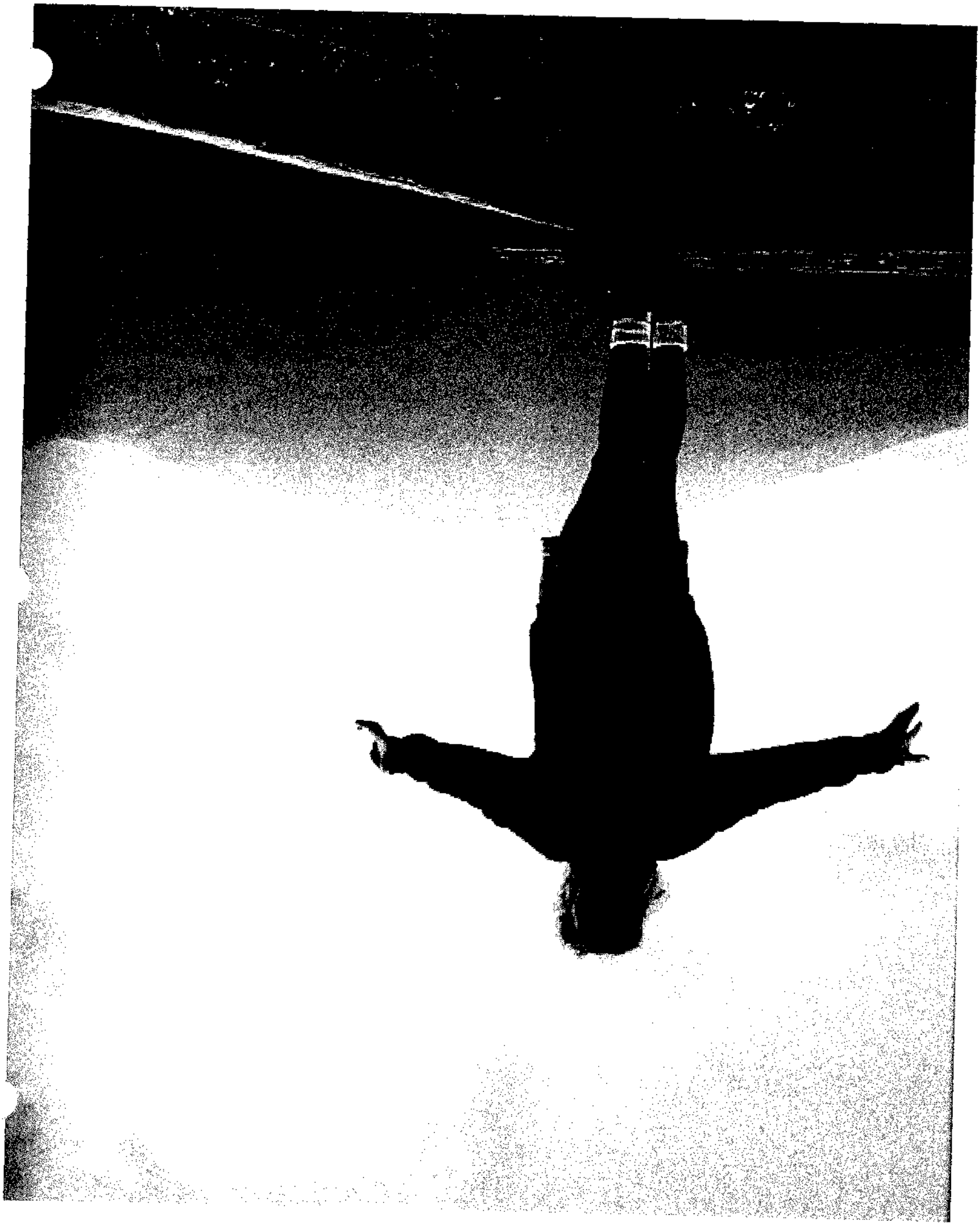
CHANGING WORLD



"The handling of chemicals or chemical waste is a very serious matter, and yet sometimes we also have time constraints working against us. Fortunately, we have the trained people and proven methodologies to tackle the most daunting tasks. Every time."

Pat Kenney
Technical Services
General Manager

LAB CHEMICAL PACKING

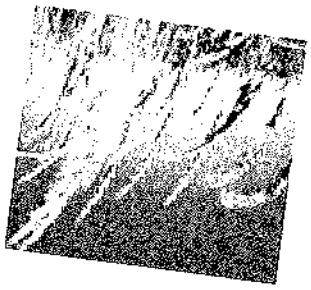
The Customer: A global, multi-billion-dollar pharmaceutical company driving breakthrough developments in the field of medicine.

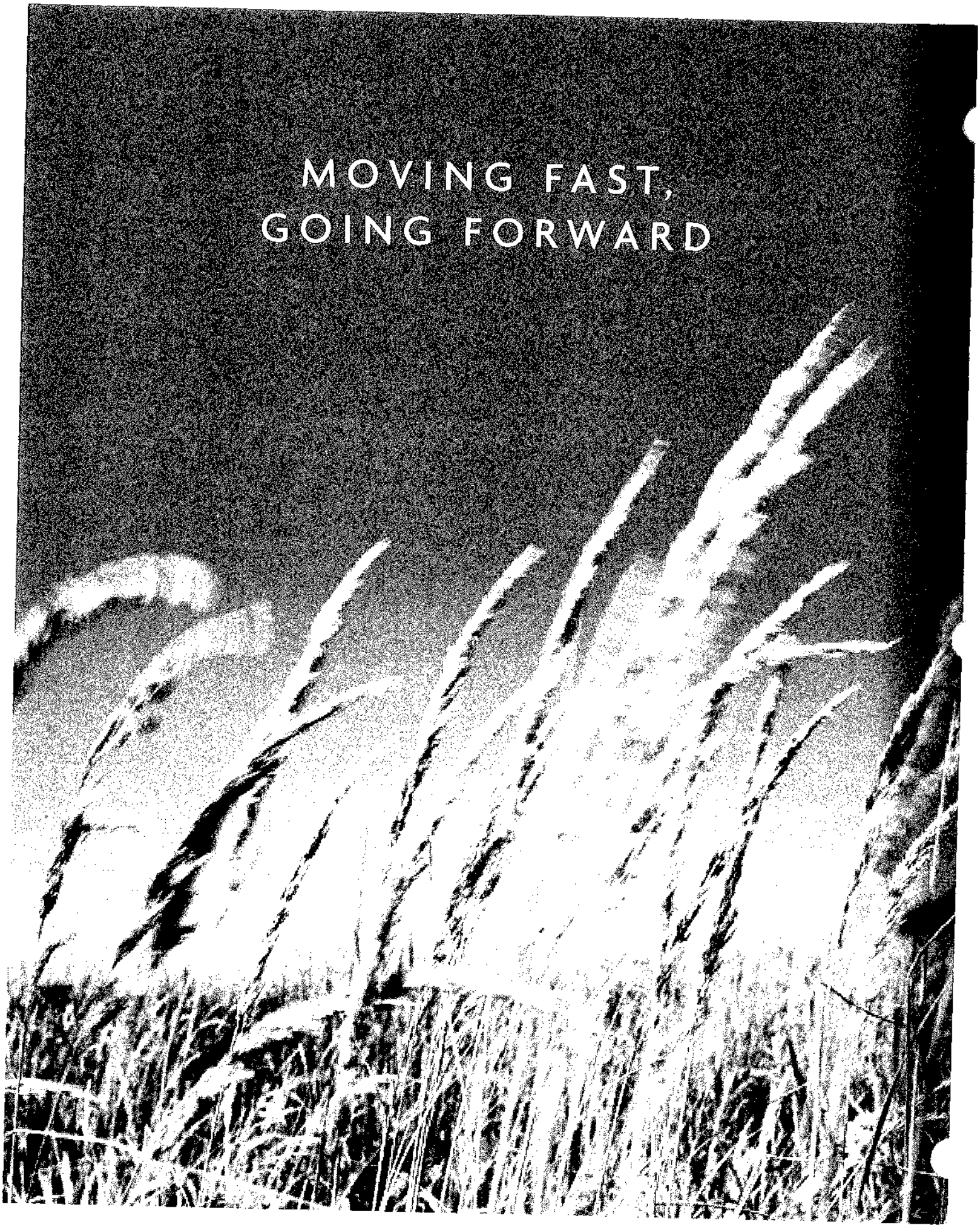
The Challenge: Having just acquired four research and development facilities with more than 600 labs combined, the customer needed to remove all outdated or undesirable chemicals before it could move in and conduct its own valuable research. Time was of the essence. The company required an environmental services company that had the capabilities to categorize, package and remove chemicals (including hazardous materials) as well as clean and decontaminate each lab.

The Solution: With incredible speed and efficiency, Clean Harbors mobilized over 30 specially trained chemists and field technicians to the four facilities to simultaneously handle laboratory moves, decontamination, lab packs, and transportation and disposal. While the logistics were overwhelming—with multiple trucks moving in and out each day and stringent safety procedures being followed to the last detail—Clean Harbors was able to complete the project using its own resources.

Today, Clean Harbors' Apollo team continues to assist the customer on site with chemical packing procedures, ensuring the safest, most efficient operation possible.

With highly trained chemists skilled in chemical recognition and compatibility, Clean Harbors' CleanPack® Service provides for the safe handling, packaging, transportation and disposal of hazardous chemicals.




MOVING FAST,
GOING FORWARD

"Whether the situation calls for us to support their personnel in flood situations or hazardous material spills, or when transformers fail in manholes or at substations, we're committed to being available 24 hours a day, 365 days a year. No exceptions. No excuses."

Howard Alexander
Senior Field Services Account Manager

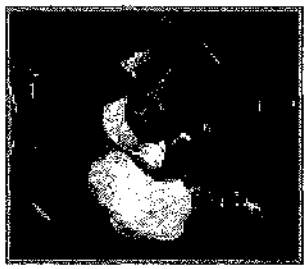
FIELD SERVICES

The Customer: A publicly-traded energy services company, providing electric and gas service to more than two million customers.

The Challenge: With a recent operational expansion, the customer's environmental service needs grew from traditional hazardous waste management and planned environmental service work to emergency spill response, manhole and vault cleaning, and industrial services. The customer was also extending its geographic reach, so it required comprehensive cross-regional environmental capabilities. In addition, the company expected its core business values to be carried forth with any suppliers offering these environmental services.

With a "can-do, hands-on" approach, Clean Harbors' Field Service professionals are dispatched to customer sites all over the country to handle a multitude of projects... quickly and safely.

The Solution: Clean Harbors proposed a comprehensive and customized nationwide program to handle the diverse waste disposal, field service and emergency response needs for all of the customer's operations, anytime, anywhere. This solution provided the customer with the flexibility to use Clean Harbors' extensive environmental experience in a wide range of projects.



Knowing Clean Harbors' trained personnel are available at a moment's notice to respond to any situation—from drum waste pickups and soil excavation to hazardous waste disposal and manhole cleanouts—helps the customer stay focused on the energy business and meeting the day-to-day needs of its ever growing customer base.

How much value do they place on this solution? Enough to recognize Clean Harbors with a Corporate Award for Supplier Excellence.

