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Agency

Office of
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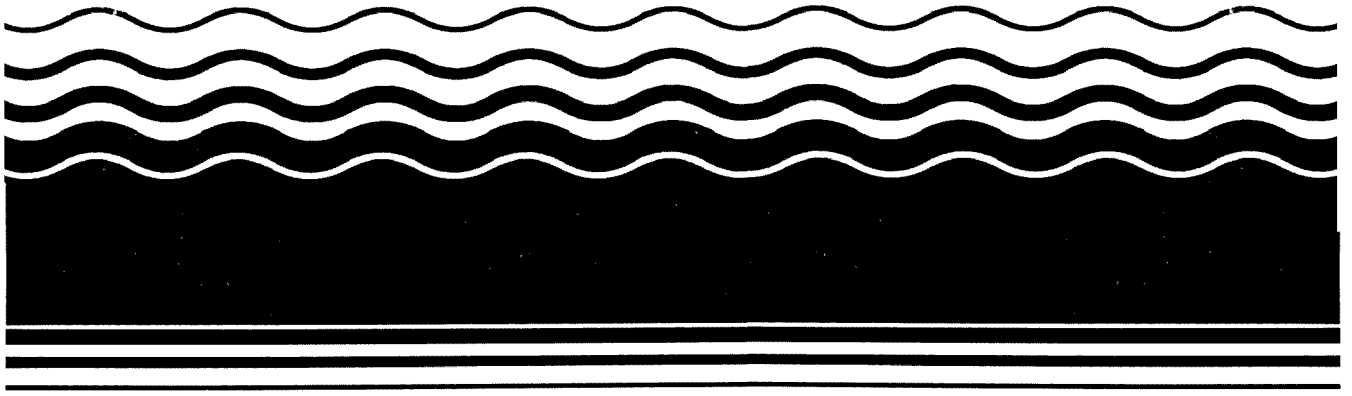
Superfund

EPA

# Health Effects Assessment Summary Tables

# FY-1995 Supplement



## 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 1995 Supplement for the May 1995 Annual Health Effects Assessment Summary Tables (HEAST) prepared by EPA's National Center for Environmental Assessment, Cincinnati, OH (NCEA-Cin) for use at both Superfund and RCRA sites. This Supplement is only intended to update the information in the May 1995 HEAST. The supplement is not produced to stand alone and does not contain the Chemical Toxicity User's Guides or the Appendix available in the Annual Update. Thus, the user must refer to the May 1995 Annual HEAST for these and for comprehensive information relevant to:

- Chemical Status Definitions or Interpretations
- Caution as to the Use of "Provisional" Risk Assessment Values
- Contributors of Information
- Chemicals Listed as to EPA's Source Documents
- Hierarchy of Sources Recommended in Evaluating Chemical Toxicity
- Questions Regarding Chemical Toxicity and Carcinogenicity, RCRA Chemicals and Radionuclide Carcinogenicity
- References as to the Availability of Agency Citations in HEAST
- Ordering information as detailed in the Annual or by calling National Technical Information Service (NTIS) Subscription Department at (703)487-4630 and refer to the following order numbers:

  PB95-921199: 1995 Annual HEAST
  PB95-921101: 1995 Supplement

## WHAT'S NEW IN THE NOVEMBER 1995 HEAST SUPPLEMENT

## GENERAL CHANGES -- CHEMICAL TOXICITY AND CARCINOGENICITY

The changes in this version of the HEAST reflect changes in IRIS through September 6, 1995. It is also current with RfD/RfC and CRAVE Work Group activities through September 1, 1995.

## CHEMICAL-SPECIFIC CHANGES -- CHEMICAL TOXICITY AND CARCINOGENICITY

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

Antimony trioxide 001309-64-4
An indicator was added to show that an inhalation RfC has been added to IRIS. The chronic inhalation RfC was adopted as the subchronic inhalation [RfC].

Boron, elemental 007440-42-8
The subchronic oral [RfD] was removed because the chronic oral RfD on which it was based is under review by the RfD/RfC Work Group.

Carbon disulfide 000075-15-0
An indicator was added to show that an inhalation RfC has been added to IRIS. The chronic inhalation RfC was adopted as the subchronic inhalation [RfC].

Hydrogen sulfide 007783-06-4
After a reevaluation of uncertainty factors by the RfD/RfC Work Group, the chronic inhalation RfC was modified to estimate the subchronic inhalation [RfC].

Mercuric chloride 007487-94-7
After a reevaluation of uncertainty factors by the RfD/RfC Work Group, The chronic oral RfD was modified to estimate the subchronic oral [RfD].

Phosphine 007803-51-2
An indicator was added to show that an inhalation RfC has been added to IRIS. The chronic inhalation RfC was modified to estimate the subchronic inhalation [RfC].

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

There were no changes to Table 2.

