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HEALTH EFFECTS ASSESSMENT

SUMMARY TABLES

FY-1994 Supplement No. 2

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HEALTH EFFECTS ASSESSMENT SUMMARY TABLES
FY-1994 SUPPLEMENT NO. 2

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DISCLAIMER

This report has been prepared by the U.S. Environmental Protection Agency. The information contained herein has been taken from final documents prepared by the Office of Health and Environmental Assessment for the Office of Solid Waste and Emergency Response and the Office of Water, Washington, DC and the Office of Air Quality Planning and Standards, Research Triangle Park, NC. These documents were reviewed in accordance with Agency policy and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

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INTRODUCTION

This document is the November 1994 Supplement No. 2 for the March 1994 Annual Update of the Health Effects Assessment Summary Tables (HEAST) prepared by EPA's Office of Health and Environmental Assessment, Environmental Criteria and Assessment Office, Cincinnati, OH for use at both Superfund and RCRA sites. Supplement No. 2 updates the information in the March 1994 HEAST Annual Update and Supplement No 1. When using this document, please refer to the Annual Update and Supplement No. 1. The supplements were not produced to stand alone and do not contain the User's Guides or Appendix that are available in the Annual Update. Thus, the user is strongly encouraged to reference the March 1994 HEAST for this information.

The HEAST is a comprehensive listing consisting almost entirely of PROVISIONAL HEALTH EFFECTS INFORMATION relative to oral and inhalation routes for chemicals of interest to Superfund, the Resource Conservation and Recovery Act (RCRA), and the EPA in general. These entries in the HEAST are limited to chemicals that have undergone review and have the concurrence of individual Agency Program Offices, and each is supported by an Agency reference. This health effects information has not, however, had enough review to be recognized as high quality, Agency-wide consensus information.

The Integrated Risk Information System (IRIS) is the Agency's official repository of Agency-wide consensus chronic human health risk information. IRIS evaluations are conducted by the Agency's Work Group Review process, i.e., they have been examined by either

the Reference Dose/Reference Concentration (RfD/RfC) Work Group or the Carcinogen Risk Assessment Verification Endeavor (CRAVE) Work Group. These Agency Work Groups conduct a process that leads to internal Agency scientific consensus regarding health effects information on a chemical. This information is recorded on IRIS, is considered to be "Work Group Verified," and does not appear on the HEAST. Thus, provisional health effects information on the HEAST is subject to possible review and revision by these Agency Work Groups.

There are two exceptions to the above discussion. The HEAST also contains information on chemicals that are a part of the National Ambient Air Quality Standards (NAAQS) or the Drinking Water Criteria Document (DWCD) series. In each of these cases, the chemicals are subject to extensive scientific peer review processes of extremely high quality.

CHEMICAL STATUS DEFINITIONS

Chemicals reviewed by the Agency Work Groups are classified according to their status as either "verified," "not verifiable," or "under review." The toxicity values (other than NAAQS or DWCD values) listed on the HEAST are considered to be "provisional." The Agency has no official definitions for these terms, but the HEAST user may interpret them as follows:

> **Provisional:** A toxicity value or a cancer value is "provisional" if the value has had some form of Agency review, but it does not appear on the IRIS system. These values are generated in several ways. Often they are determined in the course of developing an Agency document on a chemical or on a class of chemicals. Some have been generated through the Work Group process, but have not yet been input to the IRIS system. At the time each

value was derived, all available information on the chemical was evaluated, the value was calculated using the most current methodology, and a consensus was reached on the value by Agency scientists.

Brackets are placed around the names of toxicity and carcinogenicity values on the HEAST to distinguish these "provisional" values from information on IRIS. The following names are affected: RfD to [RfD], RfC to [RfC], slope factor to [slope factor], EPA group to [EPA Group] and unit risk to [unit risk].

These "provisional" values are found on the HEAST. They do not appear on IRIS.

Verified: A toxicity value or a cancer value is "Work Group Verified" if all available information on the value has been examined by an Agency Work Group, the value has been calculated using current Work Group methodology, a unanimous consensus has been reached on the value by the Work Group, and the value appears on IRIS.

Some numbers that have achieved unanimous consensus by the Work Group may appear on the HEAST for a short time until they are loaded onto IRIS, at which time they are termed, "verified." During the interim, they are considered to be "provisional" values that are still "under review" by the Work Group.

These "verified" numbers only appear on IRIS. They do not appear on the HEAST.

Not verifiable: A toxicity value is "not verifiable" if an Agency Work Group has considered all available data on a chemical and has unanimously determined that data are inadequate to generate a value that would be suitable for inclusion on IRIS. No toxicity value is calculated; no toxicity value is available for IRIS or the HEAST.

This "not verifiable" status is noted on IRIS, and is sometimes found on the HEAST, with a pointer to the IRIS system.

Under Review: A toxicity value is "under review" if an Agency Work Group is in the process of considering all available data on a chemical. All Work Group chemicals will have this status until the toxicity value is placed on the IRIS system. Toxicity values that have been withdrawn from IRIS by a Work Group for further review will have this status.

This "under review" status may be indicated on IRIS or on the HEAST. During this time, "provisional" toxicity values may appear on the HEAST.

In all cases, the status of a chemical may change as new data become available, and the assessment is revisited.

CAUTION

It is imperative for each user of the HEAST to recognize that the values listed in the toxicity tables and the cancer table are generally considered to be PROVISIONAL HEALTH EFFECTS INFORMATION. The user is referred to IRIS for "Work Group Verified" values. It is also important to remember that the numbers in these tables alone tell very little about the adverse effects of a chemical or the quality of evidence on which health effects information is based. Original assessment documents must be consulted by users of the HEAST in order to fully appreciate the strengths and limitations of a specific data base. Original source documents will allow for the most complete characterization of potential toxicity associated with the range of exposure pathways generally evaluated at Superfund and RCRA sites. The Reference Tables point the user to these sources.

CONTRIBUTORS

Chemicals commonly found at RCRA sites as identified by the Office of Solid Waste's (OSW) Technical Assessment Branch are included in the HEAST. The Office of Radiation Programs has provided data on radionuclide carcinogenicity for Tables 4A and 4B of the HEAST. Finally, the Office of Air Quality Planning and Standards (OAQPS) has provided information on chemicals for which Air Quality Criteria Documents and National Ambient Air Quality Standards have been developed.

CHEMICALS LISTED

Most of the chemicals included on the toxicity tables and carcinogenicity table are those for which at least one of the following EPA documents has been written: Health Effects Assessment Document (HEA), Health and Environmental Effects Profile (HEEP), Health and Environmental Effects Document (HEED), Health Assessment Document (HAD), Air Quality Criteria Document (AQCD), Drinking Water Criteria Document (DWCD). A description of each is provided in Appendix A, Section I. In a few cases, the values are supported by other written material, such as Work Group meeting notes or Carcinogen Assessment Group (CAG) Profiles. Radionuclide slope factor values are calculated by the EPA's Office of Radiation Programs.

The names of criteria pollutants that are regulated as National Ambient Air Quality Standards (NAAQS) under the Clean Air Act are listed in the main body of the HEAST, but the actual criteria are included as Section V of Appendix A: Technical Information. The NAAQS were not included in the tables in order to distinguish them from the reference concentration ([RfC]) values. The NAAQS and [RfC]s represent different levels of review and different methods of calculation and thus, must be interpreted and used differently.

HIERARCHY OF SOURCES

It is recognized that at any point in time there may be multiple old and new Agency documents or data bases that present different values on a specific chemical. For chemicals other than those represented by the NAAQS or DWCDs, the following hierarchy of

sources is recommended in evaluating chemical toxicity for Superfund sites:

1. The Agency's Integrated Risk Information System (IRIS) and cited references. Changes are made in this data base on a monthly basis, but there may be data gaps. Call the RISK INFORMATION HOTLINE at (513)569-7254 for further information.

2. The Health Effects Assessment Summary Tables (HEAST) and cited references.

3. Consultation with the Superfund Health Risk Technical Support Center (TSC) at (513)569-7300.

4. Do not consult either the toxicity tables (Appendix A) in the Superfund Public Health Evaluation Manual (SPHEM, U.S. EPA, 1986) or the September 1988 Public Health Risk Evaluation Data Base (PHRED) as these sources are likely to contain numerous values that have since become out-of-date.

QUESTIONS

Chemical Toxicity and Carcinogenicity

Regional EPA Superfund Staff may direct questions regarding the contents of the chemical toxicity and carcinogenicity tables on the HEAST (e.g., chemicals not covered, chemicals with pending [RfD]s) to EPA's Superfund Health Risk Technical Support Center (TSC) in Cincinnati, OH at (513)569-7300. Questions from other users must be submitted to the TSC in writing and must contain the following information:

- Superfund site name, site location and twelve-digit site number;
- Name and phone number of the site Remedial Project Manager (RPM) or Regional Risk Assessor/Toxicologist;
- Detailed description of the health effects information related question.

Please send requests via mail or FAX to:

Superfund Health Risk Technical Support Center
US EPA
26 W. Martin Luther King Dr.
Environmental Criteria and Assessment Office
MS 117
Cincinnati, OH 45268
FAX#: (513)569-7159

RCRA Chemicals

Questions about RCRA chemicals may be addressed by calling the Office of Solid Waste at (202) 260-4761.

Radionuclide Carcinogenicity

Questions concerning radionuclide carcinogenicity should first be addressed by contacting the appropriate Regional Radiation Program Manager. A listing of these managers and several contacts in the Office of Radiation Programs can be found in Exhibit 2 of the User's Guide - Radionuclide Carcinogenicity.

REFERENCES

Most cited Agency references (e.g., HEAs, HEEPs, HEEDs), are (or will soon be) available through the National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, VA 22161 [(703)487-4650]. Carcinogen Assessment Group (CAG) Profiles cited in Table 3 are available through the RCRA docket (202)260-9327.

Drinking water documents are available by calling the Drinking Water Docket at (202)260-3027.

ORDERING INFORMATION

Limited copies of the HEAST are available for EPA Superfund staff, State Superfund programs and other Federal agencies working

on Superfund sites. Users in these groups can call Syracuse Research Corporation (616) 375-2121 to be put on the mailing list.

EPA's Office of Solid Waste (OSW) requests that their users (i.e., OSW staff, contractors, State solid waste programs) call the Health Assessment Section (202) 260-4761 to obtain copies of the HEAST. Regional OSW staff are reminded that copies are sent to all EPA Regional libraries.

Users of the HEAST in EPA's Office of Air and Radiation and State air programs should call Kelly Rimer of EPA's Office of Air Quality Planning and Standards at (919) 541-2962.

All other users must purchase the document from:

National Technical Information Service (NTIS)
5285 Port Royal Road
Springfield, VA 22161
(703) 487-4650

For ordering information, call the NTIS Subscriptions Department at (703) 487-4630. NTIS normally ships 4th class United States mail. Therefore, users may wish to consult with NTIS concerning the use of an overnight delivery service. When ordering the 1994 Health Effects Assessment Summary Table annual update and supplements from NTIS refer to the following order numbers:

PB94-921100: Annual HEAST Update and Supplements

PB94-921199: Annual HEAST update

PB94-921101: July 1994 Supplement No. 1

PB94-921102: November 1994 Supplement No. 2

WHAT'S NEW IN THE NOVEMBER 1994 SUPPLEMENT NO. 2

GENERAL CHANGES -- CHEMICAL TOXICITY AND CARCINOGENICITY

The changes in this version of the HEAST reflect changes in IRIS through September, 1994. It is also current with RfD/RfC and CRAVE Work Group activities through September, 1994.

CHEMICAL-SPECIFIC CHANGES -- CHEMICAL TOXICITY AND CARCINOGENICITY

A. CHEMICAL-SPECIFIC CHANGES ON HEAST TABLE 1: SUBCHRONIC AND CHRONIC TOXICITY (OTHER THAN CARCINOGENICITY)

Acetone cyanohydrin / (2-Methyllactonitrile) 000075-86-5
The chronic oral [RfD] now under review by the RfD/RfC Work Group was added to Table 1. The chronic oral [RfD] was modified to derive the subchronic oral [RfD]. The synonym used by the RfD/RfC Work Group in its latest review is now included in HEAST.

Acrolein 000107-02-8
The subchronic [RfD] and [RfC] Risk Assessment Issue Papers for this compound were not reexamined by ECAO this year and the comment to contact the Superfund Health Risk Technical Support Center was removed from HEAST. No further change to the table.

Anthracene 000120-12-7
A comment was added to indicate that the chronic inhalation [RfC] is considered not verifiable (08/04/93) by the RfD/RfC Work Group.

Benzo[A]anthracene 000056-55-3
A comment was added to indicate that the chronic inhalation [RfC] is considered not verifiable (08/04/93) by the RfD/RfC Work Group.

Caprolactam 000105-60-2
An indicator was added to show that a comment is now on IRIS that the chronic inhalation RfC is considered not verifiable (08/03/94) by the RfD/RfC Work Group.

Chlordane 000057-74-9
The subchronic [RfC] Risk Assessment Issue Paper for this compound was not reexamined by ECAO this year and the comment to contact the Superfund Health Risk Technical Support Center was removed from HEAST. No further change to the table.

Dacthal 001861-32-1
The chronic oral RfD has been replaced on IRIS. The chronic oral RfD was adopted as the subchronic oral [RfD].

Dichlorobenzene, 1,2- 000095-50-1
The subchronic [RfD] Risk Assessment Issue Paper for this compound was not reexamined by ECAO this year and the comment to contact the Superfund Health Risk Technical Support Center was removed from HEAST. No further change to the table.

Dichloroethane, 1,2- 000107-06-2
The subchronic [RfD] and [RfC] Risk Assessment Issue Papers for this compound were not reexamined by ECAO this year. The comment to contact the Superfund Health Risk Technical Support Center was the only information on Table 1, therefore the compound was removed from Table 1.

Fluoranthene 000206-44-0
A comment was added to indicate that the chronic inhalation [RfC] is considered not verifiable (08/04/93) by the RfD/RfC Work Group.

Hexachlorobenzene 000118-74-1
The subchronic [RfD] Risk Assessment Issue Paper for this compound was not reexamined by ECAO this year and the comment to contact the Superfund Health Risk Technical Support Center was removed from HEAST. No further change to the table.

Hexachlorobutadiene 000087-68-3
The subchronic [RfC] Risk Assessment Issue Paper for this compound was not reexamined by ECAO this year and the comment to contact the Superfund Health Risk Technical Support Center was removed from HEAST. No further change to the table.

Nitric oxide 010102-43-9
The chronic oral RfD for this compound has been permanently withdrawn (09/01/94) from IRIS.

Nitrogen dioxide 010102-44-0
The chronic oral RfD for this compound has been permanently withdrawn (09/01/94) from IRIS. The subchronic oral [RfD] was removed from HEAST.