Talk the Talk

"...they valued that honesty as much

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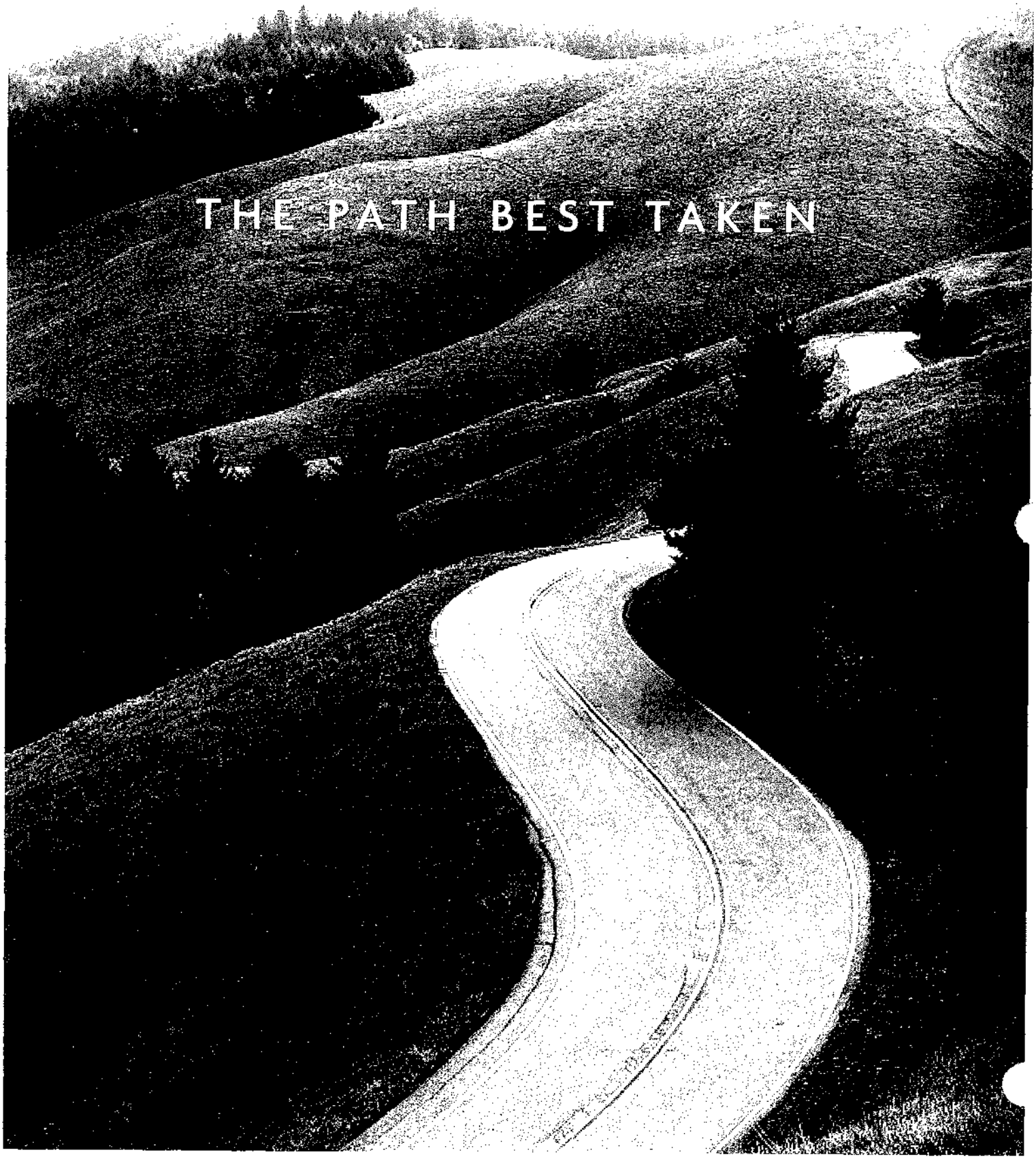
BEST TAKEN


THE PATH BEST TAKEN

"With a job of this magnitude and so much risk involved, the customer really appreciated that we came in and said exactly what could and couldn't be done. I think they valued that honesty as much as the work itself."

Dana Aaronson
Industrial Services
General Manager

INDUSTRIAL SERVICES

Clean Harbors Industrial Services is a leading provider of comprehensive cleaning service solutions for a broad range of industries — from paper and steel manufacturing to oil refining and pharmaceuticals.

The Customer: One of the country's largest petroleum refiners, pumping out an average of 935,000 barrels of crude oil per day.

The Challenge: An equalization tank—critical to the customer's operation—was filled with nearly 7,000 tons of hazardous by-product that had to be removed to continue uninterrupted manufacturing. The refinery sought a company that could not only clean the tank, but also minimize the amount of material for disposal and help keep costs down.

The Solution: Calling on its vast arsenal of equipment and trained professionals, Clean Harbors offered an end-to-end solution that included the testing, removal and disposal of the waste, as well as the thorough cleaning and decontamination of the tank and its surrounding area.

Such a project underscores Clean Harbors' wide range of capabilities. For example, treatability testing of the by-product was conducted at Clean Harbors' lab in Houston, Texas. Its crews also utilized a mobile thermal desorbtion unit to process the sludge on site and reduce the overall volume 75 percent, saving the customer a great deal on transportation and disposal costs.

The refinery was so impressed with the quality of the work that Clean Harbors was awarded other tank-cleaning projects.

Selected Financial Data

Income Statement Data (in thousands, except per share data)	*2002*	*2001*	*2000*
Revenues	$ 350,133	$ 251,601	$ 233,466
Cost of revenues	253,412	178,085	166,303
Selling, general and administrative expenses	62,250	44,460	42,238
Depreciation and amortization	15,508	11,113	10,656
Restructuring	750	—	—
Other acquisition costs	5,406	—	—
Income from operations	12,807	17,943	14,269
Other income	129	—	—
Interest expense, net	12,682	9,991	9,167
Income before provision for (benefit from) income taxes and extraordinary loss	254	7,952	5,102
Provision for (benefit from) income taxes	3,787	2,412	(2,016)
Net income (loss) before extraordinary loss	(3,533)	5,540	7,118
Extraordinary loss, early extinguishment of debt, net of no tax benefit	24,658	—	—
Net income (loss)	(28,191)	5,540	7,118
Dividends and accretion on preferred stock	1,291	448	448
Net income (loss) attributable to common shareholders	$ (29,482)	$ 5,092	$ 6,670
Basic earnings (loss) per share			
Income (loss) before extraordinary loss	$ (0.40)	$ 0.45	$ 0.60
Extraordinary loss, early extinguishment of debt	$ (2.02)	$ —	$ —
Net income (loss) attributable to common shareholders	$ (2.42)	$ 0.45	$ 0.60
Diluted earnings (loss) per share			
Income (loss) before extraordinary loss	$ (0.40)	$ 0.40	$ 0.59
Extraordinary loss, early extinguishment of debt	$ (2.02)	$ —	$ —
Net income (loss) attributable to common shareholders	$ (2.42)	$ 0.40	$ 0.59
Weighted average common shares outstanding	12,189	11,404	11,085
Weighted average common shares plus potentially dilutive common shares	12,189	12,676	11,305
Financial Data (in thousands)			
Working capital	$ 24,899	$ 10,529	$ 16,421
Total assets	$ 559,690	$ 156,958	$ 149,568
Long-term obligations, less current portion	$ 156,245	$ 49,410	$ 65,322
Redeemable preferred stock	$ 13,543	$ —	$ —
Stockholders' equity	$ 21,782	$ 49,569	$ 41,635

Directors

Alan S. McKim
President, Chief Executive Officer and Chairman of the Board, Clean Harbors, Inc.

John P. DeVillars
Managing Partner, Bluewave Strategies, LLC

Daniel J. McCarthy
Professor of Strategic Management, Northeastern University

John T. Preston
President and Chief Executive Officer, Aromic Ordered Materials

John F. Kaslow
Consultant to the Energy Industry

Thomas J. Shields
Managing Director, Shields & Co.

Lorne R. Waxlax
Former Executive Vice President, The Gillette Company

Officers

Alan S. McKim
Chairman, President and Chief Executive Officer*

Eugene A. Cookson
President Site Services**

Roger A. Koenecke
Senior Vice President and Chief Financial Officer*

Stephen H. Moynihan
Senior Vice President — Strategy and Planning*

William J. Geary, Esq.
Executive Vice President and General Counsel**

David M. Parry
Senior Vice President U.S. Technical Services**

George Curtis
Vice President — Business Management**

Eric W. Gerstenberg
Senior Vice President - U.S. Disposal Operations**

Carl D. Paschetag, Jr.
Vice President, Treasurer and Controller*

Michael A. Quinn
Senior Vice President - Human Resources**

William F. O'Connor
Senior Vice President — Risk Management**

Michael J. Twohig
Senior Vice President Administration and E-Business**

Guy Adam
Vice President Canadian Operations

Jerry E. Correll
Senior Vice President - Sales and Marketing**

* *Clean Harbors, Inc.*
** *Clean Harbors Environmental Services, Inc.*

Shareholder Information

Form 10-K
Copies of the Company's annual report on Form 10-K for the year ended December 31, 2002, filed with the Securities and Exchange Commission in April 2003, may be obtained without charge online at www.cleanharbors.com, or by writing to the Company at 1501 Washington Street PO Box 859048 Braintree, MA 02185-9048 attention: Investor Relations, 781.849.1800, ext. 4191.

Annual Meeting
9:00 a.m., May 15, 2003
Le Méridien Hotel
250 Franklin Street
Boston, MA 02210

Auditors
PricewaterhouseCoopers L.L.P.
One International Place
Boston, MA 02110

Clerk of the Corporation
C. Michael Malm
Davis, Malm & D'Agostine P.C.

Corporate Counsel
Davis, Malm & D'Agostine P.C.
One Boston Place
Boston, MA 02108

Transfer Agent
American Stock Transfer & Trust Company
40 Wall Street
New York, NY 10005
800.937.5449

Corporate Headquarters
Clean Harbors Environmental Services, Inc.
1501 Washington Street
PO Box 859048
Braintree, MA 02185-9048
781.849.1800
www.cleanharbors.com

Clean Harbors is an Affirmative Action/Equal Opportunity Employer.

Stock Listing

The Company's common stock began trading publicly in the over-the-counter market on November 24, 1987, and was added to the NASDAQ National Market System effective December 15, 1987. The Company's common stock trades on the NASDAQ Stock Market under the symbol CLHB. The following table sets forth the high and low sales prices of the Company's common stock for the indicated periods as reported by NASDAQ.

2002	*High*	*Low*	*2001*	*High*	*Low*
First quarter	$11.80	$3.02	First quarter	$2.69	$1.53
Second quarter	15.64	6.96	Second quarter	2.86	2.08
Third quarter	12.35	6.60	Third quarter	2.82	1.92
Fourth quarter	17.82	7.59	Fourth quarter	4.90	2.16

On March 27, 2003, there were 578 holders of record of the Company's common stock, excluding stockholders whose shares were held in nominee name.

In February 1993, the Board of Directors authorized the issuance of up to 156,416 shares designated as Series B Convertible Preferred Stock (the "Preferred Stock"), with a cumulative dividend of 7% during the first year and 8% thereafter, payable either in cash or by the issuance of shares of common stock. On February 16, 1993, 112,000 shares of Preferred Stock were issued in partial payment of the purchase price for the Cincinnati facility.

On August 27, 2002, the Company's Board of Directors authorized the issuance of up to 25,000 shares designated as Series C Convertible Preferred Stock (the "Series C Preferred Stock"). On September 10, 2002, 25,000 shares of Series C Preferred Stock were issued at $1,000 per share for an aggregate of $25,000,000. As of February 28, 2003, there were six shareholders of record of the Company's Series C Preferred Stock.

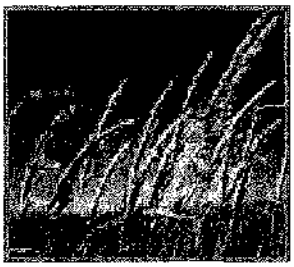
The Series C Preferred Stock is entitled to receive dividends at an annual rate of 6% (after which the first year will accrue and compound), is mandatorily redeemable after seven years at its stated value, plus accrued dividends, or at any time after issuance (together with accrued dividends thereon) will be convertible at the holder's option into shares of the Company's common stock. The conversion price will initially be $10.50 per share of common stock, subject to customary adjustments for antidilution and potential reset to $8.00 per share if both (i) the Company's Consolidated EBITDA for the year ending December 31, 2003 is less than $115 million and (ii) the average trading price for the Company's common stock for the month of December 2003 is less than $27.50. Dividends are payable or accrue quarterly on the first day of each calendar quarter in January, April, July and October.

The Company has never declared nor paid any cash dividends on its common stock and the Company is prohibited under its loan agreements from paying dividends on its common stock.

Except for payment of dividends on the Preferred Stock, the Company intends to retain all earnings for use in the Company's business and therefore does not anticipate paying any cash dividends on its common stock in the foreseeable future.

