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Screening Doses for Induction of Cancers Calculated with the Interactive RadioEpidemiological Program (IREP)

TECHNICAL REPORT

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14. ABSTRACT
This report presents tabulations of equivalent doses of ionizing radiation, referred to as screening doses, that correspond to an estimated probability of causation of specific cancers of approximately 50% at the upper 99% credibility limit. Screening doses for 32 cancer types were calculated with the Interactive RadioEpidemiological Program, which is used by the Department of Veterans Affairs in adjudicating claims for compensation for cancer by veterans of military services.

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ABSTRACT

This report presents tabulations of equivalent doses of ionizing radiation, referred to as screening doses, that correspond to an estimated probability of causation (PC) of specific cancers of approximately 50% at the upper 99% credibility limit. A PC of 50% at the upper 99% credibility limit is often used in evaluating whether it is at least as likely as not that a given cancer in an individual was caused by exposure to ionizing radiation for purposes of adjudicating claims for compensation. Screening doses for 32 cancer types were calculated with the Interactive RadioEpidemiological Program (IREP), which is used by the Department of Veterans Affairs (VA) in adjudicating claims for compensation for cancer by veterans of military services. Screening doses calculated with IREP take into account uncertainties in estimating cancer risk and PC associated with given equivalent doses to organs or tissues in which cancers occur. Except for cancers that occur only in females and breast cancer in females, tabulated screening doses apply to males. Screening doses for most cancer types depend on an individual's age at exposure and age at the time of diagnosis of cancer. Screening doses for lung cancer also depend on an individual's smoking history, and screening doses for skin cancers depend on an individual's race or ethnicity. Screening doses calculated with IREP are compared with screening doses for a limited number of cancer types calculated previously by the Committee on Interagency Radiation Research and Policy Coordination (CIRRPC), which were used by VA for many years in adjudicating claims for compensation. Screening doses calculated with IREP are higher than the corresponding values obtained from the CIRRPC table for most combinations of cancer type, age at exposure, and age at diagnosis. An analysis of the accuracy of screening doses calculated with IREP and tabulated in this report indicates that they could differ from equivalent doses that correspond to an upper 99% credibility limit of PC of exactly 50% by less than ±10% for most cancer types, ages at exposure, and ages at diagnosis of concern in VA radiation claims. Inaccuracies in screening doses are due to the randomness of statistical sampling in the method of uncertainty analysis used in IREP.

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1. INTRODUCTION

The Department of Veterans Affairs (VA) is responsible for adjudicating claims for compensation for cancers that occur in veterans of military services who were exposed to ionizing radiation.[1] In some cases, adjudication of a claim takes into account estimates of radiation dose to an organ or tissue in which a cancer occurred that are developed by the Defense Threat Reduction Agency (DTRA). In all such cases, VA uses estimated upper bounds of equivalent doses[2] provided by DTRA and other information to develop a medical opinion on whether a veteran's cancer was caused by ionizing radiation. Upper bounds of equivalent doses are intended to be at least upper 95% credibility limits when uncertainties in estimating equivalent doses to an organ or tissue of concern are taken into account. Compensation usually is awarded if VA concludes that it is at least as likely as not that a veteran's cancer was caused by radiation (i.e., the probability is at least 50%). VA gives claimants the benefit of the doubt by interpreting "at least as likely as not" to mean that the probability of causation (PC) should be at least 50% at the upper 99% credibility limit when uncertainties in estimating cancer risk and PC associated with upper-bound estimates of equivalent doses are taken into account. Thus, VA usually awards compensation when there is at least a 1% chance that PC is 50% or greater. An upper 99% credibility limit of PC of at least 50% also is used in evaluating causation of cancers in the Department of Labor's compensation program for workers at Department of Energy facilities (EEOICPA 2000; DHHS 2002).

The most common circumstance that requires VA to use estimates of radiation dose provided by DTRA in adjudicating claims for compensation involves cancers that are not one of

[1]Radiation-exposed veterans of concern to this report are specified in VA regulations [38 CFR 3.309(d)(3)]. They include participants in the atmospheric nuclear-weapons testing program between 1945 and 1962 and occupation forces or prisoners of war in Hiroshima or Nagasaki, Japan, after the atomic bombings in 1945. Diseases other than cancer that could be caused by exposure to ionizing radiation (e.g., cataract of the lens of the eye) are not considered in this report.

[2]As defined by the International Commission on Radiological Protection (ICRP 1991), equivalent dose is an average absorbed dose to an organ or tissue of concern modified by a prescribed radiation weighting factor (w_R) for the radiation type that delivers the dose. Equivalent dose was previously called "dose equivalent" by DTRA.

21 cancers that are specified as "presumptive" diseases in VA regulations [38 CFR 3.309(d)(2)]. A presumptive disease is assumed to be service-connected, without regard for the dose received, if adequate proof of participation in a radiation-risk activity is provided. Claims for compensation for cancers that are not presumptive diseases are adjudicated under VA regulations for "nonpresumptive" diseases [38 CFR 3.311]. In all such cases, VA uses estimated upper bounds of equivalent doses provided by DTRA in developing a medical opinion on whether it is at least as likely as not that a veteran's cancer was caused by radiation.[3] Skin and prostate cancer are the most common nonpresumptive cancers in claims of concern to this report.

VA currently uses computer software called the Interactive RadioEpidemiological Program (IREP) (Land et al. 2003; NIOSH 2002) when it is necessary to evaluate whether a veteran's cancer was caused by exposure to ionizing radiation (Mansfield 2005). VA uses IREP to calculate a probability distribution of PC associated with a veteran's upper-bound estimates of equivalent doses, ages at times of exposure, and age at the time of diagnosis of cancer. Probability distributions of PC calculated by IREP take into account uncertainties in estimating an individual's risk of cancer due to radiation exposure and associated PC. VA then compares the upper 99% credibility limit of the probability distribution of PC with the value 50% in evaluating whether it is at least as likely as not that the veteran's cancer was caused by radiation.

VA's current policy of using an upper 99% credibility limit of PC calculated with IREP in evaluating causation of cancers superseded a policy adopted in the late 1980s of using a table of equivalent doses that also corresponded to an estimated upper 99% credibility limit of PC of 50% for a limited number of cancer types. That table was developed by the Committee on Interagency Radiation Research and Policy Coordination (CIRRPC 1988) on the basis of data on risks of cancers that were considered to be radiogenic at the time (NIH 1985). Equivalent doses in the CIRRPC table were referred to as "screening doses," and the same terminology is used in this report to denote equivalent doses that correspond to an estimated upper 99% credibility limit

[3]In other, less common circumstances, VA is required to use estimates of radiation dose in adjudicating claims for compensation for any of the 21 cancers that are presumptive diseases. Estimates of dose must be used if adequate proof of participation in a radiation-risk activity while in service is not available, or if a claimant is seeking compensation to cover a time period prior to the time the veteran's cancer was declared to be presumptive in VA regulations. In all such cases, a claim is adjudicated under the regulations for nonpresumptive diseases.

of PC of approximately 50%. For more than a year prior to adopting a policy of using IREP exclusively, VA evaluated causation of cancers using the CIRRPC table and IREP in parallel when a cancer of concern was included in the CIRRPC table. In all such cases, the method that was more favorable to the claimant was used in adjudicating a claim (VHA/OPHEH 2003; Mather and Otchin 2004).

The primary purpose of this report is to present tabulations of screening doses for many cancer types that we calculated with IREP. Again, a screening dose is an equivalent dose that corresponds to an estimated upper 99% credibility limit of PC of approximately 50% when uncertainties in estimating cancer risk and PC associated with given equivalent doses to an organ or tissue in which a cancer occurred are taken into account. Screening doses calculated with IREP also are compared with screening doses for the limited number of cancer types given in the CIRRPC table, as used previously by VA.

The following section describes how PC is estimated, and it discusses VA's use of the CIRRPC table and IREP to evaluate causation of cancers on the basis of estimates of equivalent dose to an organ or tissue in which a cancer occurred. Section 3 describes models incorporated in IREP to estimate risks of different cancer types due to exposure to ionizing radiation. Information on risk models is intended to be helpful in understanding how screening doses calculated with IREP depend on an individual's age at exposure and age at the time of diagnosis of cancer. Section 4 describes the assumptions used to calculate screening doses and presents tabulations and discussions of screening doses, as well as comparisons with screening doses in the CIRRPC table. An evaluation of the accuracy of screening doses tabulated in this report also is presented. This evaluation is based on the consideration that screening doses calculated with IREP generally do not correspond to an upper 99% credibility limit of PC of exactly 50%. Inaccuracies in screening doses calculated with IREP are due to the randomness of statistical sampling in the method used to estimate uncertainty in cancer risk and PC.

2. APPROACHES TO EVALUATING CAUSATION OF CANCERS

This section presents an overview of approaches to evaluating causation of cancers in individuals who were exposed to ionizing radiation. Section 2.1 describes how PC is estimated and how PC depends on dose. Sections 2.2 and 2.3 discuss the two approaches (i.e., the CIRRPC table and IREP) that have been used by VA in evaluating causation of cancers in veterans who were exposed to radiation.

2.1 Description and Estimation of Probability of Causation

The term "probability of causation" refers to the probability that a diagnosed cancer in an individual was caused by prior exposure to ionizing radiation.[4] PC is defined as:

$$PC = \frac{R}{R + B}\ , \tag{1}$$

where R is the risk (probability) of the cancer of concern due to radiation exposure and B is the baseline (background) risk of that cancer due to all other causes. Risks of most cancers due to radiation exposure are assumed to depend on sex, age at exposure, and attained age (age at a given time); baseline risks generally depend on sex and attained age. Although PC is related to risk and is also a probability, there is an essential difference: whereas risk is the probability that a radiation-induced cancer will occur at some time after an exposure in an individual who is free of that cancer, PC is conditional on the occurrence of cancer.