Phenanthrene 000085-01-8
A comment was added to indicate that the chronic inhalation [RfC] is considered not verifiable (08/04/93) by the RfD/RfC Work Group.

Pyrene 000129-00-0
A comment was added to indicate that the chronic inhalation [RfC] is considered not verifiable (08/04/93) by the RfD/RfC Work Group.

Styrene 000100-42-5
The subchronic [RfD] Risk Assessment Issue Paper for this compound was not reexamined by ECAO this year and the comment to contact the Superfund Health Risk Technical Support Center was removed from HEAST. No further change to the table.

B. CHEMICAL-SPECIFIC CHANGES ON HEAST TABLE 2: ALTERNATE METHODS -- SUBCHRONIC AND CHRONIC TOXICITY (OTHER THAN CARCINOGENICITY)

No changes were made to HEAST Table 2.

C. CHEMICAL-SPECIFIC CHANGES ON HEAST TABLE 3: CARCINOGENICITY

Vinyl chloride 000075-01-4
No change in values. The General Comment was changed to reflect additional review by the CRAVE Work Group.

D. CHEMICAL-SPECIFIC CHANGES ON HEAST TABLE 4: RADIONUCLIDE CARCINOGENICITY -- SLOPE FACTORS

EPA's Office of Radiation and Indoor Air (ORIA) has recently revised its methodology for estimating radiogenic cancer risks and for deriving radionuclide slope factors[1]. Specifically, ORIA has:

✓ revised its risk models for potential cancer sites based on current epidemiological data on radiogenic cancers in humans and on recent recommendations of the National Academy of Sciences (NAS) Biological Effects of Ionizing Radiation

[1] Radionuclide ingestion and inhalation slope factors are central estimates in a linear model of the age-averaged, lifetime attributable radiation cancer incidence (fatal and nonfatal cancer) risk per unit of activity inhaled or ingested, expressed as risk per picocurie (pCi). External exposure slope factors are central estimates of lifetime attributable radiation cancer incidence risk for each year of exposure to external radiation from photon-emitting radionuclides distributed uniformly in a thick layer of soil, and are expressed as risk/yr per pCi/g soil.

(BEIR) Committee[2], the International Commission on Radiological Protection (ICRP)[3], and the U.S. Nuclear Regulatory Commission (NRC)[4]; (EPA's previous radiogenic cancer risk models were based primarily upon NAS BEIR III Committee recommendations.)

- ✓ incorporated a dose and dose rate effectiveness factor (DDREF) of 2 for low-LET radiation for all cancer sites except breast (DDREF=1) whenever the total dose is below 20 rad (0.2 Gy) or the dose rate is below 10 mrad/min (0.1 mGy/min); (In EPA's previous methodology, a value of DDREF=1 was assumed for low-LET radiation for all cancer sites. For high-LET alpha radiation, EPA has retained the value of DDREF=1.)

- ✓ revised the relative biological effectiveness (RBE) for alpha particles to RBE=20 for all cancer sites except breast (RBE=10) and leukemia (RBE=1); (In the previous methodology, EPA assumed a value of RBE=8 all cancer sites with the exception of leukemia (RBE=1.117).)

- ✓ taken survival data and vital statistics from the *U.S. Decennial Life Tables for 1979-1981*; (Previously, EPA used life table data for the 1970 decennial U.S. population in the calculation of radionuclide slope factors.)

- ✓ revised its method for integrating vital statistics and risk models for reference populations;

- ✓ re-evaluated and revised (as appropriate) the radiation dose estimates used to derive the slope factors;

- ✓ increased the Agency's estimate of the lifetime fatal cancer risk associated with uniform, whole-body irradiation of the U.S. population from low-LET radiation at low doses and dose rates by approximately 24% from 392 to 509 per 10^6 person-rad (392 to 509 per 10^4 person-Gy); and

- ✓ increased the Agency's cancer morbidity risk estimate from 623 to 761 per 10^6 person-rad (623 to 761 per 10^4 person-Gy).

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[2] National Academy of Sciences (1990). Health Effects of Exposure to Low Levels of Ionizing Radiation, BEIR V, Committee on the Biological Effects of Ionizing Radiations, National Research Council, Washington, D.C.

[3] International Commission on Radiological Protection (1991), 1990 Recommendations of the International Commission on Radiological Protection, ICRP Publication 60, Pergamon Press, New York, NY.

[4] U.S. Nuclear Regulatory Commission (1991, 1993), Health Effects Models for Nuclear Power Plant Accident Consequence Analysis, NUREG/CR-4214. Addenda documenting the scientific basis for radiogenic risk models published in 1991 (for low-LET radiation) and 1993 (for alpha radiation). See EPA 402-R-93-076 for discussion of these models.

As a result of these changes in risk assessment methodology, assumptions, and calculations, ORIA has also rederived its lifetime excess cancer incidence slope factors for all radionuclides listed in previous HEAST updates and for a few new radionuclides added to this update. The HEAST User's Guide on Radionuclide Carcinogenicity provides an overview of ORIA's revised methodology for deriving radionuclide slope factors, and interested users are directed to *Estimating Radiogenic Cancer Risks* (EPA 402-R-93-076) for a more detailed discussion of ORIA's approach and assumptions.

For simplicity and to minimize the possibility of confusion and errors, this HEAST update includes a single table—Table 4—of radionuclide slope factors in customary activity units of picocuries (pCi) only, consistent with the reporting format for radionuclide slope factors in EPA's Integrated Risk Information System (IRIS) data base. Previous HEAST updates presented radionuclide slope factors in both customary units and the International System (SI) units of becquerels (Bq) in Tables 4A and 4B, respectively.

Similar to the former HEAST Tables 4A and 4B, the new Table 4 provides reference toxicity information for each radionuclide, including a Chemical Abstract Service Reference Number (CASRN), radioactive half-life, lung clearance classification and gastrointestinal (GI) absorption factor (where appropriate). *It should be noted that the GI absorption factors, lung classifications and radioactive half-lives are provided in HEAST Table 4 for reference only and should not be used to correct, modify, or in any way adjust radionuclide slope factors or intake assumptions in risk calculations.*

Inhalation, ingestion and external exposure slope factors for radionuclides marked with the suffix "+D" in Table 4 include the added risks from associated radioactive decay chain products with half-lives less than or equal to six months, assuming

equilibrium with the principal or parent radionuclide in the environment. (Note that slope factors for all radionuclides always account for associated decay products created within the body after intake.)

In summary, key features of this HEAST update for radionuclides are:

- **All radionuclide ingestion, inhalation and external exposure cancer slope factors have been updated** to incorporate EPA's revised methodology for estimating radiogenic cancer risk.

- **Table 4 presents radionuclide slope factors in customary activity units of picocuries (pCi) only**, consistent with EPA's IRIS data base format for radionuclides.

- **Additional slope factors are now provided for the following six radionuclide decay chains:** Ag-108m+D, Ce-144+D, Cm-243+D, Pu-241+D, Pu-244+D, and Sb-125+D.

USER'S GUIDE: RADIONUCLIDE CARCINOGENICITY

Introduction

EPA classifies all radionuclides as Group A carcinogens. HEAST Table 4 lists ingestion, inhalation and external exposure cancer slope factors for radionuclides in units of picocuries (pCi).[5] Ingestion and inhalation slope factors are central estimates in a linear model of the age-averaged, lifetime attributable radiation cancer incidence (fatal and nonfatal cancer) risk per unit of activity inhaled or ingested, expressed as risk/pCi. External exposure slope factors are central estimates of lifetime attributable radiation cancer incidence risk for each year of exposure to external radiation from photon-emitting radionuclides distributed uniformly in a thick layer of soil, and are expressed as risk/yr per pCi/gram soil. When combined with site-specific media concentration data and appropriate exposure assumptions[6], slope factors can be used to estimate lifetime cancer risks to members of the general population due to radionuclide exposures.

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[5] Slope factors are reported in Table 4 in the customary units of picocuries (1 pCi = 10^{-12} curies (Ci) = 3.7×10^{-2} nuclear transformations per second) for consistency with the system used for radionuclides in the IRIS database. If required, slope factors in Table 4 can be converted into the International System (SI) units of becquerels (1 Bq = 1 nuclear transformation per second) by dividing each inhalation, ingestion, or external exposure value by 27.03. Users can calculate cancer risks using slope factors expressed in either customary units or SI units with equivalent results, provided that they also use air, water and soil concentration values in the same system of units.

[6] Agency standardized default exposure scenarios and assumptions for use in baseline risk assessment are provided in EPA (1991), *Risk Assessment Guidance for Superfund, Vol. I, Human Health Evaluation Manual, Supplemental Guidance:* "Standard Default Exposure Factors" (Interim Final), Office of Emergency and Remedial Response, OSWER Directive 9285.6-03. [NTIS order number: PB 91-921314.]

Intended Users and Applications

HEAST users include individuals from the EPA, other Federal agencies, States and contractors who are responsible for the identification, characterization and remediation of sites contaminated with radioactive materials. Radionuclide slope factors are calculated by EPA's Office of Radiation and Indoor Air (ORIA) to assist HEAST users with risk-related evaluations and decision-making at various stages of the remediation process. During site assessment, for example, slope factors are used in EPA's Hazard Ranking System (HRS) to assign toxicity factor values to radionuclides to calculate site scores. During the remedial investigation and feasibility study (RI/FS), slope factors are used to determine baseline site risk, to develop preliminary remediation goals, and to evaluate cleanup alternatives. For further examples on the application of radionuclide slope factors in risk evaluations, users are referred to the following EPA documents:

- Hazard Ranking System (HRS), Federal Register (55 FR 515320), December 1990.
- *Risk Assessment Guidance for Superfund; Volume I - Human Health Evaluation Manual* (RAGS/HHEM), Part A, Baseline Risk Assessment (EPA/540/1-89/002).
- RAGS/HHEM Part B, Development of Risk-Based Preliminary Remediation Goals (OSWER Directive 9285.7-01B). [NTIS order number: PB 92-963333.]
- RAGS/HHEM Part C, Risk Evaluation of Remedial Alternatives (OSWER Directive 9285.7-01C). [NTIS order number: PB 92-963334.]

Copies of RAGS/HHEM Parts A, B and C are available to the public from the National Technical Information Service (NTIS) at

(703) 487-4650. Copies are available to EPA staff by calling the Superfund Documents Center at (703) 603-8917.

Radiation Effects

Ionizing radiation has been shown to be a carcinogen, a mutagen, and a teratogen. Radiation can induce cancers in nearly any tissue or organ in both humans and animals, and the probability of cancer induction increases with increasing radiation dose. Cancer induction is a delayed response that has been documented extensively in epidemiological studies of Japanese atomic bomb survivors, underground uranium miners, radium dial painters, and patients subject to a variety of radiation treatments. Laboratory animal research and mammalian tissue culture studies have provided additional, collaborative data.

Mutagenic effects of radiation have been demonstrated primarily in animal and tissue culture studies; limited data from studies of A-bomb survivors indicate that humans may be as sensitive or less sensitive than animals to radiogenic mutagenicity. Data are also available from both human and animal studies on the teratogenic effects of radiation. These data show that the fetus is most sensitive to radiation injury during the early stages of organ development (between 8 and 15 weeks for the human fetus). Resultant radiation-induced malformations depend on which cells are most actively differentiating at the time of exposure.

EPA classifies all radionuclides as Group A carcinogens, based on their property of emitting ionizing radiation and on the

extensive weight of evidence provided by epidemiological studies of radiogenic cancers in humans. At Superfund radiation sites, EPA generally evaluates potential human health risks based on the radiotoxicity, i.e., adverse health effects caused by ionizing radiation, rather than on the chemical toxicity, of each radionuclide present. These evaluations consider the carcinogenic effects of radionuclides only. In most cases, cancer risks are limiting, exceeding both mutagenic and teratogenic risks.

Derivation of Radionuclide Slope Factors

EPA's Office of Radiation and Indoor Air (ORIA) calculates radionuclide slope factor values using health effects data and dose and risk models from a number of national and international scientific advisory commissions and organizations, including the National Academy of Sciences (NAS), the National Council on Radiation Protection and Measurements (NCRP), the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), and the International Commission on Radiological Protection (ICRP). A detailed discussion of ORIA's approach and assumptions is provided in *Estimating Radiogenic Cancer Risks* (EPA 402-R-93-076).

Radionuclide slope factors are calculated for each radionuclide individually, based on its unique chemical, metabolic and radioactive properties. The calculation uses dose estimates from EPA's computer code RADRISK[7], vital statistics

[7] Dunning, D.E. Jr., Leggett, R.W., and Yalcinatas, M.G. (1980). "A Combined Methodology for Estimating Dose Rates and Health Effects from Exposure to Radioactive Pollutants," ORNL/TM-7105.

from the *U.S. Decennial Life Tables for 1979-1981* (described in EPA 402-R-93-076), and cancer risk estimates based largely on the results of the NAS BEIR V report[8], ICRP Publication 60[9], and U.S. Nuclear Regulatory Commission (NRC) analyses.[10] Ingestion and inhalation slope factors for radionuclides account for:

- the amount of radionuclide transported into the bloodstream from either the gastrointestinal (GI) tract following ingestion, or from the lungs following inhalation;
- the ingrowth and decay of radioactive progeny produced within the body subsequent to intake;
- the distribution and retention of each radionuclide (and its associated progeny, if appropriate) in body tissues and organs;
- the radiation dose delivered to body tissues and organs from the radionuclide (and its associated progeny, if appropriate); and
- the sex, age, and organ-specific risk factors over the lifetime of exposure.

The slope factors are the average risk per unit intake or exposure for an individual in a stationary population with vital statistics (mortality rates) of the United States in 1980. (The expected lifetime for an individual in this population is about 74 years.) Consequently, radionuclide ingestion and inhalation slope factors are <u>not</u> expressed as a function of body weight and

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[8] National Academy of Sciences (1990). <u>Health Effects of Exposure to Low Levels of Ionizing Radiation, BEIR V</u>, Committee on the Biological Effects of Ionizing Radiations, National Research Council, Washington, D.C.

[9] International Commission on Radiological Protection (1991), <u>1990 Recommendations of the International Commission on Radiological Protection</u>, ICRP Publication 60, Pergamon Press, New York, NY.

[10] U.S. Nuclear Regulatory Commission (1991, 1993), <u>Health Effects Models for Nuclear Power Plant Accident Consequence Analysis</u>, NUREG/CR-4214. Addenda documenting the scientific basis for radiogenic risk models published in 1991 (for low-LET radiation) and 1993 (for alpha radiation). See EPA 402-R-93-076 for discussion of these models.

time, and do not require corrections for GI absorption or lung transfer efficiencies.