Safe Harbor Statement

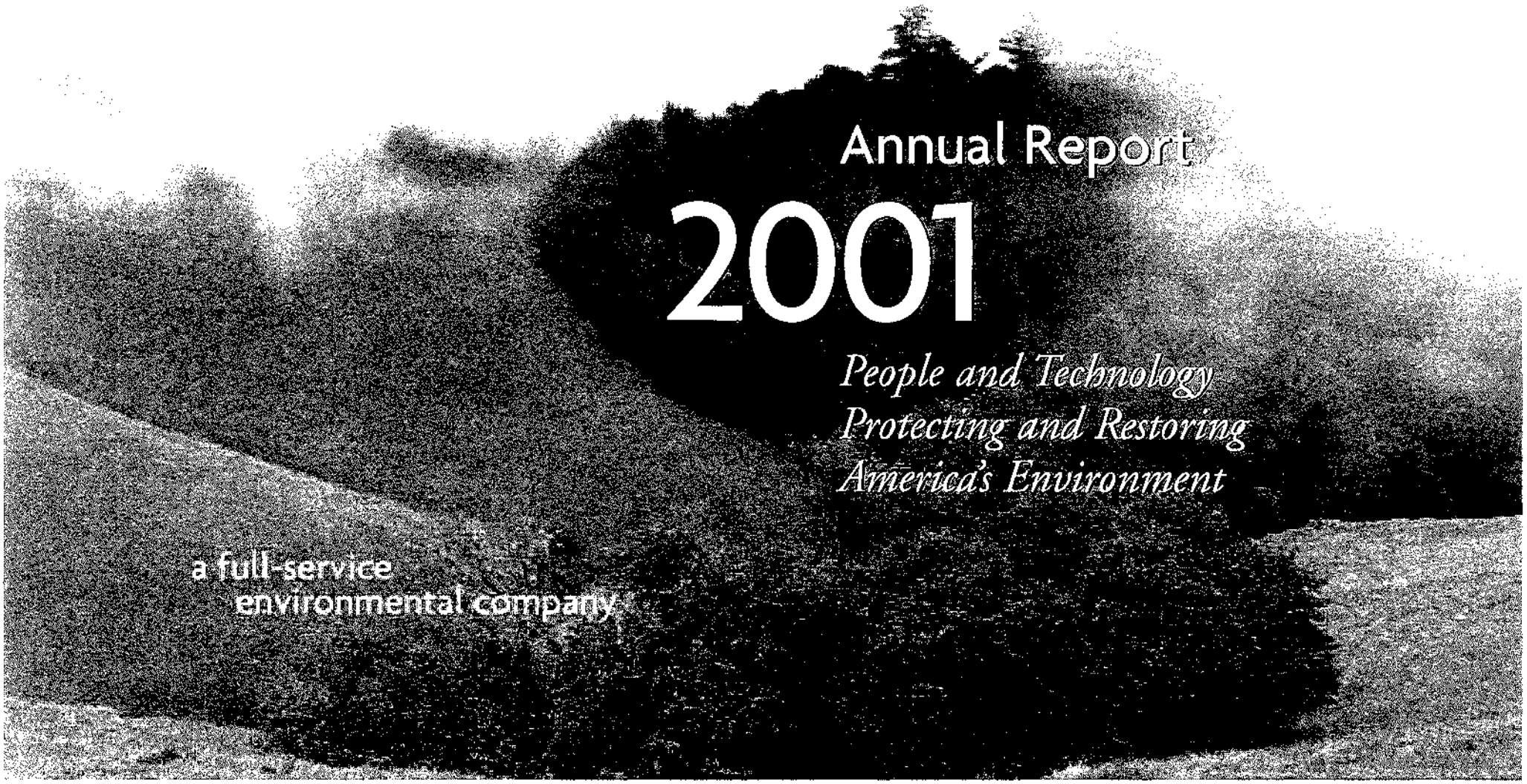
This annual report contains forward-looking statements, which are generally identifiable by use of the words "believes," "expects," "intends," "anticipates," "plans to," "estimates," "projects," or similar expressions. These forward-looking statements are subject to certain risks and uncertainties that could cause actual results to differ materially from those reflected in these forward-looking statements. Readers should carefully review the risk factors described in documents the Company files from time to time with the Securities and Exchange Commission, including the Company's Annual Report on Form 10-K dated December 31, 2002. Readers are cautioned not to place undue reliance on forward-looking statements, which reflect management's opinions only as of the date hereof. The Company undertakes no obligation to revise or publicly release the results of any revision to these forward-looking statements.




TAKING THE LEAD TOGETHER • 2002


Corporate Headquarters
Clean Harbors Environmental Services, Inc.
1501 Washington Street
PO Box 859048
Braintree, MA 02185-9048
781.849.1800
www.cleanharbors.com

CleanHarbors®
ENVIRONMENTAL SERVICES, INC.



CleanHarbors®
E' NMENTAL SERVICES, INC.

Dear Shareholder:

2001 was a pivotal year for Clean Harbors because it set the stage for what we believe will be the most significant positive event for the Company since it was founded 22 years ago. In essence, the Company has emerged as the leader of our industry, and we are now prepared to bring our leadership to a higher level.

In 2001, the Company reported record revenue of $251 million. But the Clean Harbors Balance Sheet demonstrates something far more significant than just one year's performance. It reflects the culmination of the steady momentum we have achieved over the past four years, based on our well-executed growth strategy.

- The Company's revenue growth for the past four years has been 8% compounded annually.
- Even with the economy in recession in 2001, Clean Harbors increased its non-emergency base revenue by approximately $7 million as we increased our share of the environmental market.
- EBITDA grew 16.6% year-over-year, and for the past four years has grown over 200% , from $9.5 million to $29 million at year's end.
- Free-cash flow for 2001 was $17.8 million, and the Company used that strong cash flow to reduce debt substantially. **Clean Harbors has reduced its debt by a total of $21.5 million in the past two years.**
- Accounts receivable are in the best shape in more than a decade and Days' Sales Outstanding (DSOs) have been steadily decreasing.

Most importantly, we have demonstrated to the marketplace that **we are the undisputed leader in technology innovation.** Clean Harbors is deploying our enhanced proprietary waste management software (WIN), which is Web-enabled, by utilizing Micosoft.net technologies. This will allow Clean Harbors to further streamline the Company's business processes and serve our customers more efficiently.

As this Annual Report goes to press, the success of our business model and the tremendous capabilities of our proprietary technology systems are being applied to an exciting new initiative.

On February 25, 2002, Clean Harbors announced that we had signed a definitive agreement to acquire the Chemical Services Division of Safety-Kleen Corp. (CSD/SK) for $46.3 million in cash and the assumption of certain environmental liabilities of approximately $265 million. Based on current information and subject to additional due-diligence review, we would expect the combined company to generate approximately $750 million in annual revenue and make **Clean Harbors North America's largest environmental-services company.**

By applying our sophisticated IT systems to the CSD/SK business, we expect to improve service to our combined customers and achieve substantial cost efficiencies and dramatic gains in productivity. Closure of this transaction will require completion of due-diligence, financing, approval of the Bankruptcy Court and other regulatory approvals. At this juncture, we are optimistic that we will successfully complete all these steps by the 3rd quarter of 2002.

As we close our report on 2001, we have entered 2002 with tremendous potential to return even higher shareholder value to our investors. We will continue to communicate our progress to all of our stockholders.

Yours truly,

Alan S. McKim
President, Chief Executive Officer,
Chairman of The Board

Gene Cookson
Executive Vice President,
Chief Operating Officer

A Remembrance and a Tribute

For any American company to properly reflect on the last year, it is essential to pause from our business pursuits to note the most tragic event of our lifetime. All Clean Harbors employees were deeply shocked and saddened by the cruel attack on America on September 11th. Our thoughts and prayers are with all the families who lost loved ones as a result of this brutal and senseless aggression against humanity and civilization.

We also wish to pay tribute to all the citizens of the world who rose above this catastrophe to provide aid and comfort to the victims of terrorism. We particularly want to acknowledge the brave firefighters, police officers, rescue workers and our fellow Clean Harbors employees who responded to the World Trade Center site and diligently continue to provide essential services at the disaster scene.

On Behalf of All Clean Harbors Employees

Commitment. Leadership. Confidence.

Since 1980, Clean Harbors Environmental Services, Inc. has grown to be one of the nation's largest and most trusted providers of environmental services. Offering a wide range of on-site services, from emergency response to lab chemical packing (CleanPack®), as well as transportation and disposal services, Clean Harbors is an innovative leader, committed to preserving our natural environment and adhering to strict government regulations.

Our clients include a majority of the *Fortune 500* companies; many major utilities, oil, pharmaceutical and chemical companies; the high-tech and biotech industries; and numerous local, state and federal government agencies. While these customers come from different backgrounds and industries, they all share one thing in common: confidence, knowing that their environmental or waste disposal needs are being handled with the utmost care, timeliness and efficiency.

We invite you to learn more about Clean Harbors. You'll discover a company with the ***Vision, Services, Responsiveness and Reliability*** to continue to make a positive impact in environmental management.


a better world,
a better environment
Vision
Realizing Our Vision of Service and Success
customer confidence

This past year marked significant growth for Clean Harbors as we achieved new highs in profitability, enhanced our Web-based capabilities and expanded our geographic reach, which together will strengthen our position as the most progressive leader in environmental management.

Improving the bottom line. Clean Harbors posted record results and continued to improve our leadership position despite a softening economy. We were able to sustain year-over-year revenue growth, maintain profitability, and generate healthy revenue flow. With over $251 million in revenue for 2001, Clean Harbors clearly executed on our growth strategy and built strong momentum heading into 2002.

Leveraging technology. In 2001, Clean Harbors continued its commitment to technology. By developing and deploying new software and Web-enabled tools, we've improved the level of service and value we provide our customers, while creating opportunities for growth and expansion.

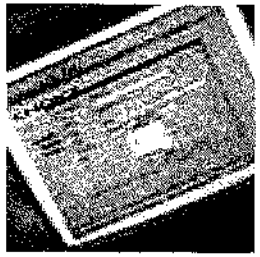
WIN (Waste Information Network) — "Accessibility" and "scalability" are two key goals of the networked systems that support our business. In 2001, we began an extensive project of making all Clean Harbors' systems Web-based. Employees have on-demand access to the critical resources they need to perform their jobs faster and more efficiently. And because the systems are Web-based, Clean Harbors has the scalability to add new employees and facilities without having to invest in more hardware and software.

This powerful network is a credit to Clean Harbors' in-house information technology team that not only performs most of the programming, but hosts our Internet and intranet. By supporting our WIN system internally, we can dramatically reduce costs and more effectively troubleshoot problems before they affect our day-to-day operations.

Beacon — Clean Harbors also introduced our new Beacon system. Unlike most customer relationship management software, Beacon uniquely integrates sales with operations. Beacon puts the management of our business at the fingertips of sales and key operations employees, who interact with customers on a daily basis. Beacon also ensures that field personnel receive the critical support they need to better serve the customer.

Stretching our boundaries. Our continued ability to offer comprehensive services on a national scale is a distinct advantage, both in attracting and serving organizations, and expanding into new markets. Clean Harbors' expanded service area allows us to provide the fast and comprehensive waste management customers depend on.

Protecting the environment. Our vision would not be completely realized if we did not continue to make inroads in protecting and preserving our natural environment. We are constantly pursuing safer methods for the proper handling of both hazardous and non-hazardous waste streams.



The Clean Harbors Vision

To be recognized by our customers as the premier supplier of a broad range of environmental services whose quality, responsiveness, customer service, risk-containment systems and disciplines are second to none.

By effectively applying technology to our business, Clean Harbors can reduce costs, shorten response times and improve service for every customer nationwide.

There's a reason Clean Harbors is the nation's premier environmental service company: We're never satisfied. In addition to providing traditional waste management and environmental services, Clean Harbors continues to introduce innovative services that cover every aspect of waste management, even those that our customers may not be familiar with—yet. By exploring, testing and perfecting leading-edge solutions, we can reduce operational costs, quicken response times and dramatically improve customer service. That's how we earn customer confidence.

