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CRCPD's Task Force on TENORM

(Technologically Enhanced Naturally Occurring Radioactive Material)

Conference of Radiation Control Program Directors, Inc. (CRCPD)
A Partnership Dedicated to Radiation Protection

MEMO

From: Thomas Cardwell, Chair E-36 Ad Hoc TENORM Committee
Thomas Cardwell

To: Ed Bailey
Steve Collins
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Paul Merges
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Subject: Peer Review of the, "Part N Implementation Guidance for Regulation and Licensing of Technologically Enhanced Naturally Occurring Radioactive Material"

The enclosed document has been published as a Committee Report. However, the E-36 Committee believes that the document will receive wider distribution if published as a CRCPD publication. You have been selected to peer review the implementation guidance document.

We ask that you review the document and provide comments to the committee within 90 days of receipt of the document. We hope to have the document published this year. Thank you for your input and cooperation.

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Implementation Guidance for Regulation and Licensing of Technologically Enhanced Naturally Occurring Radioactive Material (TENORM)

Part N

of the

Suggested State Regulations for Control of Radiation

September 1999

Prepared by the
CRCPD Task Force on TENORM (E-36)

The preparation of this document was supported by purchase order number K99-575049 of Lockeed Martin Idaho Technologies Company, on behalf of the U.S. Department of Energy.

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1.0 Introduction

This document is intended to assist both regulatory authorities and the regulated community with interpreting and implementing the provisions of Part N of the Suggested State Regulations for Control of Radiation (SSRCR), entitled, "Regulation and Licensing of Technologically Enhanced Naturally Occurring Radioactive Materials (TENORM)". No requirements are added in this document beyond those established in Part N. The concept of as low as reasonably achievable (ALARA) should be considered in application of Part N. The regulatory standards contained in Part N are based on those established by the United States Nuclear Regulatory Commission (USNRC) and the United States Environmental Protection Agency (USEPA). TENORM is generated as part of processes in many industries, and companies in these industries must assure that adequate controls are in place to prevent contamination of the environment, and to protect public and employee safety. Realizing this diversity the Conference of Radiation Control Program Directors, Inc. (CRCPD) has developed a flexible model state regulation (SSRCR) that can be adapted by the regulator to the TENORM hazards of the state. When utilizing Part N as a model for their TENORM regulations, each state must establish standards and regulations that are consistent with their current standards for protection of public health and the environment.

Different standards for radiation dose to the general public apply during a company's operations than for exposures from post operational and disposal activities. The USNRC standard for dose to the general public from operational or licensed activities is an annual limit of 1 millisievert (mSv) [100 millirem (mrem)], total effective dose equivalent (TEDE). This standard has also been adopted by the agreement states as a matter of compatibility with USNRC. USNRC in 10 CFR 61 established 250 microsieverts (μSv) [25 mrem] per year whole body as the limit for the reasonably maximally exposed individual from disposal of radioactive material. It is important to note that this limit is based on dosimetry published in an ICRP Committee 2 Report of 1958 and is not a TEDE. The USEPA recommends annual doses to members of the general public of 100 μSv [10 mrem] TEDE from any single source in the environment. Although the USNRC limits were established for by-product radioactive material, there is consensus among the authors of this document that these limits ought to apply to all radioactive materials. The USNRC limits are endorsed by Part N and this document. Having considered all aspects, the CRCPD has taken a position that the current Part N allows flexibility in the regulation of TENORM. Part N allows land and facilities to be decontaminated to a level that will limit the annual radiation dose to the reasonably maximally exposed individual to some fraction of 1 mSv [100 mrem] TEDE. The regulatory authority should establish this fraction such that no individual will likely receive a dose in excess of 1 mSv [100 mrem] TEDE annually above background from any use or release of land together with doses from other licensed sources of radiation. Part D of the SSRCR (10 CFR 20) governs occupational doses from exposure to TENORM.. Training requirements for workers are addressed in Part J.12 of the SSRCR (10 CFR 19.12).

The exemption level for TENORM under Part N is 0.18 Becquerels (Bq) [5 picocuries (pCi)] of radium per gram (any combination of radium-226 and radium-228). This is the same exemption level established for the clean up of property contaminated with uranium mill tailings.. It is important to note that this concentration is an exemption level below which most materials are exempt from regulation. It does not mean that every material above this level must necessarily be regulated. Since most TENORM is in the form of scales or sludges with a lower radon emanation fraction than uranium mill tailings, the exempting of soil or media contaminated to this level is considered protective of public health.

Part N does not attempt to regulate and should not be applied to any material that is defined as source material or uranium by-product material regulated under the Uranium Mill Tailings Radiation Control Act of 1978 (UMTRCA). Other naturally occurring radionuclides, e.g., tritium, carbon-14, and potassium-40, may also be concentrated as TENORM.

Of the diverse companies that generate TENORM and accumulate TENORM waste, many may not have personnel familiar with radiation safety. They will, nevertheless, be required to comply with state regulations based on Part N of the SSRCR and to demonstrate basic safety and environmental control. To do this they will need to have an understanding of Part N requirements and methods of complying with these requirements to prevent the spread of contamination and to assure employee and public safety. In addition states may need more detailed information than is contained in Part N to properly draft and implement their own TENORM regulations. This document was developed to address these needs by providing guidance on the following topics:

1. standards for the use of radioactive material;
2. standards for disposal of radioactive material;
3. selection of dose assessment models;
4. selection of parameters for dose assessment models; and,
5. a framework for common understanding among state regulatory agencies, companies, workers, and the general public regarding adequate measures for compliance with Part N.

This document has seven sections, followed by appendices and citations of references. Topics covered are: the material regulated; the types of licenses required; how materials contaminated with TENORM may be transferred from one person to another; TENORM disposal issues; suggested dose assessment models and parameters of the models; the decommissioning of TENORM licensed facilities; considerations for measurement of TENORM; and financial assurance considerations for TENORM.

2.0 Do I have TENORM?

Companies may question whether material they have is TENORM . TENORM may accumulate to significant levels in process operations involving the extraction, purification, filtration, smelting, or pipeline transport of virtually any material of geologic origin. Surface- and groundwater, metals, petroleum, natural gas, and process treatment sludges are among such materials. The underlying principle that distinguishes naturally occurring radioactive material (NORM) from

TENORM is that, with TENORM, an increased concentration of radionuclides over that found in the same material in nature has resulted from human activity. This section gives guidance on determining whether a material is TENORM or is NORM that is not regulated under Part N, or is radioactive material regulated under other federal or state regulations.

2.1 Is my material source material or uranium by-product material?

Part N applies to naturally occurring radioactive materials other than source material whose concentration has been technologically enhanced. Part N does not apply to materials containing concentrations of source material equal to or greater than 0.05% by weight. Source material is defined in Part A.2 of the SSRCR and in10 CFR 40.4 as "uranium or thorium, or any combination thereof, in any physical or chemical form; or, ores that contain by weight one-twentieth of one percent (0.05 percent) or more of uranium or thorium, or any combination of uranium or thorium."

Some uranium by-products and mill tailings defined by 10 CFR 40 are regulated by USNRC and agreement states. This preempts states from regulating these materials as TENORM. Uranium by-product is defined as waste material that has become contaminated from the fuel cycle or uranium recovery operations. UMTRCA also sets standards for clean-up of lands and facilities that had become contaminated from the fuel cycle industry. Waste material and tailings that were generated from recovery of source material either under the Atomic Energy Act or a USNRC license are controlled and regulated under existing regulations for uranium mill tailings. The federal regulations established under 10 CFR 40 and UMTRCA have established clean-up standards and standards for disposal of uranium mill tailings and by-product materials.

Part N of the Suggested State Regulations for Control of Radiation establishes model regulations for "technologically enhanced" naturally occurring radioactive material. Materials that are radioactive, but in which the radioactive constituents have not been concentrated through human intervention, are not addressed by Part N. Soil and rocks that are naturally radioactive and materials made from these, provided that human intervention has not concentrated the naturally occurring radioactive materials, are not regulated by Part N.

Therefore, it is essential that industries that use naturally occurring radioactive materials assess their processes to determine where NORM material could be concentrated to a degree qualifying as TENORM.. To make this determination industries must analyze the materials they are using, understand the chemical and physical properties of naturally occurring radionuclides, and analyze their products and waste streams to determine if NORM has been concentrated into material that would be considered TENORM. See the NORM 3 Report (CRCPD94-2) for discussion of industrial practices that result in concentration of NORM.

2.2 How do I know if my TENORM is included or exempted from regulations?

After determining that NORM has been or could be concentrated in a process, the company must refer to Part N, Section N.4. to determine if the material is exempted by regulation. Part N recognizes that the societal beneficial of some materials, such as fertilizers, outweigh the radiation associated risks presented by the materials and exempts these materials from regulations. Some TENORM materials are adequately contolled under other regulations such as the Comprehensive Environmental Response, Compenstaion, and Liability Act (CERCLA) and the Resources Conservation and Recovery Act (RCRA) and have been exempted from regulation by Part N for that reason. Part N does not address the regulation of TENORM while the material is in transport. Regulation of transport and storage incident to transport is addressed by Parts D and T of the SSRCR's. Section N.4. exempts persons who receive products or materials that are manufactured and distributed under a specific license to do so.

Subsection a. in Section N.4. presents the most difficult case for determining whether materials are exempt or regulated by Part N. This exemption applies to materials such as soil, scales and sludges containing TENORM that is dispersed throughout the materials. This exemption does not apply to surface contamination on equipment, such as pumps, valves and piping, that is contaminated with scales or other material containing TENORM.

To apply this exemption to equipment such as pipe, it must be determined that the concentration of total radium is less than 0.18 Bq [5 pCi] per gram in the scales excluding the weight of the pipe or object contaminated with scales or other TENORM containing material. The release of equipment for unrestricted use is addressed in Section N.7.

Subsection N.4.a. prohibits the purposeful dilution of waste to render the waste exempt from regulation without regulatory agency approval. The definition of waste has been generally accepted as being material that has no further useful purpose. Waste streams must be analyzed separately to determine if the concentration is greater than the exempt limit prior to mixing the waste streams. Waste materials subject to regulation under Part N by virtue of their TENORM concentrations may not be commingled with materials that are exempted by Section N.4 unless authorized by the regulatory agency. The regulatory agency may consider relative volumes, radionuclides and their concentrations, and chemical and physical characteristics of waste streams in approving commingling of wastes for management. This subsection disallows soil mixing, spreading, or landfarming of contaminated materials to achieve exempt concentrations unless the regulatory agency has previously authorized the activity. States may allow landfarming or on-site disposal of regulated material under section N.8.a.iii. However, alternate methods of disposal for materials that are not exempted must be approved by the regulatory authority and should not be initiated without such approval. Further discussion of landfarming is contained in Section 4 of this document. If a determination is made that the TENORM or TENORM contaminated material is regulated under Part N, then it must be determined whether the material comes under Part N's general license or specific license provisions.

3.0 Licensing

3.1 Introduction

TENORM is widely distributed and exists in conjunction with other materials desired for their non-radioactive attributes. As a result there are many products, materials and sites which contain TENORM at concentrations which require some level of control. This realization has been the driving force behind the development of Part N and requires a fundamentally different approach to regulating TENORM compared to other activities addressed in the SSRCR. An applicant for a license issued under Part C (or comparable regulations) typically intends to possess and use radiation sources for their radioactive properties and has to affirmatively seek to acquire the necessary sources, whereas the possessor of TENORM often, but not always, acquired the TENORM "passively", i.e., as an unintended, unnecessary adjunct to the material or facility acquired for its other attributes.

On the other hand, basic principles of radiation protection imply that some level of mandatory controls are necessary at many facilities possessing or contaminated with TENORM. In an attempt to strike the proper balance, the drafters of Part N concluded that the majority of facilities possessing TENORM should be subject to a general license, with provisions for specific licenses for those facilities and activities for which more stringent controls are appropriate

3.2 What is a general license and do I need one?

Part N establishes a general license for anyone who possesses TENORM and is neither exempted nor required to obtain a specific license. A state adopting Part N should review its particular administrative procedures act to ensure that the procedures for issuing the general license and making it applicable to a specific facility are consistent with those procedures and authorized under state law.