NOTE: ***The GI absorption values (f_1), ICRP lung classifications (D, W, Y) and radioactive half-lives are provided in HEAST Table 4 for reference only and should not be used to correct, modify, or in any way adjust radionuclide slope factors or intake assumptions in risk calculations.***

External slope factors provide cancer risk estimates per unit exposure to a uniform radionuclide concentration in soil. These factors, which account for photon energy flux attenuation and buildup in soil, are calculated for each radionuclide using volume and surface dose factors derived using the computer code DFSOIL.[11]

Because of the radiation risk models employed for both internal and external exposures, slope factors for radionuclides are characterized as central estimates in a linear model of the age-averaged lifetime total radiation cancer incidence risk per unit intake or exposure.

About the Information Provided in Table 4

Table 4 lists ingestion, inhalation and external exposure slope factors of principal radionuclides, and provides key parameter values used in the derivation of slope factor values. Radionuclides are presented alphabetically by element and atomic weight.

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[11] Sjoreen, A.L., Kocher, D.C., Killough, G.G. and Miller C.W. (1984). "MLSOIL and DFSOIL - Computer Codes to Estimate Effective Ground Surface Concentrations for Dose Computations," Oak Ridge National Laboratory, Oak Ridge, TN, ORNL-5974.

Selected radionuclides and radioactive decay chain products are designated in HEAST Table 4 with the suffix "+D" (e.g., U-238+D, Ra-226+D, Cs-137+D) to indicate that cancer risk estimates for these radionuclides include the contributions from their short-lived decay products, assuming equal activity concentrations (i.e., secular equilibrium) with the principal or parent nuclide in the environment.[12] Decay chains are identified in Exhibit 1.

In most cases, site-specific analytical data should be used to establish the actual degree of equilibrium between each parent radionuclide and its decay products in each media sampled. However, in the absence of empirical data, the "+D" values for radionuclides should be used unless there are compelling reasons not to. For example, the external slope factors for Cs-137 and Cs-137+D are 0.0 and 2×10^{-6} (risk per year per pCi/gram), respectively. The value for Cs-137+D is higher because it includes the risk contribution from cesium's short-lived gamma-emitting decay product Ba-137m (half-life, 25.5 minutes) which, under most environmental conditions, will be in secular equilibrium with Cs-137.

Note that there may be circumstances, such as long disposal times or technologically enhanced concentrations of naturally occurring radionuclides, that may necessitate the combination of the risks of a parent radionuclide and its decay products over several contiguous subchains. For example, Ra-226 soil analyses

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[12] There is one exception to the assumption of secular equilibrium. For the inhalation slope factor for Rn-222+D reported in HEAST Table 4, ORIA assumes a 50% equilibrium value for radon decay products (Po-218, Pb-214, Bi-214 and Po-214) in air.

at a site might show that all radium decay products are present in secular equilibrium down to stable Pb-206 (See Exhibit 1). In this case, Ra-226 risk calculations should be based on the ingestion, inhalation and external exposure slope factors for the Ra-226+D subchain, plus the ingestion, inhalation and external exposure factors for the Pb-210+D subchain. For actual sites, users should consult with a health physicist or radiochemist (1) to evaluate the site-specific analytical data to determine the degree of equilibrium between parent radionuclides and decay members of contiguous decay chains and (2) to assist in the combination of appropriate slope factor values. For health physics and radioanalytical support, HEAST users may contact EPA's Regional Radiation Program Managers, ORIA's National Air and Radiation Laboratory (NAREL) in Montgomery, Alabama, ORIA's Las Vegas Laboratory (ORIA-LV) in Las Vegas, Nevada, or the ORIA contact at EPA headquarters in Washington, D.C., listed in Exhibit 2.

A Chemical Abstract System Reference Number (CASRN) is assigned to each radionuclide for identification and reporting accuracy during risk assessments, and radioactive half-lives are provided for reference.

The designations "D", "W", and "Y" presented in Table 4 under the heading "ICRP Lung Class" in the tables refer to the lung clearance times for inhaled particulate radionuclides, expressed as days (D), weeks (W), or years (Y), as recommended by the International Commission on Radiological Protection (ICRP). Gaseous radionuclides, e.g., Rn-222, are designated with an asterisk ("*"). "GI Absorption Factors, f_1" are the fractional

amounts of each radionuclide that may be absorbed from the gastrointestinal (GI) tract into blood following an oral intake. The ICRP lung clearance classifications and GI absorption factors provided in Table 4 are the default values that EPA used to calculate radionuclide slope factors for inhalation and ingestion exposures, respectively. These factors are provided *for reference only* (see the Note Box).

Where to Address Questions About Radionuclide Slope Factors:

EPA continuously reviews the scientific literature on radiation effects to ensure that the Agency's risk assessment methodologies are consistent with current models and assumptions. As risk methodologies are refined, EPA will revise and update the slope factors in Table 4.

HEAST users with questions about radionuclide slope factor values and their use in radiation risk assessments should contact Michael Boyd of the Remedial Guidance Section of the Radiation Assessment Branch of ORIA at (202) 233-9395. Written requests for assistance can be sent by fax to (202) 233-9650.

Exhibit 1. Radionuclide Decay Chains Considered Explicitly in HEAST Table 4*

Principal Radionuclide[a]			Terminal Nuclide or Radionuclide[c]	
Nuclide	Half-life (yr)	Associated Decay Chain[b]	Nuclide	Half-life (yr)
Ac-227+D	22	[Th-227 (98.6%, 19 d)] Fr-223 (1.4%, 22 min) Ra-223 (11 d) Rn-219 (4 s) Po-215 (2 ms) Pb-211 (36 min) Bi-211 (2 min) [Tl-207 (99.7%, 5 min) Po-211 (0.3%, 0.5 s)]	Pb-207	*
Ag-108m+D	127	-[d] Ag-108 (9%, 2 min)	Pd-108 (91%) [Cd-108 (98%) Pd-108 (2%)]	* * *
Ag-110m+D	0.7	- Ag-110 (1%, 25 s)	Cd-110 (99%) [Cd-110 (99.7%) Pd-110 (0.3%)	* * *
Am-243+D	7.4×10^3	Np-239 (2 d)	Pu-239	2.4×10^4
Ce-144+D	0.8	[Pr-144 (9%, 17 min) Pr-144m (2%, 7 min)]	Nd-144	*
Cs-137+D	30	Ba-137m (95%, 3 min)	Ba-137	*
Np-237+D	2.1×10^6	Pa-233 (27 d)	U-233	1.6×10^5
Pb-210+D	22	Bi-210 (5 d) Po-210 (138 d)	Pb-206	*
Pu-241+D	14	[Am-241 (~100%, 432 y) U-237 (7 d)][e]	Np-237	2.1×10^6
Pu-244+D	8.3×10^7	U-240 (~100%, 14 h) Np-240	Pu-240	6.5×10^3
Ra-226+D	1.6×10^3	Rn-222 (4 d) Po-218 (3 min) Pb-214 (~100%, 27 min) Bi-214 (20 min) Po-214 (~100%, 1 min)	Pb-210	22
Ra-228+D	8	Ac-228 (6 h)	Th-228	2
Ru-106+D	1	Rh-106 (30 s)	Pd-106	*
Sb-125+D	3	Te-125m (23%, 58 d)	Te-125	*

000028

Principal Radionuclide[a]			Terminal Nuclide or Radionuclide[c]	
Nuclide	Half-life (yr)	Associated Decay Chain[b]	Nuclide	Half-life (yr)
Sr-90+D	29	Y-90 (64 h)	Zr-90	*
Th-228+D	2	Ra-224 (4 d) Rn-220 (56 s) Po-216 (0.2 s) Pb-212 11 h) Bi-212 (61 min) [Po-212 (64%, 0.3 μs) Tl-208 (36%, 3 min)]	Pb-208	*
Th-229+D	7.3×10^3	Ra-225 (15 d) Ac-225 (10 d) Fr-221 (5 min) At-217 (32 ms) Bi-213 (46 min) [Po-213 (98%, 4 μs) Tl-209 (2%, 2 min)] Pd-209 (3 h)	Bi-209	*
U-235+D	7.0×10^8	Th-231 (26 h)	Pa-231	3.4×10^4
U-238+D	4.5×10^9	Th-234 (24 d) [Pa-234m (99.8%, 1 min) Pa-234 (0.2%, 7 h)]	U-234	2.4×10^5

[a] Radionuclides with half-lives greater than six months. "+D" designates principal radionuclides with associated decay chains.

[b] The chain of decay products of a principal radionuclide extending to (but not including) the next principal radionuclide or a stable radionuclide. Half-lives are given in parentheses. Branches are indicated by square brackets with branching ratios in parentheses.

[c] The principal radionuclide or stable nuclide that terminates an associated decay chain. Stable nuclides are indicated by an asterisk (*) in place of a half-life.

[d] A hyphen indicates that there are no associated decay products.

[e] The branching decay for Pu-241 and Cm-243 involves multiple principal radionuclides and associated radionuclides.

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* Table adapted from: C. Yu, et al. (1994), "Manual for Implementing Residual Radioactive Materials Guidelines Using RESRAD, Version 5.0," Argonne National Laboratory.

Exhibit 2. EPA Radiation Program Staff

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Paul Wagner Radiation Program Manager, Region 4 U.S. Environmental Protection Agency 345 Courtland Street, NE Atlanta, GA 30365	(404) 347-3907
Jack Barnette Radiation Program Manager, Region 5 U.S. Environmental Protection Agency 77 West Jackson Boulevard/AT18J Chicago, IL 60604-3507	(312) 886-6175
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Exhibit 2 (Continued)

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U.S. Environmental Protection Agency
401 M Street, SW
Washington, DC 20460

CHEMICAL LEVEL	DOSE ROUTE	SPECIES EXPERIMENT	LENGTH	TARGET	CRITICAL EFFECT	Subchronic (RfC) (mg/cu m)	Subchronic (RfD) (mg/kg/day)	Chronic (RfC) (mg/cu m)	Chronic (RfD) (mg/kg/day)	REFERENCE
ACETONE CYANOHYDRIN / (2-METHYLLACTONITRILE)					000075-86-5					
NOAEL 8.75 MG/(KG-DAY)	ORAL: GAVAGE	RAT	90 DAYS	LIVER	INCREASED RELATIVE WEIGHT		8E-3 300		8E-4 3000	005776
SUBCHRONIC (RfC) COMMENT: ALSO SEE HEAST TABLE 2: ALTERNATE METHODS -- SUBCHRONIC AND CHRONIC TOXICITY (OTHER THAN CARCINOGENICITY)										
CHRONIC (RfC) COMMENT: ALSO SEE HEAST TABLE 2: ALTERNATE METHODS -- SUBCHRONIC AND CHRONIC TOXICITY (OTHER THAN CARCINOGENICITY)										
ACROLEIN					000107-02-8					
NOAEL 15.6 MG/KG/DAY	ORAL: WATER	RAT	90 DAYS						2E-2 1000	010390
GENERAL COMMENT: ALSO SEE HEAST TABLE 3: CARCINOGENICITY.								IRIS		010856
ANTHRACENE					000120-12-7					
NOEL 1000 MG/KG/DAY	ORAL: GAVAGE	MOUSE	90 DAYS		NONE OBSERVED		3E+0 300		IRIS	010166
CHRONIC (RfC) COMMENT: THE CHRONIC INHALATION (RfC) IS CONSIDERED NOT VERIFIABLE (08/04/94) BY THE RfD/RfC WORK GROUP.										010964
BENZO[A]ANTHRACENE					000056-55-3					
CHRONIC (RfC) COMMENT: THE CHRONIC INHALATION (RfC) IS CONSIDERED NOT VERIFIABLE (08/04/94) BY THE RfD/RfC WORK GROUP.										010965
GENERAL COMMENT: ALSO SEE HEAST TABLE 3: CARCINOGENICITY.										
CAPROLACTAM					000105-60-2					
									IRIS	005284
NOAEL 50 MG/KG/DAY	ORAL: DIET	RAT	90 DAYS	KIDNEY	EFFECTS		5E-1 100			005282
								IRIS		010966

000032

7284

CHEMICAL LEVEL	DOSE ROUTE	SPECIES EXPERIMENT	LENGTH	TARGET	CRITICAL EFFECT	Subchronic [RfC] (mg/cu m) UF	Subchronic [RfD] (mg/kg/day) UF	Chronic [RfC] (mg/cu m) UF	Chronic [RfD] (mg/kg/day) UF	REFERENCE
CHLORDANE		000057-74-9								
NOEL	0.055 MG/KG/DAY	RAT								
	ORAL: DIET		130 WEEKS	LIVER	HYPERTROPHY		6E-5 1000		IRIS	005296
	SUBCHRONIC [RfD] COMMENT: THE CHRONIC ORAL RfD WAS ADOPTED AS THE SUBCHRONIC ORAL [RfD].									
	GENERAL COMMENT: ALSO SEE HEAST TABLE 3: CARCINOGENICITY.									
DACTHAL		001861-32-1								
NOAEL	1 MG/KG/DAY	RAT								
	ORAL: DIET		2 YEARS	LUNG	EFFECTS		1E-2 100		IRIS	005888
				LIVER	EFFECTS					
				KIDNEY	EFFECTS					
				THYROID	EFFECTS					
				THYROID HORMONES	EFFECTS					
	SUBCHRONIC [RfD] COMMENT: THE CHRONIC ORAL RfD WAS ADOPTED AS THE SUBCHRONIC ORAL [RfD].									
DICHLOROBENZENE, 1,2-		000095-50-1							IRIS	010864
	GENERAL COMMENT: ALSO SEE HEAST TABLE 2: ALTERNATE METHODS -- SUBCHRONIC AND CHRONIC TOXICITY (OTHER THAN CARCINOGENICITY)									
FLUORANTHENE		000206-44-0								
NOAEL	125 MG/KG/DAY	MOUSE								
	ORAL: GAVAGE		90 DAYS	KIDNEY	NEPHROPATHY		4E-1 300		IRIS	010168
				LIVER	WEIGHT CHANGES					
				BLOOD	HEMATOLOGICAL CHANGES					
	CHRONIC [RfC] COMMENT: THE CHRONIC INHALATION [RfC] IS CONSIDERED NOT VERIFIABLE (08/04/94) BY THE RfD/RfC WORK GROUP.									010967