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

Arsenic, inorganic 007440-38-2
Indicators were added to show that an oral slope factor and an oral unit risk have been added to IRIS.

Bis(2-chloro-1-methylethyl) ether 000108-60-1
A typographical error in the CAS Registry Number has been corrected. There were no other changes to the record.

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

For this update of the HEAST for radionuclides, EPA's Office of Radiation and Indoor Air (ORIA) has:

✓ corrected the factor in Table 4 for converting radionuclide slope factors from the customary units of picocuries (Ci) to the International System (SI) units of becquerels (Bq). (To convert radionuclides slope factors into the SI units of Bq, users should multiply each value in Table 4 by 27.03, not by 3.70E-02, the conversion factor provided in the November 1994 update.)

✓ added ingestion, inhalation, and external exposure slope factors for californium (Cf-252), iridium (Ir-192), thallium (Tl-207), and silver (Ag-110m+D).

✓ removed the ingestion, inhalation, and external slope factors for Cm-243+D and Pu-241+D. (EPA/ORIA re-evaluated the derivation and use of "+D" slope factors for decay chains that include a parent radionuclide (e.g., Cm-243 or Pu-241) with a radioactive half-life much shorter than the half-life of its immediate decay product (e.g., Pu-239 in the case of Cm-243 and Am-241 in the case of Pu-241). ORIA concluded that using "+D" slope factors for these types of radionuclides and decay chains may significantly underestimate radiation exposure and risk at certain sites, because such factors cannot be derived to cover all possible equilibrium conditions in the

environment. At sites contaminated with these types of radionuclides, ORIA recommends that users (1) determine the radioactivity concentrations of the parent and each deca product radionuclides separately, (2) apply the appropriate slope factors in Table 4 for each radionuclide individually, and (3) add the individual risks from each radionuclide to calculate the collective risk posed by the site.)

✓ corrected the external slope factor values for Ac-227+D, Ce-144+D, Pu-244+D, Th-228+D, Th-229+D, and U-238+D in Table 4.

✓ corrected the branching factor for Ce-144 to Pr-144 from 9% to 98%, and corrected the half-life for Ra-228 from 8 years to 6 years in Exhibit 1.

# 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).[1] 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

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[1]Slope factors are reported in Table 4 in the customary units of picocuries (1 pCi = $10^{-12}$ curies (Ci) = $3.7 \times 10^{-2}$ 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 multiplying 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 use air, water and soil concentration values in the same system of units.

assumptions[2], slope factors can be used to estimate lifetime cancer risks to members of the general population due to radionucli exposures.

**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:

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[2]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.]

- 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[3], vital statistics 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[4], ICRP Publication 60[5], and U.S. Nuclear

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[3]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.

[4]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.

[5]International Commission on Radiological Protection (1991), 1990 ommendations of the International Commission on Radiological Protection,

Regulatory Commission (NRC) analyses[6]. 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 time, and do <u>not</u> require corrections for GI absorption or lung transfer efficiencies.

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ICRP Publication 60, Pergamon Press, New York, NY.

[6]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-93-07 for discussion of these models.

**NOTE:** ***The GI absorption values ($f_1$), ICRP lung classifications (D, Y) and radioactive half-lives are provided in HEAST Table 4 for ference 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.[7]

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 for principal radionuclides, and provides key parameter values used in the derivation of slope factor values.

[7]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," ORNL-5974, Oak Ridge National I ratory, Oak Ridge, TN.

Radionuclides are presented alphabetically by element and atomic weight.

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.[8] 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 $2 \times 10^{-6}$ (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.

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[8]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.

Note that there may be circumstances, such as long disppsal nes 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 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 Environmental 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 reportin 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[9]

| 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 (98.62%, 19 d)]<br>Fr-223 (1.38%, 22 min)<br>Ra-223 (11 d)<br>Rn-219 (4 s)<br>Po-215 (2 ms)<br>Pb-211 (36 min)<br>Bi-211 (2 min)<br>[Tl-207 (99.72%, 5 min)<br>Po-211 (0.28%, 0.5 s)] | Pb-207 | * |
| Ag-108m+D | 127 | -[d]<br>Ag-108 (8.90%, 2 min) | Pd-108 (91.1%)<br>[Cd-108 (97.65%)<br>Pd-108 (2.35%)] | *<br>*<br>* |
| Ag-110m+D | 0.7 | -<br>Ag-110 (1.33%, 25 s) | Cd-110 (98.67%)<br>[Cd-110 (99.7%)<br>Pd-110 (0.3%)] | *<br>*<br>* |
| Am-243+D | $7.4 \times 10^3$ | Np-239 (2 d) | Pu-239 | $2.4 \times 10^4$ |
| Ce-144+D | 0.8 | [Pr-144 (98.22%, 17 min)<br>Pr-144m (1.78%, 7 min)] | Nd-144 | * |
| Cs-137+D | 30 | Ba-137m (94.6%, 3 min) | Ba-137 | * |
| Np-237+D | $2.1 \times 10^6$ | Pa-233 (27 d) | U-233 | $1.6 \times 10^5$ |
| Pb-210+D | 22 | Bi-210 (5 d)<br>Po-210 (138 d) | Pb-206 | * |
| Pu-244+D | $8.3 \times 10^7$ | U-240 (14 h)<br>Np-240m (7.4 min) | Pu-240 | $6.5 \times 10^3$ |
| Ra-226+D | $1.6 \times 10^3$ | Rn-222 (4 d)<br>Po-218 (3 min)<br>[Pb-214 (99.98%, 27 min)<br>At-218 (0.02%, 2 s)]<br>Bi-214 (99.99%, 20 min)<br>[Po-214 (99.98%, $1.64 \times 10^{-4}$ s)<br>Tl-210 (0.02%, 1 min)] | Pb-210 | 22 |
| Ra-228+D | 6 | Ac-228 (6 h) | Th-228 | 2 |