Part N provides, as an option, for notice to be provided to the state of the facility's intent to be covered under the general license. The state may elect to require notice of intent as a prerequisite for coverage; under such a regulatory scheme, facilities which possess TENORM, but which do not notify the state TENORM licensing agency, are then operating without permits and may be subject to enforcement for such violations. On the other hand, a state having many TENORM facilities, in order to reduce the regulatory burden and the administrative overhead, may elect not to require notification as a prerequisite, or even not to provide for notification at all.

Enforcement is one factor influencing this decision. Each state must determine how compliance with the regulation and the general license will be assessed. If routine inspections are contemplated, some mechanism to identify and locate TENORM facilities is required, and building a notification requirement into the general license provisions is one way to do so.

However, if the state elects only to respond to incidents reported through other channels, notification may not be required.

Most TENORM is produced incidental to an industry's main products. Examples are scale in oil and gas production, resins in water treatment, some phosphate wastes in the fertilizer industry and wastes in the rare earths and metal industries. Other industries also may concentrate NORM that would be regulated under Part N. Section N.10. issues a general license to possess, own, use, transfer, distribute or dispose of TENORM subject to the requirements of Sections N.5 through N.8 and N.10 of Part N.

A general licensee may continue operations with minimal burdens from regulation. The general licensee must control TENORM to the extent that the spread of contamination and excessive exposure to workers and the general public is prevented. Subsection d. of Section N.10 requires each general licensee to notify the regulatory agency of TENORM in custody. This is an option that a state may choose to impose or not impose depending upon its regulatory philosophy .

A general licensee may perform routine maintenance on TENORM contaminated equipment, facilities, and land which the general licensee owns or controls. However, Section N.10c. prohibits the general licensee from performing decontamination. Routine maintenance differs from decontamination in that it does not generally involve the potential for significantly increased exposure of workers to TENORM contamination and radiation. The general licensee should therefore review all aspects of the operation to determine which activities may increase the potential for additional radiation exposure and contamamination of workers. For example, confined space entries per 29 CFR 1910 should be evaluated to determine if special procedures are required to prevent the workers from receiving a dose in excess of 10% of the occupational limits (e.g., 5 mSv [500 mrem] per year TEDE) specified in Part D of the SSRCR (see N.5.b). Any activity that increases the worker's exposure in excess of 10% of the occupational limit is considered a significant dose and should not be considered as routine maintenance. Any activity conducted for the specific purpose of removing TENORM or scale contaminated with radium at concentrations not exempt must be conducted by personnel operating under a specific license. Pipe and equipment released for use based on an approved screening procedure should be used in the same condition in which it was received. A person under a general license who accepts the pipe or equipment is not authorized to perform decontamination of the pipe or equipment received. The regulatory agency's approval of screening methods includes an assessment of the radiation levels on the equipment or pipe and a determination that a release of the pipe or equipment, as it exists at time of release, is consistent with Section N.5. Activities that remove TENORM contaminated scales from pipe or equipment generate waste that may exceed the exempt concentration of radium and increase the potential for internal and/or external exposure. Therefore, a specific license is required to perform this activity.

Contaminated equipment, facilities and land may be transferred from one general licensee to another general license under the following conditions: the transferor must notify the recipient that the facilities, equipment or land is contaminated with TENORM that is subject to regulation; and, the transferor must determine that the recipient will use contaminated facilities and/or equipment for the same purpose. For example, contaminated oilfield pipe can be transferred to another person if the contaminated pipe is to be used in oil and gas production. However, the recipient cannot use the pipe for irrigation or water pipe and should not use the pipe for construction purposes unless it has been released for unrestricted use in accordance with a method acceptable to the regulatory agency for releasing the pipe.

Land that is contaminated above release limits may be transferred from one licensee to another as authorized by the regulatory agency. Section N.10 e. i. (2) gives the state the authority to require annotation of the deed or, at a minimum, a disclosure to the recipient that the land is contaminated with TENORM above the concentrations allowable for release.

Section N.10.e.iv. prohibits the release of any equipment, facilities, or land for unrestricted use unless the general licensee complies with the requirements of Section N.7. The person who transfers contaminated equipment or property may be required under N.10.e.iv to make measurements that confirm the contamination is within the limits of N.7 and to retain the documentation of these measurement results. Recipients of equipment, facilities, or land not meeting the requirements of Section N.7. become general licensees. It then becomes their responsibility to restrict access to the contaminated property, maintain it to prevent contamination and/or exposure, and prevent unauthorized use. Section N.10.g. gives the regulatory agency the authority to require in writing that a general licensee apply for and obtain a specific license. The regulatory agency shall state the reason for determining that a specific license is required.

3.3 What is a specific license and do I need one?

A specific license requires the submission of an application to the regulatory agency and the issuance of a licensing document by the regulatory agency. The licensee is subject to all applicable portions of the agency's regulations and any limitations specified in the licensing document. The requirements for a specific license with regard to TENORM are contain in N.20 through N.31. Anyone who wishes to receive, own, possess, use, process, transfer, distribute, or dispose of TENORM that is not exempt from regulation, and who does not qualify for a general license, must apply for and receive a specific license. These activities include the manufacture and distribution of consumer retail products containing TENORM the possession and use of which are exempt under section N.4.a. Manufacture and distribution of other products (e.g. commercial products) should evaluated by the licensing authority to determine if a license is required. A transfer of products containing TENORM between general licensees under N.10.f does not require a specific license, nor do persons exempted under N.4 require a specific license. Anyone who decontaminates equipment, facilities or land that is owned by someone else, unless performing routine maintenance under contract and in accordance with Section N.10.c., must apply for and receive a specific license. Anyone who receives TENORM waste from other persons for disposal must apply for and receive a specific license.

3.4 On-site waste management

Concern should be given to proper management of TENORM waste. Good practices for managing TENORM waste on site include an evaluation of the following areas:

- erosion prevention such as use of bermed areas ;
- preventing migration and infiltration with such methods as lined areas (e.g., concrete, clay or HDPE);
- prevention of wind blown migration by use of covers or containers.

In sum, following sound principles of pollution prevention and minimization that are established in other waste management programs should result in minimizing worker and public exposure to TENORM wastes managed on site.

4.0 How do I transfer or dispose of TENORM waste?

Disposal and transfer of TENORM waste is covered in Section N.8 of Part N. The transfer of TENORM waste is a separate matter from the release of equipment or facilities contaminated with TENORM which is covered in Section N.7. The discussion that follows is intended to give guidance on:

- disposal options;
- types of TENORM that are appropriately disposed via each option;
- methods for evaluating the disposal of TENORM using each option;
- key issues to evaluate when considering TENORM disposal via each option.

4.1 What are the disposal options under Part N?

Section N. 8 contains the following options for disposing of TENORM:

1. transfer of the wastes for disposal to a facility licensed under requirements for uranium or thorium byproduct materials in either 40 CFR 192 or 10 CFR 40 Appendix A;
2. transfer of the wastes for disposal to a disposal facility licensed by the USNRC, an agreement state, or a licensing state; and,
3. By an alternate method authorized by the regulatory agency upon application or upon the regulatory agency's initiative. The authorized method must ensure that no member of the public receives an annual TEDE from TENORM in excess of whatever fraction of 1 mSv [100 mrem] the state establishes. The method must also comply with applicable Clean Water Act, Safe Drinking Water Act and other US EPA requirements for disposal of such wastes.

See the CRCPD Web Site at www.crcpd.org for information on facilities accepting TENORM wastes and other commercial radioactive waste disposal services.

Depending upon the type, physical and chemical form, and the quantities of radionuclides, there are other specific disposal options which a state may consider under Part N.8.a. iii. These include: landfills permitted under RCRA, Subtitle C and D or state equivalent; injection wells permitted under federal or state regulations, e.g., 40 CFR 144 (Underground Injection Control Program); and land application of TENORM materials.

TENORM disposal within impoundments meeting the requirements for disposal of byproduct materials under 40 CFR 192 is consistent with Part N and should be acceptable to state regulatory agencies. This method for disposal of TENORM waste should also be sanctioned within facilities operating under a specific license issued by USNRC or an agreement state. Final decisions must be approved by the appropriate regulatory agencies.

As of the publication of this guidance, USEPA has issued draft guidance on disposal of drinking water treatment wastes and regulations on uranium mill tailings, but no requirements for TENORM disposal.

Under Sec. N.8.a.iii states may authorize alternative methods for disposal of TENORM wastes. While relatively high hazard TENORM wastes may be appropriate for disposal within specifically licensed facilities, wastes with relatively low TENORM concentrations may more appropriately be disposed of in general licensed facilities such as specially designed and controlled landfills. On-site disposal, in conjunction with institutional controls, may be the most feasible option where large volumes of mildly contaminated materials are involved; and, may also present a viable disposal option. Some states have approved down-hole disposal of certain oil field wastes as an appropriate option. Section N.8.a.iii is intended to provide states with considerable flexibility in determining acceptable disposal methods for unique TENORM materials as long as the licensing agency agrees the dose criteria in section N.5 will be met. State approval of disposal options can be based on *de novo* proposals by applicants or on generic evaluations of various processes or disposal options which have been previously evaluated as acceptable by a state regulatory agency, USEPA or USNRC.

Equipment which is contaminated with TENORM in excess of levels specified in Appendix A to Part N, and which is to be disposed of as waste, has separate requirements. The disposal method must prevent any reintroduction into commerce or unrestricted use; and, the disposal area and methods must meet the same criteria as other types of TENORM wastes.

Transfers for disposal of waste containing TENORM can be made only to a person authorized to receive such waste by an appropriate governmental agency. Records of disposal, including manifests, must meet the same requirements as other types of radioactive wastes. These requirements can be found in Part D of the SSRCR. Methods involving disposal on-site, such as land farming and down-hole disposal, do not require manifests.

4.2 How do I evaluate a proposed transfer of TENORM waste for disposal?

If the TENORM for disposal is being transferred to an appropriate disposal facility licenced to accept the type of waste in question, evaluation is greatly simplified. Handling, packaging and transport of the waste will be governed by state regulations for radioactive waste in general and by the disposal facility's permit requirements for acceptance of TENORM waste.

If the TENORM in question is to be managed and disposed of in accordance with N.8.a.iii (i.e., an alternative method approved by the regulatory agency) the evaluative process becomes very important and much more formal. In this situation, TENORM waste evaluation presents some special difficulties. First, TENORM comes from a variety of sources, can take many different chemical and physical forms, and can contain many radionuclides in widely differing amounts. The CRCPD NORM 3 Report (CRCPD94-2) reviews many of the types of TENORM and their characteristics. Second, states can have differing performance criteria and dosimetric approaches for evaluating TENORM waste. So the method of evaluation will depend to a certain extent on the characteristics of specific TENORM waste under consideration and the criteria established by the particular state in which the disposal is being proposed.

An evaluation begins with the dose criteria which have been established by the host state of the disposal site. The maximum allowable annual public dose from all licensed sources established by section N.5.a. is a TEDE of 1 mSv [100 mrem]. Since it is difficult to confirm that the TENORM in question is the only licensed source exposure for consideration, states may elect to adopt some fraction of 1 mSv [100 mrem] per year as the dose criteria which must be met during the evaluation.

Once dose criteria have been established by a state, there is a need for specific guidance on modeling, sampling, analysis, etc., that will be acceptable to the regulatory agency in support of the proposed disposal methodology. The goal of the analyses is to make realistic projections of dose which indicate that the reasonably maximally exposed individual will not receive an annual TEDE in excess of the state's standard. The evaluation necessarily involves assumptions, methods of calculation and analyses of uncertainties that are compatible with the regulatory agency's expectations. Therefore, detailed guidance on these aspects should be made available by the regulatory agency. The evaluation process, as assisted by currently available computer models, is discussed in the next section of this guidance document.