000033

CHEMICAL LEVEL	DOSE ROUTE	SPECIES EXPERIMENT LENGTH	TARGET	CRITICAL EFFECT	Subchronic [RfC] (mg/cu m) UF	Subchronic [RfD] (mg/kg/day) UF	Chronic [RfC] (mg/cu m) UF	Chronic [RfD] (mg/kg/day) UF	REFERENCE
HEXACHLOROBENZENE		000118-74-1						IRIS	010868
							IRIS		010900
CHRONIC RfC COMMENT: THE CHRONIC INHALATION RfC IS CONSIDERED NOT VERIFIABLE (11/15/90) BY THE RfD/RfC WORK GROUP.									
SUBCHRONIC [RfC] COMMENT: CONTACT THE SUPERFUND HEALTH RISK TECHNICAL SUPPORT CENTER: (513) 569-7300.									
GENERAL COMMENT: ALSO SEE HEAST TABLE 3: CARCINOGENICITY.									
HEXACHLOROBUTADIENE		000087-68-3							
LOAEL 0.5 MG/KG/DAY		MOUSE							
	ORAL: DIET	13 WEEKS	RENAL TUBULES	REGENERATION				2E-4 1000	010927
CHRONIC [RfD] COMMENT: WITHDRAWN FROM IRIS (05/01/93). UNDER REVIEW, CURRENT NUMBER SUBJECT TO CHANGE.									
SUBCHRONIC [RfD] COMMENT: CONTACT THE SUPERFUND HEALTH RISK TECHNICAL SUPPORT CENTER: (513) 569-7300.									
NITRIC OXIDE		010102-43-9							
CHRONIC [RfC] COMMENT: REFER TO APPENDIX A: TECHNICAL INFORMATION, SECTION V ON NATIONAL AMBIENT AIR QUALITY STANDARDS.									010451
CHRONIC [RfD] COMMENT: THE CHRONIC ORAL RfD HAS BEEN PERMANENTLY WITHDRAWN (09/01/94) FROM IRIS.									
NITROGEN DIOXIDE		010102-44-0							
CHRONIC [RfD] COMMENT: THE CHRONIC ORAL RfD HAS BEEN PERMANENTLY WITHDRAWN (09/01/94) FROM IRIS.									010402
CHRONIC [RfC] COMMENT: REFER TO APPENDIX A: TECHNICAL INFORMATION, SECTION V ON NATIONAL AMBIENT AIR QUALITY STANDARDS.									010912
PHENANTHRENE		000085-01-8							
GENERAL COMMENT: DATA INADEQUATE FOR QUANTITATIVE RISK ASSESSMENT									005604
CHRONIC [RfC] COMMENT: THE CHRONIC INHALATION [RfC] IS CONSIDERED NOT VERIFIABLE (08/04/94) BY THE RfD/RfC WORK GROUP.									
PYRENE		000129-00-0							
NOAEL 75 MG/KG/DAY		MOUSE							
	ORAL: GAVAGE	13 WKS	KIDNEY	EFFECTS		3E-1 300		IRIS	010176
CHRONIC [RfC] COMMENT: THE CHRONIC INHALATION [RfC] IS CONSIDERED NOT VERIFIABLE (08/04/94) BY THE RfD/RfC WORK GROUP.									010968

000034

2784

CHEMICAL LEVEL	DOSE ROUTE	SPECIES EXPERIMENT LENGTH	TARGET	CRITICAL EFFECT	Subchronic [RfC] (mg/cu m) UF	Subchronic [RfD] (mg/kg/day) UF	Chronic [RfC] (mg/cu m) UF	Chronic [RfD] (mg/kg/day) UF	REFERENCE
STYRENE		000100-42-5						IRIS	010059
NOAEL 22 PPM	INHALATION: OCCUPATIONAL	HUMAN	CENTRAL NERVOUS SYSTEM	EFFECTS	3E+0 10		IRIS		010511

CHRONIC [RfC] COMMENT: THE MEAN DURATION OF EXPOSURE FOR 50 WORKERS WAS 8.6 YEARS. AIR EXPOSURE CONCENTRATIONS WERE ESTIMATED FROM THE SUMMATION OF THE PRINCIPLE URINARY METABOLITES OF STYRENE, MANDELIC ACID AND PHENYLGLYOXYLIC ACID. SEE IRIS FOR MORE INFORMATION.

GENERAL COMMENT: ALSO SEE HEAST TABLE 3: CARCINOGENICITY.

000035

REFERENCES FOR HEAST TABLE 1: SUBCHRONIC AND CHRONIC TOXICITY
(OTHER THAN CARCINOGENICITY)

November 1994

ACETONE CYANOHYDRIN / (METHYLLACTONITRILE) 000075-86-5

005776 HAZELTON LABORATORIES AMERICA. 1988. SUBCHRONIC TOXICITY STUDY IN RATS WITH 2-METHYLLACTONITRILE. HLA STUDY NO. 2399-114. REPORT PREPARED FOR DYNAMAC CORPORATION.

US EPA. 1994. RfD/RfC WORK GROUP.

ACROLEIN 000107-02-8

010390 NEWELL GW. 1958. ACUTE AND SUBACUTE TOXICITY OF ACROLEIN. STANFORD RESEARCH INSTITUTE. SRI PROJECT NO. 5-868-2.

NAS (NATIONAL ACADEMY OF SCIENCES). 1977. DRINKING WATER AND HUMAN HEALTH. WASHINGTON, DC.

US EPA. 1985. HEALTH AND ENVIRONMENTAL EFFECTS PROFILE FOR ACROLEIN. PREPARED BY THE OFFICE OF HEALTH AND ENVIRONMENTAL ASSESSMENT, ENVIRONMENTAL CRITERIA AND ASSESSMENT OFFICE, CINCINNATI, OH FOR THE OFFICE OF SOLID WASTE AND EMERGENCY RESPONSE, WASHINGTON, DC.

010856 FERON VJ, A KRUYSSE, HP TIL, AND HR IMMEL. 1978. REPEATED EXPOSURE TO ACROLEIN VAPOR: SUBACUTE STUDIES IN HAMSTERS, RATS AND RABBITS. TOXICOLOGY. 9: 47-57.

US EPA. 1991. RfD/RfC WORK GROUP.

ANTHRACENE 000120-12-7

010166 US EPA. 1989. SUBCHRONIC TOXICITY IN MICE WITH ANTHRACENE. FINAL REPORT. HAZELTON LABORATORIES AMERICA, INC. PREPARED FOR THE OFFICE OF SOLID WASTE, WASHINGTON, DC.

US EPA. 1991. DRINKING WATER CRITERIA DOCUMENT FOR ANTHRACENE. PREPARED BY THE OFFICE OF HEALTH AND ENVIRONMENTAL ASSESSMENT, ENVIRONMENTAL CRITERIA AND ASSESSMENT OFFICE, CINCINNATI, OH FOR THE OFFICE OF DRINKING WATER, WASHINGTON, DC.

US EPA. 1989. RfD/RfC WORK GROUP.

010964 US EPA. 1994. RfD/RfC WORK GROUP.

BENZO[A]ANTHRACENE 000056-55-3

010965 US EPA. 1994. RfD/RfC WORK GROUP.

000036

77284

CAPROLACTAM 000105-60-2

005284 SEROTA DG, AM HOBERMAN AND SC GAD. 1984. A THREE-GENERATION REPRODUCTION STUDY WITH CAPROLACTAM IN RATS. IN: PROCEEDINGS OF A SYMPOSIUM ON AN INDUSTRY APPROACH TO CHEMICAL RISK ASSESSMENT: CAPROLACTAM AND RELATED COMPOUNDS AS A CASE STUDY. INDUSTRY HEALTH FOUND. ARLINGTON, VA., P 191-204.

US EPA. 1988. HEALTH AND ENVIRONMENTAL EFFECTS DOCUMENT FOR CAPROLACTAM. PREPARED BY THE OFFICE OF HEALTH AND ENVIRONMENTAL ASSESSMENT, ENVIRONMENTAL CRITERIA AND ASSESSMENT OFFICE, CINCINNATI, OH FOR THE OFFICE OF SOLID WASTE AND EMERGENCY RESPONSE, WASHINGTON, DC.

US EPA. 1988. RfD/RfC WORK GROUP.

005282 POWERS WJ, JR, JC PECKHAM, KM SIINO AND SC GAD. 1984. EFFECTS OF SUBCHRONIC DIETARY CAPROLACTAM ON RENAL FUNCTION. IN: PROCEEDINGS OF A SYMPOSIUM ON AN INDUSTRY APPROACH TO CHEMICAL RISK ASSESSMENT: CAPROLACTAM AND RELATED COMPOUNDS AS A CASE STUDY. INDUSTRY HEALTH FOUND. ARLINGTON, VA.

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010966 US EPA. 1994. RfD/RfC WORK GROUP.

CHLORDANE 000057-74-9

005296 VELSICOL CHEMICAL CORP. 1983. ACC NO 252267, MRID NO. 00138591, 00144313. AVAILABLE FROM EPA. WRITE TO FOI, EPA, WASHINGTON, DC 20460.

US EPA. 1989. RfD/RfC WORK GROUP.

DACTHAL 001861-32-1

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US EPA. 1994. RfD/RfC WORK GROUP.

DICHLOROBENZENE, 1,2- 000095-50-1

010864 US EPA. 1989. RfD/RfC WORK GROUP.

000037

FLUORANTHENE 000206-44-0

010168 US EPA. 1988. 13-WEEK MOUSE ORAL SUBCHRONIC TOXICITY STUDY. PREPARED BY TOXICITY RESEARCH LABORATORIES, LTD, MUSKEGON, MI FOR THE OFFICE OF SOLID WASTE, WASHINGTON, DC.

US EPA. 1989. RfD/RfC WORK GROUP.

010967 US EPA. 1994. RfD/RfC WORK GROUP.

HEXACHLOROBENZENE 000118-74-1

010868 ARNOLD, DL, CA MOODIE, SM CHARBONNEAU ET AL. 1985. LONG-TERM TOXICITY OF HEXACHLOROBENZENE IN THE RAT AND THE EFFECT OF DIETARY VITAMIN A. FOOD CHEM TOXICOL. 23(9): 779-793.

US EPA. 1991. DRINKING WATER CRITERIA DOCUMENT FOR HEXACHLOROBENZENE. PREPARED BY THE ENVIRONMENTAL CRITERIA AND ASSESSMENT OFFICE, OFFICE OF HEALTH AND ENVIRONMENTAL ASSESSMENT, CINCINNATI, OH FOR THE OFFICE OF WATER, WASHINGTON, DC.

US EPA. 1988. RfD/RfC WORK GROUP.

010900 US EPA. 1990. RfD/RfC WORK GROUP.

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010927 NTP (NATIONAL TOXICOLOGY PROGRAM). 1991. NTP REPORT ON THE TOXICITY STUDIES OF HEXACHLORO-1,3-BUTADIENE IN B6C3F1 MICE (FEED STUDIES).

YANG ET AL. 1989. HEXACHLOROBUTADIENE - SUBCHRONIC TOXICOLOGY STUDIES OF HEXACHLORO-1,3-BUTADIENE (HCBD) IN B6C3F1 MICE BY DIETARY INCORPORATION. J ENVIRON PATHOL TOXICOL ONCOL. P. 323-332.

KOCIBA RJ, DG KEYS, GC JERESEY, ET AL. 1977. RESULTS OF A 2-YEAR CHRONIC TOXICITY STUDY WITH HEXACHLOROBUTADIENE IN RATS. AM IND HYG ASSOC J. 38: 589-602.

US EPA. 1993. RfD/RfC WORK GROUP.

NITRIC OXIDE 010102-43-9

010451 REFER TO APPENDIX A: TECHNICAL INFORMATION, SECTION V ON NATIONAL AMBIENT AIR QUALITY STANDARDS.

US EPA. 1994. RfD/RfC WORK GROUP.

NITROGEN DIOXIDE 010102-44-0

010402 US EPA. 1994. RfD/RfC WORK GROUP.

010912 REFER TO APPENDIX A: TECHNICAL INFORMATION, SECTION V ON NATIONAL AMBIENT AIR QUALITY STANDARDS.

PHENANTHRENE 000085-01-8

000038

77284

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CHEMICAL	ROUTE	EXPERIMENT LENGTH / SPECIES	TARGET	CANCER	[EPA GROUP]	[SLOPE FACTOR] ORAL (mg/kg/day)$^{-1}$	[SLOPE FACTOR] INHALATION (mg/kg/day)$^{-1}$	[UNIT RISK] ORAL (ug/L)$^{-1}$	[UNIT RISK] INHALATION (ug/cu m)-1	REFERENCE
VINYL CHLORIDE		000075-01-4								
	ORAL: DIET	1001 DAYS			A	1.9E+0		5.4E-5		010368
		RAT	LUNG	TUMORS						
			LIVER	TUMORS						
	ORAL [SLOPE] COMMENT: UNDER REVIEW, NUMBER SUBJECT TO CHANGE.									
	INHALATION:	1 YEAR			A		3.0E-1		8.4E-5	010367
	INTERMITTENT	RAT	LIVER	TUMORS						

INHALATION [SLOPE] COMMENT: SEE APPENDIX A-II: DOSE CONVERSIONS ON HEAST.
INHALATION [UNIT RISK] COMMENT: UNDER REVIEW, NUMBER SUBJECT TO CHANGE.
GENERAL COMMENT: THE MOST RECENTLY REVIEWED QUANTITATIVE TOXICITY VALUES LISTED HERE APPEAR IN EPA DOCUMENTS PUBLISHED IN 1984 AND 1985. USE OF THESE VALUES ON AN INTERIM BASIS WAS VALIDATED BY CRAVE (04/05/90) AND FURTHER REVIEWED (06/09/94). THE AGENCY IS AWARE THAT THESE VALUES DO NOT INCORPORATE CONSIDERABLE INFORMATION THAT IS NOW AVAILABLE. THE OFFICE OF HEALTH AND ENVIRONMENTAL ASSESSMENT'S POSITION IS THAT THESE TOXICITY VALUES DO NOT REFLECT STATE-OF-THE-ART SCIENCE FOR VINYL CHLORIDE. EPA NOW HAS INDIVIDUAL ANIMAL DATA, NOT AVAILABLE WHEN THE ORAL UNIT RISK WAS CALCULATED, THAT MAY INFLUENCE THIS VALUE. ADDITIONAL INFORMATION THAT MAY BE FACTORED INTO A REVISED QUANTITATIVE TOXICITY VALUE INCLUDES DATA ON INCREASED SENSITIVITY OBSERVED IN YOUNG ANIMALS AND DATA ON METABOLISM/PHARMACOKINETICS. A UNIT RISK FOR AIR THAT CONSIDERS INFORMATION ON YOUNG AGE EXPOSURE INCREASES THE RISK (I.E., LOWERS THE RISK SPECIFIC DOSE) BY AT LEAST 3-FOLD. THE CONSIDERATION OF METABOLISM PHARMACOKINETICS WILL FURTHER INCREASE THE RISK. ONE UNPUBLISHED PHYSIOLOGICALLY-BASED PHARMACOKINETIC MODEL PREDICTION RESULTS IN A 100-FOLD INCREASED RISK.

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US EPA. 1990. CARCINOGEN RISK ASSESSMENT VERIFICATION ENDEAVOR (CRAVE) WORK GROUP.