Providing end-to-end waste and environmental management. First and foremost, Clean Harbors is a full-service company, offering the comprehensive services to meet today's changing requirements. Our many offerings include:

- ***Environmental Site Services*** — Whether it's in the tank, the trench, the separator or on the mill floor, Clean Harbors has the experience to get the customer's operation back on line. With over 400 field technicians trained to follow the highest health and safety procedures, we not only limit the customer's liability exposure, but we keep the site in full compliance with a variety of regulatory requirements.

- ***Waste Transportation and Disposal*** — With seven company-owned-and-operated TSD facilities that cover a broad range of disposal technologies, Clean Harbors is the single source for waste disposal. Hazardous and non-hazardous recyclers, landfills, incinerators and treatment facilities have been rigorously audited to bring a complete range of alternatives to our customers.

Clean Harbors maintains over 5,000 waste stream disposal options. From an exotic water-reactive waste or a typical paint or oil waste, our established network provides superior speed of service with selections by lowest cost or technology.

- ***CleanPack® Laboratory Chemical Packing*** — Clean Harbors' national lab-pack program provides for the proper handling, packaging, transportation and disposal of hazardous chemicals. Our highly trained chemists are skilled in chemical recognition and compatibility. Their expertise assures that customers are in full compliance with the latest EPA and DOT regulations.

- ***Clean Harbors' Premier Onsite Services Apollo Program*** — Bringing our expertise and resources right to the customer, Clean Harbors' Apollo Program is a total waste management solution and serves the dual purpose of not only improving customers' waste stream management, but making their entire environmental program safer, more cost-effective and self-sufficient. Clean Harbors' skilled technicians work on site in tandem with customers to deliver proper waste transportation and disposal, lab chemical packing (CleanPack®), industrial cleaning and maintenance, and more.

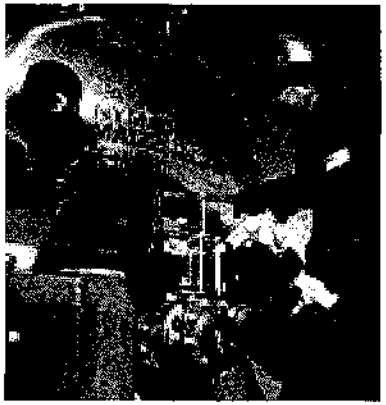
Seamless service

Full-Service

People and Technology Serving the Nation

tening to customers
and providing support

achieving success



Responsiveness and Reliability

Responding to the Call

Responding to the customer, quickly and efficiently, is something we take great pride in. It can be traced back to our founding, when Clean Harbors first focused on the emergency response needs of the chemical and petroleum industries. Our original philosophy was to provide the best-trained, hardest-working environmental professionals who would utilize innovative technologies and methods to greatly improve the customer experience. That still applies today — more than ever before.

That standard of care and quality made Clean Harbors a primary environmental responder to major natural disasters, fires and significant accidents for the past 15 years — and we will continue to be on the frontline, protecting the nation's safety, health and environment.

But responsiveness is more than timeliness. It's listening to the customer's concerns and providing comprehensive, customized

solutions tailored to meet his exact needs. Clean Harbors takes the most complex challenges and solves them simply, quickly and safely with the highest level of service in the industry.

Reliable Performance for the Long Haul

As we look ahead to 2002, Clean Harbors will continue to pursue new techniques, products and systems to further position us as the premier North American environmental services provider. However, one aspect of our operation will never change, and that's the reliability that comes with every project, every job.

Key to upholding that reliability is remaining true to the environment. We will continue to protect and conserve our precious land, water and air resources to the best of our abilities. All of our facilities and field activities will continue to adhere to the highest standards of safety and compliance for the benefit of our employees, customers and their surroundings.

We've enjoyed tremendous success since our inception, but we will always remember what helped us get there — and that's earning the trust and confidence of each and every customer, partner, shareholder and employee.

Homeland — the Honor to Serve and Protect

While overall 2001 was a very successful year for Clean Harbors, it was also a very emotional time as we joined the entire world in coping with the events of 9/11.

Within hours of the World Trade Center tragedy, Clean Harbors dispatched an Environmental Emergency Response team and 24-hour mobile command center to help clean, decontaminate and restore the devastated area. More than 140 Clean Harbors employees worked round the clock, seven days a week at Ground Zero, providing decontamination services and hygiene stations to support the rescue teams. Today, Clean Harbors continues to play a significant role supporting the recovery and cleanup efforts.

We were also called in to help during the anthrax attack, performing decontamination and remediation services at a number of private businesses and government offices, including two major national television networks and the nation's largest mail-sorting facility.

We give our praise and thanks to the many workers, volunteers and companies who came together in these critical times of need. Their tireless efforts have been an inspiration to us all.

"I want to thank your firm for your support of Con Edison in our efforts to recover from the Trade Center tragedy. Con Edison is grateful for your responsiveness to our needs and the quality of your work. It's unfortunate that it takes an event like this for us to be reminded of your commitment."

– Al Wassler
Vice President of Purchasing, Con Edison

Selected Financial Data

Income Statement Data	*2001*	*2000*	*1999*
• Revenues	$251,601	$233,466	$202,965
• Cost of revenues	178,085	166,303	149,637
• Selling, general and administrative expenses	44,460	42,238	37,190
• Depreciation and amortization of intangible assets	11,113	10,656	9,501
• Income from operations	17,943	14,269	6,637
• Interest expense, net	9,991	9,167	8,599
• Income (loss) before provision for (benefit from) income taxes	7,952	5,102	(1,962)
• Provision for (benefit from) income taxes	2,412	(2,016)	282
• Net income (loss)	$ 5,540	$ 7,118	$ (2,244)
• Basic earnings (loss) per share	$ 0.45	$ 0.60	$ (0.25)
• Diluted earnings (loss) per share	$ 0.40	$ 0.59	$ (0.25)
• Weighted average number of common shares outstanding	11,404	11,085	10,649
• Weighted average common shares plus potentially dilutive common shares	12,676	11,305	10,649
Financial Data			
• Earnings before interest, taxes, depreciation and amortization (EBITDA)	$ 29,056	$ 24,925	$ 16,138
• Working capital	$ 11,279	$ 16,421	$ 14,565
• Total assets	$151,721	$149,568	$145,247
• Long-term obligations, less current portion	$ 49,410	$ 65,322	$ 73,497
• Stockholders' equity	$ 49,569	$ 41,635	$ 34,171

Shareholder Information

Stock Listing

The Company's common stock began trading publicly in the over-the-counter market on November 24, 1987, and was added to the NASDAQ National Market System effective December 15, 1987. The Company's common stock trades on the NASDAQ Stock Market under the symbol: CLHB. The following table sets forth the high and low sales prices of the Company's common stock for the indicated periods as reported by NASDAQ.

2001	*High*	*Low*	*2000*	*High*	*Low*
First Quarter	$2.688	$1.531	First Quarter	$4.250	$1.188
Second Quarter	2.860	2.080	Second Quarter	2.969	1.531
Third Quarter	2.820	1.920	Third Quarter	3.250	1.563
Fourth Quarter	4.900	2.160	Fourth Quarter	3.000	1.500

On February 27, 2002, there were 649 holders of record of the Company's common stock, excluding stockholders whose shares were held in nominee name.

The Company has never declared nor paid any cash dividends on its common stock and the Company is prohibited under its loan agreements from paying dividends on its common stock. In February 1993, the Board of Directors authorized the issuance of up to 156,416 shares designated as Series B Convertible Preferred Stock (the "Preferred Stock"), with a cumulative dividend of 7% during the first year and 8% thereafter, payable either in cash or by the issuance of shares of common stock. On February 16, 1993, 112,000 shares of Preferred Stock were issued in partial payment of the purchase price for the Cincinnati facility. Except for payment of dividends on the Preferred Stock, the Company intends to retain all earnings for use in the Company's business and therefore does not anticipate paying any cash dividends on its common stock in the foreseeable future.

Safe Harbor Statement

This annual report contains forward-looking statements, which are generally identifiable by use of the words "believes," "expects," "intends," "anticipates," "plans to," "estimates," "projects," or similar expressions. These forward-looking statements are subject to certain risks and uncertainties that could cause actual results to differ materially from those reflected in these forward-looking statements. Readers should carefully review the risk factors described in documents the Company files from time to time with the Securities and Exchange Commission, including the Company's Annual Report on Form 10-K dated December 31, 2001. Readers are cautioned not to place undue reliance on forward-looking statements, which reflect management's opinions only as of the date hereof. The Company undertakes no obligation to revise or publicly release the results of any revision to these forward-looking statements.

Form 10-K

Copies of the Company's annual report on Form 10-K for the year ended December 31, 2001, filed with the Securities and Exchange Commission on March 18, 2002, may be obtained without charge online at www.cleanharbors.com, or by writing to the Company at 1501 Washington Street, PO Box 859048, Braintree, MA 02185-9048, attention: Investor Relations, 781.849.1800, ext. 4191.

Annual Meeting

10:00 a.m., April 24, 2002, The Seaport Ballroom, Seaport Hotel, One Seaport Lane, Boston, MA 02210

Auditors

PricewaterhouseCoopers L.L.P., One International Place, Boston, MA 02110

Clerk of the Corporation

C. Michael Malm, Esq., Davis, Malm & D'Agostine P.C.

Corporate Counsel

Davis, Malm & D'Agostine P.C., One Boston Place, Boston, MA 02108

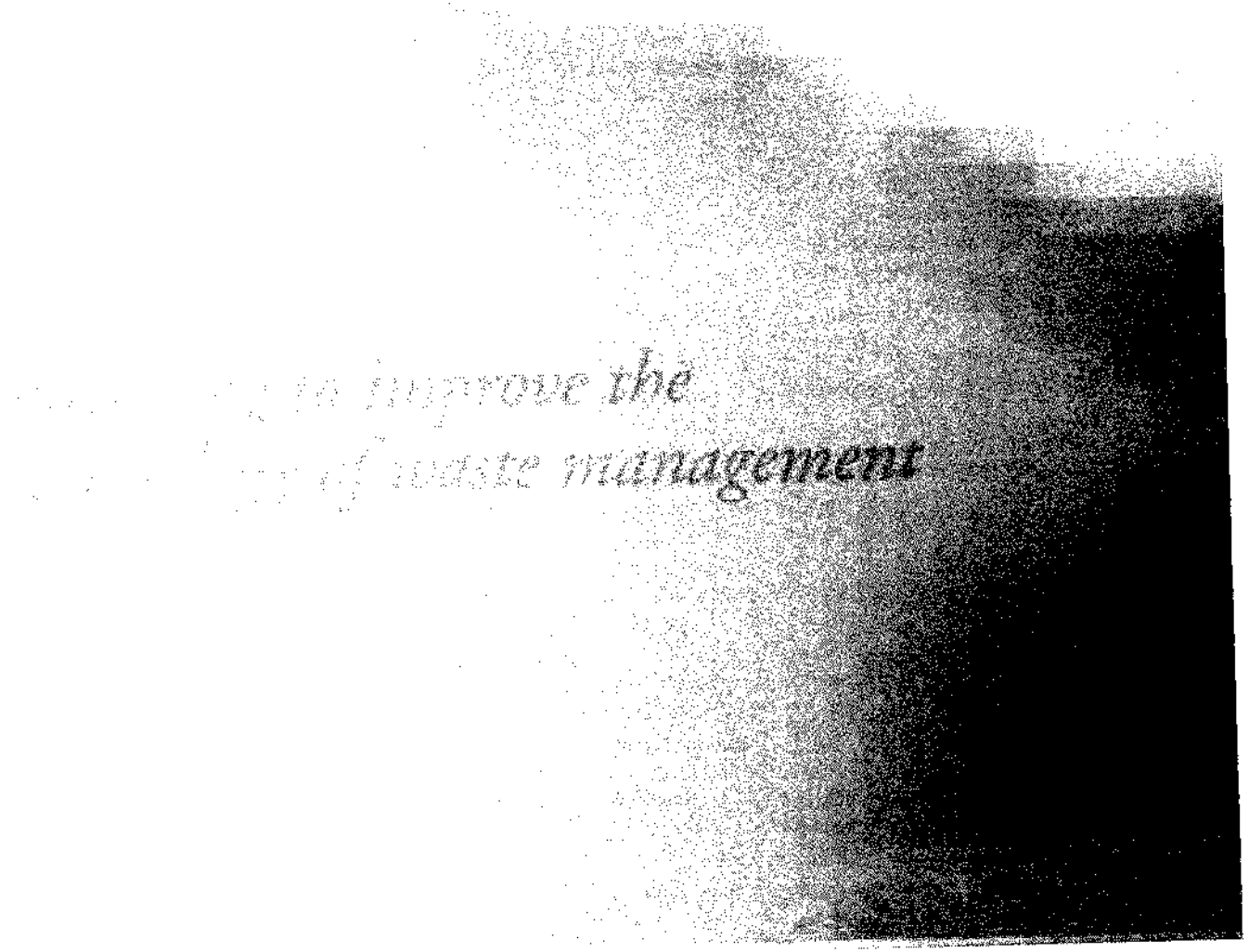
Transfer Agent

American Stock Transfer & Trust Company,
40 Wall Street, New York, NY 10005, 800.937.5449

Corporate Headquarters

Clean Harbors Environmental Services, Inc.
1501 Washington Street
PO Box 859048
Braintree, MA 02185-9048
781.849.1800
www.cleanharbors.com

Clean Harbors is an Affirmative Action/Equal Opportunity Employer.