5.0 How do I evaluate my site for release under Part N?

This section provides information on computer assisted radiation dose forecast techniques currently in use. The objective of these computational models is to use the available information to make a good approximation of the radiological health risk to the population affected, and on that basis to make informed risk management decisions about the action under consideration. In practice, state risk management decisions under Part N are governed by the projected annual dose (TEDE) to the reasonably maximally exposed individual. Section N.5.a. adopts 1 mSv [100 mrem] as the annual dose permitted to the reasonably maximally exposed individual from all regulated uses of radioactive materials and ionizing radiation. States are given the flexibility to adopt some fraction of 1 mSv [100 mrem] to allot to TENORM exposures in order to keep doses within the 1 mSv [100 mrem] standard.

Dose forecast techniques depend upon pathway modeling to translate environmental concentrations or radiation measurements into doses, and/or risks, to selected populations or individuals. They involve hypothetical calculations and are intended to be an aid to decision making. Since conservative assumptions are usually involved, they may overestimate what will actually occur. There have been extensive efforts over the last decade to develop user-friendly computer programs which incorporate multiple-pathways models. Several programs currently available do not require special expertise in modeling, but should only be used by personnel with professional radiation protection experience. Computer programs are available which calculate the radiation dose and health risk from a broad spectrum of radionuclides for numerous environmental pathways and exposure scenarios. Although some computer programs incorporate models that have extensive flexibility and can be used for assessing the doses from numerous exposure scenarios, generally, they are focused on a limited number of scenarios. Table 1 identifies several models and indicates their primary applications.

5.1 What are environmental exposure pathways and exposure scenarios?

The term "environmental exposure pathway" refers to a relationship among contaminated environmental media, various pathways and mechanisms for contaminant transport resulting in human exposure. Figure 1 provides an illustration of environmental exposure pathways. TENORM exposure primarily occurs via direct exposure to external gamma radiation and via inhalation of TENORM contaminated particles. Other modes of potential exposure include ingestion of contaminated water and food. Indoor radon may also be a pathway for radiation dose, but is excluded from the radiation dose criteria of Part N.

The term "exposure scenario" refers to the environmental setting in which people may be exposed via an environmental pathway to a contaminant. Possible scenarios include an infant living in a residential environment where there is TENORM contamination, adults living in a "residential farming" situation, children exposed to TENORM in metal pipes used for playground equipment, and people working in a building contaminated with TENORM. The detailed RESRAD example discussed later in this section of the guidance document focuses on the "residential farmer" setting. However, models applicable to other settings, to the general population, and to commercial or industrial settings, are also discussed. RESRAD-Build code (RESRAD94) is a software package designed for assessing the radiation dose to people working in contaminated buildings, and MicroShield (Grove93) is a computer program used for calculating the external gamma dose for various geometries of radiation sources containing various radionuclides.

5.2 Which computer programs for dose assessment are useful for TENORM evaluations?

Table 1 provides a representative list of computer programs available for radiation dose assessment under different scenarios. References for each program, the agency for whom the program was developed and the company developing the program are given. Selected comments on each program are also provided. Most of these programs use multiple pathway models to provide assessments for all of the environmental pathways shown in Figure 1. MicroShield and RESRAD-Build, unlike the multiple pathway models, can be customized to a greater extent and have special applications. However, it should be emphasized that while all computer dose models are useful tools, each has its own limitations and needs to be applied with professional judgement.

5.3 What special use programs can be applied to TENORM evaluations?

MicroShield (Grove93) and RESRAD-Build (RESRAD94) incorporate unique coding which has special capabilities not present in most multiple pathway models. While relatively user-friendly, these programs require that the modeler have a reasonable understanding of the proposed dose scenarios in order to select the proper input parameters. In contrast, the multiple pathways programs have default parameters to cover most required inputs. MicroShield can be used to calculate external gamma dose for numerous source geometries. For example, the program can be used to calculate the external gamma dose from a single pipe containing TENORM (Bernhardt96, Rogers95), from configurations of multiple pipes, and from various geometries of slabs. MicroShield has a WIN95 (Version 5.01) and a MicroSoft DOS version.

RESRAD-Build provides the ability to determine the external gamma dose, inhalation dose, and ingestion dose from occupancy of buildings with residual contamination. The assessments require the modeler to provide "knowledgeable" input parameters for the residual contamination and parameters related to inhalation and ingestion. The ingestion scenario can be structured as a dirty-hands concept, where a person interacts with removable contamination and accidentally ingests it.

5.4 What multiple environmental pathways programs are useful for TENORM evaluations?

The RESRAD family of computer programs, developed by Argonne National Laboratory for the United States Department of Energy (USDOE), has received wide use due to courses and consultation provided by USDOE for state and other agencies. Since its inception, the model has had a user-friendly, menu-driven interface, which has made it relatively easy to use. The programs have been continuously upgraded since their introduction in the early 1990's. The RESRAD programs feature a relatively complete set of input parameters. The positive aspect of this feature is the relative ease of using the model. The negative aspect is the possibility of performing a dose assessment without understanding the underlying model and without having gone through the "thought process" which takes place when developing input values .

The PRESTO and PATHRAE families of computer programs have been developed by Rogers and Associates Engineering (RAE) of Salt Lake City, Utah for the USEPA. Most of the versions of these programs are oriented towards assessing the performance of waste disposal sites. Although the PRESTO program listed in Table 1 has a menu interface for use in WIN95, these programs generally require users to be very familiar with the underlying models and with the concepts involved in pathway models. The PRESTO and PATHRAE programs include some of the basic modeling parameters, but generally require the user to provide most of the input data. This family of programs has been used mostly by its developer and USEPA and is not in general use.

The GEN II computer program evolved out of a series of models developed by the Pacific Northwest Laboratory, Richland, Washington. The program has a user interface requiring a detailed knowledge of numerous parameters and is not user-friendly. It requires extensive interpretation of underlying parameters and exposure scenarios.

The National Council on Radiation Protection and Measurements (NCRP) developed a comprehensive catalog of screening values which can be used to estimate radiation doses for a spectrum of pathways and exposure scenarios. The models and screening levels are provided as extensive tabular listings in NCRP Report 123 (NCRP96). The report allows for the assessment of doses from environmental pathways for numerous radionuclides, including TENORM radionuclides.

The USNRC has developed extensive models to support its recent rule making on decommissioning and decontamination (D&D) of nuclear facilities. The pathway models and screening levels have been issued as sereral drafts, and have not been finalized. Screening criteria and the basis models are provided in NUREG 5512 (USNRC92)

Training on various pathway models may be available through the USDOE National Low-Level Waste Management Program at Idaho National Engineering and Environmental Lab (www. inel.gov/national/national.html) and the computer code developers (see CRCPD web site).

5.5 How do I use the RESRAD computer program for TENORM dose assessments?

Although the basic RESRAD program (Version 5.82) does not have the sophistication and flexibility for custom calculations exhibited by the PRESTO, PATHRAE, and GEN II models, it is much more user-friendly. We shall use RESRAD (current version 5.82) as the tool to discuss the details of performing dose assessments for purposes of complying with TENORM regulations patterned after Part N. However, much of the information is also applicable to other programs.

5.5.1 In general, what information do I need for RESRAD?

You will need to select pathways, scenarios, and modeling parameters for estimating the radiation dose from residual TENORM on a site. The RESRAD program allows you to determine the radiation dose from a broad spectrum of radionuclides, and allows you to "turn on or off" the various environment pathways (e.g., radon in a residence or eating fish from a farm pond). Therefore, the RESRAD program, with appropriate insight and understanding by the modeler, can be used to customize the dose assessment to specific exposure scenarios (e.g., a home built on a contaminated lot without intake of contaminated food or water). The relative significance of some parameters is dependent on the scenarios being included in the dose assessment. For example, food-pathway parameters do not affect the dose if food is not raised on the site. Similarly, the radon modeling parameters have little pertinence if buildings are not being built on a site, or the radon dose is not included in decision criteria.

The proper selection of the exposure scenario, including the basic criteria for characterizing the site, is of foremost importance. If there is residual contamination on the site, an important decision is whether the residual contamination is on the surface, or eventually will be on the surface due to erosion. Some of the alternative considerations related to external gamma dose include:

1. Contamination beneath the surface with surface conditions such that the material will likely remain beneath the surface. In this situation the external gamma radiation will be largely mitigated by shielding from the surface material, and possibly not be significant.

2. Cover with uncontaminated soil. There may be soil with residual contamination on the surface, but constraints on future uses may allow covering the site with a layer of uncontaminated soil. Depending on the specifications for the cover and the longevity of the cover, the external gamma dose and other pathways will be reduced and may be eliminated.

3. Retention of contaminated soil on the surface. The specifications may allow for soil with residual contamination to remain on the surface. Depending on the specifics of the scenario, the external gamma dose may be the primary dose pathway.

Some of the alternative considerations related to dose from use of groundwater include:

1. No use of groundwater: The specified use of the site or availability of groundwater may exclude the use of groundwater as a viable pathway.

2. No well actually located on the site: Due to the characteristics of the site or proposed controls of the site, the closest possible use of groundwater may be at a location outside of the site boundary; e.g., 15 meters away from the site.

3. Well for potable water on a contaminated site: The proposed site uses may include full unrestricted use and the site characteristics may make it viable to place a well for human consumption in the center of the site or at the down-gradient boundary of the site. These two options are the basic scenarios modeled by the RESRAD Pathways code.

Present and future land use considerations, as agreed with the licensing authority, may exclude residential uses including growing of food crops, and placement of wells for recovery of groundwater on the site. These specifications, if they are accepted for long-term enforcement, allow excluding the food and groundwater pathways.

5.5.2 What input parameters do I use with RESRAD?

Table 2 identifies the various categories of parameters that may be used as input data. These include parameters for the basic description of the site (area and depth of contamination), geological parameters (thicknesses and characteristics of the geological structure of the site), parameters for transfer of contaminants from TENORM to food, and parameters specifying the uptake through food, drinking water, and inhalation of air. The parameters are organized into categories in the menu, and default values are given for most of them. As noted in Table 2, early versions of RESRAD used default dose parameters from USDOE references. With Version 5.61, RESRAD adapted the USEPA dose factors from Federal Guidance Report No.11 (EPA88) as defaults. However, RESRAD, version 5.82 can use user-specific dose parameters, if desired. If default parameters are used exclusively, the only parameters that the user must provide are the radionuclides of concern and the concentrations for these radionuclides. The default parameters in the basic RESRAD code (version 5.82) are generally conservative, and the use of site-specific parameters will generally result in lower, more realistic radiation doses.

In setting up an assessment one must first decide which pathways are to be included and the time frames for which calculations are to be performed. The available pathways are identified at the bottom of Table 2 and include "external gamma" exposure , "indoor radon" dose, and doses from contamination of groundwater. The groundwater and radon-dose pathways in RESRAD have limited options for customizing assessments, although the radon-dose pathway incorporates many of the features of the Rogers and Associates Engineering Corp.(RAE) radon diffusion codes (Nielson92, Rogers84). The present version of RESRAD offers only two options for calculating the groundwater dose: in the center of the site; or at the down-gradient edge of the site. Supplemental calculations are required to determine the dose at an off-site location. The PRESTO model (PRESTO98) provides more sophisticated radon and groundwater calculations than

RESRAD. A RESRAD-groundwater model is in the test phase, and is expected to be available in the near future.

Table 3 identifies selected parameters related to site specific conditions and scenarios. It provides information on specific parameters which can significantly impact the environmental pathways modeling and provides some references for obtaining parameter values.