In IREP, PC is calculated on the basis of an estimate of the excess relative risk (ERR) associated with a given radiation dose to an organ or tissue in which a cancer occurred (Land et al. 2003). ERR is calculated as:

[4]PC is referred to as "assigned share" by Land et al. (2003) to indicate that it is calculated on the basis of estimates of cancer risks obtained in epidemiological studies of exposed populations. Thus, PC is a property of a group to which an individual belongs that is assigned to that individual; it may not be the true PC for that individual.

$$\mathrm{ERR} = \mathrm{RR} - 1 \ , \tag{2}$$

where RR is the relative risk, defined as the risk in an exposed population relative to the risk in a similar unexposed population, given by:

$$\mathrm{RR} = \frac{\mathrm{R} + \mathrm{B}}{\mathrm{R}} \ , \tag{3}$$

Thus, using the definition in eq. (1) and the relations in eqs. (2) and (3), PC is estimated as:

$$\mathrm{PC} = \frac{\mathrm{ERR}}{\mathrm{ERR} + 1} \ . \tag{4}$$

Although PC is a probability and, thus, has a value between 0 and 1, we express PC in percent (e.g., a PC of 0.5 is expressed as 50%) to be consistent with output from IREP.

For any cancer type, ERR is assumed to be an increasing function of dose, without threshold. Risk models for all cancer types incorporated in IREP, except for leukemia under conditions of acute exposure to low-LET radiations (photons or electrons), assume that ERR is a linear function of dose (Land et al. 2003). Thus, in most cases, PC is estimated as:

$$\mathrm{PC} = \frac{\alpha \times D}{(\alpha \times D) + 1} \ , \tag{5}$$

where α is the ERR per unit equivalent dose for a cancer type of concern and D is the equivalent dose to the organ or tissue where that cancer occurs. Risk models for all types of leukemia under conditions of acute exposure to low-LET radiations assume that ERR is a linear-quadratic function of dose given by $\alpha(D + D^2)$ (Land et al. 2003), and PC in these cases is estimated as:

$$\mathrm{PC} = \frac{\alpha \times (D + D^2)}{[(\alpha \times (D + D^2)] + 1} \ . \tag{6}$$

Thus, for any cancer type, PC is a nonlinear function of dose, and the dose corresponding to a given PC increases nonlinearly as the risk, R, and ERR associated with radiation exposure decrease, and vice versa.

2.2 Evaluation of Causation of Cancers Using CIRRPC Table

From the late 1980s until April 2005, VA evaluated causation of some cancers in veterans who were exposed to ionizing radiation using a table of screening doses that was developed by CIRRPC (1988); the CIRRPC table of screening doses, which correspond to an estimated upper 99% credibility limit of PC of 50%, is reproduced in Table 2-1. If an estimated upper bound of the total equivalent dose to an organ or tissue in which a cancer occurred, as provided by DTRA, equaled or exceeded the screening dose obtained from the CIRRPC table that applied to the veteran of concern, VA usually rendered a favorable medical opinion.[5] Screening doses in the CIRRPC table were calculated on the basis of estimates of PC at various equivalent doses obtained from the 1985 Radioepidemiological Tables (NIH 1985)[6] and estimates of uncertainty in cancer risks associated with given equivalent doses in each organ or tissue of concern (CIRRPC 1988). Cancer types for which screening doses were given in the CIRRPC table are those that were considered to be radiogenic on the basis of a statistically significant dose-response in Japanese atomic-bomb survivors and other study populations (NIH 1985). It should be noted that VA did not actually estimate PC when screening doses obtained from the CIRRPC table were used in evaluating causation of cancer.

[5]Comparison of an estimated upper bound of the total equivalent dose with the applicable screening dose obtained from the CIRRPC table was not the only factor that could be considered by VA in formulating a medical opinion on causation of a veteran's cancer. For example, information on a veteran's history of exposure to ionizing radiation and other carcinogens at times other than during participation in a radiation-risk activity also could be considered. Similar considerations apply to VA's use of IREP. However, VA has rarely based its medical opinions on causation of cancer on factors other than screening doses obtained from Table 2-1 or estimates of upper 99% credibility limits of PC calculated with IREP (N. Otchin, Department of Veterans Affairs, personal communication).

[6]The 1985 Radioepidemiological Tables were based on cancer risk models that were developed in the BEIR III report (NRC, 1980) on the basis of data obtained from studies of Japanese atomic-bomb survivors and medical patients who had been exposed mainly to x rays or high-energy gamma rays.

The following points about screening doses in the CIRRPC table are of interest. First, for all cancer types considered, screening doses increased with increasing age at exposure from age 20 to 40 and remained constant thereafter. Those increases were based on data which indicated that risks due to radiation exposure relative to baseline risks declined with increasing age at exposure (NRC 1980). Second, for all cancer types except leukemia, screening doses were independent of the time since exposure when cancer was diagnosed, provided the time between exposure and diagnosis exceeded an assumed minimum latency period. Finally, screening doses for the various types of leukemia were higher at times since exposure when cancer was diagnosed of 20 years or more than at times between exposure and diagnosis less than 20 years. The assumed dependencies on time since exposure were based on data which indicated that risks of radiation-induced leukemia declined nearly to baseline levels at times beyond a few decades after exposure (NRC 1980).

The CIRRPC table did not include screening doses for some cancer types for which an estimate of radiation dose was required in adjudicating claims for compensation. Important examples include skin and prostate cancer. Prior to 2003, VA formulated a medical opinion on causation of such cancers on the basis of information obtained from the medical or epidemiological literature or information provided by the physician who diagnosed the cancer. For example, beginning in the late 1990s, VA evaluated causation of basal cell carcinoma (the most common type of skin cancer) on the basis of an estimate of the lowest equivalent dose at which an excess of that cancer type had been observed in epidemiological studies. That dose was about 9 rem (NRC 1990).

2.3 Evaluation of Causation of Cancers Using IREP

In 2003, VA began using IREP in parallel with the CIRRPC table when an evaluation of causation of cancers was required (VHA/OPHEH 2003; Mather and Otchin 2004), and a policy of using IREP exclusively was adopted in April 2005 (Mansfield 2005). IREP was developed to update and replace the 1985 Radioepidemiological Tables, which provided the basis for screening doses in the CIRRPC table.

In contrast to the CIRRPC table, IREP assumes that all cancers except chronic lymphocytic leukemia (CLL) are radiogenic, including cancers that show only a weak association with exposure to ionizing radiation in Japanese atomic-bomb survivors (Land et al. 2003). IREP also incorporates more recent data on cancer risks due to exposure to ionizing radiation and revised models to estimate ERRs associated with given equivalent doses to specific organs or tissues (Land et al. 2003). IREP calculates a probability distribution of PC associated with given equivalent doses to an organ or tissue in which a cancer occurred. Probability distributions of PC take into account several sources of uncertainty in estimating ERR associated with an individual's radiation exposure, as well as uncertainties in estimated equivalent doses if they are included in input to a calculation.[7] Probability distributions of PC calculated with IREP include an upper 99% credibility limit, which VA compares with the value 50% for the purpose of evaluating causation of cancer in veterans who were exposed to ionizing radiation.

[7]VA does not use uncertainties in estimated equivalent doses provided by DTRA in evaluating causation of cancers. Rather, in accordance with VA regulations [38 CFR 3.311(a)(1)], only estimated upper bounds of equivalent doses, which are intended to be at least upper 95% credibility limits, are used in adjudicating claims for compensation. This approach usually results in a higher estimate of the upper 99% credibility limit of PC than would be obtained by using probability distributions of equivalent doses as input to a calculation. Exceptions could occur only when the uncertainty in the dose is larger than other uncertainties in estimating ERR associated with an individual's given doses. Statistical uncertainties in estimating ERRs in Japanese atomic-bomb survivors and other study populations on the basis of fits to data on dose-response are always important, and uncertainties in transferring ERRs in atomic-bomb survivors to the U.S. population are important for many cancers.

Table 2-1. Screening doses (rem) for specific cancer types calculated by CIRRPC (1988) and used by VA in adjudicating claims for compensation for radiation-induced cancer[a]

Type of cancer	Age at exposure (y)		
	< 20	30	> 40
Chronic granulocytic leukemia[b]			
Within 20 years of exposure[c]	0.9	1.3	1.4
20 or more years post-exposure[c]	2.7	3.2	5.9
Acute leukemia[b]			
Within 20 years of exposure[c]	1.1	1.8	4.1
20 or more years post-exposure[c]	3.5	4.1	5.5
Leukemia (excluding chronic lymphatic)[b,d]			
Within 20 years of exposure[c]	1.1	1.7	3.3
20 or more years post-exposure[c]	3.3	3.9	5.5
Colon cancer	17.0	33.1	58.1
Esophageal cancer	3.9	9.9	16.7
Female breast cancer	18.8	37.0	78.6
Kidney and bladder cancer	13.4	23.1	34.7
Liver cancer	1.0	3.3	8.2
Lung cancer			
Known smokers[e]	25.5	48.8	72.1
Others[f]	4.3	9.3	15.0
Pancreatic cancer	5.8	13.7	24.3
Stomach cancer	6.9	13.8	23.2
Thyroid cancer	3.3	7.4	8.8

See following page for footnotes to table.

Footnotes to Table 2-1

[a]Adapted from Table 3 of CIRRPC (1988). Screening doses were developed on the basis of the 1985 Radioepidemiological Tables (NIH 1985) for cancer types that were considered to be radiogenic. Screening doses corresponded to an estimated upper 99% credibility limit of PC of 50% when uncertainties in estimating cancer risks associated with given equivalent doses in each organ or tissue of concern were taken into account. Screening doses for ages at exposure between 20 and 30 years or 30 and 40 years should be obtained by linear interpolation.

[b]Dose to active bone marrow.

[c]Time since exposure when cancer was diagnosed.

[d]Cancer type refers to all leukemia as a group and was assumed when the diagnosed leukemia was not a particular type listed separately.

[e]Category applied when the veteran was known to have been a regular smoker (10 or more cigarettes per day) within five years of diagnosis. Screening doses were calculated by assuming that the veteran was a member of an average U.S. population that included smokers and nonsmokers.

[f]Category applied when the veteran's smoking habits were unknown, the veteran was known to have stopped smoking five years or more before diagnosis, or the veteran was known to be a nonsmoker. Screening doses were calculated by assuming that the veteran was a nonsmoker.