CleanHarbors®
ENVIRONMENTAL SERVICES, INC.
1501 Washington Street • PO Box 859048 • Braintree, Massachusetts 02185-9048 • 800.282.0058 • www.cleanharbors.com

ATTACHMENT D

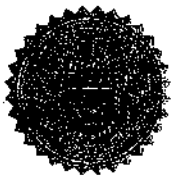
ARTICLES OF INCORPORATION, BYLAWS, AND FORM 10K

Delaware

PAGE 1

The First State

I, HARRIET SMITH WINDSOR, SECRETARY OF STATE OF THE STATE OF DELAWARE, DO HEREBY CERTIFY THE ATTACHED IS A TRUE AND CORRECT COPY OF THE CERTIFICATE OF FORMATION OF "CLEAN HARBORS DEER TRAIL, LLC", FILED IN THIS OFFICE ON THE FIRST DAY OF MAY, A.D. 2002, AT 10 O'CLOCK A.M.



Harriet Smith Windsor

Harriet Smith Windsor, Secretary of State

3520413 8100

020277151

AUTHENTICATION: 1756353

DATE: 05-02-02

MAY-01-2002 08:39 P.09

Clean Harbors Deer Trail, LLC

CERTIFICATE OF FORMATION

Pursuant to the provisions of Section 18-201 of the Limited Liability Company Act of the State of Delaware (the "Act"), the undersigned, being duly authorized, hereby certifies and states as follows:

1. Name of the Limited Liability Company. The name of the limited liability company formed hereby is Clean Harbors Deer Trail, LLC (the "LLC").

2. Registered Agent and Office of the LLC. The name of the registered agent of the LLC in the State of Delaware is Capitol Corporate Services, Inc. and the registered office address of the registered agent for the purposes of Section 18-104 of the Act is 32 Loockerman Square, Suite 109, Dover, Kent County, Delaware 19901.

IN WITNESS WHEREOF, the undersigned hereby affirms that the facts stated herein are true, this 30th day of April, 2002.

C. Michael Malm, Authorized Person

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STATE OF DELAWARE
SECRETARY OF STATE
DIVISION OF CORPORATIONS
FILED 10:00 AM 05/01/2002
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CLEAN HARBORS DEER TRAIL, LLC

LIMITED LIABILITY COMPANY AGREEMENT

LIMITED LIABILITY COMPANY AGREEMENT effective as of May 1, 2002, by and among Eric W. Gerstenberg, Gene A. Cookson, Stephen H. Moynihan, Roger A. Koenecke, Carl Paschetag, and William J. Geary, as Managers; and Clean Harbors Disposal Services, Inc., a Delaware corporation, as the sole Member. Certain capitalized terms used herein have the respective meanings set forth in Section 14.01 hereof.

ARTICLE I
CAPITAL CORPORATE SERVICES, INC.,
ORGANIZATION

SECTION 1.01 Formation of the Company. Clean Harbors Deer Trail, LLC (the "Company") has been formed as a limited liability company under the Delaware Limited Liability Company Act *(6 Del. C § 18-101, et seq.)*, as amended from time to time (the "Delaware Act"), through the filing of the Certificate with the Delaware Secretary of State on the effective date of this Agreement. The parties hereto agree to conduct the business of the Company in accordance with the provisions of the Act and of this Agreement.

SECTION 1.02 Name, Registered Office, and Maintenance of Books and Records. The name of the Company is "Clean Harbors Deer Trail, LLC." The initial address of the Company's registered office in Delaware is 32 Lookerman Square, Suite 109, Dover, Dent County, Delaware 19901, and its initial agent at such address for service of process is Capitol Corporate Services, Inc. The Company's books and records shall be maintained at c/o Clean Harbors, Inc., 1501 Washington Street, Braintree, Massachusetts 02184. A Majority of the Managers may change the location at which the Company's books and records shall be maintained to such other location within the United States as such Managers may determine at any time, upon written notice to the Member stating such new location. A Majority of the Managers may also change the Company's registered agent from time to time in their sole discretion.

SECTION 1.03 Purposes. The purposes and objectives of the Company are to own, lease, manage and/or operate a licensed hazardous waste facility, to provide environmental services, and to engage in any other lawful activities allowed to be conducted by a limited liability company.

SECTION 1.04 Powers. Subject to the terms of this Agreement, and consistent with the purposes stated in Section 1.03 hereof, the Company shall have the following powers: (i) to enter into all agreements and engage in all activities and transactions necessary or advisable to carry out the Company's purposes; and (ii) to have all other powers available to it as a limited liability company organized under the laws of the State of Delaware. Without limitation of the foregoing, the Company shall have the powers: to acquire and dispose of assets and other property; to act as a general partner, limited partner, manager and/or member of any other Person; negotiate, enter into, and modify agreements including, without limitation, partnership

agreements, limited liability company agreements, and leases or subleases of any real estate or personal property; to incur obligations for and in connection with its business; to borrow money and provide guarantees for the obligations of other Persons and, if required by any lender, as security therefor to mortgage, pledge and grant security interests in all or any part of the assets and other property owned by the Company; to repay, in whole or in part, refinance, consolidate, recast, increase, modify or extend any loans which may affect any of the assets and other property owned by the Company; and to execute any and all other documents and instruments and exercise all powers necessary or appropriate to carry out the business of the Company.

ARTICLE II

CONDUCT AND MANAGEMENT OF THE LLC

SECTION 2.01 Managers. Except as otherwise provided in this Agreement for actions which require or permit approval by the sole Member, the business of the Company shall be under the control of the Managers. The names and current addresses of the initial Managers are as described in Schedule A hereto. One or more substitute or additional Managers may be elected at any time in the future by the sole Member. Each of the original Managers and any such substitute or additional Managers shall serve as a Manager until either (i) his voluntary resignation as a Manager, or (ii) his removal as a Manager with or without cause at any time by a Majority of the Managers or the sole Member. The Managers shall not be required to make any Capital Contributions to the Company.

SECTION 2.02 Officers.

(a) In order to facilitate the day-to-day operation of the Company's business, the Company shall have the following Officers: a President, Senior Vice Presidents, a Treasurer and a Secretary, and any such additional Officers as a Majority of the Managers may from time to time deem appropriate. The President shall be a Manager, but none of the other Officers need be a Manager. Unless otherwise determined from time to time by a Majority of the Managers or by the sole Member, Eric W. Gerstenberg shall be the President, Steven H. Moynihan shall be a Senior Vice President and an Assistant Treasurer, Roger Koenecke shall be a Senior Vice President, Carl Paschetag shall be the Treasurer, William J. Geary shall be a Vice President and the Assistant Secretary, and C. Michael Malm shall be Secretary. Unless otherwise determined from time to time by a Majority of the Managers or the sole Member, the President shall be the chief executive officer of the LLC, the Treasurer shall be responsible for maintaining the funds and financial books and records of the LLC, and the Secretary shall be responsible for maintaining the records of actions (whether by written consent or meeting) of the Managers and of the sole Member and the other non-financial records of the LLC. Each of the Officers of the LLC may be removed (and his successors elected) at any time by a Majority of the Managers or the sole Member.

(b) Except as may otherwise be determined from time to time by a Majority of the Managers or the sole Member, the Managers hereby delegate to the President and any Senior Vice President then in office full authority to act on behalf of the LLC. Except as may otherwise be determined from time to time by a Majority of the Managers or the sole Member, each of the President and Senior Vice Presidents shall have, without further approval or consent of any of

the other Managers or the sole Member, full authority: to acquire and dispose of assets and other property on behalf of the LLC; to negotiate, enter into, execute or modify agreements on behalf of the LLC including, without limitation, partnership agreements, limited liability company agreements, and leases or subleases of any real estate or personal property; to incur obligations for and on behalf of the LLC for and in connection with its business; to borrow money and provide guarantees for the obligations of other Persons and, if required by any lender, as security therefor to mortgage, pledge and grant security interests in all or any part of the assets and other property owned by the Company; to repay, in whole or in part, refinance, consolidate, recast, increase, modify or extend any loans which may affect any of the assets and other property owned by the Company; and to execute any and all other documents and instruments and exercise all powers necessary or appropriate to carry out the business of the Company.

SECTION 2.03 Authorization.

(a) Every contract, agreement, and other instrument executed on behalf of the Company by any Manager, the President or any Senior Vice President, or by another Officer of the Company, if such execution is authorized by a Majority of the Managers, shall be conclusive evidence in favor of every person or entity relying thereon or claiming thereunder that at the time of the delivery thereof (i) the Company was in existence, (ii) this Agreement had not been terminated or canceled or amended in any manner so as to restrict such authority (except as shown in the Certificate or other instrument duly filed with the Secretary of State of the State of Delaware), and (iii) the execution and delivery of such instrument were duly authorized by the Managers and/or the sole Member to the extent required.

(b) Any person or entity dealing with the Company may always rely on a certificate signed by any Manager, the President, any Senior Vice President, the Secretary or an Assistant Secretary:

(i) as to who are the Managers, the Officers or the Member of the Company,

(ii) as to the existence or nonexistence of any fact or facts which (A) constitute conditions precedent to acts by the Company, or (B) are in any other manner germane to the affairs of the Company,

(iii) as to who is authorized to execute and deliver any instrument or document on behalf of the Company,

(iv) as to the authenticity of any copy of this Agreement and amendments thereto, or

(v) as to any act or failure to act by the Company, or as to any other matter whatsoever involving the Company or any Manager or Officer or Member of the Company.

SECTION 2.04 Actions by Managers or the Sole Member. Approval of any action by the Company which under the terms of this Agreement requires approval by a Majority of the Managers may be granted either by a written consent signed by a Majority of the Managers or by an affirmative vote of a Majority of the Managers at a meeting held for such purpose either with or without prior notice. Any Manager may participate in any such meeting by telephone if all

Managers participating in any such meeting shall be able to hear the other participating Managers. The participation of a Majority of the Managers shall constitute a quorum for all purposes. If any action is approved by a Majority of the Managers but any Manager shall not sign any written consent by which, or shall not participate in any meeting at which, such approval was granted, the Secretary of the Company shall promptly provide to such Manager following the date of such written consent or meeting a copy of such written consent or minutes of such meeting. Any action taken by the sole Member under the terms of this Agreement shall be by written consent of the sole Member.