Table 4 provides selected distribution coefficients (K_d), i.e., ratios of concentrations in soil divided by concentrations in water, (units of milliliters per gram) used for determining the leaching of contaminants from TENORM residues and for modeling the flow of groundwater. Although there is extensive literature on K_d's, it is difficult to accurately specify K_d values for materials and sites without performing site specific analyses. K_d values are needed for the contaminated material (residual TENORM), the unsaturated zone, and the saturated zone. A very good general references for K_d's is provided by Sheppard (Sheppard90). This reference and additional Sheppard references on K_d's are listed in the Reference section of this Guidance (Sheppard85, Sheppard84, Sheppard80). Additional information on K_d's can be found in the support documents for RESRAD (Yu93). Table 4 provides a range of K_d values including those of Auxier and Associates (Auxier96), which are based on measurements of TENORM from oil and gas production. The American Society for Testing & Materials publishes an empirical method (ASTM84) for determining K_d's. There are also various leaching procedures used for K_d calculation involving analysis of the leachate. The USEPA TCLP leach procedure (40 CFR 264) is an example of a procedure that can be used to obtain data for K_d's

5.5.3 What output reports are available from RESRAD?

RESRAD can produce several output reports of which the most useful and concise is the summary report, denoted as "Summary.rpt.". Other reports include the "Concentration Report," and the "Detailed Report." The listing of the groups of parameters in the 2^{nd} column of Table 2 is based on the sequence of parameters listed in a typical RESRAD "Summary Report." The sequence of parameters, examples of typical input parameters (mostly default values), and examples of the dose results for a demonstration run using RESRAD are included as Appendix D.

5.5.4 What are the results of a typical RESRAD dose assessment?

Table 5 provides the results for an example of a RESRAD dose assessment for residual TENORM on a property. The input parameters used for this assessment are the default parameters from RESRAD. The assumed depth of residual TENORM is 15 cm, with an average concentration of 0.15 Bq [4 pCi] per gram of Ra-226 and Pb-210, and 0.04 Bq [1 pCi] per garm of Ra-228 above natural background. Options in the RESRAD model include the short half-life decay products. Also, it is assumed that the radioactive decay products are in secular equilibrium with their respective parents (e.g., Ra-226). The environmental scenario is that of a resident farmer. The assessment is for all of the environmental pathways, assuming that the family obtains all of its food from the site. The results for the indoor-radon assessment are given on the right-hand side of the Table, and are not included in the totals, since the dose from radon is excluded from the dose specification of the Part N regulations. Although the dose for the groundwater pathway is slightly higher at 500 years, the time frame of 1,000 years is used because many other scenarios produce a higher dose at 1,000 years, and 1000 years is often the longest time used for dose assessment.

Table 6 gives the doses from five assessments scenarios. The totals in the table, both for the doses at 1 year and the doses at 1,000 years are for all of the pathways except indoor radon. Indoor radon dose, although a separate consideration under Part N, is not included in the dose standard contained in N.5.a.

Scenario #1 is for the base scenario given in Table 5.

Scenario #2 is for the same basic scenario with a depth of residual TENORM of 30 cm [1 foot] instead of 15 cm [0.5 foot].

Scenario #3, uses parameters similar to those for the Scenario #2, except that K_d's specific to oil and gas TENORM scale are used (see Table 4). Material specific K_d's are generally higher than defaults, and their use generally gives lower doses than with default K_d's. However, in this case they result in increases in doses for several of the pathways, with the notable exception of the groundwater pathway. This happens because the RESRAD code uses K_d's, which are distribution coefficients, not only to estimate diffusion in groundwater, but also to estimate leaching of the contamination from the source term into the groundwater. With the higher material specific K_d's, there is less removal of the source term by infiltrating precipitation. This results in higher doses than for Scenario #2, which uses "more conservative default parameters." This example illustrates why, for accurate assessments, the user needs more than a casual understanding of the modeling process. What appears to be conservative is not always conservative and the most health protective.

Scenario #4 introduces a 1 millimeter [0.04 inch] per year decrease in the depth of the groundwater table. This may represent the historic depletion of the groundwater table, or in the case of remediation of a site, it may represent changes in the water table due to excavations or other changes in site conditions. Incorporating this parameter generally produces a significant decrease in the groundwater related dose. For the parameter values used in this assessment the change is minimal.

Scenario #5 introduces a 30-cm [1-foot] layer of clean material over the residual TENORM. This is equivalent to a layer of TENORM 1 foot beneath the surface. The layer of clean material greatly reduces the external gamma dose and the inadvertent soil ingestion dose since the TENORM is not accessible. However, these doses increase with time as the clean material diminishes by surface erosion (assumed to be 1 millimeter [0.04 inch] per year). Proper design and stabilization of the cover material can eliminate erosion., thereby preserving the cover. Assessments of erosion can be performed using the Universal-Soil-Loss equation and other evaluations (Corbitt99, PRESTO98).

Inspection of the range of results in Table 6 illustrates the impact of varying selected parameters. The interactions between parameters are many and complex., and the impacts of changing parameters are not always self evident. In dose assessment, conservative assumptions for modeling do not necessarily lead to conservative results. Even a relatively simple model like RESRAD requires a professional understanding of the concepts of the model and interaction of the parameters.

An example of the conservatism that can result from the use of generic input parameters is the impact of using what appear to be reasonable default parameters for infiltration of precipitation. RESRAD calculates the infiltration rate using a water-balance equation at the ground surface. While that equation takes the soil type into account in a general way, it does not consider the ability or inability of the soil to move the water downward from the surface. The downward water movement from the surface is limited to the value of the saturated hydraulic conductivity of those soils. Unfortunately, RESRAD does not limit the water infiltration rate to this parameter value. For sites designed to prevent ponding and for soils with a low permeability (e.g., 10^{-9} m/sec), RESRAD allows more water to move downward from the surface than can often be transmitted through the soil once it leaves the surface. This often results in unrealistically high peak annual doses within the first one-thousand years. One can compensate for this aspect of RESRAD by using a site specific infiltration fraction (fraction of precipitation that infiltrates), rather than the default value. A site specific infiltration fraction can be calculated using equation E.4 on p.198 of reference Yu93.

6.0 What radiation measurements are required for complying with Part N?

States adopting TENORM regulations will be faced with a variety of exposure scenarios depending upon the type of material processed and the processes involved. To accommodate this diversity Part N gives states the option of setting limits for the release of equipment based on screening methodologies. These methods must assure protection of the health and safety of the general public and protection of the environment consistent with existing state regulations. Part N establishes surface contamination limits for alpha contamination and separate limits for beta/gamma contamination. When determining which limit applies, there must first be a determination as to which isotopes are involved with the process. For example, in gas production the gas flow lines and separators may only be contaminated with radon progeny which decay to the longer half-life lead-210. Lead-210 is a beta emitter requiring that beta sensitive equipment be used to determine the surface contamination. In operations where scale deposits from water circulation are a problem, the contaminants may include radium and radium progeny. The person responsible for operations where TENORM is accumulated must understand the chemical and physical characteristics of the particular radioactive isotopes involved with the materials and processes, where they are likely to accumulate, and how to properly evaluate resulting radiation hazards. This section discusses the radioactive elements and the selection of equipment that should be used to detect and/or measure the radioactive constituents.

6.1 What instruments are available for conducting radiation measurements?

Alpha detectors and beta/gamma detectors are used in the evaluation of TENORM contamination. Several types of alpha detectors are available. The most popular are the gas filled detector, the gas flow detector and the silver activated zinc sulfide scintillation detector. The simplest detector to use is the zinc sulfide scintillation detector. The radiation sensitive area of this instrument is a mylar foil externally coated with aluminum to exclude light, and internally coated with a thin layer of silver activated zinc sulfide that faces a photomultiplier tube. Alpha particles can pass through the foil and stimulate the zinc sulfide to emit photons of visual light which interact with the photomultiplier tube producing an electrical pulse which is registered as a count. As this type of instrument counts approximately 30% of incident alpha particles, it has a 30% "detection efficiency".

The gas flow and gas filled detectors operate on the same principle, ionization of the gas by alpha particles. Some of the gas filled detectors must have the gas replenished by purging and refilling of the active volume of the detector. The gas flow detector has a gas cylinder attached, which provides a continuous flow of gas through the detector at a regulated pressure, so this apparatus is not as mobile as the two previously discussed detectors.

Several types of beta/gamma detectors are available. When measuring beta/gamma, efficiencies for these types of instruments are generally in the range of 25%. However, the efficiency for gamma detection alone is generally less than one percent.

Another popular gamma detector is the sodium iodide crystal, a scintillation detector. Sodium iodide crystals come in different sizes referred to as 1 by 1, 2 by 2, etc. The numbers refer to the diameter and length of the crystal. The larger the crystal, the higher the efficiency for higher energy gamma emissions. These detectors only detect gamma rays. The high-energy sodium iodide detectors are covered with a metal cap, usually aluminum, that attenuates the alpha and beta particles before they reach the crystal. A low energy gamma probe using sodium iodide is available. This detector has a thin wafer crystal with an end window made of mylar. The mylar allows low energy gamma rays to enter the detector through the end window. The thin wafer crystal has a relatively high efficiency for lower energy gamma rays. Conversely, it has a relatively low efficiency for high-energy gamma rays. When using the low energy sodium iodide detector, the surveyor must be aware that the detector will also detect alpha and beta particles. Due to the thin mylar window, alpha and/or beta particles can enter the active volume of the detector, give up their energy in the crystal, and emit a photon.

The manufacturer's literature provides approximate values of an instrument's radiation detection efficiency for each radiation type. These values serve for rough survey work; but, for measurements relative to regulatory limits, each instrument must be calibrated to a known radiation source traceable to a standard certified by the National Institute of Standards and Technology (NIST). Persons unfamiliar with radiation detection instruments should consult radiation professionals before selecting instruments.

6.2 What are the procedures for releasing equipment for unrestricted use?

Equipment released for unrestricted use must meet the levels of contamination indicated in Appendix A of Part N. Alpha contamination should be measured using a detector that has an active surface area of 100 square centimeters. If a detector with a smaller surface area is used, the surveyor needs several measurements to determine if the maximum contamination level is exceeded. If the total contamination indicated within any 100 square centimeter area exceeds 83 Bq [5,000 disintegrations per minute (dpm)], the surveyor must determine if the average contamination over a square meter exceeds the 83 Bq [5000 dpm] limit. If the level of contamination is greater than 83 Bq [5,000 dpm] per 100 square centimeters after averaging the contamination over a square meter, the equipment may not be released for unrestricted use without decontaminating to below the specified limits . If any single 100 square centimeter area exceeds 250 Bq [15,000 dpm], the equipment may not be released for unrestricted use.

When using survey equipment, the readings should be acquired at the closest point to the contamination. The surveyor should be aware that windows on gas filled, as well as scintillation, probes can be easily ruptured. A tear in the mylar film window of a scintillation detector allows stray light to enter the probe causing pulses to be generated in the photomultiplier tube. A tear in the mylar film of a gas filled detector allows gas to escape causing the detector to cease acquiring information. The presence of a magnetic field poses another problem when using a scintillation detectors because the photomultiplication and associated count rate can be affected. This can occur when surveying drill stem that has become slightly magnetized from the vibration and rotation of the drill stem during the drilling process.

As described in Appendix A to Part N, a wipe sample is collected for evaluation of removable contamination. Generally, the wipe is submitted to a laboratory for analysis; however, the wipe analysis may be performed on site if the analytical instrument used is of laboratory quality . Analytical control samples must be part of the quality assurance program to assure that the instrument and procedures are precise and accurate. The analytical procedures must include calibration of the equipment with known radiation sources that are traceable to standards certified by the NIST. Daily operational checks must be performed to verify that calibration is within control boundaries. Duplicate samples and blind standards must be analyzed along with the routine samples to assure that reproducible and accurate results are being obtained. Quality assurance data must be plotted and remedial action taken when controls are not within the limits of variation established for the analytical procedure. For release of equipment, wipe analyses must verify that removable contamination is less than 17 Bq [1,000 dpm] per 100 square centimeters for gross alpha and 17 Bq [1000 dpm] per 100 square centimeters or gross beta and gamma.