3. CANCER RISK MODELS INCORPORATED IN IREP

This section describes models incorporated in IREP to estimate ERRs for specific cancers that are associated with given doses of ionizing radiation to organs or tissues in which those cancers occur. These discussions are intended to be helpful in understanding how screening doses calculated with IREP depend on an individual's age at exposure and age at diagnosis. Risk models for all cancer types are described in detail elsewhere (Land et al. 2003; NIOSH 2002). Except as noted, risk models discussed in this section are incorporated in versions of IREP that were developed by the National Institute for Occupational Safety and Health (NIOSH) for use in the Department of Labor's compensation program for workers at Department of Energy facilities. Versions of IREP developed by NIOSH have been used by VA in evaluating causation of cancers in veterans who were exposed to ionizing radiation.

3.1 Categories of Cancer Risk Models

Cancer risk models incorporated in IREP are categorized into four groups, as summarized in Table 3-1. Use of a variety of risk models for cancer types other than leukemia contrasts with models for those cancer types incorporated in CIRRPC screening doses, which assumed that risks decrease with increasing age at exposure from age 20 to 40 but are independent of attained age (NIH 1985). Another difference involves assumed dependencies of cancer risks on dose. In IREP, a linear relationship between dose and risk is assumed, except a linear-quadratic relationship is assumed for all types of leukemia under conditions of acute exposure to low-LET radiations (Land et al. 2003). In risk models that were used to calculate screening doses in the CIRRPC table, a linear dose-response relationship was assumed for breast and thyroid cancer but a linear-quadratic relationship was assumed for all other cancer types (NIH 1985).

Risk models for cancer types in each category are discussed in the following sections, except the model for lung cancer due to exposure to radon (Group 4) is not discussed because exposure to radon is not a concern in VA radiation claims. An implicit assumption in these discussions is that the time since exposure is sufficiently long that the minimum latency period

does not have a significant effect on estimated risks. Assumptions in IREP about the minimum latency period for each cancer type are discussed in Section 3.2.

3.1.1 *Group 1 Cancers*

For cancer types in Group 1, ERR is assumed to depend on age at exposure and attained age. For a given age at exposure, ERR decreases linearly with increasing attained age to age 50 and remains constant thereafter. For a given attained age, ERR decreases exponentially between ages at exposure of 15 and 30 and remains constant outside that interval. The model includes a cancer-specific parameter to modify the assumed linear dose-response relationship, and dependencies of ERR on age at exposure and attained age are modified by parameters that also are assumed to be cancer-specific. The various model parameters are assumed to be strongly correlated on the basis of data for the relatively large number of cases of these cancer types in Japanese atomic-bomb survivors. The model for breast cancer is based on data in females and is assumed to apply to males as well.

In modeling the dose-response for cancer types in Group 1 in Japanese atomic-bomb survivors, only ERRs for all digestive cancers other than stomach, colon, and rectum are assumed to depend on sex; ERRs for liver cancer are the same in males and females. However, in applying estimated ERRs for liver cancer, as well as breast cancer in females, to the U.S. population, sex-specific baseline risks were taken into account (Land et al. 2003).

3.1.2 *Group 2 Cancers*

The risk model for cancer types in Group 2 is similar to the model for Group 1 cancers. Specifically, ERR for a given age at exposure decreases linearly with increasing attained age to age 50 and remains constant thereafter, and ERR for a given attained age decreases exponentially between ages at exposure of 15 and 30 and remains constant outside that interval. However, because there have been fewer cases of Group 2 cancers in Japanese atomic-bomb survivors, the cancer-specific parameter that modifies the assumed linear dose-response relationship was found

to be practically independent of cancer-specific parameters that modify the assumed dependencies of ERR on age at exposure and attained age (Land et al. 2003). Therefore, the model for Group 1 cancers is replaced by an approximation in which the parameters that modify the dependencies of ERR on age at exposure and attained age are assumed to be the same for all cancer types. The model for lung cancer in Group 2 also depends on an individual's smoking history.[8] As discussed in the following two sections, an alternative model for lung cancer in Group 3 is included in the version of IREP currently used by NIOSH.

For all cancer types in Group 2 that occur in males and females, ERRs in Japanese atomic-bomb survivors are assumed to depend on sex (Land et al. 2003). As with all cancer types in Group 1, sex-specific baseline risks were taken into account in transferring ERRs in atomic-bomb survivors to the U.S. population.

3.1.3 *Group 3 Cancers*

For cancer types in Group 3, ERR is assumed to be independent of age at exposure and attained age. A dependence of ERR on sex similar to the sex-dependence in the risk model for cancer types in Group 2 is assumed in the model for lung cancer in Group 3.

3.1.4 *Risk Models for Lung Cancer*

As indicated in Table 3-1, two different risk models for lung cancer are incorporated in the version of IREP currently used by VA. In the model described by NIOSH (2002), ERR for lung cancer is assumed to be independent of age at exposure and attained age, and lung cancer is included in Group 3. In the model developed more recently by the National Institutes of Health (NIH), ERR for lung cancer is assumed to depend on age at exposure and attained age (Land et al. 2003), and lung cancer is included in Group 2. In addition, although both models use the

[8] In cases of exposure to sources other than radon, IREP calculates ERRs for lung cancer for the following smoking categories: never-smokers, former smokers, current smokers with an unspecified consumption rate of cigarettes, and four categories of current smokers defined by the number of cigarettes smoked per day.

same categories of smoking history for an exposed individual, the two models use somewhat different approaches to calculating ERR in the different categories.[9]

The version of IREP currently used by VA calculates PC using both models for lung cancer, and the higher estimate of PC at the upper 99% credibility limit is emphasized in the output from IREP. As indicated by screening doses tabulated in this report, the model that gives the higher upper 99% credibility limit of PC depends on smoking history and the time since exposure when cancer was diagnosed (see Section 4.1.3).

3.1.5 *Group 4 Cancers*

Cancer types in Group 4 each have a unique risk model. The model for each cancer type in this group is described in the following paragraphs.

Two models are assumed for skin cancers. ERRs for basal cell carcinoma decrease exponentially with increasing age at exposure to age 40 and remain constant thereafter, but are independent of attained age; the model for basal cell carcinoma also is applied to malignant melanoma, for which there were too few cases in Japanese atomic-bomb survivors to establish a dose-response relationship (Land et al. 2003). ERRs for non-melanoma skin cancers other than basal cell carcinoma (e.g., squamous cell carcinoma) are independent of age at exposure and attained age. ERRs for all skin cancers are independent of sex but depend on race or ethnicity.[10] Differences in baseline risks of skin cancers in different racial and ethnic groups are taken into account in the transfer of ERRs in Japanese atomic-bomb survivors to the U.S. population.

ERR for thyroid cancer decreases exponentially with increasing age at exposure to age 50 and remains constant thereafter, but is independent of attained age and sex.

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[9]The two models estimate ERR for lung cancer using the same smoking-related adjustment factors but apply them differently. In the model for lung cancer in Group 3, adjustments for smoking history are applied to an estimated ERR that is an average over all smoking categories. In the model for lung cancer in Group 2, those adjustments are applied to an estimated ERR in never-smokers only.

[10]IREP calculates ERRs for skin cancers for the following racial or ethnic groups: American Indians or Alaska natives; Asians, native Hawaiians, or other Pacific islanders; blacks; white Hispanics; and white non-Hispanics. ERRs for all other cancer types are assumed to be independent of race or ethnicity.

ERR for all leukemia as a group, excluding CLL,[11] decreases exponentially with increasing age at exposure to age 55 and increasing time since exposure to 50 years, and remains constant thereafter. The effect of time since exposure on ERR is similar to the effect that is incorporated in screening doses for various types of leukemia in the CIRRPC table (see Section 2.2). Modifications of this model are used for specific types of leukemia. ERRs for acute myeloid leukemia (AML) and chronic myeloid leukemia (CML) are independent of age at exposure, and the exponential decrease in ERR for CML with increasing time since exposure is faster in males than in females. ERR for acute lymphocytic leukemia (ALL) decreases exponentially with increasing time since exposure when exposure occurs before age 20, but is independent of time since exposure when exposure occurs at age 20 or beyond. ERRs for AML, ALL, and all leukemia as a group are independent of sex.

3.2 Minimum Latency Period for Different Cancer Types

Descriptions of risk models for different cancer types in Section 3.1 presume that the time between exposure and diagnosis of cancer exceeds the minimum latency period for each cancer type. The minimum latency period is the elapsed time between exposure to a hazardous agent and the earliest occurrence of detectable disease caused by that agent. In IREP, the effect of the minimum latency period on cancer risks due to radiation exposure is assumed to be represented by an S-shaped (sigmoid) function of time that increases from 0 shortly after exposure to 1 at a time when latency no longer has an effect on estimated risks (Land et al. 2003; NIOSH 2002).[12] The value of this function is 0.5 at the midpoint between the two times. Thus, the effect of the minimum latency period is to rapidly decrease estimates of cancer risk as the time since exposure decreases below times at which the S-shaped function has values near 1.

[11]Although CLL is not considered to be a radiogenic cancer in IREP, VA estimates PC in cases of CLL by assuming that CLL is a form of non-Hodgkin's lymphoma and uses the risk model for lymphoma and multiple myeloma in Group 2 (N. Otchin, Department of Veterans Affairs, personal communication; April 18, 2006).

[12]The assumption of an S-shaped function takes into account that the minimum time required for radiation exposure to result in an increase in cancer risk is difficult to estimate, and it avoids an assumption of an abrupt increase in risk at some time after exposure.