[9]Source: International Commission on Radiological Protection (1983). Radionuclide Transformations: Energy and Intensity of Emission, ICRP Publication 38, Annals of the ICRP, Vols. 11-13, Pergamon Press, New York, NY.

Exhibit 1. Radionuclide Decay Chains Considered Explicitly in HEAST Table 4 (continued)

| Principal Radionuclide [a] | | Associated Decay Chain [b] | Terminal Nuclide or Radionuclide [c] | |
|---|---|---|---|---|
| Nuclide | Half-life (yr) | | Nuclide | Half-life (yr) |
| Ru-106+D | 1 | Rh-106 (30 s) | Pd-106 | * |
| Sb-125+D | 3 | Te-125m (22.8%, 58 d) | Te-125 | * |
| Sr-90+D | 29 | Y-90 (64 h) | Zr-90 | * |
| Th-228+D | 2 | Ra-224 (4 d)<br>Rn-220 (56 s)<br>Po-216 (0.2 s)<br>Pb-212 (11 h)<br>Bi-212 (61 min)<br>[Po-212 (64.07%, 0.3 μs)<br>Tl-208 (35.93%, 3 min)] | Pb-208 | * |
| Th-229+D | $7.3 \times 10^3$ | Ra-225 (15 d)<br>Ac-225 (10 d)<br>Fr-221 (5 min)<br>At-217 (32 ms)<br>Bi-213 (46 min)<br>[Po-213 (97.8%, 4 μs)<br>Tl-209 (2.2%, 2 min)]<br>Pd-209 (3 h) | Bi-209 | * |
| U-235+D | $7.0 \times 10^8$ | Th-231 (26 h) | Pa-231 | $3.3 \times 10^4$ |
| U-238+D | $4.5 \times 10^9$ | Th-234 (24 d)<br>[Pa-234m (99.80%, 1 min)<br>Pa-234 (0.33%, 7 h)] | U-234 | $2.4 \times 10^5$ |

(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 percentages 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.

Exhibit 2. EPA Radiation Program Staff

| | |
|---|---|
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Exhibit 2 (Continued)

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## ARSENIC, INORGANIC 007440-38-2

005007 BROWN, CC AND KC CHU. 1983. APPROACHES TO EPIDEMIOLOGIC ANALYSIS OF PROSPECTIVE AND RETROSPECTIVE STUDIES: EXAMPLE OF LUNG CANCER AND EXPOSURE TO ARSENIC. IN: RISK ASSESSMENT: PROC SIMS CONFERENCE ON ENVIRONMENTAL EPIDEMIOLOGY, JUNE 28-JULY 2, 1982, ALTA UT. SIAM PUBLICATION.

BROWN, CC AND KC CHU. 1983. IMPLICATIONS OF THE MULTISTAGE THEORY OF CARCINOGENESIS APPLIED TO OCCUPATIONAL ARSENIC EXPOSURE. J NAT CANCER INST. 70: 455-463.

LEE-FELDSTEIN, A. 1983. ARSENIC AND RESPIRATORY CANCER IN MAN: FOLLOW-UP OF AN OCCUPATIONAL STUDY. IN: ARSENIC: INDUSTRIAL, BIOMEDICAL, AND ENVIRONMENTAL PERSPECTIVES, W LEDERER AND R FENSTERHEIM, EDS, VAN NOSTRAND REINHOLD, NEW YORK.

BROWN, CC AND KC CHU. 1983. A NEW METHOD FOR THE ANALYSIS OF COHORT STUDIES: IMPLICATIONS OF THE MULTISTAGE THEORY OF CARCINOGENESIS APPLIED TO OCCUPATIONAL ARSENIC EXPOSURE. ENVIRON HEALTH PERSP. 50: 293-308.