As an alternative to the above procedure for release of equipment, a state may adopt a screening procedure for release of equipment. Generally screening limits will be established based on exposure levels measured in micrograys (μGy) or microroentgen (μR) per hour at the surface of the equipment. It is more difficult to adequately screen equipment that is internally contaminated since the activity may be either removable or fixed, inside the equipment, and not easily accessible. Many μGy (μR) per hour instruments use sodium iodide crystals for which the radiation dectection efficiency varies with the radiation energy. The instrument used to verify compliance with screening limits should be calibrated to the radiation energies that are being measured. The screening method should within reason assure that the equipment is adequately characterized. Should any portion of the equipment exceed the screening level, the equipment cannot be released unless a wipe sample analysis and surface survey of the equipment indicates that the limits specified in Appendix A to Part N are met. Appendix C contains information on release limits adopted by various states.

Conditional release based on screening of equipment is an alternative which some regulatory jurisdictions may wish to consider. Screening methods may not clearly determine whether the concentration of contaminants contained within the equipment, e.g, pumps or pipe, meet the exemption level specified in Section 4 of Part N. Such factors as inconsistent geometry, uneven scale thickness and uneven wall thickness make it difficult to relate a dose rate to a concentration of contaminant. As a result, some regulatory jurisdictions may be reluctant to release equipment for unrestricted use based on screening measurements. Also, some jurisdictions may wish to consider requests to use various screening levels dependent upon the intended disposition of the equipment. For instance, pipe could be conditionally released for such purposes as smelting, construction of fences or other use that will not result in an exposure to the public that exceeds the fraction of 1 mSv [100 mrem] adopted by the jurisdiction under Section 5 of Part N.

6.3 What are the procedures for the release of facilities for unrestricted use?

Released facilities refer to buildings, other structures, and building ruble that are to be left in place, transferred to the general public or disposed of at an industrial or municipal landfill.

When preparing a survey of a building for potential release, divide the inside and outside walls, and the floors and roof of the building into one-meter grid squares identifying each square with a reference code. Make an historical review of the use of the building to determine the most likely areas of contamination. With an appropriate survey instrument, measure the contamination levels of a minimum of ten percent of the grid squares with special attention to areas such as TENORM storage areas, used equipment storage areas, equipment cleaning areas and septic systems. Evaluate each area that has an elevated measurement for compliance with Appendix A to Part N in accordance with the following. If the total contamination is less than 17 Bq [1,000 dpm] per 100 square centimeters, a wipe sample analysis is not required. However, for compliance with Appendix A of Part N, any surface contamination exceeding 17 Bq [1,000 dpm] per 100 square centimeters must be evaluated to determine if the contamination is removable. Should the survey indicate that greater than 10% of the grids surveyed are above the limits for release, a more thorough survey is required.

Survey concrete slabs using a grid pattern as previously described. Give special attention to cracks and joints where contamination may have a conduit to the soil beneath the slab. Should a determination be made that contamination has accumulated in cracks posing the potential for contamination of the surface or subsurface soil, core samples may be required to show compliance with the regulations.

6.4 What are the procedures for release of open land for unrestricted use?

A general or specific licensee responsible for land known or suspected to be TENORM-contaminated must follow and document compliance with applicable procedures established by the regulatory agency before land may be released for unrestricted use. The licensee should perform a review of historical use of the land to determine areas that could be affected by TENORM. For areas greater than one acre, the licensee should perform a survey that is statistically defensible. For guidance in performing large open land surveys, the licensee may refer to the "Multi-Agency Radiation Survey and Site Investigation Manual" (MARSSIM), NUREG-1575. For areas less than one acre, the licensee should grid the area in no more than 100 square meter sample areas with not less than five meters on any one side.

The determination of how many soil samples to collect and where to collect them should only be made after conducting an instrument survey and a review of the historical use of the land. Since it is difficult to determine actual concentrations of a contaminant in the soil based on instrument surveys, a correlation study should be undertaken. Soil samples from several areas should be analyzed and compared with instrument readings for those areas to determine at what instrument reading all samples are below the release limit. Instrument readings above this level can then be used to identify areas in need of soil analysis. For areas requiring soil analyses it is impractical to analyze the entire volume of the sampling area, 100 square meter by 15 centimeters deep. Therefore, for any area that has elevated readings, a representative sampling of the 100 square meter area must be performed and analyzed. The individual samples collected from the sampling area may be commingled prior to analysis or they may be analyzed separately and averaged to determine the average concentration.

Using the results of the survey described above, the licensee must estimate an annual total effective dose equivalent (TEDE) to the reasonably maximally exposed individual should the land be released for unrestricted use. Dose modeling for this purpose is discussed in Section 5 of this document. The licensee is responsible for assuring that the reasonably maximally exposed individual is unlikely to receive a TEDE greater than the limit established by the regulatory authority, some fraction of 1 mSv [100 millirem] per year.

6.5 What are the requirements for documentation of surveys and sample analyses, and what must be submitted for release concurrence?

All surveys for releasing equipment, facilities, and land must be documented. The documentation should include: the exact location of the survey samples and measurements; instrument readings; identification of the individual performing the survey and the survey instruments; and, date the survey was performed. Documentation of each sample should include: the date and time of collection; identification of the individual collecting the sample; location of sampling (for soil samples include depth of sample); and, the results of sample analyses. The use of chain of custody procedures should be considered.

The regulatory authority may require that the licensee notify the authority of any proposed release of equipment, facilities, and/or land for unrestricted use and receive the authority's concurrence prior to release. This notification should include copies of all documentation supporting the proposal. The licensee should maintain the documentation until authorization to dispose of the documentation is granted.

7.0 Financial Assurance

Under what circumstances should someone possessing TENORM have to provide financial assurance? The following does not address financial assurance which might be required of someone who distributes products containing TENORM; rather, financial assurance that may be required of licensees who possess TENORM is discussed.

Authority to require provision of financial assurance is predicated on the authority to require a license. An entity required regulations modeled on Part N, or by regulations promulgated in conformance with another Part (for example, a manufacturer licensed under Part C) to obtain and maintain a license may be required to maintain financial assurance as a prerequisite for the license. A 'license' is an authorization to do something. In this sense, any requirement to maintain financial assurance, with penalties for non-compliance, is a 'license' whether so denominated or not. The proposed regulations provide for general and specific licenses. The regulation could have been drafted to include a requirement for demonstration of financial assurance as a precondition for acquiring coverage under the general license. However, inasmuch as the general license is unilaterally imposed on anyone who possesses TENORM without any precondition for notice or request or election, it is doubtful that financial assurance can be required of general licensees.

Specific licenses are required for manufacture of products containing TENORM, decontamination of equipment or land, or receipt of TENORM for disposal. With the proper regulatory authority, any applicant for a specific license for any of these activities can be required to provide proof of financial assurance in such form and amount as the licensing agency deems appropriate.

Examples of frameworks for financial assurance include Part S of the SSRCR and the following provisions of 40 CFR Part 264.143 (RCRA):

> (a) Coverage for sudden accidental occurrences. An owner or operator of a hazardous waste treatment, storage, or disposal facility, ... must demonstrate financial responsibility for bodily injury and property damage to third parties caused by sudden accidental occurrences arising from operations of the facility or group of facilities. The owner or operator must have and maintain liability coverage for sudden accidental occurrences in the amount of at least $1 million per occurrence with an annual aggregate of at least $2 million, exclusive of legal defense costs. This liability coverage may be demonstrated as specified in paragraphs (a) (1), (2), (3), (4), (5), or (6) of this section:
> (1) An owner or operator may demonstrate the required liability coverage by having liability insurance as specified in this paragraph.
> (i) Each insurance policy must be amended by attachment of the Hazardous Waste Facility Liability Endorsement or evidenced by a Certificate of Liability Insurance. The wording of the endorsement must be identical to the wording specified in §

264.151(i). The wording of the certificate of insurance must be identical to the wording specified in § 264.151(j). ...

(2) An owner or operator may meet the requirements of this section by passing a financial test or using the guarantee for liability coverage as specified in paragraphs (f) and (g) of this section.

(3) An owner or operator may meet the requirements of this section by obtaining a letter of credit for liability coverage as specified in paragraph (h) of this section.

(4) An owner or operator may meet the requirements of this section by obtaining a surety bond for liability coverage as specified in paragraph (i) of this section.

(5) An owner or operator may meet the requirements of this section by obtaining a trust fund for liability coverage as specified in paragraph (j) of this section.

(6) An owner or operator may demonstrate the required liability coverage through the use of combinations of insurance, financial test, guarantee, letter of credit, surety bond, and trust fund, ...

Other sections specify the amount of financial assurance required for closure and for post-closure maintenance and monitoring. These regulations also spell out, in great detail, the form and content of the various financial instruments which may be used to satisfy the requirement.

To put this in perspective, EPA designed the RCRA land disposal regulations to ensure that there would be a "reasonable degree of certainty" that a land disposal unit would not allow migration of hazardous constituents through the final barrier during the post-closure period. The post-closure period is defined as 30 years, unless the licensee can demonstrate that a lesser period is equally protective, 40 CFR Part 264.117(a). The choice of a thirty-year period for post-closure monitoring is not based on a technical determination that the wastes in question will decay away; it is more a policy decision that in thirty years we will know more about the behavior of the disposal facility and the fate of the contaminants, and that thirty years, compared to the span of social and political institutions, is a period of time over which control can reasonably be assured and after which the situation can be reevaluated.

Inasmuch as the effective half-lives of TENORM radionuclides are long compared to 30 years, the same considerations should be applied to a choice of post-closure monitoring. The TENORM isotopes will not decay away; however, the behavior of the facility should be better understood and the potential for eventual exposure to the radioactive constituents should be better defined after 30 years.

Appendix A: Figures and Tables

Figure 1. Environmental Transport Pathways

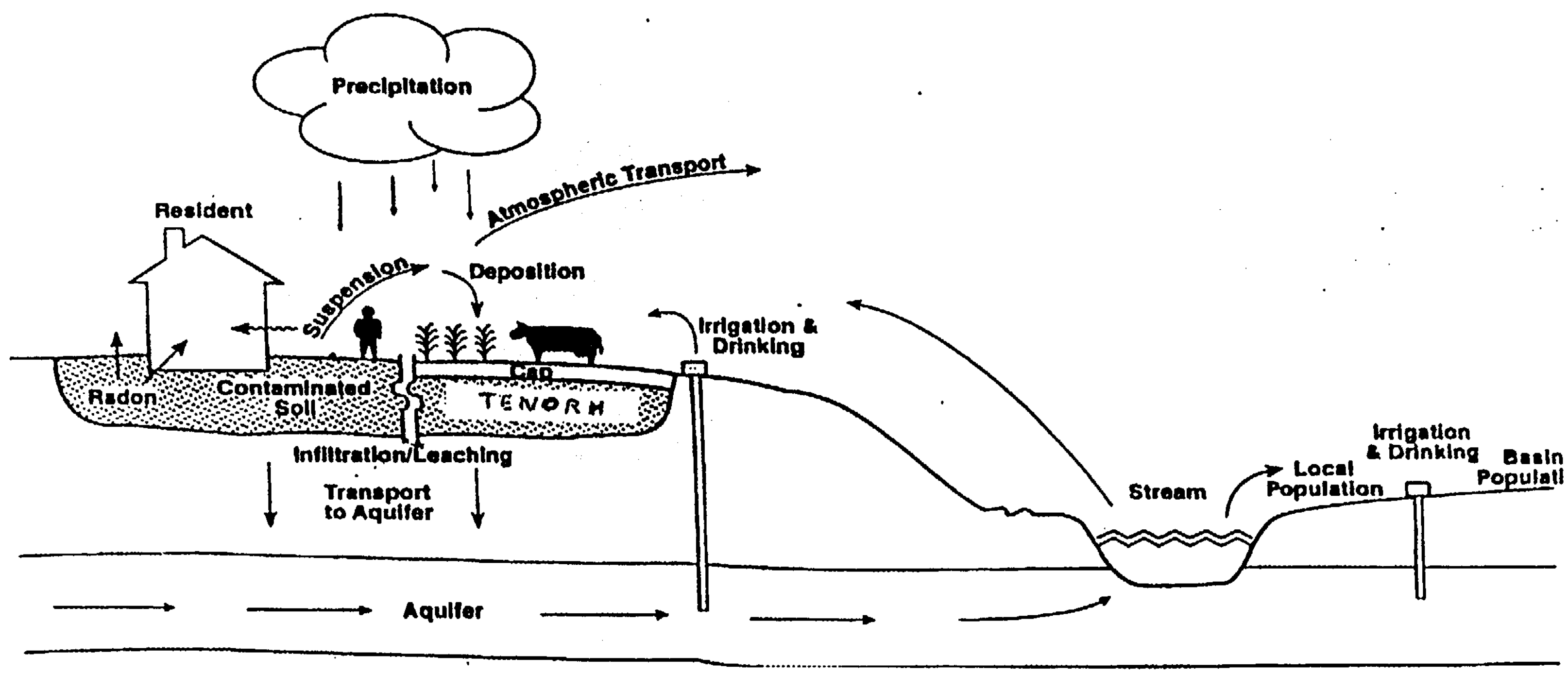

Table 1 Selected Models for Assessing the Radiation Exposure from Residual Radioactivity