One of three parameterizations of the S-shaped function is assumed to represent the effect of latency on risk, depending on the cancer type (Land et al. 2003). For all solid tumors except thyroid and bone cancer, the minimum and maximum values of 0 and 1 in the S-shaped function are essentially attained at times after exposure less than 4 years and greater than 11 years, respectively (i.e., the values at 4 and 11 years are 0.01 and 0.99), and the midpoint is at 7.5 years. This function is given by the solid curve in Fig. 3-1; it is also used to represent the minimum latency period for lymphoma and multiple myeloma. For thyroid and bone cancer, which have a shorter minimum latency period than other solid tumors, the minimum and maximum values in the S-shaped function are essentially attained at times after exposure less than 2 years and greater than 7 years, respectively, and the midpoint is at 4.5 years. For all types of leukemia, which have a shorter minimum latency period than all other cancer types, the minimum and maximum values in the S-shaped function are essentially attained at times after exposure less than 1 year and about 5 years, respectively, and the midpoint is at 2.25 years.

To represent uncertainty in the assumed effects of the minimum latency period on cancer risks, the midpoint of each S-shaped function described above is represented by a triangular probability distribution that has a maximum value at 7.5, 4.5, or 2.25 years and ranges from 5 to 10 years, 4 to 5.5 years, or 2 to 2.5 years, respectively (Land et al. 2003). The effect of the assumed uncertainty in the midpoint of the S-shaped function for all solid cancers except thyroid and bone cancer is also shown in Fig. 3-1. For all cancer types, this uncertainty results in substantial increases in estimates of ERR and PC at times after exposure less than the midpoints of the triangular distributions, compared with estimates obtained by assuming no uncertainty in the S-shaped function (Land et al. 2003). Effects of this uncertainty on estimates of ERR and PC are less at times after exposure beyond the midpoints of the triangular distributions.

Table 3-1. Categories of cancer risk models incorporated in IREP[a]

Category	Cancer types	Description of risk model
Group 1	All digestive cancers other than stomach, colon, and rectum; stomach (female only); liver; breast	Risk depends on age at exposure, attained age, and sex (all digestive cancers other than stomach, colon, and rectum only).
Group 2	Oral cavity and pharynx; esophagus; stomach (male only); colon; rectum; gallbladder; pancreas; lung (including trachea and bronchus)[b]; respiratory other than lung (e.g., nasal cavity, larynx); bone; all connective tissue; ovary; all male genitalia (including prostate); bladder; kidney and other urinary organs except bladder; eye; nervous system (including brain); endocrine glands other than thyroid; other and ill-defined sites; lymphoma and multiple myeloma	Risk depends on age at exposure, attained age, and sex, but model structure describing dependencies on age at exposure and attained age is different from model for cancer types in Group 1; risk of lung cancer also depends on smoking history.
Group 3	Lung (including trachea and bronchus)[b]; all female genitalia except ovary	Risk is independent of age at exposure and attained age; risk of lung cancer depends on sex and smoking history.
Group 4	Malignant melanoma and non-melanoma skin cancers (basal cell carcinoma and others including squamous cell carcinoma)[c]; thyroid; leukemia (other than chronic lymphocytic leukemia, CLL), acute myeloid leukemia (AML), chronic myeloid leukemia (CML), and acute lymphocytic leukemia (ALL); lung cancer due to exposure to radon	Unique risk model for each cancer type.

[a]Risk models, excluding model for lung cancer due to exposure to radon, are discussed in Section 3.1. All cancers except CLL are considered to be radiogenic in IREP.

[b]Risk model for lung cancer in Group 2 was developed by Land et al. (2003), whereas a different model in Group 3 was used originally by NIOSH (2002). Both risk models for lung cancer are incorporated in the version of IREP currently used by VA.

[c]Risks of skin cancers depend on race or ethnicity.

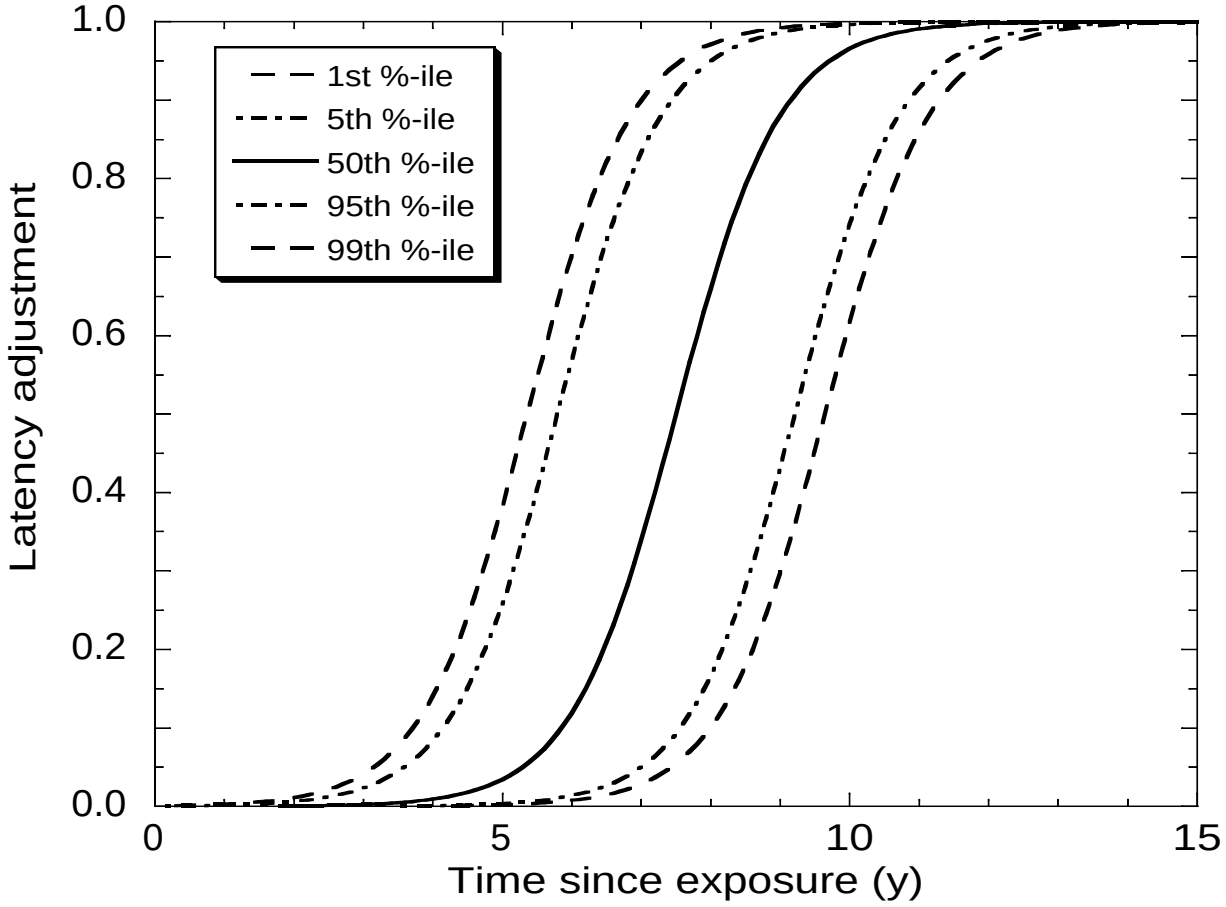

Figure 3-1. S-shaped (sigmoid) function assumed in IREP to represent effect of minimum latency period on reducing risks of all solid cancers except thyroid and bone cancer at early times since exposure and its uncertainty.

4. SCREENING DOSES CALCULATED WITH IREP

This section presents screening doses for different cancer types that were calculated with IREP. These screening doses are tabulated and discussed in Section 4.1. In Section 4.2, screening doses calculated with IREP are compared with previous screening doses in the CIRRPC table (see Table 2-1). Use of tabulated screening doses in cases of exposure to multiple radiation types or exposures in more than one year is discussed in Section 4.3. A summary of important points about screening doses tabulated in this report is given in Section 4.4.

4.1 Tabulation and Discussion of Screening Doses

Screening doses for different cancer types that were calculated with IREP are given in Tables 4-1 through 4-34.[13] Screening doses were calculated for selected ages at exposure and times since exposure when cancer is diagnosed. The latter quantity is given by the difference between the age at diagnosis and age at exposure. Screening doses were estimated by iteration using constant equivalent doses, with no uncertainty, as input to IREP. For reasons discussed in Section 4.1.2, all screening doses are given to two significant figures.

Sections 4.1.1 and 4.1.2 discuss assumptions used in calculating screening doses and the accuracy of the results. Section 4.1.3 then discusses screening doses for specific cancer types.

4.1.1 *Calculation of Screening Doses*

With one exception, screening doses in Tables 4-1 through 4-34 were calculated with versions of IREP that were developed by NIOSH (2002);[13] versions developed by NIOSH have been used by VA in evaluating causation of cancers in veterans who were exposed to ionizing radiation. Screening doses for lung cancer in Table 4-11 were calculated with a version of IREP

[13]Most calculations were performed using Version 5.4 of NIOSH-IREP. Screening doses for thyroid and bone cancer were calculated using Version 5.5, which incorporated recent changes in models used to estimate ERRs for those cancer types.

that was developed by NIH (Land et al. 2003).[14] As discussed in Section 3.1.4, the current version of NIOSH-IREP incorporates both risk models for lung cancer.

IREP calculates probability distributions of PC by repeated random sampling of probability distributions that represent uncertainties in all parameters and propagation of the randomly selected parameter values through the models used to estimate ERR and PC.[15] Probability distributions of PC generated in IREP include an upper 99% credibility limit, which is used to estimate the screening dose in each case. All screening doses were calculated using 2000 iterations per run, and the random seed to initiate the sampling process was set to 99. These are the default settings in NIOSH-IREP and are generally used by VA.

All calculations of screening doses assumed acute exposure to high-energy (> 250 keV) photons or, in cases of skin cancer, acute exposure to higher-energy (>15 keV) electrons; the latter assumption gives the same PC as an assumption of acute exposure to high-energy photons.[16] An assumption of acute exposure to photons or electrons results in a higher estimate of PC than an assumption of chronic exposure,[17] due to the influence of a dose and dose-rate

[14]Calculations were performed using Version 5.3 of NIH-IREP.