HIGGINS, I. 1982. ARSENIC AND RESPIRATORY CANCER AMONG A SAMPLE OF ANACONDA SMELTER WORKERS. REPORT SUBMITTED TO THE OCCUPATIONAL SAFETY HEALTH ADMINISTRATION IN THE COMMENTS OF THE KENNECOTT MINERALS ON THE INORGANIC ARSENIC RULE MAKING, EXHIBIT 203-5.

ENTERLINE, PE AND GM MARSH. 1982. CANCER AMONG WORKERS EXPOSED TO ARSENIC AND OTHER SUBSTANCES IN A COPPER SMELTER. AM J EPIDEMIOL. 116: 895-911.

US EPA. 1984. HEALTH EFFECTS ASSESSMENT FOR ARSENIC. PREPARED BY THE OFFICE OF HEALTH AND ENVIRONMENTAL ASSESSMENT, ENVIRONMENTAL CRITERIA AND ASSESSMENT OFFICE, CINCINNATI, OH FOR THE OFFICE OF EMERGENCY AND REMEDIAL RESPONSE, WASHINGTON DC.

US EPA. 1994. CARCINOGEN RISK ASSESSMENT VERIFICATION ENDEAVOR (CRAVE) WORK GROUP.

010925 TSENG WP. 1977. EFFECTS AND DOSE RESPONSE RELATIONSHIPS OF SKIN CANCER AND BLACKFOOT DISEASE WITH ARSENIC. ENVIRON HEALTH PERSPECT. 19: 108-119.

TSENG WP, HM CHU, SW HOU, ET AL. 1968. PREVALENCE OF SKIN CANCER IN AN EMDEMIC AREA OF CHRONIC ARSENICISM IN TAIWAN. J NATL CANCER INST. 40: 453-463.

US EPA. 1994. CARCINOGEN RISK ASSESSMENT VERIFICATION ENDEAVOR (CRAVE) WORK GROUP.

## BIS(2-CHLORO-1-METHYLETHYL) ETHER 000108-60-1

005079 NTP (NATIONAL TOXICOLOGY PROGRAM). 1982. CARCINOGENIC BIOASSAY OF BIS(2-CHLORO-1-METHYLETHYL) ETHER (70%) CONTAINING 2-CHLORO-1-METHYLETHYL(2-CHLOROPROPYL) ETHER (30%) IN B6C3F1 MICE (GAVAGE STUDY). NCI CARCINOGEN TECH REP SER NO 239. 105 P. ALSO PUBL AS DHHS (NIH) 83-1795

US EPA. 1987. HEALTH AND ENVIRONMENTAL EFFECTS DOCUMENT FOR HALOETHERS. 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.

| 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 |
|---|---|---|---|---|---|---|---|---|---|---|
| ARSENIC, INORGANIC | 007440-38-2 | | | | | | | | | |
| | | | | | | IRIS | | IRIS | | 010925 |
| | INHALATION: OCCUPATIONAL | HUMAN | RESPIRATORY SYSTEM | TUMORS | IRIS | | IRIS | | IRIS | 005007 |
| | GENERAL COMMENT: ALSO SEE HEAST TABLE 1: SUBCHRONIC AND CHRONIC TOXICITY (OTHER THAN CARCINOGENICITY). | | | | | | | | | |
| BIS(2-CHLORO-1-METHYLETHYL) ETHER | 000108-60-1 | | | | | | | | | |
| | ORAL: GAVAGE | 2 YEARS MOUSE | LIVER | TUMORS | C | 7E-2 | 3.5E-2 | 2E-6 | 1E-5 | 005079 |
| | | | LUNG | TUMORS | | | | | | |
| | INHALATION [SLOPE] COMMENT: BASED ON ROUTE TO ROUTE EXTRAPOLATION (50% RESPIRATORY ABSORPTION). SEE APPENDIX A-II: DOSE CONVERSIONS ON HEAST. GENERAL COMMENT: COMPOUND TESTED CONTAINED 70% BIS(2-CHLORO-1-METHYLETHYL)ETHER AND 30% BIS(2-CHLOROISOPROPYL)ETHER. ALSO SEE HEAST TABLE 1: SUBCHRONIC AND CHRONIC TOXICITY (OTHER THAN CARCINOGENICITY). | | | | | | | | | |

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

Novem. 1995

## ANTIMONY TRIOXIDE 001309-64-4


005242 SCHROEDER HA, M MITCHENER AND AP NASON. 1970. ZIRCONIUM, NIOBIUM, ANTIMONY AND LEAD IN RATS: LIFE-TIME STUDIES. J. NUTR. 100: 59-69.