010367 MALTONI, C, G LEFEMINE, A CILIBERTI ET AL. 1980. VINYL CHLORIDE CARCINOGENICITY BIOASSAYS (BT PROJECT) AS AN EXPERIMENTAL MODEL FOR RISK IDENTIFICATION AND ASSESSMENT IN ENVIRONMENTAL AND OCCUPATIONAL CARCINOGENESIS. EPIDEMIOL ANIM EPIDEMIOL HUM: CAS CHLORURE VINYLE MONOMERE, (REUN CLUB CANCEROG CHIM), 20TH, MEETING DATE 1979, P. 11-112. PUBL ESSENT, PARIS, FRANCE.

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Table 4

Radionuclide Carcinogencity -- Slope Factors (In Units of Picocuries)

NOVEMBER 1994

NOTE: To convert radionuclide slope factors into the International System (SI) activity units of becquerels (Bq), multiply each value in Table 4 by 3.70E-02.

Table 4: Radionuclide Carcinogenicity -- Slope Factors[a] (In Units of Picocuries[b])

NOVEMBER 1994

Element (Atomic Number)	Isotope[c]	CASRN[d]	Radioactive Half-life[e]		ICRP Lung Class[f]	GI Absorption Factor (f_1)[g]	Slope Factor Lifetime Excess Total Cancer Risk Per Unit Intake or Exposure: Ingestion (Risk/pCi)	Inhalation (Risk/pCi)	External Exposure (Risk/yr per pCi/g soil)
Actinium (89)	Ac-225	014265-85-1	1.00E+01	D	Y	1.00E-03	1.42E-10	4.16E-09	7.81E-09
	Ac-227	014952-40-0	2.18E+01	Y	Y	1.00E-03	3.52E-10	7.08E-08	2.35E-11
	Ac-227+D	014952-40-0(+D)	2.18E+01	Y	Y	1.00E-03	6.26E-10	7.87E-08	5.97E-07
	Ac-228	014331-83-0	6.13E+00	H	Y	1.00E-03	1.62E-12	3.27E-11	3.28E-06
Americium (95)	Am-241	014596-10-2	4.32E+02	Y	W	1.00E-03	3.28E-10	3.85E-08	4.59E-09
	Am-242	013981-54-9	1.60E+01	H	W	1.00E-03	1.47E-12	1.04E-11	5.76E-09
	Am-242m	013981-54-9(m)	1.52E+02	Y	W	1.00E-03	2.92E-10	3.49E-08	8.76E-11
	Am-243	014993-75-0	7.38E+03	Y	W	1.00E-03	3.27E-10	3.82E-08	2.43E-08
	Am-243+D	014993-75-0(+D)	7.38E+03	Y	W	1.00E-03	3.31E-10	3.82E-08	2.66E-07
Antimony (51)	Sb-122	014374-79-9	2.70E+00	D	W	1.00E-01	8.81E-12	5.46E-12	1.61E-06
	Sb-124	014683-10-4	6.02E+01	D	W	1.00E-01	1.07E-11	1.32E-11	7.35E-06
	Sb-125	014234-35-6	2.77E+00	Y	W	1.00E-01	2.97E-12	5.20E-12	1.34E-06
	Sb-125+D	014234-35-6(+D)	2.77E+00	Y	W	1.00E-01	3.54E-12	5.85E-12	1.34E-06
	Sb-126	015756-32-8	1.24E+01	D	W	1.00E-01	9.73E-12	8.41E-12	1.03E-05
	Sb-126m	015756-32-8(m)	1.90E+01	M	W	1.00E-01	7.28E-14	6.43E-14	5.78E-06
	Sb-127	013968-50-8	3.85E+00	D	W	1.00E-01	8.48E-12	6.05E-12	2.40E-06
	Sb-129	014331-88-5	4.40E+00	H	W	1.00E-01	1.86E-12	8.60E-13	5.56E-06
Argon (18)	Ar-41	014163-25-8	1.83E+00	H	*	---	---	4.71E-16	---

[Table 4 continues on the following page: Refer to Endnotes on the last page.]

000012

Table 4: Radionuclide Carcinogenicity -- Slope Factors[a] (In Units of Picocuries[b])

NOVEMBER 1994

Element (Atomic Number)	Isotope[c]	CASRN[d]	Radioactive Half-life[e]		ICRP Lung Class[f]	GI Absorption Factor (f_1)[g]	Slope Factor Lifetime Excess Total Cancer Risk Per Unit Intake or Exposure: Ingestion (Risk/pCi)	Inhalation (Risk/pCi)	External Exposure (Risk/yr per pCi/g soil)
Astatine (85)	At-217	017239-90-6	3.23E-02	S	D	9.50E-01	8.99E-18	5.14E-16	8.71E-10
Barium (56)	Ba-131	014914-75-1	1.18E+01	D	D	1.00E-01	1.70E-12	4.79E-13	1.27E-06
	Ba-133	013981-41-4	1.05E+01	Y	D	1.00E-01	2.70E-12	4.03E-12	9.15E-07
	Ba-133m	013981-41-4(m)	3.89E+01	H	D	1.00E-01	2.76E-12	5.60E-13	1.00E-07
	Ba-137m	013981-97-0(m)	2.55E+00	M	D	1.00E-01	2.43E-15	1.57E-15	2.21E-06
	Ba-139	014378-25-7	8.31E+01	M	D	1.00E-01	3.04E-13	1.53E-13	8.35E-08
	Ba-140	014798-08-4	1.28E+01	D	D	1.00E-01	1.18E-11	3.17E-12	6.00E-07
Beryllium (4)	Be-7	013966-02-4	5.34E+01	D	Y	5.00E-03	8.64E-14	1.78E-13	1.73E-07
Bismuth (83)	Bi-206	015776-19-9	6.24E+00	D	W	5.00E-02	7.11E-12	5.07E-12	1.20E-05
	Bi-207	013982-38-2	3.34E+01	Y	W	5.00E-02	5.05E-12	9.42E-12	5.49E-06
	Bi-210	014331-79-4	5.01E+00	D	W	5.00E-02	7.29E-12	5.12E-11	0.00E+0
	Bi-211	015229-37-5	2.13E+00	M	W	5.00E-02	1.82E-14	1.74E-12	1.48E-07
	Bi-212	014913-49-6	6.06E+01	M	W	5.00E-02	6.20E-13	3.65E-11	6.67E-07
	Bi-213	015776-20-2	4.57E+01	M	W	5.00E-02	4.40E-13	3.09E-11	4.62E-07
	Bi-214	014733-03-0	1.99E+01	M	W	5.00E-02	1.95E-13	1.46E-11	6.02E-06
Bromine (35)	Br-82	014686-69-2	3.53E+01	H	D	9.50E-01	1.42E-12	7.86E-13	1.01E-05
Cadmium (20)	Cd-109	014109-32-1	4.64E+02	D	Y	5.00E-02	8.01E-12	1.85E-11	5.62E-10
	Cd-115	014336-68-6	5.35E+01	H	Y	5.00E-02	7.29E-12	4.93E-12	7.02E-07

[Table 4 continues on the following page: Refer to Endnotes on the last page.]

000044

7284

Table 4: Radionuclide Carcinogenicity -- Slope Factors[a] (In Units of Picocuries[b])

NOVEMBER 1994

Element (Atomic Number)	Isotope[c]	CASRN[d]	Radioactive Half-life[e]		ICRP Lung Class[f]	GI Absorption Factor (f_1)[g]	Slope Factor Lifetime Excess Total Cancer Risk Per Unit Intake or Exposure: Ingestion (Risk/pCi)	Inhalation (Risk/pCi)	External Exposure (Risk/yr per pCi/g soil)
	Cd-115m	014336-68-6(m)	4.46E+01	D	Y	5.00E-02	1.42E-11	1.70E-11	8.55E-08
Calcium (20)	Ca-45	013966-05-7	1.63E+02	D	W	3.00E-01	2.02E-12	2.51E-12	3.88E-18
	Ca-47	001439-99-2	4.54E+00	D	W	3.00E-01	6.66E-12	5.22E-12	4.12E-06
Carbon (6)	C-11	014333-33-6	2.05E+01	M	D	9.50E-01	4.49E-14	3.38E-14	3.61E-06
	C-14	014762-75-5	5.73E+03	Y	•	1.00E+00	1.03E-12	6.99E-15	0.00E+0
	C-15	015929-23-4	2.45E+00	S	D	9.50E-01	6.62E-16	8.06E-16	---
Cerium (58)	Ce-141	013967-74-3	3.25E+01	D	[illegible]	3.00E-04	3.91E-12	4.32E-12	1.41E-07
	Ce-143	014119-19-8	3.30E+01	H	Y	3.00E-04	5.91E-12	3.84E-12	7.32E-07
	Ce-144	014762-78-8	2.84E+02	D	Y	3.00E-04	2.96E-11	1.08E-10	2.58E-08
	Ce-144+D	014762-78-8(+D)	2.84E+02	D	Y	3.00E-04	2.97E-11	1.08E-10	1.56E-07
Cesium (55)	Cs-131	014914-76-2	9.69E+00	D	D	9.50E-01	1.80E-13	1.06E-13	2.34E-09
	Cs-134	013967-70-9	2.06E+00	Y	D	9.50E-01	4.73E-11	2.89E-11	5.88E-06
	Cs-134m	013967-70-9(m)	2.90E+00	H	D	9.50E-01	4.54E-14	3.10E-14	1.96E-08
	Cs-135	015726-30-4	2.30E+06	Y	D	9.50E-01	4.53E-12	2.71E-12	0.00E+0
	Cs-136	014234-29-8	1.32E+01	D	D	9.50E-01	7.74E-12	4.65E-12	8.13E-06
	Cs-137	010045-97-3	3.02E+01	Y	D	9.50E-01	3.16E-11	1.91E-11	0.00E+0
	Cs-137+D	010045-97-3(+D)	3.02E+01	Y	D	9.50E-01	3.16E-11	1.91E-11	2.09E-06
	Cs-138	015758-29-9	3.22E+01	M	D	9.50E-01	1.76E-13	1.30E-13	9.45E-06

[Table 4 continues on the following page: Refer to Endnotes on the last page.]

000045

Table 4: Radionuclide Carcinogenicity -- Slope Factors[a] (In Units of Picocuries[b])

NOVEMBER 1994

Element (Atomic Number)	Isotope[c]	CASRN[d]	Radioactive Half-life[e]		ICRP Lung Class[f]	GI Absorption Factor (f_1)[g]	Slope Factor Lifetime Excess Total Cancer Risk Per Unit Intake or Exposure: Ingestion (Risk/pCi)	Inhalation (Risk/pCi)	External Exposure (Risk/yr per pCi/g soil)
Chlorine (17)	Cl-36	013981-43-6	3.01E+05	Y	D	9.50E-01	2.23E-12	1.30E-12	0.00E+0
	Cl-38	014158-34-0	3.72E+01	M	D	9.50E-01	2.07E-13	1.63E-13	6.47E-06
Chromium (24)	Cr-51	014392-02-0	2.77E+01	D	Y	1.00E-01	1.38E-13	1.74E-13	1.02E-07
Cobalt (27)	Co-57	013981-50-5	2.71E+02	D	Y	3.00E-01	9.71E-13	2.88E-12	2.07E-07
	Co-58	01381-38-9	7.08E+01	D	Y	3.00E-01	2.82E-12	5.17E-12	3.73E-06
	Co-58m	01381-38-9(m)	9.15E+00	H	Y	3.00E-01	9.46E-14	8.90E-14	3.21E-11
	Co-60	010198-40-0	5.27E+00	Y	Y	3.00E-01	1.89E-11	6.88E-11	9.76E-06
Copper (29)	Cu-64	013981-25-4	1.27E+01	H	Y	5.00E-01	5.25E-13	4.18E-13	6.72E-07
Curium (96)	Cm-242	015510-73-3	1.63E+02	D	W	1.00E-03	3.83E-11	3.16E-09	2.34E-11
	Cm-243	015757-87-6	2.85E+01	Y	W	1.00E-03	2.51E-10	2.89E-08	1.71E-07
	Cm-243+D	015757-87-6(+D)	2.85E+01	Y	W	1.00E-03	2.52E-10	2.90E-08	1.72E-07
	Cm-244	013981-15-2	1.81E+01	Y	W	1.00E-03	2.11E-10	2.43E-08	2.07E-11
	Cm-245	015621-76-8	8.50E+03	Y	W	1.00E-03	3.35E-10	3.92E-08	5.51E-08
	Cm-246	015757-90-1	4.75E+03	Y	W	1.00E-03	3.32E-10	3.90E-08	1.81E-11
	Cm-247	015758-32-4	1.56E+07	Y	W	1.00E-03	3.09E-10	3.58E-08	1.03E-06
	Cm-248	015758-33-5	3.39E+05	Y	W	1.00E-03	1.31E-09	1.46E-07	1.47E-11
Dysprosium (66)	Dy-165	013967-64-1	2.33E+00	H	W	3.00E-04	3.26E-13	2.24E-13	6.18E-08
	Dy-166	015840-01-4	8.16E+01	H	W	3.00E-04	9.42E-12	7.82E-12	2.72E-08

[Table 4 continues on the following page: Refer to Endnotes on the last page.]

000046

2784

Table 4: Radionuclide Carcinogenicity -- Slope Factors[a] (In Units of Picocuries[b])

NOVEMBER 1994

Element (Atomic Number)	Isotope[c]	CASRN[d]	Radioactive Half-life[e]		ICRP Lung Class[f]	GI Absorption Factor (f_1)[g]	Slope Factor Lifetime Excess Total Cancer Risk Per Unit Intake or Exposure: Ingestion (Risk/pCi)	Inhalation (Risk/pCi)	External Exposure (Risk/yr per pCi/g soil)
Erbium (63)	Er-169	015840-13-8	9.40E+00	D	W	3.00E-04	2.12E-12	1.51E-12	6.52E-12
	Er-171	014391-45-8	7.52E+00	H	W	3.00E-04	1.63E-12	7.50E-13	1.04E-06
Europium (63)	Eu-152	014683-23-9	1.36E+01	Y	W	1.00E-03	5.73E-12	7.91E-11	4.08E-06
	Eu-154	015585-10-1	8.80E+00	Y	W	1.00E-03	9.37E-12	9.15E-11	4.65E-06
	Eu-155	014391-16-3	4.96E+00	Y	W	1.00E-03	1.65E-12	9.60E-12	6.08E-08
	Eu-156	014280-35-4	1.52E+01	D	W	1.00E-03	1.09E-11	9.26E-12	5.40E-06
Fluorine (9)	F-18	013981-56-1	1.10E+02	M	D	9.50E-01	1.09E-13	6.54E-14	3.50E-06
Francium (87)	Fr-221	015756-41-9	4.80E+00	M	D	9.50E-01	1.45E-13	8.02E-12	6.74E-08
	Fr-223	015756-98-6	2.18E+00	M	D	9.50E-01	4.46E-13	5.90E-13	4.17E-08
Gadolinium (64)	Gd-153	014276-65-4	2.42E+02	D	W	3.00E-04	1.32E-12	3.20E-12	7.22E-08
	Gd-159	014041-42-0	1.86E+01	H	W	3.00E-04	2.60E-12	1.24E-12	9.59E-08
Gallium (31)	Ga-67	014119-09-6	3.26E+00	D	W	1.00E-03	8.36E-13	5.14E-13	3.61E-07
	Ga-72	013982-22-4	1.41E+01	H	W	1.00E-03	4.77E-12	2.17E-12	1.12E-05
Germanium (32)	Ge-71	014374-81-3	1.18E+01	D	W	9.50E-01	1.18E-14	5.84E-14	1.56E-11
Gold (79)	Au-196	014914-16-0	6.18E+00	D	Y	1.00E-01	1.30E-12	1.04E-12	1.41E-06
	Au-198	010043-49-0	2.70E+00	D	Y	1.00E-01	5.28E-12	3.64E-12	1.37E-06
Holmium (67)	Ho-166	013967-65-2	2.68E+01	H	W	3.00E-04	7.57E-12	4.06E-12	6.96E-08
Hydrogen (1)	H-3	010028-17-8	1.23E+01	Y	V	1.00E+00	7.15E-14	9.59E-14	0.00E+0

[Table 4 continues on the following page: Refer to Endnotes on the last page.]