[15]The technique of random sampling used in IREP is a form of Monte Carlo sampling referred to as midpoint Latin hypercube sampling. In this method, probability distributions of model parameters are divided into N intervals of equal probability, where N is the number of iterations per run, and values at the midpoints of each of the N intervals are selected in random order. Use of Latin hypercube sampling assures that the entire range of probability distributions of all parameters is sampled. This technique thus gives a more robust probability distribution of PC for a given number of iterations, especially at an upper credibility limit, than conventional Monte Carlo sampling in which parameter values are selected at random in each iteration without regard for previously sampled values.

[16]It is intended that doses will be entered into IREP by radiation type. Equivalent doses for the following radiation types can be entered: photons of energy < 30 keV, 30-250 keV, and > 250 keV; electrons of energy < 15 keV and > 15 keV; neutrons of energy < 10 keV, 10-100 keV, 0.1-2 MeV (including spectra of fission neutrons), 2-20 MeV, and > 20 MeV; and alpha particles of any energy emitted in radioactive decay (Land et al. 2003). When equivalent doses are entered by radiation type, the biological effectiveness of each radiation type relative to reference high-energy (> 250 keV) photons and its uncertainty are taken into account in calculating probability distributions of PC.

[17]To follow guidance by NIOSH (2002), VA assumes that all external exposures to photons or electrons are acute, because that assumption is more favorable to claimants than an assumption of chronic exposure (N. Otchin, Department of Veterans Affairs, personal communication; April 26, 2006).

effectiveness factor (DDREF) in reducing risks from chronic exposure to those radiation types (Land et al. 2003).[18] Use of screening doses in cases of exposure to other radiation types is discussed in Section 4.3.1.

Screening doses for ages at exposure or times since exposure when cancer was diagnosed that are not included in the tables can be estimated by interpolation. Two-dimensional linear interpolation should be adequate when screening doses are not changing rapidly. In the tables of screening doses, this condition is met when the time since exposure is more than 3 years for all types of leukemia, 5 years for thyroid and bone cancer, and 10 years for all other cancer types. Of course, the more precise option of running IREP for specific cases is always available. This option is recommended when the time since exposure is sufficiently short that the minimum latency period has an effect on reducing estimates of ERR and increasing screening doses.

Except for cancers of the female breast, ovary, and all female genitalia except ovary, tabulated screening doses apply to males only. For cancer types in Groups 1, 2, or 3 that occur in males and females and for chronic myeloid leukemia (CML) in Group 4 (see Table 3-1), ERRs are assumed to depend on sex, and screening doses for females differ from values for males.[19]

4.1.2 *Accuracy of Calculated Screening Doses*

As noted previously, all screening doses in Tables 4-1 through 4-34 are presented to two significant figures only. More specifically, each screening dose is the lowest equivalent dose to two significant figures at which the calculated upper 99% credibility limit of PC is 50% or greater. Thus, a screening dose is not necessarily the equivalent dose at which the calculated

[18]Probability distributions of DDREF with mean values greater than 1.0 are used in IREP to estimate ERRs for all cancer types, except leukemia, from chronic exposure to photons or electrons. For acute exposure to those radiation types, DDREF is phased in as the dose decreases below an uncertain reference dose between 3 and 20 rem and approaches the assumed DDREF for chronic exposure as the dose decreases toward zero (Land et al. 2003). A DDREF also is implicit in the assumed linear-quadratic dose-response relationship for leukemia under conditions of acute exposure to photons or electrons.

[19]Screening doses for males and females may differ even when ERRs in Japanese atomic-bomb survivors are independent of sex, because baseline risks used in modeling the transfer of ERRs to the U.S. population may be sex-specific (Land et al. 2003).

upper 99% credibility limit of PC is closest to 50%.[20] By using this approach, an equivalent dose (to two significant figures) less than an applicable screening dose corresponds to a calculated upper 99% credibility limit of PC less than 50% when the default settings of 2000 iterations per run and a random seed of 99 are used.

Reporting of screening doses to no more than two significant figures can be justified by considering the accuracy of the calculations. If the number of iterations per run is fixed at the default setting of 2000, a change in the random seed can have a substantial effect on the calculated upper 99% credibility limit of PC. This effect is illustrated by calculations we performed with Version 5.5 of NIOSH-IREP, in which an equivalent dose that gave an upper 99% credibility limit of PC close to 50% for particular combinations of cancer type, age at exposure, and attained age were assumed; some of these combinations were selected with the intent of maximizing the effect of a change in the random seed.[21] By performing calculations at the same equivalent dose but using up to 50 different random seeds, the maximum variation in

[20]If, for example, an equivalent dose (to two significant figures) of 110 rem gives an upper 99% credibility limit of PC of 49.96% and an equivalent dose of 120 rem gives a value of 51.23%, the tabulated screening dose would be 120 rem.

[21]Calculations were performed for the following combinations of cancer type, age at exposure (ae), and age at diagnosis of cancer (ad): (1) liver cancer, ae = 18 and ad = 28; (2) cancers of the respiratory tract other than lung cancer, ae = 18 and ad = 28; (3) non-melanoma basal cell carcinoma (white, non-Hispanics), ae = 18 and ad = 70; (4) basal cell carcinoma (white, non-Hispanics), ae = 40 and ad = 70; (5) cancers of all male genitalia (including prostate), ae = 20 and ad = 70; (6) thyroid cancer, ae = 18 and ad = 60; and (7) all leukemia excluding CLL, ae = 18 and ad = 70. The first two calculations apply to the cancer types in Group 1 and Group 2 (see Section 3.1 and Table 3-1) for which uncertainties in the estimated ERR per unit equivalent dose are the highest (Land et al. 2003) and, thus, calculated upper 99% credibility limits of PC at a fixed dose are among the most sensitive to changes in the random seed. The age at exposure and age at diagnosis in those two calculations were chosen to maximize the effect of changes in the random seed. Calculations for basal cell carcinoma and prostate cancer were included because these are the most common types of nonpresumptive cancers in VA radiation claims of concern to this report. The ages at exposure and ages at diagnosis in the calculations for those two cancer types were selected to represent a variety of likely combinations and, in the first calculations for basal cell carcinoma, to maximize the effect of changes in the random seed. Calculations for thyroid cancer and leukemia were included to investigate the effect for cancer types other than skin cancer with unique risk models (see Section 3.1.5). In all calculations, the equivalent dose was fixed at the applicable screening dose given in Table 4-7, 4-12, 4-16, 4-22, 4-27, or 4-31.

the upper 99% credibility limit of PC about the nominal value of 50% was ±3.0 percentage points, or ±6.0% of the nominal value of 50%.[22,23]

For the purpose of estimating screening doses, we are interested in the variation in the dose that gives a calculated upper 99% credibility limit of PC of 50% due to a change in the random seed in IREP, rather than the variation in an upper 99% credibility limit of PC of about 50% at a fixed dose. Since PC is a nonlinear function of dose (see Section 2.1), the two variations are not the same. Our analysis of the variation of interest is described as follows.

We define the variation in PC due to a change in the random seed as $\Delta(PC)/PC$ and the corresponding variation in dose as $\Delta D/D$. When ERR is a linear function of dose, as in all risk models incorporated in IREP except the model for all types of leukemia under conditions of acute exposure to photons and electrons (Land et al. 2003), PC is estimated using eq. (5). By differentiating eq. (5) with respect to dose and taking into account that $\alpha \times D = 1$ at a PC of 50%, we find that when PC is about 50%, a variation in PC of x at a fixed dose corresponds to a variation in dose of $2x$ at a fixed PC of 50%. This result means that a screening dose is twice as sensitive to a change in the random seed as the upper 99% credibility limit of PC of about 50% at a fixed dose.[24] Thus, in the example calculations discussed above, in which the maximum variation in the upper 99% credibility limit of PC was ±6.0% of the nominal value of 50% at a fixed dose, the corresponding variation in the equivalent dose that gives an upper 99% credibility

[22]The maximum variation was obtained in the calculations for liver cancer. In all calculations for basal cell carcinoma and prostate cancer, the variation in PC was no more than about ±2.2 percentage points, or ±4.4% of the nominal value of 50%.

[23]The variation in the upper 99% credibility limit of PC at a fixed dose due to a change in the random seed is reduced by increasing the number of iterations per run. When the number of iterations per run was increased to 10,000, which is the maximum normally allowed in IREP, the maximum variation in the upper 99% credibility limit of PC was about ±1 percentage point, or about ±2% of the nominal value of 50%. We used 2000 iterations per run in all calculations to conform to the default used by VA.

[24]When ERR is assumed to be a linear-quadratic function of dose, as in the risk models incorporated in IREP for various types of leukemia under conditions of acute exposure to photons and electrons (Land et al. 2003), the same method can be used to show that a screening dose is less than twice as sensitive to a change in the random seed as an upper 99% credibility limit of PC of about 50% at a fixed dose. Thus, a linear dose-response relationship provides the bounding case for the sensitivity of a screening dose to a change in the random seed.

limit of PC of 50% (i.e., the maximum variation in the screening dose) is ±12%. This result applies to the cancer type, age at exposure, and age at time of diagnosis for which the effect is expected to be the greatest. The maximum variation in a screening dose due to a change in the random seed is less for other cancer types, ages at exposure, and ages at diagnosis.[25]

The choice of a random seed to be used as a default in IREP is arbitrary. Therefore, results of the analysis described above indicate that reporting of screening doses calculated with IREP to more than two significant figures when the default number of iterations per run and random seed are used would imply an accuracy in the calculations that is unwarranted.