Name of Model	Developer of Model	Basic Application of Model	Comment on Model
RESRAD (RESRAD93)	Argonne National Laboratory, for the DOE	People living on contaminated sites. Models numerous pathways.	DOS or Win95 Menu driven, relatively user friendly and easy to use. User should understand pathway models.
RESRAD-Build (RESRAD94)	Argonne National Laboratory, for the USDOE	Personnel occupying buildings contaminated with residual radioactivity.	DOS menu driven, relatively user friendly, harder to use than RESRAD.
PRESTO (Presto98)	Rogers and Associates Engineering for USEPA	People living on contaminated sites. Models numerous pathways.	Win95 menu driven, but requires knowledgeable person. Relatively hard to use.
PATHRAE (EPA87)	Rogers and Associates Engineering for USEPA	People living on contaminated sites. Models numerous pathways	Not menu driven. Requires knowledgeable person with insight.
GEN II	Pacific Northwest Laboratory	People living on contaminated sites. Models numerous pathways	Not menu driven, relatively hard to use. Many options, sometimes hard to interpret the definition of scenarios and the results.
NCRP Report No. 123 (NCRP96)	Prepared by a committee of the National Council on Radiation Protection and Measurements (NCRP96)	People living on contaminated sites. Models numerous pathways.	Parameters and results published in tables, allowing extraction of values to perform assessments.
NRC NUREG 5512 (USNRC92)	Prepared for USNRC	People living on contaminated sites. Models numerous pathways.	Tends towards using default values and providing very conservative results.
MicroShield (Grove93)	Grove Engineering	External gamma dose for various source geometries and exposure geometries.	Commercial model, versions available for DOS and WIN95, relatively easy to use.

Table 2. Summary of Parameters Used in RESRAD

Menu Identifier	Source or Description of Factor	Reference	Comment
B-1	Dose Conv. Factors, Inhalation	Fed Guidance 11	Previous versions used DOE factors, current versions use Fed Guide 11. Users can develop case specific results.
D-1	Dose Conv. Factors, Ingestion	Fed Guidance 11	Previous versions used DOE factors, current versions use Fed Guide 11.
D-34	Food transfer factors	RESRAD default	Generally conservative, factors for soil to humans via food chain. Users can develop case specific results.
D-5	Fresh water bioaccumulation factors	RESRAD default	
R011	Site characterization parameters	Default/site specific	Default values given, can provide site specific data
RO12	Specification of radionuclides & conc.		
R013	Site characterization parameters	Default/site specific	Default values given, can provide site specific data
RO14	Groundwater site parameters	Default/site specific	Default values given, can provide site specific data
R015	Groundwater parameters, unsat zone	Default/site specific	Default values given, can provide site specific data
R016	Distribution coefficients; K_d	Default/site specific	Default values given, generally conservative, select site specific when possible
R017	Inhalation pathway parameters	Default/site specific	Default values given, generally conservative, select site specific when possible
	Site size parameters	Default/site specific	Default values given, used to modify pathway doses,based on slze of site
R018	Food consumption and intake param	Default values given	Default values given, can change to U.S. EPA or site specific.
R019	Livestock pathway parameters	Default values given	
	Depth of mixing layer and root depth	Default values given	Important to use site specific parameters for root depth.
	Drinking water and water use param.	Default values given	
R19B	Food pathway parameters	Default values given	
C14	C-14 modeling parameters	Default values given	Not pertinent to TENORM
STOR	Storage times for food products	Default values given	Generally not pertinent to TENORM
R021	Radon pathway parameters	Default values given	

Additional input decisions:

Time increments for calculating doses and maximum time to which doses will be calculated; recommend maximum of 1,000 years.

Which pathways are included in calculations:

- a External gamma
- b Inhalation
- c Radon/indoor
- d Food, vegetables, fruits, meat and milk
- e Water dependent pathways (Drinking water/well water & Fish)

Table 3: Specific Parameters for Site Specific Conditions

Menu Identifier	Parameter	Alternate References	Comment
	Parameters Specifying the Depth Distribution of Residual TENORM or Site Contamination		
R011	Thickness of contaminated zone		Thickness of zone effects external gamma dose, depth of material for root uptake, and radon emission.
R013	Thickness of cover		A cover of 15 cm significally reduces the external gamma. A concern is longevity of the cover.
R013	Cover depth erosion rate		Proper design of the cover can minimize erosion. The default parameter erodes a 1 m cover in 1000 years.
		Universal soil loss	Assessments can be performed for site-specific parameters using the Universal-Soil-Loss Equation.
	Erosion rate for contaminated material	equation, Corbitt99	The default value results in elimination of the source TENORM over time; should be assessed.
	Parameters of Special Concern related to Groundwater		
R011,13,14	Parameters defining dimensions related to the site	Site measurements	These parameters can generally be measured as physical dimensions or conservative assumptions made.
R014	Water table drop rate	7th value in R014	This is an extremely important parameter. It is used to adjust to changes in the depth of the water table. The water table can be modeled to drop faster than material is transported in groundwater, resulting in contamination not reaching the groundwater.
R016	Distribution coefficients; Kd	Default/site specific	Default values given, generally conservative, select site specific when possible. Separate values for contaminated zone and for neutral zone.
		ASTM84, Sheppard90 Sheppard85,84,80; Y93	See Table 4 and related text.
R013	Precipitation parameters	Meteorological refs Mathe 64	The precipitation rate and fraction infiltrating the surface determine the source term of water infiltrating the site.
	Food Pathway Parameters and Ingestion		
D-34	Food transfer factors	RESRAD default Yu93, Oztunali84, EPA91	Generally conservative, factors for soil to humans via food chain. Default values can be modified to correspond to Kds.
R011	Site dimensions		Determine the amount of food that can be raised on a site and the viability of the resident-farmer scenario.
R018	Soil Ingestion, #7 of R018	EPA 91	One of the ingestion pathways is accidential soil ingestion, which can be characterized as the "dirty hands" scenario.
R018	Food consumption and intake parameter	Default values given	Default values given, can change to U.S. EPA or site specific.

Inhalation of Airborne Material

R017		EPA88, Yu93	RESRAD uses a mass loading resuspension concept which is very conservative. The code specifies an airborne concentration of 100 micrograms per cubic meter of contaminated soil. USEPA ambien air standards specify an annual average of about 60 micrograms per cubic meter, and all of the material would not have originated from the site.

Indoor Radon

RQ21	Radon emanating power	Material/site specific Rogers84, Nielson92	Fraction of radon released from material to pore space, material specific.
RQ21	Design of Buildings	Site specific	Contact of building with contaminated soil and building design.
RQ21	Building ventillation rate	Site specific	Air exchange rate of building

Table 4. Alternative K_d Values

K_d's in Units of ml/gram							
Reference	**Material**	**U**	**Th**	**Ra**	**Pb**	**Pa**	**Ac**
Sheppard, H.P., Jr	Sand	35	3200	500	270	550	450
Oct 90 59/4,p471	Loss	15	3300	36000	16000	1800	150
	Clay	1600	5800	9100	550	2700	2400
	Organic	410	89000	2400	22000	6600	5400
Geometric Mean, Sand & Clay	Average	237	4308	2133	385	1219	1039
RESRAD V 5.61 Default		50	60000	70	100	50	20
Example of Site Specific; Clay		900	110000	94000			
Auxier96 Oil & Gas NORM Waste							
Soil contaminated with NORM				6000	5600		
Scale from Pipe				79000	72000		

Table 5. RESRAD Assessment of Residual TENORM for a Resident Farmer

Dose Per Year At 1 Year After Placement of Radioactive Contaminant							
Nuclide	pCi/g	Ext Gam mrem	Ingestion mrem	Inhalation mrem	Total Dose At 1 Year mrem	1000 yr Water mrem	Radon At 1 yr mrem
Ra-226	4	21.8	3.7	0.002	25	4	100
Pb-210	4	0.01	5.4	0.003	5	0	0.0
Ra-228	1	7.5	1.7	0.01	9	0	0.3
Total		29	11	0.01	40	4	101
Notes: Default parameters 15-cm depth of TENORM; 1 pCi/g of Ra-228 and 4 pCi/g of Ra-226							

Table 6. Comparison of Doses from Selected Scenarios

Scenario	Characteristics of Scenario	Doses At 1 Year After Placement of Materials (mrem/yr)						Doses At 1,000 Year After Placement of Materials (mrem/yr)					
		External Gamma	Inadvert Soil Ingestion	Food Ingestion	In-door Radon	Ground Water	No Radon Total	External Gamma	Inadvert Soil Ingestion	Food Ingestion	Indoor Radon	Ground Water	No Radon Total
#1	Default Parameters, 15 cm depth of contamination	29.3	1.0	9	100	0.0	40	0.0	0.0	0.0	0	4.1	4
#2	Default Parameters, 30 cm depth of contamination	33.4	1.0	17	148	0.0	52	0.0	0.0	0.0	0	7.9	8
#3	Material Specific Kd's 30 cm depth, no cover	33.9	1.0	18	150	0.0	53	13.0	0.5	5.9	66	0.7	20
#4	Material Specific Kd's 30 cm depth, no cover 0.001 m/yr decrease in water table	33.9	1.0	18	150	0.0	53	13.0	0.5	5.9	66	0.6	20
#5	Material Specific Kd's 30 cm depth, 30 cm cover	0.8	0	17	150	0	18	13.3	0.5	6.8	71	0.7	21

Appendix B: References and Information Sources

General References

USNRC99 Committee on Evaluation of EPA Guidelines for Exposure to NORM, National Research Council. Evaluation of Guidelines for Exposure to Technologically Enhanced Naturally Occurring Radioactive Materials. 1999.

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CRCPD98-2 Rationale for Part N "Regulation and Licensing of Technically Enhanced Naturally Occurring Radioactive Materials (TENORM). December 1998.Conference of Radiation Control Program Directors Inc. Frankfort KY.

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USNRC97 Multi-Agency Radiation Site Survey and Investigation Manual (MARSSIM) NUREG-1575 (Final Report). December 1997. U.S. Nuclear Regulatory Commission, Washington D.C. (Available from The Superintendent of Documents, U.S. Government Printing Office, P. O. Box 37082, Washington, DC 20402-9328 or the NRC's web site).

USEPA96-1 Technology Screening Guide for Radioactively Contaminated Sites EPA/402-R-96-017. November 1996. Office of Radiation and Indoor Air (6601J), U.S. Environmental Protection Agency.