000047

Table 4: Radionuclide Carcinogenicity -- Slope Factors[a] (In Units of Picocuries[b])

NOVEMBER 1994

Element (Atomic Number)	Isotope[c]	CASRN[d]	Radioactive Half-life[e]		ICRP Lung Class[f]	GI Absorption Factor (f_1)[g]	Slope Factor Lifetime Excess Total Cancer Risk Per Unit Intake or Exposure: Ingestion (Risk/pCi)	Inhalation (Risk/pCi)	External Exposure (Risk/yr per pCi/g soil)
Indium (49)	In-113m	014885-78-0(m)	1.66E+00	H	W	2.00E-02	8.30E-14	5.77E-14	7.82E-07
	In-114	013981-55-0	7.19E+01	S	W	2.00E-02	4.53E-15	5.81E-15	1.13E-07
	In-114m	013981-55-0(m)	4.95E+01	D	W	2.00E-02	2.06E-11	2.53E-11	2.00E-07
	In-115	014191-71-0	4.60e+15	Y	W	2.00E-02	3.49E-11	2.07E-10	0.00E+0
	In-115m	014191-71-0(m)	4.36E+00	H	W	2.00E-02	3.42E-13	1.75E-13	4.29E-07
Iodine (53)	I-122	018287-75-7	3.62E+00	M	D	9.50E-01	2.16E-14	2.24E-14	3.41E-06
	I-123	015715-08-9	1.31E+01	H	D	9.50E-01	5.42E-13	2.94E-13	2.52E-07
	I-125	014158-31-7	6.01E+01	D	D	9.50E-01	2.58E-11	1.71E-11	2.39E-09
	I-126	014158-32-8	1.29E+01	D	D	9.50E-01	4.82E-11	3.15E-11	1.49E-06
	I-129	015046-84-1	1.57E+07	Y	D	9.50E-01	1.84E-10	1.22E-10	2.69E-09
	I-130	014914-02-4	1.24E+01	H	D	9.50E-01	4.85E-12	2.61E-12	7.93E-06
	I-131	010043-66-0	8.04E+00	D	D	9.50E-01	3.62E-11	2.33E-11	1.25E-06
	I-132	014683-16-0	2.30E+00	H	D	9.50E-01	6.62E-13	3.52E-13	8.75E-06
	I-133	014834-67-4	2.08E+01	H	D	9.50E-01	1.06E-11	6.02E-12	2.20E-06
	I-134	014914-27-3	5.26E+01	M	D	9.50E-01	2.31E-13	1.38E-13	1.02E-05
	I-135	014834-68-5	6.61E+00	H	D	9.50E-01	2.27E-12	1.18E-12	6.23E-06
Iridium (77)	Ir-190	014981-91-0	1.18E+01	D	Y	1.00E-02	4.95E-12	4.49E-12	4.65E-06
	Ir-194	014158-35-1	1.92E+01	H	Y	1.00E-02	7.00E-12	4.18E-12	3.17E-07

[Table 4 continues on the following page: Refer to Endnotes on the last page.]

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7841

Table 4: Radionuclide Carcinogenicity -- Slope Factors[a] (In Units of Picocuries[b])

NOVEMBER 1994

Element (Atomic Number)	Isotope[c]	CASRN[d]	Radioactive Half-life[e]		ICRP Lung Class[f]	GI Absorption Factor (f_1)[g]	Slope Factor Lifetime Excess Total Cancer Risk Per Unit Intake or Exposure: Ingestion (Risk/pCi)	Inhalation (Risk/pCi)	External Exposure (Risk/yr per pCi/g soil)
Iron (26)	Fe-55	014681-59-5	2.70E+00	Y	W	1.00E-01	3.51E-13	5.60E-13	0.00E+0
	Fe-59	014596-12-4	4.46E+01	D	W	1.00E-01	5.87E-12	7.08E-12	4.63E-06
Krypton (36)	Kr-83m	013965-98-5(m)	1.83E+00	H	•	---	---	3.48E-17	---
	Kr-85	013983-27-2	1.07E+01	Y	•	---	---	2.87E-16	---
	Kr-85m	013983-27-2(m)	4.48E+00	H	•	---	---	2.75E-16	---
	Kr-87	014809-68-8	7.63E+01	M	•	---	---	1.20E-15	---
	Kr-88	014995-61-0	2.84E+00	H	•	---	---	2.20E-15	---
	Kr-89	016316-03-3	3.16E+00	M	•	---	---	1.61E-15	---
	Kr-90	015741-13-6	3.23E+01	S	•	---	---	1.60E-15	---
Lanthanum (57)	La-140	013981-28-7	4.02E+01	H	W	1.00E-03	9.46E-12	5.10E-12	9.11E-06
Lead (82)	Pb-203	014687-25-3	5.20E+01	H	D	2.00E-01	1.03E-12	3.10E-13	6 40E-07
	Pb-209	014119-30-3	3.25E+00	H	D	2.00E-01	2.09E-13	6.85E-14	0 00E+0
	Pb-210	014255-04-0	2.23E+01	Y	D	2.00E-01	6.75E-10	1.67E-09	1.12E-10
	Pb-210+D	014255-04-0(+D)	2.23E+01	Y	D	2.00E-01	1.01E-09	3.86E-09	1.45E-10
	Pb-211	015816-77-0	3.61E+01	M	D	2.00E-01	3.38E-13	1.03E-11	1.85E-07
	Pb-212	015092-94-1	1.06E+01	H	D	2.00E-01	1.80E-11	3.85E-11	3.00E-07
	Pb-214	015067-28-4	2.68E+01	M	D	2.00E-01	2.94E-13	6.23E-12	7.09E-07
Lutetium (71)	Lu-177	014265-75-9	6.71E+00	D	Y	3.00E-04	2.95E-12	2.20E-12	7.22E-08

[Table 4 continues on the following page: Refer to Endnotes on the last page.]

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Table 4: Radionuclide Carcinogenicity -- Slope Factors[a] (In Units of Picocuries[b])

NOVEMBER 1994

Element (Atomic Number)	Isotope[c]	CASRN[d]	Radioactive Half-life[e]		ICRP Lung Class[f]	GI Absorption Factor (f_1)[g]	Slope Factor Lifetime Excess Total Cancer Risk Per Unit Intake or Exposure: Ingestion (Risk/pCi)	Inhalation (Risk/pCi)	External Exposure (Risk/yr per pCi/g soil)
Manganese (25)	Mn-52	014092-99-0	5.59E+00	D	W	1.00E-01	6.01E-12	4.40E-12	1.34E-05
	Mn-54	013966-31-9	3.13E+02	D	W	1.00E-01	1.96E-12	3.69E-12	3.26E-06
	Mn-56	014681-52-8	2.58E+00	H	W	1.00E-01	8.57E-13	5.21E-13	6.95E-06
Mercury (80)	Hg-197	013981-51-6	6.41E+01	H	W	2.00E-02	1.18E-12	6.95E-13	5.47E-08
	Hg-203	013982-78-0	4.66E+01	D	W	2.00E-02	2.64E-12	3.03E-12	6.27E-07
Molybdenum (42)	Mo-99	014119-15-4	6.60E+01	H	Y	8.00E-01	2.27E-12	4.48E-12	5.46E-07
Neodymium (60)	Nd-147	014269-74-0	1.10E+01	D	Y	3.00E-04	5.88E-12	4.84E-12	3.22E-07
	Nd-149	015749-81-2	1.73E+00	H	Y	3.00E-04	4.55E-13	4.22E-13	1.08E-06
Neptunium (93)	Np-236	015700-36-4	1.15E+05	Y	W	1.00E-03	9.31E-13	3.87E-12	9.22E-08
	Np-237	013994-20-2	2.14E+06	Y	W	1.00E-03	2.95E-10	3.45E-08	7.56E-09
	Np-237+D	013994-20-2(+D)	2.14E+06	Y	W	1.00E-03	3.00E-10	3.45E-08	4.62E-07
	Np-238	015766-25-3	2.12E+00	D	W	1.00E-03	4.56E-12	4.68E-12	1.95E-06
	Np-239	013968-59-7	2.36E+00	D	W	1.00E-03	4.27E-12	2.41E-12	2.42E-07
	Np-240	015690-84-3	6.50E+01	M	W	1.00E-03	1.77E-13	1.31E-13	3.65E-06
	Np-240m	015690-84-3(m)	7.40E+00	M	W	1.00E-03	2.42E-14	2.83E-14	1.05E-06
Nickel (28)	Ni-59	014336-70-0	7.50E+04	Y	W	5.00E-02	1.85E-13	4.01E-13	0.00E+0
	Ni-63	013981-37-8	1.00E+02	Y	W	5.00E-02	5.50E-13	1.01E-12	0.00E+0
	Ni-65	014833-49-9	2.52E+00	H	W	5.00E-02	5.62E-13	3.59E-13	2.14E-06

[Table 4 continues on the following page: Refer to Endnotes on the last page.]

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7284

Table 4: Radionuclide Carcinogenicity -- Slope Factors[a] (In Units of Picocuries[b])

Element (Atomic Number)	Isotope[c]	CASRN[d]	Radioactive Half-life[e]		ICRP Lung Class[f]	GI Absorption Factor (f_1)[g]	Slope Factor Lifetime Excess Total Cancer Risk Per Unit Intake or Exposure: Ingestion (Risk/pCi)	Inhalation (Risk/pCi)	External Exposure (Risk/yr per pCi/g soil)
Niobium (41)	Nb-93m	007440-03-1(m)	1.46E+01	Y	Y	1.00E-02	6.64E-13	4.33E-12	3.64E-11
	Nb-94	014681-63-1	2.03E+04	Y	Y	1.00E-02	6.91E-12	8.20E-11	6.08E-06
	Nb-95	013967-76-5	3.51E+01	D	Y	1.00E-02	2.25E-12	3.11E-12	2.94E-06
	Nb-95m	013967-76-5(m)	8.66E+01	H	Y	1.00E-02	3.06E-12	2.25E-12	8.71E-08
	Nb-97	018496-04-3	7.21E+01	M	Y	1.00E-02	1.75E-13	2.13E-13	2.49E-06
	Nb-97m	018496-04-3(m)	6.00E+01	S	Y	1.00E-02	3.27E-15	3.34E-15	2.78E-06
Osmium (76)	Os-185	015766-50-4	9.36E+01	D	Y	1.00E-02	1.80E-12	4.62E-12	2.45E-06
	Os-191	014119-24-5	1.54E+01	D	Y	1.00E-02	3.04E-12	2.70E-12	8.74E-08
	Os-191m	014119-24-5(m)	1.30E+01	H	Y	1.00E-02	4.95E-13	3.32E-13	3.22E-09
	Os-193	016057-77-5	3.00E+01	H	Y	1.00E-02	4.36E-12	2.68E-12	1.82E-07
Palladium (46)	Pd-100	015690-69-4	3.64E+00	D	Y	5.00E-03	3.74E-12	3.55E-12	---
	Pd-101	015749-54-9	8.48E+00	H	Y	5.00E-03	3.74E-13	2.29E-13	---
	Pd-103	014967-68-1	1.70E+01	D	Y	5.00E-03	1.05E-12	1.08E-12	5.38E-10
	Pd-107	017637-99-9	6.50E+06	Y	Y	5.00E-03	2.09E-13	1.46E-12	0.00E+0
	Pd-109	014981-64-7	1.35E+01	H	Y	5.00E-03	3.33E-12	1.99E-12	2.43E-09
Phosphorus (15)	P-32	014596-37-3	1.43E+01	D	D	8.00E-01	6.11E-12	2.93E-12	0.00E+0
	P-33	015749-66-3	2.54E+01	D	D	8.00E-01	7.81E-13	3.96E-13	0.00E+0
Platinum (78)	Pt-191	015706-36-2	2.71E+00	D	D	1.00E-02	1.50E-12	4.13E-13	6.74E-07

[Table 4 continues on the following page: Refer to Endnotes on the last page.]