An important implication of the analysis described above is that screening doses tabulated in this report should be interpreted with caution. Although the tabulated screening doses are intended to correspond to an upper 99% credibility limit of PC of 50%, this correspondence clearly is not exact. Thus, it is not necessarily the case that an estimated equivalent dose (to two significant figures) equal to or greater than a screening dose tabulated in this report corresponds to an actual upper 99% credibility limit of PC of 50% or greater, nor is it necessarily the case that an estimated equivalent dose less than a screening dose corresponds to an actual upper 99% credibility limit of PC less than 50%.[26]

Results of our analysis of the sensitivity of screening doses to the choice of a random seed also indicate the extent to which a screening dose tabulated in this report could differ from the equivalent dose that corresponds to an actual upper 99% credibility limit of PC of 50%. As

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[25]The maximum variation in a calculated upper 99% credibility limit of PC due to a change in the random seed in IREP can be much higher than obtained in our analysis if the equivalent dose is assumed to be uncertain, rather than fixed at a single value. For example, in a calculation in which the uncertainty in an estimated dose was represented by a geometric standard deviation (GSD) of 3 and the median dose was set at a value that gave an upper 99% credibility limit of PC close to 50%, the maximum variation in the upper 99% credibility limit of PC due to changes in the random seed was nearly ±10% of the nominal value of 50% (B.A. Thomas, SENES Oak Ridge, Inc., personal communication; March 9, 2006). An assumption of a fixed dose is appropriate for our analysis when VA uses point estimates of equivalent dose in evaluating causation of cancer (see Section 2.3, footnote 6).

[26]An actual upper 99% credibility limit of PC would only be obtained by specifying a very large (essentially infinite) number of iterations per run. When the number of iterations is very large, the choice of a random seed no longer has an effect on the calculated probability distribution of PC, essentially because nearly all possible combinations of parameter values are selected by random sampling.

derived above, the largest difference between a calculated screening dose and its actual value should be no more than ±12%. Furthermore, the greatest effect of a change in the random seed was obtained in the calculations for liver cancer that assumed a very young age at the time of diagnosis of cancer (see footnote 21). Such a young age at diagnosis should rarely, if ever, occur in VA radiation claims of concern to this report. For more common ages at diagnosis, the difference between a calculated screening dose and the equivalent dose that corresponds to an actual upper 99% credibility limit of PC of 50% should be less than ±10%.[27]

4.1.3 *Discussion of Screening Doses*

Screening doses in Tables 4-1 through 4-34 show certain dependencies on age at exposure and time since exposure when cancer was diagnosed (i.e., difference between age at diagnosis and age at exposure). The following discussion of these dependencies assumes that the time since exposure when cancer was diagnosed is sufficiently long that assumptions about the minimum latency period described in Section 3.2 do not have a significant effect on estimates of ERR and PC. When the time since exposure is short (e.g., less than the midpoint of the S-shaped function that is assumed to represent the effect of the minimum latency period on risk), screening doses increase rapidly with decreasing time since exposure.

For all cancer types in Groups 1 and 2 (see Table 3-1), which are the majority of cancer types considered in IREP, screening doses increase with increasing age at exposure and time since exposure when cancer was diagnosed until a plateau region is reached, where screening doses are constant. These dependencies are the result of assumptions about the dependence of ERRs on age at exposure and attained age, as described in Section 3.1. In most such cases, the minimum screening dose for any age at exposure occurs at a time since exposure when cancer

[27]When more common ages at diagnosis that apply to recent or future VA radiation claims are considered (e.g., an age at diagnosis of at least 50), additional calculations indicated that the largest difference between a screening dose tabulated in this report and the equivalent dose that corresponds to an actual upper 99% credibility limit of PC of 50% is greatly reduced for cancer types in Groups 1 and 2 (see Section 3.1 and Table 3-1), including liver cancer. The calculation that gives the largest difference then becomes basal cell carcinoma for an age at exposure of 18, and the maximum difference between a screening dose and its actual value for that cancer type should not exceed about ±9%.

was diagnosed of about 10 years or less, depending on the assumption about the effect of the minimum latency period on risk (see Section 3.2). Further discussion of screening doses for selected cancer types is provided in the following paragraphs.

Lung cancer. Screening doses for lung cancer in Tables 4-10 and 4-11 were calculated using different risk models (see Section 3.1.4). For younger ages at exposure and earlier times since exposure when cancer was diagnosed, screening doses in Table 4-11 often are substantially lower than the corresponding values in Table 4-10. This difference is explained by the following: screening doses in Table 4-10 were calculated on the basis of an estimate of the average ERR associated with radiation exposure in a population of all ages, and that ERR is substantially lower than estimated ERRs for younger ages at exposure and earlier attained ages that were used in calculating screening doses at those ages in Table 4-11. For never-smokers, however, screening doses in Table 4-11 are substantially higher than the corresponding screening doses in Table 4-10 for ages at exposure beyond about 25 and times since exposure beyond about 15 years. At those ages and times, age-specific ERRs used to calculate screening doses for never-smokers in Table 4-11 are lower than the average ERR for never-smokers in a population of all ages.

Skin cancer. Skin cancers are the only cancer types for which risks due to radiation exposure are assumed to depend on race or ethnicity. Screening doses for basal cell carcinoma (Table 4-16) and squamous cell carcinoma (Table 4-17) are about a factor of 2 higher in white, non-hispanics than in blacks. For malignant melanoma, however, screening doses (Table 4-15) are less dependent on race or ethnicity.

Breast cancer. Screening doses for breast cancer in males (Table 4-19) are slightly lower than the corresponding values for females (Table 4-18). Even though the risk model for breast cancer is the same for both sexes, there are differences in uncertainties in baseline risks in the two sexes that affect upper 99% credibility limits of PC for an individual in the U.S. population.

Thyroid cancer. Screening doses for thyroid cancer (Table 4-27) increase more slowly with increasing age at exposure than screening doses for other solid tumors. In this case, an increase in uncertainty in ERR with increasing age at exposure (Land et al. 2003) has a substantial effect on upper 99% credibility limits of PC. In addition, screening doses are

constant for ages at exposure beyond 50, even though ERR for thyroid cancer is expected to decrease with increasing age at exposure beyond age 50. However, the number of thyroid cancers in this age group in Japanese atomic-bomb survivors was judged to be too small to establish a dependence of ERR on age at exposure, and ERR for thyroid cancer is assumed to be independent of age at exposure beyond age 50 (Land et al. 2003).

Leukemia. A noteworthy characteristic of screening doses for all leukemia excluding CLL (Table 4-31) is that values in the lower-right portion of the table decrease with increasing age at exposure and time since exposure when cancer was diagnosed. This behavior is seen even though ERR associated with radiation exposure is assumed to decrease exponentially with increasing age at exposure to age 55 and time since exposure to 50 years. In the portion of Table 4-31 where this behavior is seen, the uncertainty in the estimated ERR is increasing more rapidly with increasing age at exposure and time since exposure than the corresponding decrease in the central estimate of ERR (Land et al. 2003), resulting in increases in upper 99% credibility limits of PC.

Screening doses for acute lymphocytic leukemia (ALL) (Table 4-33) show a pronounced increase as the age at exposure increases from 18 to 20, provided the time since exposure when cancer was diagnosed is about 20 years or less. Those large increases do not result from an assumption that the ERR for ALL associated with radiation exposure decreases greatly when the age at exposure increases by only 2 years. Rather, screening doses for an age at exposure of 18 were calculated on the basis of an average ERR for all ages at exposure up to age 20, and that ERR is determined primarily by the high ERRs in infants and children when ERR is assumed to decrease exponentially with increasing age at exposure.

4.2 Comparison with Screening Doses in CIRRPC Table

For cancer types included in the CIRRPC table (Table 2-1), the corresponding screening doses calculated with IREP usually are higher. Those increases are due in part to reductions in uncertainties in estimated ERRs in exposed populations, mainly Japanese atomic-bomb survivors, as the number of cancers on those populations has increased over time. A decrease in

uncertainty in an estimated ERR results in a decrease in uncertainty in PC and, therefore, an increase in the equivalent dose corresponding to an upper 99% credibility limit of PC.

In a few cases, a lower screening dose was calculated with IREP compared with the corresponding screening dose obtained from the CIRRPC table. These cases include: colon cancer and breast cancer for ages at exposure of about 20 years or less and times since exposure when cancer was diagnosed of about 10-15 years, and acute lymphocytic leukemia (ALL) for ages at exposure less than 20 years and times since exposure less than about 10 years. In those cases, changes in data and assumptions used to estimate ERRs other than reductions in uncertainties in estimated ERRs in Japanese atomic-bomb survivors are important. Depending on the cancer type, important changes may include: (a) increases in central estimates of ERR, (b) differences in assumptions about the transfer of ERRs in atomic-bomb survivors to the U.S. population to account for differences in baseline risks in the two populations, and (c) a change from a linear-quadratic dose-response relationship, as used to calculate screening doses for most cancers in the CIRRPC table, to a linear relationship and a DDREF at low doses and low dose rates in IREP (Land et al. 2003; NIH 1985). However, a change in the dose-response relationship is not relevant for breast cancer, since a linear relationship was assumed previously. Furthermore, a change from a linear-quadratic relationship to a linear relationship with a DDREF for solid tumors does not apply to any type of leukemia (excluding CLL), since a linear-quadratic dose-response relationship for those cancer types was assumed previously and is assumed in IREP under conditions of acute exposure to low-LET radiations.

Although screening doses calculated with IREP are higher in most cases than the corresponding screening doses obtained from the CIRRPC table, increases in screening doses should affect compensation decisions in only a small fraction of VA claims. All cancers included in the CIRRPC table are presumptive diseases in VA regulations [38 CFR 3.309(d)(2)]. Therefore, except as noted in Section 1 (see footnote 2), adjudication of claims for compensation for those cancers does not require an evaluation of causation. Screening doses for the most common cancers in VA radiation claims (basal cell carcinoma and prostate cancer) are not included in the CIRRPC table. However, the lowest screening doses for basal cell carcinoma

calculated with IREP (Table 4-16) are similar to or less than the screening dose of about 9 rem used previously by VA (see Section 2.2).

Another difference between screening doses calculated with IREP and screening doses in the CIRRPC table concerns their dependence on time since exposure when cancer was diagnosed. Screening doses for many cancer types calculated with IREP increase with increasing time since exposure when that time is sufficiently long that an assumption about the minimum latency period (see Section 3.2) does not have a significant effect on estimated ERRs. However, with the exception of the various types of leukemia, screening doses in the CIRRPC table are independent of time since exposure when cancer was diagnosed.

4.3 Application of Screening Doses

Comparisons of estimated equivalent doses to individuals with screening doses tabulated in this report may be straightforward in some cases. However, additional consideration needs to be given to cases in which an individual was exposed to multiple radiation types or exposures occurred in more than one year. These situations are discussed in the following sections.