SECTION 2.05 Duty of Care. The sole Member acknowledges that decisions concerning the Company's activities will involve the exercise of judgment and a risk of loss. The Managers, the Officers and their Affiliates shall not be liable to the Company or the Member for any loss suffered by the Company or the Member which arises out of any action or omission of a Manager, an Officer or any Affiliate of a Manager or an Officer, provided that (i) such Manager, Officer or Affiliate determined, in good faith, that such course of conduct was in, or not opposed to, the best interest of the Company or was otherwise permitted by this Agreement, and (ii) such course of conduct did not constitute gross negligence or willful malfeasance, a material breach of this Agreement, or an intentional violation of federal or state law by such Manager, Officer or Affiliate. The Managers, the Officers, and their Affiliates shall not be liable for the negligence, whether of omission or commission, dishonesty or bad faith of any employee, broker or other agent of the Company selected by the Managers or the Officers with reasonable care. Furthermore, the Managers, the Officers, and their Affiliates shall be entitled to indemnification by the Company to the extent provided in Article X hereof.

ARTICLE III

MEMBER

SECTION 3.01 Name, Address, and Capital Contribution. The name and current address of the sole Member are as described in Schedule A hereto. On and after the date of this Agreement, the Member shall make to the Company either in cash or in other tangible or intangible property such Capital Contributions as shall be determined by the Member. The Treasurer shall record the Member's Capital Contributions on the financial records of the Company.

SECTION 3.02 Limited Liability. In accordance with the Delaware Act, the liability of the Member to the Company and its creditors shall be limited to (i) any unpaid Capital Contribution which the Member has agreed to make to the Company; (ii) the amount of any distribution previously received from the Company which the Member may be required to return to the Company pursuant to Section 18-607(b) of the Delaware Act; and (iii) the unpaid balance of any other payments (if any) that the Member expressly is required, pursuant to this Agreement, to make to the Company.

SECTION 3.03 No Control of Company. Except as otherwise provided in this Agreement, the Member, in its capacity as such, shall not take part in the management or control of the affairs of the Company, or undertake any transactions on behalf of the Company, or have any power to sign for or otherwise to bind the Company.

SECTION 3.04 Dissolution, Liquidation or Bankruptcy. The dissolution, liquidation or bankruptcy of the Member shall not result in the termination of the Company, but the rights of the Member under this Agreement shall accrue to the Member's successors, estate or legal representatives. Except as expressly provided in this Agreement, no other event affecting the Member (including but not limited to insolvency) shall affect this Agreement.

ARTICLE IV

EXPENSES AND COMPENSATION

SECTION 4.01 No Management Fee. The Company shall not be obligated to pay to the Managers (or any Affiliate of the Managers) any management fee or similar compensation. However, the Managers shall be entitled to receive compensation from the Member and its Affiliates in the Managers' respective capacities as officers and employees of the Member and its Affiliates.

SECTION 4.02 Expenses. The Company shall be responsible for the payment from its own funds of all of the Company's expenses.

ARTICLE V

DISTRIBUTIONS

SECTION 5.01 Amount, Timing and Form. The Managers shall determine in their discretion the amount, timing and form of all distributions of Distributable Cash to be made by the Company to the sole Member.

ARTICLE VI

TAX ALLOCATIONS

SECTION 6.01 Allocations of Net Profit or Net Loss. As described in Articles II, III and V above, the sole Member shall be responsible for all Capital Contributions to the Company, and the Company shall make all distributions to the Member. All distributions of Net Profit or Net Loss by the Company will accordingly be made to the Member. The Company shall therefore be treated for U.S. federal income tax purposes as a "disregarded entity" of which all of the beneficial interests are held by the sole Member.

ARTICLE VII

DURATION OF THE COMPANY

SECTION 7.01 Term of Company. The term of the Company commenced on the filing of the Certificate with the Delaware Secretary of State and shall continue until the date on which the Company is dissolved as provided in Sections 7.02 or 7.03 or by operation of law.

SECTION 7.02 Dissolution Upon Sale of Assets. The Company shall be dissolved in the event of the sale or distribution by the Company of all or substantially all of the assets of the Company.

SECTION 7.03 Dissolution by Written Consent of Member. The sole Member may dissolve the Company at any time by written consent executed by the Member and a copy of which shall be provided to the Managers.

ARTICLE VIII

LIQUIDATION OF THE COMPANY

SECTION 8.01 General Provisions. Following the dissolution of the Company in accordance with Article VII hereof, the Company's assets shall be liquidated in an orderly manner. The Managers (or, at the Managers' election, another Person selected by a Majority of the Managers) shall be the liquidator to wind up the affairs of the Company pursuant to this Agreement.

SECTION 8.02 Liquidating Distributions. The liquidator shall pay or provide for the satisfaction of the Company's liabilities and obligations to creditors. Any Net Profit or Net Loss realized in connection with the liquidation of the Company shall be allocated to the Member pursuant to Article VI hereof, and the remaining assets of the Company shall then be distributed to the Member. In performing its duties, the liquidator is authorized to sell, exchange or otherwise dispose of the assets of the Company in such reasonable manner as the liquidator shall determine to be in the best interest of the Company and the Member.

SECTION 8.03 Expenses of Liquidator. The expenses incurred by the liquidator in connection with winding up the Company, and all other losses or liabilities of the Company incurred in accordance with the terms of this Agreement, shall be borne by the Company.

SECTION 8.04 Duration of Liquidation. A reasonable time shall be allowed for the winding up of the affairs of the Company in order to minimize any losses otherwise associated with such a winding up.

SECTION 8.05 Duty of Care. The liquidator shall not be liable to the Company or the Member for any loss attributable to any act or omission of the liquidator in good faith and in a manner such liquidator reasonably believed to be in, or not opposed to, the best interests of the Company in connection with the liquidation of the Company and distribution of its assets and provided that such act or omission did not constitute gross negligence, willful misconduct or a material breach of this Agreement. The liquidator may consult with counsel, investment banking firms, consultants and accountants with respect to liquidating the Company and distributing its assets and may act or omit to act in accordance with the advice of such counsel, investment banking firms, consultants or accountants, provided they shall have been selected with reasonable care.

SECTION 8.06 No Liability for Return of Capital. The liquidator(s), the Managers and their respective officers, directors, agents and Affiliates shall not be personally liable for the return of the Capital Contribution of the Member to the Company.

ARTICLE IX

TRANSFER OF INTERESTS

SECTION 9.01 Limitation on Transfer of Rights and Obligations of Managers. The Managers shall not assign, pledge, mortgage, hypothecate, sell or otherwise dispose of or encumber all or any part of their rights or obligations under this Agreement without the prior written consent of the Member.

SECTION 9.02 Transfer of Member Interests. Except as may otherwise be required to comply with applicable federal and state laws, the sole Member shall have the right to transfer all or any part of its interests in the Company by delivery to the Company of an assignment in writing duly executed by the Member.

ARTICLE X

INDEMNIFICATION

SECTION 10.01 General Provisions.

(a) Subject to the limitations set forth below in this Article X, each of the Managers, the Officers, the Affiliates of the Managers and the Officers, and the liquidator (if any), (each such Person being referred to hereafter as an "Indemnitee"), shall be indemnified by the Company (but only out of Company assets, including the proceeds of liability insurance) against any claim, demand, controversy, dispute, cost, loss, damage, expense (including attorneys' fees), judgment and/or liability incurred by or imposed upon the Indemnitee in connection with any action, suit or proceeding (including any proceeding before any administrative or legislative body or agency), to which the Indemnitee shall become a party or shall be threatened to become a party, by reason of the Indemnitee's being at the time the cause of action arose or thereafter, a Manager, an Officer, an Affiliate of a Manager or an Officer,, a liquidator (if any), or a director, officer, member, partner, employee, consultant or other agent of any other organization in which the Company owns an interest, which other organization the Indemnitee serves or has served as director, officer, manager, member, partner, employee, consultant or other agent at the request of the Company (whether or not the Indemnitee continues to serve in such capacity at the time such action, suit or proceeding is brought or threatened). Each Indemnitee may be entitled to such indemnification notwithstanding that the Company has sold, assigned, distributed or otherwise transferred its investment in such other organization prior to the time that such action, suit or proceeding is brought or threatened.

(b) The Indemnitee shall not be indemnified with respect to matters as to which the Indemnitee shall have been finally adjudicated in any such action, suit or proceeding (i) not to have acted in good faith and in the reasonable belief that the Indemnitee's action was in accordance with such Person's obligations to the Company or to have acted with gross negligence or a willful disregard of his duties, or in breach of his fiduciary obligations, or (ii) with respect to any criminal action or proceeding, not to have had cause to believe beyond any reasonable doubt the Indemnitee's conduct was criminal. In the event of settlement of any action, suit or proceeding brought or threatened, the indemnification provided for in this Article X shall

apply to all matters covered by the settlement except for matters as to which the Company is advised by counsel (who may be counsel regularly retained to represent the Company) that the Person seeking indemnification, in the opinion of such counsel, did not act in good faith or acted with gross negligence or a willful disregard of such Person's duties, or in breach of such Person's fiduciary obligations, or, with respect to any criminal action or proceeding, that the Person seeking indemnification had reasonable cause to believe such Person's conduct was criminal.

(c) The right of indemnification provided for in this Article X shall be in addition to any rights to which any Indemnitee may otherwise be entitled and shall inure to the benefit of the executors, administrators, personal representatives, successors or assigns of each such Indemnitee. Such Indemnitee shall first use reasonable efforts to pursue other readily available sources of indemnification before pursuing a claim for indemnification against the Company under this Article X.

SECTION 10.02 Advance Payment of Expenses. The Company shall pay the expenses incurred by an Indemnitee in defending a civil or criminal action, suit or proceeding, or in opposing any claim arising in connection with any potential or threatened civil or criminal action, suit or proceeding, in advance of the final disposition of such action, suit or proceeding, upon receipt of an undertaking by such Indemnitee satisfactory to the Managers to repay such payment if he shall be determined to be not entitled to indemnification therefor as provided herein; provided, however, that in such instance the Indemnitee is not commencing an action, suit, or proceeding against the Company, or defending an action, suit or proceeding commenced against the Indemnitee by the Company, or opposing a claim by the Company arising in connection with any such potential or threatened action, suit or proceeding.

SECTION 10.03 Insurance. At its election, the Managers may cause the Company to purchase and maintain insurance, at the expense of the Company and to the extent available, for the protection of the Managers, the Officers, the Affiliates of the Managers and the Officers, any liquidator, and the directors, officers, employees, consultants or other agents of any such Person, against any liability incurred by any such Person in any such capacity or arising out of his status as such, whether or not the Company has the power to indemnify such Person against such liability. The Managers may also cause the Company to purchase and maintain insurance for the protection of any officer, director, employee, consultant or other agent of any other organization in which the Company owns an interest or of which the Company is a creditor against similar liabilities, whether or not the Company has the power to indemnify any such Person against such liabilities.

ARTICLE XI

ACCOUNTING; RECORDS AND REPORTS

SECTION 11.01 Fiscal Year. The fiscal year of the Company shall be the calendar year, or such other year as required by the Code.

SECTION 11.02 Keeping of Accounts and Records. At all times the Managers shall cause to be kept proper and complete books of account, in which shall be entered fully and

accurately the transactions of the Company. Such books of account, together with (i) an executed copy of this Agreement (and any amendments hereto); (ii) the Certificate of the Company (and any amendments thereto); (iii) executed copies of any powers of attorney pursuant to which any of the aforesaid documents has been executed; and (iv) financial statements of the Company for each of the prior three years, shall at all times be maintained at the location specified in Section 1.02 hereof.

SECTION 11.03 Inspection Rights. Until the liquidation of the Company has been completed, the Member may examine the Company's books, records, accounts and assets, including bank balances, and may make, or cause to be made, any audit thereof at the Company's expense.

SECTION 11.04 Reports. The Managers shall prepare and transmit to the Member at the Company's expense such financial and other reports as shall be determined from time to time by the Member.

ARTICLE XII

WAIVER AND AMENDMENT

SECTION 12.01 Waiver and Amendment. Except for any waiver or amendment of the provisions of Sections 2.5 and 10.01 through 10.03 hereof which would adversely affect any Manager (or any Affiliate of a Manager), the terms and provisions of this Agreement may be waived, modified, terminated or amended at any time by the sole Member. The sole Member shall not waive or amend any provision of Sections 2.05 or 10.01 through 10.03 hereof in such a manner as would adversely affect any Manager (or any Affiliate of a Manager) without the written consent of such Manager.