US EPA. 1987. HEALTH EFFECTS ASSESSMENT FOR ANTIMONY AND COMPOUNDS. PREPARED BY THE OFFICE OF HEALTH AND ENVIRONMENTAL ASSESSMENT, ENVIRONMENTAL CRITERIA AND ASSESSMENT OFFICE, CINCINNATI, OH FOR THE OFFICE OF EMERGENCY AND REMEDIAL RESPONSE, WASHINGTON, DC.

US EPA. 1985. HEALTH AND ENVIRONMENTAL EFFECTS PROFILE FOR ANTIMONY OXIDES. 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.

010974 NEWTON PE, HF BOLTS, IW DALY ET AL. 1994. SUBCHRONIC AND CHRONIC INHALATION TOXICITY OF ANTIMONY TRIOXIDE IN THE RAT. FUND APPL TOXICOL 32: 561-576.

US EPA. 1995. RfD/RfC WORK GROUP.


## BORON, ELEMENTAL 007440-42-8


005272 WEIR RJ, JR AND RS FISHER. 1972. TOXICOLOGIC STUDIES ON BORAX AND BORIC ACID. TOXICOL APPL PHARMACOL. 23(3): 351-364.

US EPA. 1987. HEALTH EFFECTS ASSESSMENT FOR BORON AND COMPOUNDS. PREPARED BY THE OFFICE OF HEALTH AND ENVIRONMENTAL ASSESSMENT, ENVIRONMENTAL CRITERIA AND ASSESSMENT OFFICE, CINCINNATI, OH FOR THE OFFICE OF EMERGENCY AND REMEDIAL RESPONSE, WASHINGTON, DC.

US EPA. 1989. RfD/RfC WORK GROUP.

US EPA. 1993. REVISED AND UPDATED DRINKING WATER QUANTIFICATION OF TOXICOLOGIC EFFECTS FOR BORON. PREPARED BY THE OFFICE OF HEALTH AND ENVIRONMENTAL ASSESSMENT, ENVIRONMENTAL CRITERIA AND ASSESSMENT OFFICE, CINCINNATI, OH FOR THE OFFICE OF WATER, WASHINGTON, DC.

005269 GARABRANT DH, L BERNSTEIN, JM PETERS ET AL. 1985. RESPIRATORY EFFECTS OF BORAX DUST. BR J IND MED. 42: 831-837.

US EPA. 1991. HEALTH AND ENVIRONMENTAL EFFECTS DOCUMENT FOR BORON AND BORON COMPOUNDS. 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.


## CARBON DISULFIDE 000075-15-0


010259 HARDIN BD, GP BOND, MR SIKOR, FD ANDREW, RP BELILES AND RW NIEMEIR. 1981. TESTING OF SELECTED WORKPLACE CHEMICALS FOR TERATOGENIC POTENTIAL. SCAND J WORK ENVIRON HEALTH. 7(SUPPL 4): 66-75.

US EPA. 1985. RfD/RfC WORK GROUP.

010975 JOHNSON BL, J BOYD, JR BURG ET AL. 1983. EFFECTS ON THE PERIPHERAL NERVOUS SYSTEM OF WORKERS' EXPOSURE TO CARBON DISULFIDE. NEUROTOXICOLOGY 4: 53-66.

US EPA. 1995. RfD/RfC WORK GROUP.

## HYDROGEN SULFIDE 007783-06-4

010269 WATTERAU H, W OECKERT AND UG KNAPE. 1964. TESTS FOR THE APPLICATION OF DRIED GREEN FODDER WITH HIGH H2S CONTENT (EXPERIMENTS WITH POULTRY AND FATTENED PIGS). LETTIN FEEDS TESTING CENTER AND FEEDING HALL. FEEDS SCIENCE. FETTERUNG. 5: 383-393.

US EPA. 1985. RfD/RfC WORK GROUP.

010354 CIIT. 1983. 90 DAY VAPOR INHALATION TOXICITY STUDY OF HYDROGEN SULFIDE IN B6C3F1 MICE. EPA OTS PUBLIC FILES. FICHE NO0000255-0. DOCUMENT NO FYI-OTS-0883-0255.

US EPA. 1990. HEALTH AND ENVIRONMENTAL EFFECTS DOCUMENT FOR HYDROGEN SULFIDE. 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. 1995. RfD/RfC WORK GROUP.

## MERCURIC CHLORIDE 007487-94-7

005800 ANDRES P. 1984. IGA-AGG DISEASE IN THE INTESTINE OF BROWN-NORWAY RATS INGESTING MERCURIC CHLORIDE. CLIN IMMUNOL IMMUNOPATHOL 20: 488-494.

BERNAUDIN JF, E DRUET, P DRUET, R MASSE. 1981. INHALATION OR INGESTION OF ORGANIC OR INORGANIC MERCURIALS PRODUCES AUTO-IMMUNE DISEASE IN RATS. CLIN IMMUNOL IMMUNOPATHOL 20: 129-135.