4.3.1 *Exposure to Multiple Radiation Types*

Screening doses in Tables 4-1 through 4-34 are equivalent doses to organs or tissues in which each cancer type occurs. Therefore, the dose to an individual that should be compared with a screening dose is a total equivalent dose from all radiation types combined that takes into account the biological effectiveness of different radiation types. Alpha particles and neutrons are the high-LET radiations of concern for which the biological effectiveness is considerably greater than for high-energy photons.

As noted in Section 1, estimates of equivalent dose that are provided by DTRA for use by VA in adjudicating claims are intended to be at least upper 95% credibility limits of uncertain doses. Therefore, upper credibility limits of total equivalent doses to be compared with tabulated screening doses should take into account uncertainties in the biological effectiveness of alpha

particles and neutrons when exposure to those radiation types occurred, as well as uncertainties in absorbed doses.[28] Uncertainties in the biological effectiveness of alpha particles and neutrons that can be used in estimating upper bounds of equivalent dose from these radiation types are represented by probability distributions of radiation effectiveness factors (REFs) that were developed by Kocher et al. (2002; 2005) for use in IREP (Land et al. 2003).[29,30] Uncertainties in the biological effectiveness of alpha particles and neutrons should also take into account a small correction to probability distributions of REFs to represent an assumed inverse dose-rate effect and its uncertainty.[31]

[28]These considerations also apply to the use of screening doses in the CIRRPC table (Table 2-1).

[29]It is important to emphasize that uncertainties in the biological effectiveness of alpha particles and neutrons should *not* be taken into account when estimating equivalent doses from those radiation types to be used as input to IREP. Since uncertainties in REFs are incorporated in IREP, they are taken into account when IREP is used to calculated an upper 99% credibility limit of PC. Therefore, when IREP is used, equivalent doses from alpha particles and neutrons (including upper bounds used by VA in adjudicating claims for compensation) should be estimated using point values of radiation weighting factors (w_R) recommended by ICRP (1991), without uncertainty; the recommended w_R is 20 for alpha particles and fission neutrons. The need to account for uncertainty in the biological effectiveness of alpha particles and neutrons in estimating equivalent doses arises only when an estimated upper bound of the total equivalent dose from all radiation types combined is compared with a tabulated screening dose.

[30]Caution is advised when estimated total equivalent doses to be compared with tabulated screening doses for various types of leukemia include significant contributions from alpha particles or neutrons. Such comparisons are difficult when the dose-response relationship for acute exposure to photons assumed in calculating screening doses is linear-quadratic, but the dose-response relationship for alpha particles and neutrons is linear. This difference is not a concern for cancer types other than leukemia.

[31]This correction represents an assumption that the biological effectiveness of high-LET radiations increases with decreasing dose rate and, thus, that the risk from chronic exposure at a given dose is higher than the risk from acute exposure at the same dose. In using IREP, VA assumes that all exposures to alpha particles are chronic and, to follow guidance provided by NIOSH (2002), VA uses the same assumption for external exposure to neutrons because it is more favorable to claimants. Therefore, when using tabulated screening doses in cases of exposure to those radiation types, an inverse dose-rate effect should be taken into account in estimating upper bounds of equivalent doses, to be consistent with VA's assumptions. If VA were to change its policy and assume that all exposures of service personnel to neutrons at atmospheric nuclear-weapons tests were acute, an REF for neutrons uncorrected for an inverse dose-rate effect should be used in estimating upper bounds of equivalent doses.

4.3.2 *Exposures in More Than One Year*

Another complicating factor in using tabulated screening doses arises when exposures occurred in more than one year (i.e., at more than one age). Exposures in more than one year can affect comparisons of estimated equivalent doses with screening doses when the screening dose depends on age at exposure and time since exposure when cancer was diagnosed. This situation occurs for most cancer types. As described below, suitable approaches to addressing exposures in more than one year depend on whether the intent is to use a screening dose to show that the upper 99% credibility limit of PC associated with estimated equivalent doses is clearly less than 50% or clearly greater than 50%. All suitable approaches discussed below involve comparisons of the total equivalent dose from all years of exposure with an applicable screening dose for the cancer type of concern.

If a screening dose is used to determine whether estimated equivalent doses correspond to an upper 99% credibility limit of PC that is clearly less than 50%, the simplest approach to accounting for exposures in multiple years is to compare the total equivalent dose with the lowest screening dose for the cancer type of concern that applies to any age at exposure and time since exposure when cancer was diagnosed. In making such comparisons, it is important to take into account the accuracy of screening doses calculated with IREP (i.e., potential differences between tabulated screening doses and the equivalent dose that corresponds to an actual upper 99% credibility limit of PC of 50%), as discussed in Section 4.1.2. The lowest tabulated screening dose for each cancer type is given in Table 4-35. If the estimated upper bound (at least an upper 95% credibility limit) of the total equivalent dose from exposure in all years is less than the lowest screening dose that applies to the cancer type of concern, the upper 99% credibility limit of PC is less than 50%. This conclusion applies without regard for the distribution of equivalent dose with age at exposure or the age at the time of diagnosis.

For all cancer types except leukemia, an alternative approach can be used to demonstrate that estimated equivalent doses correspond to an upper 99% credibility limit of PC that is clearly less than 50%. In this approach, the total equivalent dose is compared with the screening dose (again with due consideration of its accuracy) that applies to the *youngest* age at exposure and a

time since exposure given by the difference between the age at diagnosis and the *oldest* age at exposure (age during the year of last exposure). This alternative is valid when screening doses do not decrease with increasing age at exposure or time since exposure when cancer was diagnosed. However, it should be used only when the difference between the age at diagnosis and oldest age at exposure exceeds the time over which the minimum latency period for the cancer type of concern has a significant effect on estimated risks.

The alternative approach described above also is valid for specific types of leukemia (CML, ALL, and AML) in many cases, given the dependence of screening doses (Tables 4-32, 4-33, and 4-34) on age at exposure and time since exposure when cancer was diagnosed. However, as indicated by the dependence of screening doses for all leukemia as a group (Table 4-31) on age at exposure and time since exposure when cancer was diagnosed (see Section 4.1.3), this alternative may not be valid when using screening doses in that table. For example, it may not be valid if significant external doses were received in different years, or if a substantial fraction of the total equivalent dose resulted from intakes of long-lived radionuclides that are tenaciously retained in the body and deliver a dose over many years. In both examples, an assumption that a total equivalent dose was received at the youngest age at exposure could result in a substantial underestimate of ERR and PC in some cases.

We now consider the use of screening doses to demonstrate that estimated equivalent doses correspond to an upper 99% credibility limit of PC that is clearly greater than 50%. One of two approaches to comparing the total equivalent dose with a screening dose (again with due consideration of its accuracy) can be used.[32] The first approach, which can be used for all cancer types, is to use only the highest equivalent dose in any year. This approach is particularly

[32]The approaches described here apply only if acute exposure is assumed, because an assumption of acute exposure to photons or electrons was used in calculating all screening doses. If chronic exposure were assumed, in which case the full DDREF in IREP would be applied, the estimated PC at a given dose would be less and, therefore, the applicable screening dose would be greater than values tabulated in this report. As noted previously, VA assumes that all external exposures to photons or electrons are acute in using IREP to calculate an upper 99% credibility limit of PC, in order to be more favorable to claimants; only internal exposures to those radiation types are assumed to be chronic. The restriction to an assumption of acute exposure does not apply when a screening dose is used to demonstrate that estimated equivalent doses correspond to an upper 99% credibility limit of PC that is clearly less than 50%.

appropriate when the total dose is dominated by the dose in a single year. If the highest equivalent dose in any year equals or exceeds the screening dose for that age at exposure and time since exposure when cancer was diagnosed, the upper 99% credibility limit of PC would clearly be greater than 50%. The second approach is to compare the total equivalent dose with the screening dose that applies to the *oldest* age at exposure and a time since exposure given by the difference between the age at diagnosis and the *youngest* age at exposure (age during the year of first exposure). This approach is valid except when using screening doses for all leukemia as a group (Table 4-31) or ALL (Table 4-33) for some ages at exposure and times since exposure.

4.4 Summary Discussion of Calculated Screening Doses

In considering and using screening doses tabulated in this report, certain assumptions embodied in the calculations with IREP and the implications of those assumptions should be borne in mind. Important points about screening doses are summarized as follows:

- All screening doses were calculated using the default number of iterations per run (2000) and random seed (99) in IREP; these defaults are assumed by VA when IREP is used to calculate an upper 99% credibility limit of PC for the purpose of evaluating causation of cancer in veterans who were exposed to ionizing radiation. Since calculated screening doses can vary substantially with changes in the number of iterations per run and the random seed, screening doses should not be interpreted as giving equivalent doses that correspond to an upper 99% credibility limit of PC of exactly 50% (see Section 4.1.2).
- All screening doses were calculated by assuming acute exposure to high-energy photons (> 250 keV) or higher-energy electrons (> 15 keV) to be consistent with assumptions used by VA in using IREP to calculate an upper 99% credibility limit of PC in cases of external exposure to those radiation types. Screening doses that would be obtained by assuming chronic exposure to those radiation types are higher (see Section 4.1.1.).
- Screening doses can be used when exposure to alpha particles or neutrons occurred. However, uncertainties in the biological effectiveness of those radiations (including an

inverse dose-rate effect) need to be taken into account when an estimated equivalent dose to be used in comparisons with a screening dose is intended to be an upper bound (at least an upper 95% credibility limit). Caution is also advised in using screening doses for various types of leukemia when doses from alpha particles or neutrons are a significant contributor to the total equivalent dose (see Section 4.3.1).