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Table 4: Radionuclide Carcinogenicity -- Slope Factors[a] (In Units of Picocuries[b])

NOVEMBER 1994

Element (Atomic Number)	Isotope[c]	CASRN[d]	Radioactive Half-life[e]		ICRP Lung Class[f]	GI Absorption Factor (f_1)[g]	Slope Factor Lifetime Excess Total Cancer Risk Per Unit Intake or Exposure: Ingestion (Risk/pCi)	Inhalation (Risk/pCi)	External Exposure (Risk/yr per pCi/g soil)
	Pt-193	015735-70-3	5.00E+01	Y	D	1.00E-02	1.62E-13	7.89E-14	0.00E+0
	Pt-193m	015735-70-3(m)	4.33E+00	D	D	1.00E-02	2.51E-12	5.76E-13	7.44E-09
	Pt-197	015735-74-7	1.83E+01	H	D	1.00E-02	2.12E-12	4.54E-13	3.15E-08
	Pt-197m	015735-74-7(m)	9.44E+01	M	D	1.00E-02	3.25E-13	1.00E-13	1.65E-07
Plutonium (94)	Pu-236	015411-92-4	2.85E+00	Y	Y	1.00E-03	7.68E-11	1.34E-08	2.32E-11
	Pu-238	013981-16-3	8.78E+01	Y	Y	1.00E-03	2.95E-10	2.74E-08	1.94E-11
	Pu-239	015117-48-3	2.41E+04	Y	Y	1.00E-03	3.16E-10	2.78E-08	1.26E-11
	Pu-240	014119-33-6	6.57E+03	Y	Y	1.00E-03	3.15E-10	2.78E-08	1.87E-11
	Pu-241	014119-32-5	1.44E+01	Y	Y	1.00E-03	5.20E-12	2.81E-10	0.00E+0
	Pu-241+D	014119-32-5(+D)	1.44E+01	Y	Y	1.00E-03	3.33E-10	3.88E-08	4.59E-09
	Pu-242	013982-10-0	3.76E+05	Y	Y	1.00E-03	3.00E-10	2.64E-08	1.55E-11
	Pu-243	015706-37-3	4.96E+00	H	Y	1.00E-03	3.69E-13	2.67E-13	1.89E-08
	Pu-244	014119-34-7	8.26E+07	Y	Y	1.00E-03	3.13E-10	2.67E-08	1.29E-11
	Pu-244+D	014119-34-7(+D)	8.26E+07	Y	Y	1.00E-03	3.19E-10	2.67E-08	3.65E-06
Polonium (84)	Po-210	013981-52-7	1.38E+02	D	W	1.00E-01	3.26E-10	2.14E-09	3.30E-11
	Po-212	015389-34-1	2.98E-07	S	W	1.00E-01	4.51E-23	5.93E-21	0.00E+0
	Po-213	015756-57-7	4.20E-06	S	W	1.00E-01	6.70E-22	7.80E-20	1.18E-10
	Po-214	015735-67-8	1.64E-04	S	W	1.00E-01	2.12E-20	2.77E-18	3.23E-10

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Table 4: Radionuclide Carcinogenicity -- Slope Factors[a] (In Units of Picocuries[b])

NOVEMBER 1994

Element (Atomic Number)	Isotope[c]	CASRN[d]	Radioactive Half-life[e]		ICRP Lung Class[f]	GI Absorption Factor (f_1)[g]	Slope Factor Lifetime Excess Total Cancer Risk Per Unit Intake or Exposure: Ingestion (Risk/pCi)	Inhalation (Risk/pCi)	External Exposure (Risk/yr per pCi/g soil)
	Po-215	015706-52-2	1.78E-03	S	W	1.00E-01	4.99E-19	4.48E-17	5.11E-10
	Po-216	015756-58-8	1.46E-01	S	W	1.00E-01	8.79E-17	2.95E-15	5.62E-11
	Po-218	015422-24-9	3.05E+00	M	W	1.00E-01	5.08E-14	3.69E-12	0.00E+0
Potassium (19)	K-40	013966-00-2	1.28E+09	Y	D	9.50E-01	1.25E-11	7.46E-12	6.11E-07
	K-42	014378-21-3	1.24E+01	H	D	9.50E-01	1.29E-12	7.56E-13	1.09E-06
Praseodymium (59)	Pr-142	014191-64-1	1.91E+01	H	Y	3.00E-04	6.98E-12	4.16E-12	2.34E-07
	Pr-143	014981-79-4	1.36E+01	D	Y	3.00E-04	6.60E-12	5.60E-12	3.41E-14
	Pr-144	014119-05-2	1.73E+01	M	Y	3.00E-04	8.08E-14	1.31E-13	1.33E-07
	Pr-144m	014119-05-2(m)	7.20E+00	M	Y	3.00E-04	3.23E-14	5.61E-14	1.85E-09
Promethium (61)	Pm-147	014380-75-7	2.62E+00	Y	Y	3.00E-04	1.41E-12	7.49E-12	6.35E-12
	Pm-148	014683-19-3	5.37E+00	D	Y	3.00E-04	1.44E-11	1.05E-11	2.21E-06
	Pm-148m	014683-19-3(m)	4.13E+01	D	Y	3.00E-04	9.93E-12	2.95E-11	7.32E-06
	Pm-149	015765-31-8	5.31E+01	H	Y	3.00E-04	5.52E-12	3.57E-12	3.65E-08
Protactinium (91)	Pa-231	014331-85-2	3.73E+04	Y	Y	1.00E-03	1.49E-10	2.42E-08	2.71E-08
	Pa-233	013981-14-1	2.70E+01	D	Y	1.00E-03	4.69E-12	4.92E-12	4.54E-07
	Pa-234	015100-28-4	6.70E+00	H	Y	1.00E-03	2.13E-12	1.30E-12	6.60E-06
	Pa-234m	015100-28-4(m)	1.17E+00	M	Y	1.00E-03	4.77E-15	6.27E-15	4.05E-08
Radium (88)	Ra-223	015623-45-7	1.14E+01	D	W	2.00E-01	2.34E-10	3.60E-09	2.44E-07

[Table 4 continues on the following page: Refer to Endnotes on the last page.]

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Table 4: Radionuclide Carcinogenicity -- Slope Factors[a] (In Units of Picocuries[b])

NOVEMBER 1994

Element (Atomic Number)	Isotope[c]	CASRN[d]	Radioactive Half-life[e]		ICRP Lung Class[f]	GI Absorption Factor (f_1)[g]	Slope Factor Lifetime Excess Total Cancer Risk Per Unit Intake or Exposure: Ingestion (Risk/pCi)	Inhalation (Risk/pCi)	External Exposure (Risk/yr per pCi/g soil)
	Ra-224	013233-32-4	3.62E+00	D	W	2.00E-01	1.49E-10	2.25E-09	2.48E-08
	Ra-225	013981-53-8	1.48E+01	D	W	2.00E-01	1.57E-10	2.38E-09	1.71E-09
	Ra-226	013982-63-3	1.60E+03	Y	W	2.00E-01	2.95E-10	2.72E-09	1.31E-08
	Ra-226+D	013982-63-3(+D)	1.60E+03	Y	W	2.00E-01	2.96E-10	2.75E-09	6.74E-06
	Ra-228	015262-20-1	5.75E+00	Y	W	2.00E-01	2.46E-10	9.61E-10	0.00E+0
	Ra-228+D	015262-20-1(+D)	5.75E+00	Y	W	2.00E-01	2.48E-10	9.94E-10	3.28E-06
Radon (86)	Rn-219	014835-02-0	3.96E+00	S	•	---	---	6.91E-14	1.72E-07
	Rn-220	022481-48-7	5.56E+01	S	•	---	---	1.92E-13	1.88E-09
	Rn-222+D[i]	014859-67-7(+D)	3.82E+00	D	•	---	---	7.57E-12	---
Rhodium (45)	Rh-103m	007440-16-6(m)	5.61E+01	M	Y	5.00E-02	8.19E-15	1.28E-14	5.85E-11
	Rh-105	014913-89-4	3.54E+01	H	Y	5.00E-02	1.93E-12	1.22E-12	2.49E-07
	Rh-105m	014913-89-4(m)	4.50E+01	S	Y	5.00E-02	1.08E-15	9.25E-16	2.27E-08
	Rh-106	014234-34-5	2.99E+01	S	Y	5.00E-02	3.63E-15	4.62E-15	7.57E-07

[i] To derive the inhalation slope factor for Rn-222+D, EPA's Office of Radiation and Indoor Air (ORIA) uses a slightly different risk model and set of exposure assumptions, including an inhalation rate of 2.2E+04 L/day; 50% equilibrium for decay products; and a risk coefficient of 2.36E-4 cases per working level month (WLM). A more detailed description of ORIA's radon risk assessment methodology is provided in the EPA CRAVE Summary Sheet, *Inhaled Rn-222 and its Short Half-Life Decay Products.*

[Table 4 continues on the following page: Refer to Endnotes on the last page.]

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Table 4: Radionuclide Carcinogenicity -- Slope Factors[a] (In Units of Picocuries[b])

Element (Atomic Number)	Isotope[c]	CASRN[d]	Radioactive Half-life[e]		ICRP Lung Class[f]	GI Absorption Factor (f_1)[g]	Slope Factor Lifetime Excess Total Cancer Risk Per Unit Intake or Exposure: Ingestion (Risk/pCi)	Inhalation (Risk/pCi)	External Exposure (Risk/yr per pCi/g soil)
Rubidium (37)	Rb-82	014391-63-0	1.25E+00	M	D	9.50E-01	1.05E-14	1.17E-14	3.89E-06
	Rb-86	014932-53-7	1.87E+01	D	D	9.50E-01	7.12E-12	4.21E-12	3.71E-07
	Rb-87	013982-13-3	4.73e+10	Y	D	9.50E-01	3.68E-12	2.26E-12	0.00E+0
	Rb-88	014928-36-0	1.78E+01	M	D	9.50E-01	1.46E-13	1.36E-13	2.60E-06
	Rb-89	014191-65-2	1.54E+01	M	D	9.50E-01	8.65E-14	6.92E-14	8.47E-06
Ruthenium (44)	Ru-97	015758-35-7	2.90E+00	D	Y	5.00E-02	5.88E-13	4.09E-13	4.52E-07
	Ru-103	013968-53-1	3.94E+01	D	Y	5.00E-02	3.32E-12	4.59E-12	1.70E-06
	Ru-105	014331-95-4	4.44E+00	H	Y	5.00E-02	1.15E-12	8.02E-13	2.88E-06
	Ru-106	013967-48-1	3.68E+02	D	Y	5.00E-02	3.45E-11	1.15E-10	0.00E+0
	Ru-106+D	013967-48-1(+D)	3.68E+02	D	Y	5.00E-02	3.45E-11	1.15E-10	7.57E-07
Samarium (62)	Sm-147	014392-33-7	1.06e+11	Y	W	3.00E-04	2.51E-11	6.93E-09	0.00E+0
	Sm-151	015715-94-3	9.00E+01	Y	W	3.00E-04	4.60E-13	4.63E-12	2.92E-13
	Sm-153	015766-00-4	4.67E+01	H	W	3.00E-04	4.02E-12	2.18E-12	4.65E-08
Scandium (21)	Sc-46	013967-63-0	8.38E+01	D	Y	1.00E-04	5.73E-12	1.31E-11	7.89E-06
	Sc-47	014391-96-9	3.42E+00	D	Y	1.00E-04	2.95E-12	2.01E-12	2.50E-07
	Sc-48	014391-86-7	4.37E+01	H	Y	1.00E-04	6.65E-12	4.20E-12	1.31E-05
Selenium (34)	Se-75	014265-71-5	1.20E+02	D	W	8.00E-01	6.53E-12	4.92E-12	8.89E-07
Silicon (14)	Si-31	014276-49-4	1.57E+02	M	W	1.00E-02	5.04E-13	3.29E-13	3.45E-09

[Table 4 continues on the following page: Refer to Endnotes on the last page.]

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Table 4: Radionuclide Carcinogenicity -- Slope Factors[a] (In Units of Picocuries[b])

NOVEMBER 1994

Element (Atomic Number)	Isotope[c]	CASRN[d]	Radioactive Half-life[e]		ICRP Lung Class[f]	GI Absorption Factor (f_1)[g]	Slope Factor Lifetime Excess Total Cancer Risk Per Unit Intake or Exposure: Ingestion (Risk/pCi)	Inhalation (Risk/pCi)	External Exposure (Risk/yr per pCi/g soil)
Silver (47)	Ag-105	014928-14-4	4.13E+01	D	Y	5.00E-02	1.63E-12	2.33E-12	--
	Ag-108	014391-65-2	2.37E+00	M	Y	5.00E-02	6.94E-15	9.43E-15	5.78E-08
	Ag-108m	014391-65-2m	1.27E+02	Y	Y	5.00E-02	6.05E-12	7.02E-11	5.61E-06
	Ag-108m+D	014391-65-2m(+D)	1.27E+02	Y	Y	5.00E-02	6.05E-12	7.02E-11	5.62E-06
	Ag-109m	014378-38-2(m)	3.96E+01	S	Y	5.00E-02	2.71E-16	3.46E-16	1.16E-09
	Ag-110	014391-76-5	2.46E+01	S	Y	5.00E-02	2.44E-15	3.16E-15	1.13E-07
	Ag-110m	014391-76-5(m)	2.50E+02	D	Y	5.00E-02	8.43E-12	3.21E-11	1.05E-05
	Ag-111	157690-04-0	7.46E+00	D	Y	5.00E-02	6.83E-12	5.24E-12	8.51E-08
Sodium (11)	Na-22	013966-32-0	2.60E+00	Y	D	9.50E-01	8.02E-12	4.88E-12	8.18E-06
	Na-24	013982-04-2	1.50E+01	H	D	9.50E-01	1.38E-12	7.51E-13	1.77E-05
Strontium (38)	Sr-82	014809-50-8	2.50E+01	D	D	3.00E-01	2.58E-11	8.87E-12	9.00E-11
	Sr-85	013967-73-2	6.48E+01	D	D	3.00E-01	1.40E-12	1.14E-12	1.54E-06
	Sr-85m	013967-73-2(m)	6.77E+01	M	D	3.00E-01	1.80E-14	7.13E-15	5.24E-07
	Sr-89	014158-27-1	5.06E+01	D	D	3.00E-01	1.03E-11	3.68E-12	5.38E-10
	Sr-90	010098-97-2	2.86E+01	Y	D	3.00E-01	4.09E-11	5.94E-11	0.00E+0
	Sr-90+D	010098-97-2(+D)	2.86E+01	Y	D	3.00E-01	5.59E-11	6.93E-11	0.00E+0
	Sr-91	014331-91-0	9.50E+00	H	D	3.00E-01	2.82E-12	7.79E-13	2.67E-06
	Sr-92	014928-29-1	2.71E+00	H	D	3.00E-01	2.03E-12	4.70E-13	5.20E-06

[Table 4 continues on the following page: Refer to Endnotes on the last page.]