DRUET P, E DRUET, F POTDEVIN C SAPIN. 1978. IMMUNE-TYPE GLOMERULONEPHRITIS INDUCED BY HG CL2 IN THE BROWN NORWAY RAT. ANN IMMUNOL 129C: 777-702.

US EPA. 1987. PEER REVIEW WORKSHOP ON MERCURY ISSUES. OCTOBER 26-27, 1987. ENVIRONMENTAL CRITERIA AND ASSESSMENT OFFICE. CINCINNATI, OH.

US EPA. 1995. MERCURY STUDY REPORT TO CONGRESS. OFFICE OF RESEARCH AND DEVELOPMENT. WASHINGTON, DC. EXTERNAL REVIEW DRAFT. EPA/600/P-94/002AB.

US EPA. 1988. RfD/RfC WORK GROUP.

## PHOSPHINE 007803-51-2

010174 HACKENBERG, J. 1972. CHRONIC INGESTION BY RATS OF STANDARD DIET TREATED WITH ALUMINUM PHOSPHIDE. TOXICOL APPL PHARMACOL. 23: 147-158.

US EPA. 1989. HEALTH AND ENVIRONMENTAL EFFECTS DOCUMENT FOR PHOSPHINE. 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. 1985. RfD/RfC WORK GROUP.

010976 BARBOSA A, E ROSINOVA, J DEMPSEY AND AM BONIN. 1994. DETERMINATION OF GENOTOXIC AND OTHER EFFECTS IN MICE FOLLOWING SHORT-TERM, REPEATED DOSE, AND SUBCHRONIC INHALATION EXPOSURE TO PHOSPHINE. ENVIRON MOLEC MUTAGENESIS 24: 81-88.

US EPA. 1995. RfD/RfC WORK GROUP.

| 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 |
|---|---|---|---|---|---|---|---|---|---|---|
| **ANTIMONY TRIOXIDE** | | 001309-64-4 | | | | | | | | |
| LOAEL 0.42 MG/KG/DAY | | RAT | | | | | | | | |
| | ORAL: DRINKING WATER | | LIFETIME | WHOLE BODY | INCREASED MORTALITY | | 4E-4 | | 4E-4 | 005242 |
| | | | | BLOOD | ALTERED CHEMISTRIES | | 1000 | | 1000 | |
| | SUBCHRONIC [RfD] COMMENT: CALCULATED BY ANALOGY TO ANTIMONY BY CORRECTING FOR DIFFERENCES IN MOLECULAR WEIGHT. | | | | | | | | | |
| | CHRONIC [RfD] COMMENT: CALCULATED BY ANALOGY TO ANTIMONY BY CORRECTING FOR DIFFERENCES IN MOLECULAR WEIGHT. | | | | | | | | | |
| BMC 0.87 MG/CU M | | RAT | | | | | | | | |
| | INHALATION, INTERMITTENT | | 1 YEAR | LUNG | PULMONARY TOXICITY | 2E-4 | | IRIS | | 010974 |
| | | | | LUNG | INTERSTITIAL INFLAMMATION, CHRONIC | 30 | | | | |
| | CHRONIC RfC COMMENT: A BENCHMARK DOSE APPROACH WAS USED RATHER THAN A NOAEL/LOAEL TO DERIVE THE RfC. | | | | | | | | | |
| | SUBCHRONIC [RfC] COMMENT: THE CHRONIC INHALATION RfC IS ADOPTED AS THE SUBCHRONIC INHALATION [RfC]. | | | | | | | | | |
| **BORON, ELEMENTAL** | | 007440-42-8 | | | | | | | | |
| NOAEL 8.8 MG/KG/DAY | | DOG | | | | | | | | |
| | ORAL: DIET | | 2 YEARS | TESTIS | LESIONS | | | | IRIS | 005272 |
| | SUBCHRONIC [RfD] COMMENT: THE SUBCHRONIC ORAL [RfD] WAS REMOVED BECAUSE THE CHRONIC ORAL RfD UPON WHICH IT WAS BASED IS UNDER REVIEW BY THE RfD/RfC WORK GROUP. | | | | | | | | | |
| | CHRONIC RfD COMMENT: THE CHRONIC ORAL RfD, WHILE STILL ON IRIS, IS BEING RECONSIDERED BY THE RfD/RfC WORK GROUP. | | | | | | | | | |
| LOAEL 4.5 MG/CU M | | HUMAN | | | | | | | | |
| | INHALATION: INTERMITTENT | | | RESPIRATORY TRACT | IRRITATION | 2E-2 | | 2E-2 | | 005269 |
| | | | | BRONCHUS | BRONCHITIS | 100 | | 100 | | |
| | SUBCHRONIC [RfC] COMMENT: THE SUBCHRONIC INHALATION [RfC] IS SPECIFICALLY FOR ANHYDROUS BORAX. | | | | | | | | | |
| | CHRONIC [RfC] COMMENT: THE CHRONIC INHALATION [RfC] IS SPECIFICALLY FOR ANHYDROUS BORAX. | | | | | | | | | |