USEPA96-2 Radiation Exposure and Risks Assessment Manual (RERAM) EPA/402-R-96-016 Stabilization/Solidification Processes for Mixed Waste, EPA/402-R-96-014. June 1996. , Office of Radiation and Indoor Air (6601J), U.S. Environmental Protection Agency.

USEPA96-3 Documenting Ground Water Modeling at Sites Contaminated with Radioactive Substances EPA/540-R-96-003. January 1996. Office of Radiation and Indoor Air (6601J), U.S. Environmental Protection Agency.

USEPA96-4 Three Multimedia Models Used at Hazardous and Radioactive Waste Sites EPA/540-R-96-004. January 1996. Office of Radiation and Indoor Air (6601J), U.S. Environmental Protection Agency.

CRCPD94-1 CRCPD Recognition of Licensing States for the Regulation and Control of NARM. CRCPD Publication 94-8. August 1994. Conference of Radiation Control Program Directors Inc. Frankfort KY.

USEPA94 A Technical Guide to Ground Water Model Selection at Sites Contaminated with Radioactive Substances EPA/402-R-94-012. June 1994. Office of Radiation and Indoor Air (6601J), U.S. Environmental Protection Agency,

CRCPD94-2 Report of the E-4 Committee on NORM Contamination and Decontamination/Decommissioning, Report 3. CRCPD Publication 94-6. April 1994. Conference of Radiation Control Program Directors Inc. Frankfort KY

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USEPA93-2 Computer Models Used to Support Cleanup Decision-Making at Hazardous and Radioactive Waste Sites EPA 402-R-93-005. March 1993. Office of Radiation and Indoor Air (6601J), U.S. Environmental Protection Agency.

USEPA93-3 Environmental Pathway Models- Ground Water Modeling. March 1993. Office of Radiation and Indoor Air (6601J), U.S. Environmental Protection Agency

USEPA93-4 Environmental Characteristics of EPA, NRC, and DOE Sites Contaminated with Radioactive Substances EPA/402-R-93-011. March 1993. Office of Radiation and Indoor Air (6601J), U.S. Environmental Protection Agency.

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Information Sources

Regulations:

Summaries of state and federal regulations on NORM, including radiation and radioactivity limits for release of materials, are published by Peter Gray in his quarterly newsletter, "NORM Report" Ph. 501/646-5142 (CRCPD does not compile regualtions.)

A summary of radioactive waste acceptance criteria is available on the U.S. DOE National Low-Level Waste Management Program web site, www.inel.gov/national/ national.html .

A glossary of terms used in the regulation of TENORM and other radioactive material is available from CRCPD.

Available on the CRCPD web site, www.crcpd.org
:

Summary of CRCPD assistance with unwanted radioactive material.

"Dealing with Discovered Radioactive Material" a 1 page overview

"Notes on the Scope and Use of the DOT Exemptions, E10656 & 11406" for moving scrap or trash, shipment approval forms, and telephone directory of radiation control program staff who issue shipment approvals. (Text of the exemptions from U.S. DOT for moving scrap and trash discovered to be radioactive is available from the CRCPD office but not yet posted on the CRCPD web site.)

List of publications, with ordering capability.

Radiation control program telephone numbers, accessed through a map on t web site.

Directory of commercial services for site inspection, decon and waste disposal: "Radioactive Waste Brokers" for small jobs, and "Providers of Radioactive Site Investigation and Decontamination" for larger jobs.

A directory of commercial laboratories for assay of radioactivity in samples of materials.

Manufacturers of portal radiation monitors, and portable equipment. Most manufacturers provide installation, training and calibration services

Directory of developers of computer codes for radiation dose from residual radioactivity. These companies provide training and assistance.
Information on radioactive waste disposal facilities.

Appendix C: Screening Limits Adopted by Various States for Release of Contaminated Equipment

State	Screening Level (μR/hr)	Comments
Georgia	50	Includes background
Louisiana	50	Includes background
Mississippi	25	Above background
New Mexico	50	Includes background
South Carolina	50	Includes Background
Texas	50	Includes Background

Source: The NORM Report, May 1999 (See Reference GRAY99)

Appendix D: Sample RESRAD Summary Report

Appendix D

Example of a RESRAD Run for TENORM

Using: Default parameters
15 cm depth of TENORM
Constant depth of water table

Table of Contents

Part I: Mixture Sums and Single Radionuclide Guidelines

Dose Conversion Factor (and Related) Parameter Summary
File: DOSFAC.BIN

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	Ra-228+D	5.080E-03	5.080E-03	DCF2(3)
B-1	Th-228+D	3.450E-01	3.450E-01	DCF2(4)
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	Ra-228+D	1.440E-03	1.440E-03	DCF3(3)
D-1	Th-228+D	8.080E-04	8.080E-04	DCF3(4)
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	Ra-228+D , plant/soil concentration ratio, dimensionless	4.000E-02	4.000E-02	RTF(3,1)
D-34	Ra-228+D , beef/livestock-intake ratio, (pCi/kg)/(pCi/d)	1.000E-03	1.000E-03	RTF(3,2)
D-34	Ra-228+D , milk/livestock-intake ratio, (pCi/L)/(pCi/d)	1.000E-03	1.000E-03	RTF(3,3)
D-34				
D-34	Th-228+D , plant/soil concentration ratio, dimensionless	1.000E-03	1.000E-03	RTF(4,1)
D-34	Th-228+D , beef/livestock-intake ratio, (pCi/kg)/(pCi/d)	1.000E-04	1.000E-04	RTF(4,2)
D-34	Th-228+D , milk/livestock-intake ratio, (pCi/L)/(pCi/d)	5.000E-06	5.000E-06	RTF(4,3)
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	Ra-228+D , fish	5.000E+01	5.000E+01	BIOFAC(3,1)
D-5	Ra-228+D , crustacea and mollusks	2.500E+02	2.500E+02	BIOFAC(3,2)
D-5				
D-5	Th-228+D , fish	1.000E+02	1.000E+02	BIOFAC(4,1)
D-5	Th-228+D , crustacea and mollusks	5.000E+02	5.000E+02	BIOFAC(4,2)

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)	1.000E+04	1.000E+04	---	AREA
R011	Thickness of contaminated zone (m)	1.500E-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)	1.000E+02	3.000E+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+01	3.000E+00	---	T(3)
R011	Times for calculations (yr)	5.000E+02	1.000E+01	---	T(4)
R011	Times for calculations (yr)	1.000E+03	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	4.000E+00	0.000E+00	---	S1(1)
R012	Initial principal radionuclide (pCi/g): Ra-226	4.000E+00	0.000E+00	---	S1(2)
R012	Initial principal radionuclide (pCi/g): Ra-228	1.000E+00	0.000E+00	---	S1(3)
R012	Initial principal radionuclide (pCi/g): Th-228	1.000E+00	0.000E+00	---	S1(4)
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): Ra-228	not used	0.000E+00	---	W1(3)
R012	Concentration in groundwater (pCi/L): Th-228	not used	0.000E+00	---	W1(4)
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-04	1.000E-03	---	VCZ
R013	Contaminated zone total porosity	4.000E-01	4.000E-01	---	TPCZ
R013	Contaminated zone effective porosity	2.000E-01	2.000E-01	---	EPCZ
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 hydraulic conductivity (m/yr)	1.000E+02	1.000E+02	---	HCSZ
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)	0.000E+00	1.000E-03	---	VWT
R014	Well pump intake depth (m below water table)	1.000E+01	1.000E+01	---	DWIBWT

Site-Specific Parameter Summary (continued)

Menu	Parameter	User Input	Default	Used by RESRAD (If different from user input)	Parameter Name
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, 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	2.217E-02	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	3.165E-02	ALEACH(2)
R016	Solubility constant	0.000E+00	0.000E+00	not used	SOLUBK(2)
R016	Distribution coefficients for Ra-228				
R016	Contaminated zone (cm**3/g)	7.000E+01	7.000E+01	---	DCNUCC(3)
R016	Unsaturated zone 1 (cm**3/g)	7.000E+01	7.000E+01	---	DCNUCU(3,1)
R016	Saturated zone (cm**3/g)	7.000E+01	7.000E+01	---	DCNUCS(3)
R016	Leach rate (/yr)	0.000E+00	0.000E+00	3.165E-02	ALEACH(3)
R016	Solubility constant	0.000E+00	0.000E+00	not used	SOLUBK(3)
R016	Distribution coefficients for Th-228				
R016	Contaminated zone (cm**3/g)	6.000E+04	6.000E+04	---	DCNUCC(4)
R016	Unsaturated zone 1 (cm**3/g)	6.000E+04	6.000E+04	---	DCNUCU(4,1)
R016	Saturated zone (cm**3/g)	6.000E+04	6.000E+04	---	DCNUCS(4)
R016	Leach rate (/yr)	0.000E+00	0.000E+00	3.704E-05	ALEACH(4)
R016	Solubility constant	0.000E+00	0.000E+00	not used	SOLUBK(4)
R017	Inhalation rate (m**3/yr)	8.400E+03	8.400E+03	---	INHALR
R017	Mass loading for inhalation (g/m**3)	5.000E-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	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	1.000E+00	>0 shows circular AREA.	FS

Site-Specific Parameter Summary (continued)

Menu	Parameter	User Input	Default	Used by RESRAD (If different from user input)	Parameter Name
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)	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+00	1.000E+00	---	FIRW
R018	Contamination fraction of aquatic food	5.000E-01	5.000E-01	---	FR9
R018	Contamination fraction of plant food	-1	-1	0.500E+00	FPLANT
R018	Contamination fraction of meat	-1	-1	0.500E+00	FMEAT
R018	Contamination fraction of milk	-1	-1	0.500E+00	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

Site-Specific Parameter Summary (continued)

Menu	Parameter	User Input	Default	Used by RESRAD (If different from user input)	Parameter Name
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	1.000E+00	1.000E+00	---	FGWDW
R019	Household water fraction from ground water	1.000E+00	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	---	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
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)
R021	Thickness of building foundation (m)	1.500E-01	1.500E-01	---	FLOOR
R021	Bulk density of building foundation (g/cm**3)	2.400E+00	2.400E+00	---	DENSFL
R021	Total porosity of the cover material	not used	4.000E-01	---	TPCV
R021	Total porosity of the building foundation	1.000E-01	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	3.000E-02	3.000E-02	---	PH2OFL

Site-Specific Parameter Summary (continued)

Menu	Parameter	User Input	Default	Used by RESRAD (If different from user input)	Parameter Name
R021	Diffusion coefficient for radon gas (m/sec):				
R021	in cover material	not used	2.000E-06	---	DIFCV
R021	in foundation material	3.000E-07	3.000E-07	---	DIFFL
R021	in contaminated zone soil	2.000E-06	2.000E-06	---	DIFCZ
R021	Radon vertical dimension of mixing (m)	2.000E+00	2.000E+00	---	HMIX
R021	Average building air exchange rate (1/hr)	5.000E-01	5.000E-01	---	REXG
R021	Height of the building (room) (m)	2.500E+00	2.500E+00	---	HRM
R021	Building interior area factor	0.000E+00	0.000E+00	code computed (time dependent)	FAI
R021	Building depth below ground surface (m)	-1.000E+00	-1.000E+00	code computed (time dependent)	DMFL
R021	Emanating power of Rn-222 gas	2.500E-01	2.500E-01	---	EMANA(1)
R021	Emanating power of Rn-220 gas	1.500E-01	1.500E-01	---	EMANA(2)

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	active
7 -- drinking water	active
8 -- soil ingestion	active
9 -- radon	active
Find peak pathway doses	suppressed