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Table 4: Radionuclide Carcinogenicity -- Slope Factors[a] (In Units of Picocuries[b])

NOVEMBER 1994

Element (Atomic Number)	Isotope[c]	CASRN[d]	Radioactive Half-life[e]		ICRP Lung Class[f]	GI Absorption Factor (f_1)[g]	Slope Factor Lifetime Excess Total Cancer Risk Per Unit Intake or Exposure: Ingestion (Risk/pCi)	Inhalation (Risk/pCi)	External Exposure (Risk/yr per pCi/g soil)
Sulfur (16)	S-35	015117-53-0	8.74E+01	D	D	8.00E-01	4.16E-13	1.85E-13	0.00E+0
Tantalum (73)	Ta-182	013982-00-8	1.15E+02	D	Y	1.00E-03	7.03E-12	1.65E-11	4.66E-06
Technetium (43)	Tc-95	014809-56-4	2.00E+01	H	W	8.00E-01	6.81E-14	3.38E-14	2.72E-06
	Tc-95m	014809-56-4(m)	6.10E+01	D	W	8.00E-01	1.24E-12	2.10E-12	2.08E-06
	Tc-96	014808-44-7	4.28E+00	D	W	8.00E-01	2.28E-12	1.94E-12	9.36E-06
	Tc-96m	014808-44-7(m)	5.15E+01	M	W	8.00E-01	2.61E-14	2.26E-14	7.72E-08
	Tc-97	015759-35-0	2.60E+06	Y	W	8.00E-01	1.58E-13	3.44E-13	2.49E-10
	Tc-97m	015759-35-0(m)	8.90E+01	D	W	8.00E-01	1.20E-12	1.96E-12	2.67E-10
	Tc-99	014133-76-7	2.13E+05	Y	W	8.00E-01	1.40E-12	2.89E-12	6.19E-13
	Tc-99m	014133-76-7(m)	6.02E+00	H	W	8.00E-01	5.58E-14	3.49E-14	2.51E-07
Tellurium (52)	Te-125m	014390-73-9(m)	5.80E+01	D	W	2.00E-01	2.51E-12	2.85E-12	2.16E-09
	Te-127	013981-49-2	9.35E+00	H	W	2.00E-01	8.55E-13	4.32E-13	1.62E-08
	Te-127m	013981-49-2(m)	1.09E+02	D	W	2.00E-01	6.01E-12	1.31E-11	7.10E-10
	Te-129	014269-71-7	6.96E+01	M	W	2.00E-01	1.48E-13	1.46E-13	1.46E-07
	Te-129m	014269-71-7(m)	3.36E+01	D	W	2.00E-01	1.17E-11	1.33E-11	6.92E-08
	Te-131	014683-12-6	2.50E+01	M	W	2.00E-01	3.90E-13	2.48E-13	1.35E-06
	Te-131m	014683-12-6(m)	3.00E+01	H	W	2.00E-01	8.81E-12	8.40E-12	5.31E-06
	Te-132	014234-28-7	7.82E+01	H	W	2.00E-01	1.22E-11	8.38E-12	4.31E-07

[Table 4 continues on the following page: Refer to Endnotes on the last page.]

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Table 4: Radionuclide Carcinogenicity -- Slope Factors[a] (In Units of Picocuries[b])

NOVEMBER 1994

Element (Atomic Number)	Isotope[c]	CASRN[d]	Radioactive Half-life[e]		ICRP Lung Class[f]	GI Absorption Factor (f_1)[g]	Slope Factor Lifetime Excess Total Cancer Risk Per Unit Intake or Exposure: Ingestion (Risk/pCi)	Inhalation (Risk/pCi)	External Exposure (Risk/yr per pCi/g soil)
Terbium (65)	Tb-158	015759-55-4	1.50E+02	Y	W	3.00E-04	4.20E-12	7.04E-11	—
	Tb-160	013981-29-8	7.23E+01	D	W	3.00E-04	7.62E-12	1.14E-11	4.03E-06
Thallium (81)	Tl-202	015720-57-7	1.22E+01	D	D	9.50E-01	1.01E-12	6.07E-13	1.42E-06
	Tl-204	013968-51-9	3.78E+00	Y	D	9.50E-01	1.97E-12	1.15E-12	8.72E-10
	Tl-208	014913-50-9	3.05E+00	M	D	9.50E-01	1.75E-14	1.36E-14	1.45E-05
	Tl-209	015690-73-0	2.20E+00	M	D	9.50E-01	1.40E-14	1.12E-14	7.83E-06
Thorium (90)	Th-227	015623-47-9	1.87E+01	D	Y	2.00E-04	4.04E-11	4.31E-09	1.74E-07
	Th-228	014274-82-9	1.91E+00	Y	Y	2.00E-04	6.29E-11	9.45E-08	5.28E-10
	Th-228+D	014274-82-9(+D)	1.91E+00	Y	Y	2.00E-04	2.31E-10	9.68E-08	9.94E-07
	Th-229	015594-54-4	7.34E+03	Y	Y	2.00E-04	5.65E-11	7.60E-08	5.94E-08
	Th-229+D	015594-54-4(+D)	7.34E+03	Y	Y	2.00E-04	3.56E-10	8.26E-08	5.99E-07
	Th-230	014269-63-7	7.70E+04	Y	Y	2.00E-04	3.75E-11	1.72E-08	4.40E-11
	Th-231	014932-40-2	2.55E+01	H	Y	2.00E-04	1.79E-12	1.10E-12	2.09E-09
	Th-232	007440-29-1	1.41E+10	Y	Y	2.00E-04	3.28E-11	1.93E-08	1.97E-11
	Th-234	015065-10-8	2.41E+01	D	Y	2.00E-04	1.93E-11	1.90E-11	3.50E-09
Thulium (69)	Tm-170	013981-30-1	1.29E+02	D	W	3.00E-04	7.50E-12	1.10E-11	3.84E-09
	Tm-171	014333-45-0	1.92E+00	Y	W	3.00E-04	5.86E-13	1.84E-12	3.15E-10
Tin (50)	Sn-113	013966-06-8	1.15E+02	D	W	2.00E-02	3.72E-12	6.61E-12	2.96E-09

[Table 4 continues on the following page: Refer to Endnotes on the last page.]

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Table 4: Radionuclide Carcinogenicity -- Slope Factors[a] (In Units of Picocuries[b])

Element (Atomic Number)	Isotope[c]	CASRN[d]	Radioactive Half-life[e]		ICRP Lung Class[f]	GI Absorption Factor (f_1)[g]	Slope Factor Lifetime Excess Total Cancer Risk Per Unit Intake or Exposure: Ingestion (Risk/pCi)	Inhalation (Risk/pCi)	External Exposure (Risk/yr per pCi/g soil)
	Sn-121	014683-06-8	2.71E+01	H	W	2.00E-02	1.22E-12	6.13E-13	---
	Sn-121m	014683-06-8(m)	5.55E+01	Y	W	2.00E-02	2.00E-12	7.46E-12	---
	Sn-125	014683-08-0	9.64E+00	D	W	2.00E-02	1.68E-11	1.19E-11	1.21E-06
	Sn-126	015832-50-5	1.00E+05	Y	W	2.00E-02	2.12E-11	4.26E-11	3.32E-08
Tungsten (74)	W-181	015749-46-9	1.21E+02	D	D	3.00E-01	2.72E-13	8.02E-14	2.11E-08
	W-185	014932-41-3	7.51E+01	D	D	3.00E-01	2.04E-12	4.26E-13	5.03E-11
	W-187	014983-48-3	2.38E+01	H	D	3.00E-01	2.46E-12	5.29E-13	1.63E-06
Uranium (92)	U-232	014158-29-3	7.20E+01	Y	Y	5.00E-02	8.12E-11	5.29E-08	3.42E-11
	U-233	013968-55-3	1.59E+05	Y	Y	5.00E-02	4.48E-11	1.41E-08	3.52E-11
	U-234	013966-29-5	2.45E+05	Y	Y	5.00E-02	4.44E-11	1.40E-08	2.14E-11
	U-235	015117-96-1	7.04E+08	Y	Y	5.00E-02	4.52E-11	1.30E-08	2.63E-07
	U-235+D	015117-96-1(+D)	7.04E+08	Y	Y	5.00E-02	4.70E-11	1.30E-08	2.65E-07
	U-236	013982-70-2	2.34E+07	Y	Y	5.00E-02	4.21E-11	1.32E-08	1.72E-11
	U-237	014269-75-1	6.75E+00	D	Y	5.00E-02	3.98E-12	3.12E-12	1.37E-07
	U-238	007440-61-1	4.47E+09	Y	Y	5.00E-02	4.27E-11	1.24E-08	1.50E-11
	U-238+D	007440-61-1(+D)	4.47E+09	Y	Y	5.00E-02	6.20E-11	1.24E-08	5.25E-08
	U-240	015687-53-3	1.41E+01	H	Y	5.00E-02	5.47E-12	3.35E-12	1.09E-10
Vanadium (23)	V-48	014331-97-6	1.60E+01	D	W	1.00E-02	7.56E-12	6.84E-12	1.12E-05

[Table 4 continues on the following page: Refer to Endnotes on the last page.]

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Table 4: Radionuclide Carcinogenicity -- Slope Factors[a] (In Units of Picocuries[b])

NOVEMBER 1994

Element (Atomic Number)	Isotope[c]	CASRN[d]	Radioactive Half-life[e]		ICRP Lung Class[f]	GI Absorption Factor (f_1)[g]	Slope Factor Lifetime Excess Total Cancer Risk Per Unit Intake or Exposure: Ingestion (Risk/pCi)	Inhalation (Risk/pCi)	External Exposure (Risk/yr per pCi/g soil)
Xenon (54)	Xe-122	015151-09-4	2.01E+01	H	•	---	---	3.08E-15	---
	Xe-123	015700-10-4	2.14E+00	H	•	---	---	8.92E-16	---
	Xe-125	013994-18-8	1.68E+01	H	•	---	---	1.20E-15	---
	Xe-127	013994-19-9	3.64E+01	D	•	---	---	4.09E-16	---
	Xe-129m	013965-99-6(m)	8.89E+00	D	•	---	---	5.74E-16	---
	Xe-131m	014683-11-5(m)	1.18E+01	D	•	---	---	4.13E-16	---
	Xe-133	014932-42-4	5.25E+00	D	•	---	---	4.14E-16	---
	Xe-133m	014932-42-4(m)	2.19E+00	D	•	---	---	5.12E-16	---
	Xe-135	014995-62-1	9.11E+00	H	•	---	---	7.45E-16	---
	Xe-135m	014995-62-1(m)	1.54E+01	M	•	---	---	1.88E-16	---
	Xe-137	014835-21-3	3.83E+00	M	•	---	---	1.39E-15	---
	Xe-138	015751-81-2	1.41E+01	M	•	---	---	2.06E-15	---
Yttrium (39)	Y-90	010098-91-6	6.41E+01	H	Y	1.00E-04	1.50E-11	9.90E-12	0.00E+0
	Y-91	014234-24-3	5.85E+01	D	Y	1.00E-04	1.35E-11	1.85E-11	1.41E-08
	Y-91m	014234-24-3(m)	4.97E+01	M	Y	1.00E-04	3.69E-14	2.99E-14	1.90E-06
	Y-92	015751-59-4	3.54E+00	H	Y	1.00E-04	1.95E-12	1.61E-12	9.80E-07
	Y-93	014981-70-5	1.01E+01	H	Y	1.00E-04	5.74E-12	3.48E-12	3.41E-07
Zinc (30)	Zn-65	013982-39-3	2.44E+02	D	Y	5.00E-01	9.93E-12	9.98E-12	2.27E-06

[Table 4 continues on the following page: Refer to Endnotes on the last page.]

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Table 4: Radionuclide Carcinogenicity -- Slope Factors[a] (In Units of Picocuries[b])

NOVEMBER 1994

Element (Atomic Number)	Isotope[c]	CASRN[d]	Radioactive Half-life[e]		ICRP Lung Class[f]	GI Absorption Factor (f_1)[g]	Slope Factor Lifetime Excess Total Cancer Risk Per Unit Intake or Exposure: Ingestion (Risk/pCi)	Inhalation (Risk/pCi)	External Exposure (Risk/yr per pCi/g soil)
	Zn-69	013982-23-5	5.56E+01	M	Y	5.00E-01	6.19E-14	1.04E-13	2.03E-11
	Zn-69m	013982-23-5(m)	1.38E+01	H	Y	5.00E-01	1.52E-12	1.17E-12	1.43E-06
Zirconium (40)	Zr-93	015751-77-6	1.53E+06	Y	W	2.00E-03	5.21E-13	5.26E-12	0.00E+0
	Zr-95	013967-71-0	6.40E+01	D	W	2.00E-03	3.92E-12	6.48E-12	2.81E-06
	Zr-97	014928-30-4	1.69E+01	H	W	2.00E-03	1.04E-11	4.73E-12	6 85E-07

[Table 4 continues on the following page: Refer to Endnotes on the last page.]

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Table 4: Radionuclide Carcinogenicity -- Slope Factors[a] (In Units of Picocuries[b])

NOVEMBER 1994

Element (Atomic Number)	Isotope[c]	CASRN[d]	Radioactive Half-life[e]	ICRP Lung Class[f]	GI Absorption Factor (f_1)[g]	Slope Factor Lifetime Excess Total Cancer Risk Per Unit Intake or Exposure: Ingestion (Risk/pCi)	Inhalation (Risk/pCi)	External Exposure (Risk/yr per pCi/g soil)

ENDNOTES:

a EPA classifies all radionuclides as Group A (known human) carcinogens. Radionuclide slope factors are calculated by EPA's Office of Radiation and Indoor Air (ORIA) to assist HEAST users with risk-related evaluations and decision-making at various stages of the remediation process. Ingestion and inhalation slope factors are central estimates in a linear model of the age-averaged, lifetime attributable radiation cancer incidence (fatal and nonfatal cancer) risk per unit of activity inhaled or ingested, expressed as risk/picocurie (pCi). External exposure slope factors are central estimates of the lifetime attributable radiation cancer incidence risk for each year of exposure to external radiation from photon-emitting radionuclides distributed uniformly in a thick layer of soil, and are expressed as risk/yr per pCi/gram of soil. If required, slope factors in Table 4 can be converted into the International System (SI) units of becquerels (1 Bq = 1 nuclear transformation per second) by dividing each inhalation, ingestion, or external exposure value by 27.03. Users can calculate cancer risks using slope factors expressed in either customary units or SI units with equivalent results, provided that they also use air, water and soil concentration values in the same system of units. For a discussion on the derivation of radionuclide slope factors and guidance on their use, refer to the User's Guide section on radionuclide carcinogenicity.

b A curie (Ci), the customary unit of activity, is equal to 3.7×10^{10} nuclear transformations per second. 1 picocurie (pCi) = 10^{-12} Ci.

c For each radionuclide listed, slope factors correspond to the risks per unit intake or exposure for that radionuclide only, except when marked with a "+D" to indicate that the risks from associated short-lived radioactive decay products (i.e., those decay products with radioactive half-lives less than or equal to 6 months) are also included. Refer to Exhibit 1 in the User's Guide section on radionuclide carcinogenicity for guidance on determining slope factors for partial or complete radioactive decay chains.

d Chemical Abstract Service Reference Number (CASRN). For risk calculations involving decay chains, a CASRN should be reported for the parent radionuclide and each chain member.

e Radioactive half-life: S = Second, M = Minute, D = Day, Y = Year. For those radionuclides with decay products (+D), half-lives are listed for the parent radionuclide.

f Lung clearance classification recommended by the International Commission on Radiological Protection (ICRP): Y = Year, W = Week, D = Day, * = Gas.

g Gastrointestinal (GI) absorption factors are the fractional amounts of each radionuclide absorbed across the GI tract into the bloodstream. Lung clearance classifications and GI absorption factors are provided for reference only. Do not use these factors to adjust inhalation or ingestion slope factors. See the User's Guide for instructions.

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