| CHEMICAL / DOSE LEVEL | 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 |
|---|---|---|---|---|---|---|---|---|---|---|
| **CARBON DISULFIDE** | | **000075-15-0** | | | | | | | | |
| NOEL 11 MG/KG/DAY | | RABBIT | | | | | | | | |
| | INHALATION: INTERMITTENT | | | FETUS | TOXICITY | | 1E-1 100 | | IRIS | 010259 |
| SUBCHRONIC [RfD] COMMENT: THE CHRONIC ORAL RfD WAS ADOPTED AS THE SUBCHRONIC ORAL [RfD]. CHRONIC [RfD] COMMENT: THE CHRONIC ORAL RfD WAS DETERMINED FROM A TERATOLOGY STUDY WITH EXPOSURES BEFORE AND DURING THE ENTIRE GESTATION PERIOD. | | | | | | | | | | |
| BMC 19.7 MG/CU M | | HUMAN OCCUPATIONAL | | | | | | | | |
| | INHALATION: INTERMITTENT | | 12.1 +/- 6.9 YEARS | PERIPHERAL NERVOUS SYSTEM | DYSFUNCTION | 7E-1 30 | | IRIS | | 010975 |
| CHRONIC RfC COMMENT: A BENCHMARK DOSE APPROACH WAS USED RATHER THAN A NOAEL/LOAEL TO DERIVE THE RfC. SUBCHRONIC [RfC] COMMENT: THE CHRONIC INHALATION RfC WAS ADOPTED AS THE SUBCHRONIC INHALATION [RfC]. | | | | | | | | | | |
| **HYDROGEN SULFIDE** | | **007783-06-4** | | | | | | | | |
| NOAEL 3.1 MG/KG/DAY | | PIG | | | | | | | | |
| | ORAL: FOOD | | 105 DAYS | GASTRO-INTESTINAL SYSTEM | DISTURBANCE | | 3E-2 100 | | IRIS | 010269 |
| NOAEL 42 MG/CU M | | MOUSE | | | | | | | | |
| | INHALATION: INTERMITTENT | | 13 WEEKS | NASAL MUCOSA | INFLAMMATION | 1E-2 100 | | IRIS | | 010354 |
| **MERCURIC CHLORIDE** | | **007487-94-7** | | | | | | | | |
| | | RAT | | | | | | | | |
| | ORAL; SUBCUTANEOUS | | | IMMUNE SYSTEM | AUTOIMMUNE EFFECTS | | 3E-3 100 | | IRIS | 005800 |

| 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 |
|---|---|---|---|---|---|---|---|---|---|
| PHOSPHINE | | 007803-51-2 | | | | | | | |
| NOEL | 0.026 MG/KG/DAY | RAT | | | | | | | |
| | ORAL: DIET | 2 YEARS | | | | 3E-4<br>100 | | IRIS | 010174 |
| | SUBCHRONIC [RfD] COMMENT: THE CHRONIC ORAL RfD WAS ADOPTED AS THE SUBCHRONIC ORAL [RfD]. | | | | | | | | |
| NOAEL | 1.4 MG/CU M | MOUSE | | | | | | | |
| | INHALATION: INTERMITTENT | 13 WKS | WHOLE BODY | DECREASED WEIGHT | | 3E-3<br>100 | | IRIS | 010976 |

# Table 4

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

**NOVEMBER 1995**

NOTE: To convert radionuclide slope factors into the International System (SI) activity units of becquerels (Bq), multiply each value in Table 4 by 27.03.

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

November 1995

| 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 | 9 30E-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 |

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

# 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) |
|---|---|---|---|---|---|---|---|---|---|
| Argon (18) | Ar-41 | 014163-25-8 | 1 83E+00 | H | * | — | — | 4.71E-16 | — |
| 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 |
| | 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 |

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

# Table 4: Radionuclide Carcinogenicity -- Slope Factors[a] November 1995
# (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) |
|---|---|---|---|---|---|---|---|---|---|
| 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 |
| | 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 |
| Californium (98) | Cf-252 | [To be added.] | 2.64E+00 | Y | Y | 1.00E-03 | 1 80E-10 | 2.59E-08 | 1.79E-11 |
| 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 |
| | 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 | Y | 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 | 1.59E-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 |

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

# 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) |
|---|---|---|---|---|---|---|---|---|---|
| | 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 |
| | 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 |
| Chlorine (17) | Cl-36 | 013981-43-6 | 3 01E+05 | Y | D | 9 50E-01 | 2 23E-12 | 1.30E-12 | 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-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 |

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

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

November 1995

| 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) |
| | 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 |
| 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 |