Contaminated Zone Dimensions

Area:	10000.00 square meters
Thickness:	0.15 meters
Cover Depth:	0.00 meters

Initial Soil Concentrations, pCi/g

Pb-210	4.000E+00
Ra-226	4.000E+00
Ra-228	1.000E+00
Th-228	1.000E+00

Total Dose TDOSE(t), mrem/yr

Basic Radiation Dose Limit = 100 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+01	5.000E+02	1.000E+03
TDOSE(t):	1.448E+02	1.399E+02	1.011E+02	4.590E+00	4.142E+00
M(t):	1.448E+00	1.399E+00	1.011E+00	4.590E-02	4.142E-02

Maximum TDOSE(t): 1.448E+02 mrem/yr at t = 0.000E+00 years

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-	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	1.420E-02	0.0001	2.969E-03	0.0000	0.000E+00	0.0000	4.220E+00	0.0291	4.497E-01	0.0031	2.375E-01	0.0016	7.961E-01	0.0055
Ra-226	2.250E+01	0.1554	1.101E-03	0.0000	1.037E+02	0.7158	3.086E+00	0.0213	1.598E-01	0.0011	2.122E-01	0.0015	1.456E-01	0.0010
Ra-228	3.057E+00	0.0211	1.625E-04	0.0000	0.000E+00	0.0000	8.354E-01	0.0058	4.326E-02	0.0003	5.743E-02	0.0004	3.942E-02	0.0003
Th-228	4.954E+00	0.0342	1.104E-02	0.0001	2.934E-01	0.0020	1.180E-02	0.0001	1.302E-03	0.0000	9.467E-05	0.0000	2.212E-02	0.0002
Total	3.052E+01	0.2108	1.527E-02	0.0001	1.040E+02	0.7179	8.153E+00	0.0563	6.541E-01	0.0045	5.072E-01	0.0035	1.003E+00	0.0069

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-	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	5.720E+00	0.0395
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	1.298E+02	0.8961
Ra-228	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	4.032E+00	0.0278
Th-228	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	5.293E+00	0.0366
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	1.448E+02	1.0000

*Sum of all water independent and dependent pathways.

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 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	1.346E-02	0.0001	2.813E-03	0.0000	0.000E+00	0.0000	4.001E+00	0.0286	4.269E-01	0.0031	2.252E-01	0.0016	7.543E-01	0.0054
Ra-226	2.178E+01	0.1557	1.154E-03	0.0000	1.004E+02	0.7174	3.129E+00	0.0224	1.703E-01	0.0012	2.132E-01	0.0015	1.646E-01	0.0012
Ra-228	4.015E+00	0.0287	3.235E-03	0.0000	8.234E-02	0.0006	7.261E-01	0.0052	3.806E-02	0.0003	4.943E-02	0.0004	4.004E-02	0.0003
Th-228	3.447E+00	0.0246	7.679E-03	0.0001	2.042E-01	0.0015	8.209E-03	0.0001	9.059E-04	0.0000	6.585E-05	0.0000	1.539E-02	0.0001
Total	2.926E+01	0.2092	1.488E-02	0.0001	1.006E+02	0.7195	7.865E+00	0.0562	6.361E-01	0.0045	4.879E-01	0.0035	9.743E-01	0.0070

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	0.000E+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	5.424E+00	0.0388
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	1.258E+02	0.8995
Ra-228	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	4.954E+00	0.0354
Th-228	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	3.684E+00	0.0263
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	1.399E+02	1.0000

*Sum of all water independent and dependent pathways.

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+01 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	8.334E-03	0.0001	1.732E-03	0.0000	0.000E+00	0.0000	2.463E+00	0.0244	2.627E-01	0.0026	1.386E-01	0.0014	4.642E-01	0.0046
Ra-226	1.629E+01	0.1612	1.393E-03	0.0000	7.490E+01	0.7411	3.089E+00	0.0306	2.078E-01	0.0021	2.015E-01	0.0020	2.657E-01	0.0026
Ra-228	2.298E+00	0.0227	3.657E-03	0.0000	9.692E-02	0.0010	1.865E-01	0.0018	9.950E-03	0.0001	1.251E-02	0.0001	1.580E-02	0.0002
Th-228	1.319E-01	0.0013	2.927E-04	0.0000	7.831E-03	0.0001	3.129E-04	0.0000	3.453E-05	0.0000	2.510E-06	0.0000	5.864E-04	0.0000
Total	1.873E+01	0.1853	7.074E-03	0.0001	7.501E+01	0.7422	5.739E+00	0.0568	4.805E-01	0.0048	3.526E-01	0.0035	7.463E-01	0.0074

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+01 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	3.338E+00	0.0330
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	9.496E+01	0.9396
Ra-228	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	2.624E+00	0.0260
Th-228	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	1.410E-01	0.0014
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	1.011E+02	1.0000

*Sum of all water independent and dependent pathways.

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 5.000E+02 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	3.722E-14	0.0000	5.393E-15	0.0000	0.000E+00	0.0000	7.670E-12	0.0000	8.182E-13	0.0000	4.317E-13	0.0000	1.446E-12	0.0000
Ra-226	2.083E-06	0.0000	3.930E-10	0.0000	8.553E-06	0.0000	6.697E-07	0.0000	5.928E-08	0.0000	4.045E-08	0.0000	9.461E-08	0.0000
Ra-228	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	0.000E+00	0.0000
Th-228	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	0.000E+00	0.0000
Total	2.083E-06	0.0000	3.930E-10	0.0000	8.553E-06	0.0000	6.697E-07	0.0000	5.928E-08	0.0000	4.045E-08	0.0000	9.461E-08	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 = 5.000E+02 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	1.041E-11	0.0000
Ra-226	3.983E+00	0.8677	5.673E-02	0.0124	1.652E-01	0.0360	3.076E-01	0.0670	3.599E-02	0.0078	4.183E-02	0.0091	4.590E+00	1.0000
Ra-228	4.026E-28	0.0000	1.945E-30	0.0000	0.000E+00	0.0000	3.114E-29	0.0000	4.312E-30	0.0000	9.405E-30	0.0000	4.494E-28	0.0000
Th-228	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	0.000E+00	0.0000
Total	3.983E+00	0.8677	5.673E-02	0.0124	1.652E-01	0.0360	3.076E-01	0.0670	3.599E-02	0.0078	4.183E-02	0.0091	4.590E+00	1.0000

*Sum of all water independent and dependent pathways.

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	8.579E-26	0.0000	7.346E-27	0.0000	0.000E+00	0.0000	1.045E-23	0.0000	1.115E-24	0.0000	5.880E-25	0.0000	1.969E-24	0.0000
Ra-226	1.544E-13	0.0000	2.122E-17	0.0000	0.000E+00	0.0000	3.616E-14	0.0000	3.201E-15	0.0000	2.184E-15	0.0000	5.108E-15	0.0000
Ra-228	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	0.000E+00	0.0000
Th-228	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	0.000E+00	0.0000
Total	1.544E-13	0.0000	2.122E-17	0.0000	0.000E+00	0.0000	3.616E-14	0.0000	3.201E-15	0.0000	2.184E-15	0.0000	5.108E-15	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	1.364E-13	0.0000	2.286E-15	0.0000	0.000E+00	0.0000	1.051E-14	0.0000	1.168E-15	0.0000	9.587E-16	0.0000	1.513E-13	0.0000
Ra-226	3.598E+00	0.8687	5.153E-02	0.0124	1.446E-01	0.0349	2.779E-01	0.0671	3.247E-02	0.0078	3.740E-02	0.0090	4.142E+00	1.0000
Ra-228	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	0.000E+00	0.0000
Th-228	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	0.000E+00	0.0000
Total	3.598E+00	0.8687	5.153E-02	0.0124	1.446E-01	0.0349	2.779E-01	0.0671	3.247E-02	0.0078	3.740E-02	0.0090	4.142E+00	1.0000

*Sum of all water independent and dependent pathways.

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+01	5.000E+02	1.000E+03
Pb-210	Pb-210	1.000E+00	1.430E+00	1.356E+00	8.346E-01	2.602E-12	3.782E-14
Ra-226	Ra-226	1.000E+00	3.244E+01	3.141E+01	2.345E+01	2.763E-01	2.418E-01
Ra-226	Pb-210	1.000E+00	0.000E+00	4.650E-02	2.918E-01	8.713E-01	7.937E-01
Ra-226	ΣDSR(j)		3.244E+01	3.145E+01	2.374E+01	1.148E+00	1.036E+00
Ra-228	Ra-228	1.000E+00	4.032E+00	3.463E+00	8.778E-01	4.474E-28	0.000E+00
Ra-228	Th-228	1.000E+00	0.000E+00	1.491E+00	1.746E+00	2.483E-30	0.000E+00
Ra-228	ΣDSR(j)		4.032E+00	4.954E+00	2.624E+00	4.499E-28	0.000E+00
Th-228	Th-228	1.000E+00	5.293E+00	3.684E+00	1.410E-01	0.000E+00	0.000E+00

*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 = 100 mrem/yr

Nuclide (i)	t= 0.000E+00	1.000E+00	1.000E+01	5.000E+02	1.000E+03
Pb-210	6.993E+01	7.375E+01	1.198E+02	3.843E+13	*7.631E+13
Ra-226	3.082E+00	3.179E+00	4.212E+00	8.714E+01	9.657E+01
Ra-228	2.480E+01	2.019E+01	3.811E+01	*2.726E+14	*2.726E+14
Th-228	1.889E+01	2.715E+01	7.094E+02	*8.192E+14	*8.192E+14

*At specific activity limit

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	4.000E+00	0.000E+00	1.430E+00	6.993E+01	1.430E+00	6.993E+01
Ra-226	4.000E+00	0.000E+00	3.244E+01	3.082E+00	3.244E+01	3.082E+00
Ra-228	1.000E+00	2.381 ± 0.005	5.309E+00	1.883E+01	4.032E+00	2.480E+01
Th-228	1.000E+00	0.000E+00	5.293E+00	1.889E+01	5.293E+00	1.889E+01

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+01	5.000E+02	1.000E+03
Pb-210	Pb-210	1.000E+00	5.720E+00	5.424E+00	3.338E+00	1.041E-11	1.513E-13
Pb-210	Ra-226	1.000E+00	0.000E+00	1.860E-01	1.167E+00	3.485E+00	3.175E+00
Pb-210	ΣDOSE(j):		5.720E+00	5.610E+00	4.506E+00	3.485E+00	3.175E+00
Ra-226	Ra-226	1.000E+00	1.298E+02	1.256E+02	9.379E+01	1.105E+00	9.672E-01
Ra-228	Ra-228	1.000E+00	4.032E+00	3.463E+00	8.778E-01	4.474E-28	0.000E+00
Th-228	Ra-228	1.000E+00	0.000E+00	1.491E+00	1.746E+00	2.052E-30	0.000E+00
Th-228	Th-228	1.000E+00	5.293E+00	3.684E+00	1.410E-01	0.000E+00	0.000E+00
Th-228	ΣDOSE(j):		5.293E+00	5.174E+00	1.887E+00	2.052E-30	0.000E+00

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

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+01	5.000E+02	1.000E+03
Pb-210	Pb-210	1.000E+00	4.000E+00	3.793E+00	2.348E+00	1.090E-11	2.969E-23
Pb-210	Ra-226	1.000E+00	0.000E+00	1.191E-01	8.130E-01	6.340E-07	6.847E-14
Pb-210	ΣS(j):		4.000E+00	3.912E+00	3.161E+00	6.340E-07	6.847E-14
Ra-226	Ra-226	1.000E+00	4.000E+00	3.874E+00	2.902E+00	4.319E-07	4.664E-14
Ra-228	Ra-228	1.000E+00	1.000E+00	8.588E-01	2.183E-01	8.931E-34	0.000E+00
Th-228	Ra-228	1.000E+00	0.000E+00	2.806E-01	3.303E-01	1.540E-33	0.000E+00
Th-228	Th-228	1.000E+00	1.000E+00	6.960E-01	2.669E-02	0.000E+00	0.000E+00
Th-228	ΣS(j):		1.000E+00	9.767E-01	3.570E-01	1.540E-33	0.000E+00

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