ARTICLE XIII

GENERAL PROVISIONS

SECTION 13.01 Notices. Except where otherwise specifically provided in this Agreement, all notices, requests, consents, approvals and statements shall be in writing and shall be deemed to have been properly given by (i) personal delivery, (ii) first class mail, postage prepaid, (iii) electronic facsimile transmission, or (iv) courier service, addressed in each case: if to the Company, at the address where the Company's books and records are maintained as specified in Section 1.02 hereof; if to a Manager, at such Manager's address set forth in Schedule A; and if to the Member, to the Member's address set forth in Schedule A, or, in each case, to such other address or addresses (and/or by e-mail or other manner of delivery) as the addressee may have specified by written notice as aforesaid.

SECTION 13.02 Binding on Successors. This Agreement shall be binding upon and inure to the benefit of the respective heirs, successors, assigns and legal representatives of the parties hereto.

SECTION 13.03 Counterparts. This Agreement or any amendment hereto may be signed in any number of counterparts, each of which shall be an original, but all of which taken together shall constitute one agreement (or amendment, as the case may be).

SECTION 13.04 Governing Law. This Agreement shall be governed by and construed in accordance with the laws of the State of Delaware.

SECTION 13.05 Construction. Whenever the content of this Agreement permits, the masculine gender shall include the feminine and neuter genders, and reference to singular or plural shall be interchangeable with the other. The invalidity or unenforceability of any one or more provisions of this Agreement shall not affect the other provisions, and this Agreement shall be construed and reformed in all respects as if any such invalid or unenforceable provision(s) were omitted in order to give effect to the intent and purposes of this Agreement. References in this Agreement to particular sections of the Code or the Delaware Act shall be deemed to refer to such sections or provisions of the Code or the Delaware Act (or any successor legislation) as they may be amended after the date of this Agreement.

ARTICLE XIV

CERTAIN DEFINITIONS

SECTION 14.01 Certain Definitions. For purposes of this Agreement, the following terms have the respective meanings set forth below:

"Affiliate " means, with respect to the Person to which it refers, a Person that either (i) directly or indirectly through one or more intermediaries, controls or is controlled by, or is under common control with, such Person or (ii) is the successor or assign to such Person.

"Agreement" means this Limited Liability Company Agreement, as it may be subsequently amended or restated in accordance with its terms.

"Capital Contribution " means the aggregate amount of cash or other property contributed by the Member to the Company pursuant to this Agreement.

"Certificate " means the certificate of formation of the Company and any amendments or restatements thereof as filed with the Delaware Secretary of State under the Delaware Act.

"Code " means the United States Internal Revenue Code of 1986 and the rules and regulations promulgated thereunder, as amended from time to time, or any successor statute thereto.

"Delaware Act" means the Delaware Limited Liability Company Act, as amended from time to time.

"Distributable Cash " means all cash of the Company that the Managers determine is available for distribution to the Member after the payment or provision for payment by the Company of all expenses incurred by the Company and in collecting any amounts then owed to the Company and so attributable.

"Indemnitee " shall have the meaning set forth in Section 10.01.

"Majority of the Managers" means (i) at least four of the Managers if there are then six Managers, (ii) at least three of the Managers if there are then five or four Managers, (iii) at least two of the Managers if there are then three Managers, and (ii) both of the Managers if there are then only two Managers.

"Manager" means each of the Persons then serving as a Manager of the Company in accordance to Section 2.01 hereof, in his capacity as a Manager of the LLC.

"Member" means Clean Harbors Disposal Services, Inc., a Delaware corporation.

"Net Profit" or "Net Loss " means, with respect to any fiscal year, the sum of the Company's: (a) net profit or loss as determined in accordance with the Code and the Regulations thereunder, and (b) any income exempt from federal income tax, after deduction of all expenses properly chargeable to the Company for such fiscal year (whether deductible or non-deductible and whether described in Section 705(a)(2)(B) of the Code, treated as so described pursuant to Treasury Regulations Section 1.704-1(b)(2)(iv)(i), or otherwise). For this purpose, Net Profit or Net Loss shall be determined in accordance with tax accounting principles rather than generally accepted accounting principles, and any expenses required to be capitalized and included in the Company's adjusted tax basis in any asset or which reduce the amount realized by the Company on the disposition of any asset shall be disregarded.

"Officers" means the President, the Senior Vice President, the Treasurer, the Secretary, and any such other officers of the Company as shall be elected by a Majority of the Managers or the sole Member in accordance with Section 2.02(a) hereof.

"Person " means any individual, general partnership, limited partnership, limited liability company, corporation, joint venture, trust, business trust, cooperative or association and the heirs, executors, administrators, legal representative, successors and assigns of such Person where the context so admits.

"Treasury Regulations" mean the Regulations promulgated by the United States Department of the Treasury under the Code, as amended.

IN WITNESS WHEREOF, the undersigned have executed this Limited Liability Company Agreement as of the effective date first above written.

MANAGERS:

Eric W. Gerstenberg

Gene A. Cookson

Stephen H. Moynihan

Roger A. Koenecke

Carl Paschetag

William J. Geary

MEMBER:

CLEAN HARBORS DISPOSAL SERVICES, INC.

By: Stephen H. Moynihan
Senior Vice President

CLEAN HARBORS DEER TRAIL, LLC

SCHEDULE A

Name and Address

Managers:

Eric W. Gerstenberg
c/o Clean Harbors, Inc.
1501 Washington Street
Braintree, MA 02184

Gene A. Cookson
c/o Clean Harbors, Inc.
1501 Washington Street
Braintree, MA 02184

Stephen H. Moynihan
c/o Clean Harbors, Inc.
1501 Washington Street
Braintree, MA 02184

Roger A. Koenecke
c/o Clean Harbors, Inc.
1501 Washington Street
Braintree, MA 02184

Carl Paschetag
c/o Clean Harbors, Inc.
1501 Washington Street
Braintree, MA 02184

William J. Geary
c/o Clean Harbors, Inc.
1501 Washington Street
Braintree, MA 02184

Sole Member:

Clean Harbors Disposal Services, Inc.
1501 Washington Street
Braintree, MA 02184

J:\mail\CLEANHBS\safety-klee\NewSubsidiaries\LLC Agreement 1.Doc

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CEO and CFO Form 10-K Certifications

I, Alan S. McKim, certify that:

1. I have reviewed this annual report on Form 10-K of Clean Harbors, Inc.;

2. Based on my knowledge, this annual report does not contain any untrue statement of a material fact or omit to state a material fact necessary to make the statements made, in light of the circumstances under which such statements were made, not misleading with respect to the period covered by this annual report;

3. Based on my knowledge, the financial statements, and other financial information included in this annual report, fairly present in all material respects the financial condition, results of operations and cash flows of the registrant as of, and for, the periods presented in this annual report;

4. The registrant's other certifying officers and I are responsible for establishing and maintaining disclosure controls and procedures (as defined in Exchange Act Rules 13a-14 and 15d-14) for the registrant and have:

a. designed such disclosure controls and procedures to ensure that material information relating to the registrant, including its consolidated subsidiaries, is made known to us by others within those entities, particularly during the period in which this annual report is being prepared;

b. evaluated the effectiveness of the registrant's disclosure controls and procedures as of a date within 90 days prior to the filing date of this annual report (the "Evaluation Date"); and

c. presented in this annual report our conclusions about the effectiveness of the disclosure controls and procedures based on our evaluation as of the Evaluation Date;

5. The registrant's other certifying officers and I have disclosed, based on our most recent evaluation, to the registrant's auditors and the audit committee of the registrant's board of directors (or persons performing the equivalent function):

a. all significant deficiencies in the design or operation of internal controls which could adversely affect the registrant's ability to record, process, summarize and report financial data and have identified for the registrant's auditors any material weaknesses in internal controls;

b. and any fraud, whether or not material, that involves management or other employees who have a significant role in the registrant's internal controls; and

6. The registrant's other certifying officers and I have indicated in this annual report whether or not there

were significant changes in internal controls or in other factors that could significantly affect internal controls subsequent to the date of our most recent evaluation, including any corrective actions with regard to significant deficiencies and material weaknesses.

Date: April 8, 2003 /s/ ALAN S. MCKIM

Alan S. McKim
President and Chief Executive Officer

I, Roger A. Koenecke, certify that:

1. I have reviewed this annual report on Form 10-K of Clean Harbors, Inc.

2. Based on my knowledge, this annual report does not contain any untrue statement of a material fact or omit to state a material fact necessary to make the statements made, in light of the circumstances under which such statements were made, not misleading with respect to the period covered by this annual report

3. Based on my knowledge, the financial statements, and other financial information included in this annual report, fairly present in all material respects the financial condition, results of operations and cash flows of the registrant as of, and for, the periods presented in this annual report;

4. The registrant's other certifying officers and I are responsible for establishing and maintaining disclosure controls and procedures (as defined in Exchange Act Rules 13a-14 and 15d-14) for the registrant and have:

a. designed such disclosure controls and procedures to ensure that material information relating to the registrant, including its consolidated subsidiaries, is made known to us by others within those entities, particularly during the period in which this annual report is being prepared;

b. evaluated the effectiveness of the registrant's disclosure controls and procedures as of a date within 90 days prior to the filing date of this annual report (the "Evaluation Date"); and

c. presented in this annual report our conclusions about the effectiveness of the disclosure controls and procedures based on our evaluation as of the Evaluation Date;

5. The registrant's other certifying officers and I have disclosed, based on our most recent evaluation, to the registrant's auditors and the audit committee of the registrant's board of directors (or persons performing the equivalent function):

a. all significant deficiencies in the design or operation of internal controls which could adversely affect the registrant's ability to record, process, summarize and report financial data and have identified for the registrant's auditors any material weaknesses in internal controls; and

b. any fraud, whether or not material, that involves management or other employees who have a significant role in the registrant's internal controls; and

6. The registrant's other certifying officers and I have indicated in this annual report whether or not there were significant changes in internal controls or in other factors that could significantly affect internal controls subsequent to the date of our most recent evaluation, including any corrective actions with regard to significant deficiencies and material weaknesses.

Date: April 8, 2003 /s/ ROGER A. KOENECKE

Roger A. Koenecke
Senior Vice President and Chief Financial Officer

Any statements contained herein that are not historical facts are forward-looking statements within the meaning of the Private Securities Litigation Reform Act of 1995, and involve risks and uncertainties. These forward-looking statements are generally identifiable by use of the words "believes," "expects," "intends," "anticipates," "plans to," "estimates," "projects," or similar expressions. These forward-looking statements are subject to certain risks and uncertainties that could cause actual results to differ materially from those reflected in these forward-looking statements. Readers are cautioned not to place undue reliance on these forward-looking statements, which reflect management's opinions only as of the date hereof. The Company undertakes no obligation to revise or publicly release the results of any revision to these forward-looking statements.

A variety of factors beyond the control of the Company affect the Company's performance, including, but not limited to:

- The effects of general economic conditions in the United States, Canada and other territories and countries where the Company does business;
- The effect of economic forces and competition in specific marketplaces where the Company competes;
- The possible impact of new regulations or laws pertaining to all activities of the Company's operations;
- The outcome of litigation or threatened litigation or regulatory actions;
- The effect of commodity pricing on overall revenues and profitability;
- Possible fluctuations in quarterly or annual results or adverse impacts on the Company's results caused by the adoption of new accounting standards or interpretations or regulatory rules and regulations;
- The effect of weather conditions or other aspects of the forces of nature on field or facility operations;
- The effects of industry trends in the environmental services and waste handling marketplace;
- The effects of conditions in the financial services industry on the availability of capital and financing;
- The Company's ability to successfully complete the integration of the CSD acquisition which became effective in September 2002 and to manage the significant environmental liabilities which it assumed in connection with that acquisition;
- The availability and costs of liability insurance and financial assurances required by governmental entities relating to our facilities.

Any of the above factors and numerous others not listed nor foreseen may adversely impact the Company's financial performance. Additional information on the potential factors that could affect the Company's actual results of operations is included in its filings with the Securities and Exchange Commission, including but not limited to its Annual Report on Form 10-K, in its entirety and specifically Item 7, for the fiscal year ended December 31, 2003, and its subsequent reports on Form 10-Q, which are filed with the SEC.