[Table tinues on the following page: Refer to Endnotes on the last page ]

# 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) |
| 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 |
| 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 |
| | 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 |

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

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

November 1995

| 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) |
|---|---|---|---|---|---|---|---|---|---|
| | 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 |
| Indium (77) | Ir-190 | 014981-91-0 | 1.18E+01 | D | Y | 1.00E-02 | 4 95E-12 | 4.49E-12 | 4 65E-06 |
| | Ir-192 | [To be added.] | 7.40E+01 | D | Y | 1.00E-02 | 6 43E-12 | 1.12E-11 | 2 70E-06 |
| | Ir-194 | 014158-35-1 | 1 92E+01 | H | Y | 1 00E-02 | 7 00E-12 | 4 18E-12 | 3 17E-07 |
| Iron (26) | Fe-55 | 014681-59-5 | 2.70E+00 | Y | W | 1 00E-01 | 3 51E-13 | 5 60E-13 | 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 |

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

# 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) |
| 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 |
| | 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 |
| 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-236a | 015700-36-4a | 1.15E+05 | Y | W | 1.00E-03 | 2 73E-11 | 3.05E-09 | 9 22E-08 |

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

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

November 1995

| 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) |
|---|---|---|---|---|---|---|---|---|---|
| | Np-236b | 015700-36-4b | 2 25E+00 | H | W | 1 00E-03 | 9 31E-13 | 3.87E-12 | 5.40E-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 |
| | Ni-63 | 013981-37-8 | 1.00E+02 | Y | W | 5 00E-02 | 5.50E-13 | 1.01E-12 | 0 |
| | Ni-65 | 014833-49-9 | 2 52E+00 | H | W | 5.00E-02 | 5 62E-13 | 3 59E-13 | 2 14E-06 |
| 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 |

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

# 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) |
|---|---|---|---|---|---|---|---|---|---|
| | 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 |
| | 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 |
| | P-33 | 015749-66-3 | 2 54E+01 | D | D | 8 00E-01 | 7.81E-13 | 3 96E-13 | 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 |
| | Pt-193 | 015735-70-3 | 5.00E+01 | Y | D | 1 00E-02 | 1 62E-13 | 7.89E-14 | 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 |

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

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

November 1995

| 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) |
|---|---|---|---|---|---|---|---|---|---|
| | 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 |
| | 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 | 1.05E-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 |
| | 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 |
| | 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 |
| 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 |

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

# 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) |
| | 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 |
| | 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 |

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

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

November 1995

| 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-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[1] | 014859-67-7(+D) | 3.82E+00 | D | * | — | — | 7 57E-12 | —[2] |
| 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 |
| 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 |
| | Rb-88 | 014928-36-0 | 1.78E+01 | M | D | 9 50E-01 | 1 46E-13 | 1.36E-13 | 2.68E-06 |

[1]To derive the inhalation slope factor for Rn-222+D, EPA's Office of Radiation and Indoor Air (ORIA) uses a risk model based on radon decay product exposure and the following exposure assumptions: 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.*

[2]Included with the Ra-226+D external slope factor.

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

# 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) |
|---|---|---|---|---|---|---|---|---|---|
| | 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 |
| | 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 |
| | 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 |
| 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 |

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

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

November 1995

| 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) |
|---|---|---|---|---|---|---|---|---|---|
| | 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-110m+D | 014391-76-5(m)+D | 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 |
| | Sr-90+D | 010098-97-2(+D) | 2 86E+01 | Y | D | 3 00E-01 | 5 59E-11 | 6 93E-11 | 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 |
| Sulfur (16) | S-35 | 015117-53-0 | 8.74E+01 | D | D | 8 00E-01 | 4 16E-13 | 1.85E-13 | 0 |

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

# 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) |
| 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 |
| Tellunum (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 ]

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

November 1995

| 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-207 | [To be added.] | 4.77E+00 | M | D | 950E-01 | 1.07E-14 | 1.24E-14 | 8,53E-09 |
| | 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 | 6 20E-06 |
| | 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 | 7.68E-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 |

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

# 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) |
|---|---|---|---|---|---|---|---|---|---|
| | 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 |
| | 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 |

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

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

November 1995

| 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) |
|---|---|---|---|---|---|---|---|---|---|
| | U-238+D | 007440-61-1(+D) | 4 47E+09 | Y | Y | 5.00E-02 | 6 20E-11 | 1.24E-08 | 6 57E-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 |
| 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 |
| | Y-91 | 014234-24-3 | 5 85E+01 | D | Y | 1 00E-04 | 1 35E-11 | 1 85E-11 | 1.41E-08 |

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

# 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) |
| | 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 |
| | 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 |
| | 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 ]

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

November 1995

| 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 multiplying 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 $3.7 \times 10^{10}$ 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.