ATTACHMENT E

CERTIFICATE OF LIABILITY INSURANCE

Client#: CLEANHARBORS

ACORD™ CERTIFICATE OF LIABILITY INSURANCE

DATE (11/18/04)

PRODUCER
Arthur Lyev (p) 212-553-3608
Zurich NA
1 Liberty Plaza
New York, NY 10006

THIS CERTIFICATE IS ISSUED AS A MATTER OF INFORMATION ONLY AND CONFERS NO RIGHTS UPON THE CERTIFICATE HOLDER. THIS CERTIFICATE DOES NOT AMEND, EXTEND OR ALTER THE COVERAGE AFFORDED BY THE POLICIES BELOW.

INSURERS AFFORDING COVERAGE	NAIC #
INSURER A: Steadfast Insurance Company	
INSURER B:	
INSURER C:	
INSURER D:	
INSURER E:	

INSURED
Clean Harbors Deer Trail, LLC
EPA ID No. COD981300484
108555 East Highway 36; Deer Trail, CO 80105

COVERAGES

THE POLICIES OF INSURANCE LISTED BELOW HAVE BEEN ISSUED TO THE INSURED NAMED ABOVE FOR THE POLICY PERIOD INDICATED. NOTWITHSTANDING ANY REQUIREMENT, TERM OR CONDITION OF ANY CONTRACT OR OTHER DOCUMENT WITH RESPECT TO WHICH THIS CERTIFICATE MAY BE ISSUED OR MAY PERTAIN, THE INSURANCE AFFORDED BY THE POLICIES DESCRIBED HEREIN IS SUBJECT TO ALL THE TERMS, EXCLUSIONS AND CONDITIONS OF SUCH POLICIES. AGGREGATE LIMITS SHOWN MAY HAVE BEEN REDUCED BY PAID CLAIMS.

INSR LTR	ADD'L INSRD	TYPE OF INSURANCE	POLICY NUMBER	POLICY EFFECTIVE DATE (MM/DD/YY)	POLICY EXPIRATION DATE (MM/DD/YY)	LIMITS	
		GENERAL LIABILITY				EACH OCCURRENCE	$
		☐ COMMERCIAL GENERAL LIABILITY				DAMAGE TO RENTED PREMISES (Ea occurrence)	$
		☐ CLAIMS MADE ☐ OCCUR				MED EXP (Any one person)	$
						PERSONAL & ADV INJURY	$
						GENERAL AGGREGATE	$
		GEN'L AGGREGATE LIMIT APPLIES PER:				PRODUCTS - COMP/OP AGG	$
		☐ POLICY ☐ PRO-JECT ☐ LOC					
		AUTOMOBILE LIABILITY				COMBINED SINGLE LIMIT (Ea accident)	$
		☐ ANY AUTO					
		☐ ALL OWNED AUTOS				BODILY INJURY (Per person)	$
		☐ SCHEDULED AUTOS					
		☐ HIRED AUTOS				BODILY INJURY (Per accident)	$
		☐ NON-OWNED AUTOS					
		☐ $				PROPERTY DAMAGE (Per accident)	$
		☐ $					
		GARAGE LIABILITY				AUTO ONLY - EA ACCIDENT	$
		☐ ANY AUTO				OTHER THAN AUTO ONLY: EA ACC	$
						AGG	$
		EXCESS/UMBRELLA LIABILITY				EACH OCCURRENCE	$
		☐ OCCUR ☐ CLAIMS MADE				AGGREGATE	$
							$
		☐ DEDUCTIBLE					$
		☐ RETENTION $					$
		WORKERS COMPENSATION AND EMPLOYERS' LIABILITY				☐ WC STATU-TORY LIMITS ☐ OTH-ER	
		ANY PROPRIETOR/PARTNER/EXECUTIVE OFFICER/MEMBER EXCLUDED?				E.L. EACH ACCIDENT	$
		If yes, describe under SPECIAL PROVISIONS below				E.L. DISEASE - EA EMPLOYEE	$
						E.L. DISEASE - POLICY LIMIT	$
A		OTHER Pollution Legal Liability Sudden/Non-Sudden	PLC 3743936-03	05/01/04	05/01/05	$3mm/$6mm Sudden Accidental $5mm/$10mm NonSudden Accidental	

DESCRIPTION OF OPERATIONS / LOCATIONS / VEHICLES / EXCLUSIONS ADDED BY ENDORSEMENT / SPECIAL PROVISIONS

This Certificate certifies that the policy to which this Certificate applies, provides Liability insurance covering bodily injury and property damage in connection with the insured's obligation to demonstrate financial responsibility under section 266.16 of the Colorado Hazardous Waste Regulations, C.R.S. 1973, as amended.

CERTIFICATE HOLDER

Director, Haz Mat. Wate Mangement Division - Attn: Mira Neumiller
Colo. Department of Public Health and Environment
4300 Cherry Creek Dr. - South-Mail Code: HMWMD-CP-B2
Denver, CO 80246

CANCELLATION

SHOULD ANY OF THE ABOVE DESCRIBED POLICIES BE CANCELLED BEFORE THE EXPIRATION DATE THEREOF, THE ISSUING INSURER WILL MAIL 30 DAYS WRITTEN NOTICE TO THE CERTIFICATE HOLDER NAMED TO THE LEFT.

AUTHORIZED REPRESENTATIVE - Arthur Lyev

ACORD 25 (2001/08) #351822/M45844 ACK © ACORD CORPORATION 1988

Client#: CLEANHARBORS

ACORD CERTIFICATE OF LIABILITY INSURANCE

DATE (11/18/04)

PRODUCER
Arthur Lyev (p) 212-553-5608
Zurich NA
1 Liberty Plaza
New York, NY 10008

THIS CERTIFICATE IS ISSUED AS A MATTER OF INFORMATION ONLY AND CONFERS NO RIGHTS UPON THE CERTIFICATE HOLDER. THIS CERTIFICATE DOES NOT AMEND, EXTEND OR ALTER THE COVERAGE AFFORDED BY THE POLICIES BELOW.

INSURERS AFFORDING COVERAGE	NAIC #
INSURER A: Steadfast Insurance Company	
INSURER B:	
INSURER C:	
INSURER D:	
INSURER E:	

INSURED
Clean Harbors Deer Trail, LLC
EPA ID No. COD991300484
108555 East Highway 36; Deer Trail, CO 80105

COVERAGES

THE POLICIES OF INSURANCE LISTED BELOW HAVE BEEN ISSUED TO THE INSURED NAMED ABOVE FOR THE POLICY PERIOD INDICATED. NOTWITHSTANDING ANY REQUIREMENT, TERM OR CONDITION OF ANY CONTRACT OR OTHER DOCUMENT WITH RESPECT TO WHICH THIS CERTIFICATE MAY BE ISSUED OR MAY PERTAIN, THE INSURANCE AFFORDED BY THE POLICIES DESCRIBED HEREIN IS SUBJECT TO ALL THE TERMS, EXCLUSIONS AND CONDITIONS OF SUCH POLICIES. AGGREGATE LIMITS SHOWN MAY HAVE BEEN REDUCED BY PAID CLAIMS.

INSR LTR	ADD'L INSRD	TYPE OF INSURANCE	POLICY NUMBER	POLICY EFFECTIVE DATE (MM/DD/YY)	POLICY EXPIRATION DATE (MM/DD/YY)	LIMITS
		GENERAL LIABILITY				EACH OCCURRENCE $
		COMMERCIAL GENERAL LIABILITY				DAMAGE TO RENTED PREMISES (Ea occurrence) $
		CLAIMS MADE OCCUR				MED EXP (Any one person) $
						PERSONAL & ADV INJURY $
						GENERAL AGGREGATE $
		GEN'L AGGREGATE LIMIT APPLIES PER:				PRODUCTS - COMP/OP AGG $
		POLICY PRO-JECT LOC				
		AUTOMOBILE LIABILITY				COMBINED SINGLE LIMIT (Ea accident) $
		ANY AUTO				BODILY INJURY (Per person) $
		ALL OWNED AUTOS				
		SCHEDULED AUTOS				BODILY INJURY (Per accident) $
		HIRED AUTOS				
		NON-OWNED AUTOS				PROPERTY DAMAGE (Per accident) $
		$				
		$				
		GARAGE LIABILITY				AUTO ONLY - EA ACCIDENT $
		ANY AUTO				OTHER THAN AUTO ONLY: EA ACC $
						AGG $
		EXCESS/UMBRELLA LIABILITY				EACH OCCURRENCE $
		OCCUR CLAIMS MADE				AGGREGATE $
						$
		DEDUCTIBLE				$
		RETENTION $				$
		WORKERS COMPENSATION AND EMPLOYERS' LIABILITY				WC STATU-TORY LIMITS OTH-ER
		ANY PROPRIETOR/PARTNER/EXECUTIVE OFFICER/MEMBER EXCLUDED?				E.L. EACH ACCIDENT $
		If yes, describe under SPECIAL PROVISIONS below				E.L. DISEASE - EA EMPLOYEE $
						E.L. DISEASE - POLICY LIMIT $
A		OTHER Closure Post Closure	PLC 5254333	09/06/03	09/06/06	$3,619,006 $2,700,537

DESCRIPTION OF OPERATIONS / LOCATIONS / VEHICLES / EXCLUSIONS ADDED BY ENDORSEMENT / SPECIAL PROVISIONS

This Certificate certifies that the policy to which this Certificate applies, provides Closure and Post-Closure Care coverage in connection with the insured's obligation to demonstrate financial responsibility under section 226.14 of the Colorado Hazardous Waste Regulations, C.R.S. 1973, as amended. .

CERTIFICATE HOLDER

Director, Haz Mat. Wate Mangement Division - Attn: Mira Neumiller
Colo. Department of Public Health and Environment
4300 Cherry Creek Dr. South-Mail Code: HMWMD-CP-B2
Denver, CO 80246

CANCELLATION

SHOULD ANY OF THE ABOVE DESCRIBED POLICIES BE CANCELLED BEFORE THE EXPIRATION DATE THEREOF, THE ISSUING INSURER WILL MAIL 60 DAYS WRITTEN NOTICE TO THE CERTIFICATE HOLDER NAMED TO THE LEFT.

AUTHORIZED REPRESENTATIVE - Arthur Lyev

ACORD 25 (2001/08) #S51622/M45544 ACK © ACORD CORPORATION 1988

ATTACHMENT F

CERTIFICATE OF CLOSURE AND POSTCLOSURE INSURANCE

COLORADO CERTIFICATE OF INSURANCE
FOR CLOSURE OR POST-CLOSURE CARE

Name and Address of Insurer (herein called the "Insurer"):	Steadfast Insurance Company 1400 American Lane Schaumburg, Illinois 60196
Name and Address of Insured (herein called the "Insured"):	Clean Harbors, Inc. 1501 Washington Street Braintree, MA 02184-7535
Facilities Covered:	EPA Identification No. COD 991-300-484 Clean Harbors Deer Trail, LLC 108555 East Highway 36 Deer Trail, CO 80195 Closure Costs: $3,619,006 Post Closure Costs: $2,700,537
Face Amount:	$6,319,543
Policy Number:	PLC 5254333-01
Effective Date:	September 6, 2003

This certificate certifies that the policy to which this Certificate applies, provided Closure and Post-Closure Care coverage in connection with the insured's obligation to demonstrate financial responsibility under section 266.14 of the Colorado Hazardous Waste Regulations C.R.S. 973, as amended.

Cancellation of this policy, whether by the Insurer or the Insured, will be effective only upon written notice and only after the expiration of sixty (60) days after a written notice of cancellation is received by the Department.

Whenever requested by the Department, the Insurer agrees to furnish to the Department a duplicate original of the policy listed above, including all endorsements thereon.

Arthur Lyev – Senior Underwriter

Authorized Representative of: Steadfast Insurance Company
Administrative Officer
1400 American Lane
Schaumburg, IL 60196-1056

Signature of witness or notary:

Date: 07-02-2005

CERTIFICATE HOLDER