- All screening doses are presented to two significant figures. This is an important consideration when a screening dose is 100 rem or greater. Each screening dose is the lowest equivalent dose (to two significant figures) at which the calculated upper 99% credibility limit of PC is 50% or greater; a screening dose is not necessarily the equivalent dose that gives a calculated upper 99% credibility limit of PC closest to 50%.
- On the basis of an analysis of the variation in calculated screening doses due only to a change in the random seed in IREP when the number of iterations per run is fixed at the default value (see Section 4.1.2), the equivalent dose that corresponds to an actual upper 99% credibility limit of PC of 50% could differ from a screening dose tabulated in this report by no more than ±12% in the worst case. This difference should be less than ±10% in almost all cases of practical interest in VA radiation claims.

Screening doses tabulated in this report are potentially useful in several ways. When due consideration is given to their accuracy, screening doses can be used to indicate whether the upper 99% credibility limit of PC associated with estimated equivalent doses is clearly less than 50% or clearly greater than 50%. Thus, for example, they can be used to provide a check of the validity of calculated upper 99% credibility limits of PC and the resulting decision on granting a claim for compensation for cancer in specific cases. More generally, we believe that the most important use of screening doses is to give a general indication of the magnitude of radiation doses that are required to warrant a favorable compensation decision.

Table 4-1. Screening doses (rem) calculated with IREP: Cancers of oral cavity and pharynx (including lip)[a,b]

Age at exposure (y)	Time since exposure when cancer was diagnosed (y)[c]					
	5	10	15	20	25	≥ 30
18	110	32	45	61	77	93 (98)[d]
20	160	43	59	76	95	120
25	300	82	110	140	160	160
30	530	150	170	210	210	210
35	740	190	210	210	210	210
≥ 40	890	210	210	210	210	210

[a]Screening doses are equivalent doses, to two significant figures, to the organ or tissue in which cancer type occurs that are intended to correspond to an upper 99% credibility limit of PC of 50%. Calculations are described in Section 4.1.1 and the accuracy of screening doses is discussed in Section 4.1.2.

[b]Calculations were performed with Version 5.4 of NIOSH-IREP (NIOSH, 2002). The risk model for this cancer type is described in Section 3.1.2.

[c]Difference between age at diagnosis and age at exposure.

[d]First entry applies at time since exposure of 30 years; second entry in parentheses applies at time since exposure of 32 years or greater (age at diagnosis of 50 years or greater).

Table 4-2. Screening doses (rem) calculated with IREP: Cancer of esophagus[a,b]

Age at exposure (y)	Time since exposure when cancer was diagnosed (y)[c]					
	5	10	15	20	25	≥ 30
18	41	12	16	22	28	33 (35)[d]
20	56	15	21	28	34	40
25	120	28	37	47	56	56
30	210	50	61	72	72	72
35	270	64	72	72	72	72
≥ 40	340	77	72	72	72	72

[a]Screening doses are equivalent doses, to two significant figures, to the organ or tissue in which cancer type occurs that are intended to correspond to an upper 99% credibility limit of PC of 50%. Calculations are described in Section 4.1.1 and the accuracy of screening doses is discussed in Section 4.1.2.

[b]Calculations were performed with Version 5.4 of NIOSH-IREP (NIOSH, 2002). The risk model for this cancer type is described in Section 3.1.2.

[c]Difference between age at diagnosis and age at exposure.

[d]First entry applies at time since exposure of 30 years; second entry in parentheses applies at time since exposure of 32 years or greater (age at diagnosis of 50 years or greater).

Table 4-3. Screening doses (rem) calculated with IREP: Cancer of stomach[a,b]

Age at exposure (y)	Time since exposure when cancer was diagnosed (y)[c]					
	5	10	15	20	25	≥ 30
18	40	9.0	13	17	22	26 (27)[d]
20	54	12	16	21	27	32
25	110	22	29	37	44	44
30	210	40	48	58	58	58
35	270	50	58	58	58	58
≥ 40	330	61	58	58	58	58

[a]Screening doses are equivalent doses, to two significant figures, to the organ or tissue in which cancer type occurs that are intended to correspond to an upper 99% credibility limit of PC of 50%. Calculations are described in Section 4.1.1 and the accuracy of screening doses is discussed in Section 4.1.2.

[b]Calculations were performed with Version 5.4 of NIOSH-IREP (NIOSH, 2002). The risk model for this cancer type is described in Section 3.1.2.

[c]Difference between age at diagnosis and age at exposure.

[d]First entry applies at time since exposure of 30 years; second entry in parentheses applies at time since exposure of 32 years or greater (age at diagnosis of 50 years or greater).

Table 4-4. Screening doses (rem) calculated with IREP: Cancer of colon[a,b]

Age at exposure (y)	Time since exposure when cancer was diagnosed (y)[c]					
	5	10	15	20	25	≥ 30
18	40	12	17	24	31	37 (39)[d]
20	54	16	23	31	38	45
25	110	33	41	54	64	64
30	210	57	70	85	85	85
35	280	74	85	85	85	85
≥ 40	330	89	85	85	85	85

[a]Screening doses are equivalent doses, to two significant figures, to the organ or tissue in which cancer type occurs that are intended to correspond to an upper 99% credibility limit of PC of 50%. Calculations are described in Section 4.1.1 and the accuracy of screening doses is discussed in Section 4.1.2.

[b]Calculations were performed with Version 5.4 of NIOSH-IREP (NIOSH, 2002). The risk model for this cancer type is described in Section 3.1.2.

[c]Difference between age at diagnosis and age at exposure.

[d]First entry applies at time since exposure of 30 years; second entry in parentheses applies at time since exposure of 32 years or greater (age at diagnosis of 50 years or greater).

Table 4-5. Screening doses (rem) calculated with IREP: Cancer of rectum (including anus and anal canal)[a,b]

Age at exposure (y)	Time since exposure when cancer was diagnosed (y)[c]					
	5	10	15	20	25	≥ 30
18	150	36	50	66	83	100 (110)[d]
20	190	48	63	83	110	130
25	370	91	120	150	180	180
30	650	160	200	230	230	230
35	880	210	230	230	230	230
≥ 40	1100	240	230	230	230	230

[a]Screening doses are equivalent doses, to two significant figures, to the organ or tissue in which cancer type occurs that are intended to correspond to an upper 99% credibility limit of PC of 50%. Calculations are described in Section 4.1.1 and the accuracy of screening doses is discussed in Section 4.1.2.

[b]Calculations were performed with Version 5.4 of NIOSH-IREP (NIOSH, 2002). The risk model for this cancer type is described in Section 3.1.2.

[c]Difference between age at diagnosis and age at exposure.

[d]First entry applies at time since exposure of 30 years; second entry in parentheses applies at time since exposure of 32 years or greater (age at diagnosis of 50 years or greater).

Table 4-6. Screening doses (rem) calculated with IREP: Cancers of digestive tract other than stomach, colon, and rectum[a,b]

Age at exposure (y)	Time since exposure when cancer was diagnosed (y)[c]					
	5	10	15	20	25	≥ 30
18	76	22	30	42	53	63 (66)[d]
20	110	28	38	51	64	75
25	190	49	63	81	96	96
30	310	79	96	120	120	120
35	410	110	120	120	120	120
≥ 40	510	130	120	120	120	120

[a]Screening doses are equivalent doses, to two significant figures, to the organ or tissue in which cancer type occurs that are intended to correspond to an upper 99% credibility limit of PC of 50%. Calculations are described in Section 4.1.1 and the accuracy of screening doses is discussed in Section 4.1.2.

[b]Calculations were performed with Version 5.4 of NIOSH-IREP (NIOSH, 2002). Specific organs and tissues to which this cancer type applies are listed in Table 4 of NIOSH (2002), and the risk model for this cancer type is described in Section 3.1.1.

[c]Difference between age at diagnosis and age at exposure.

[d]First entry applies at time since exposure of 30 years; second entry in parentheses applies at time since exposure of 32 years or greater (age at diagnosis of 50 years or greater).

Table 4-7. Screening doses (rem) calculated with IREP: Cancer of liver (including biliary system)[a,b]

Age at exposure (y)	Time since exposure when cancer was diagnosed (y)[c]					
	5	10	15	20	25	≥ 30
18	15	4.0	5.3	7.3	8.8	11 (11)[d]
20	19	5.2	6.7	8.5	11	13
25	35	8.5	11	14	16	16
30	60	14	17	20	20	20
35	78	18	20	20	20	20
≥ 40	96	22	20	20	20	20

[a]Screening doses are equivalent doses, to two significant figures, to the organ or tissue in which cancer type occurs that are intended to correspond to an upper 99% credibility limit of PC of 50%. Calculations are described in Section 4.1.1 and the accuracy of screening doses is discussed in Section 4.1.2.

[b]Calculations were performed with Version 5.4 of NIOSH-IREP (NIOSH, 2002). The risk model for this cancer type is described in Section 3.1.1.

[c]Difference between age at diagnosis and age at exposure.

[d]First entry applies at time since exposure of 30 years; second entry in parentheses applies at time since exposure of 32 years or greater (age at diagnosis of 50 years or greater).

Table 4-8. Screening doses (rem) calculated with IREP: Cancer of gallbladder (including bile ducts)[a,b]

Age at exposure (y)	Time since exposure when cancer was diagnosed (y)[c]					
	5	10	15	20	25	≥ 30
18	24	6.0	7.8	11	13	16 (17)[d]
20	33	7.6	9.8	13	16	18
25	68	14	17	21	24	24
30	130	24	27	33	33	33
35	160	30	33	33	33	33
≥ 40	190	34	33	33	33	33

[a]Screening doses are equivalent doses, to two significant figures, to the organ or tissue in which cancer type occurs that are intended to correspond to an upper 99% credibility limit of PC of 50%. Calculations are described in Section 4.1.1 and the accuracy of screening doses is discussed in Section 4.1.2.

[b]Calculations were performed with Version 5.4 of NIOSH-IREP (NIOSH, 2002). The risk model for this cancer type is described in Section 3.1.2.

[c]Difference between age at diagnosis and age at exposure.

[d]First entry applies at time since exposure of 30 years; second entry in parentheses applies at time since exposure of 32 years or greater (age at diagnosis of 50 years or greater).

Table 4-9. Screening doses (rem) calculated with IREP: Cancer of pancreas[a,b]

Age at exposure (y)	Time since exposure when cancer was diagnosed (y)[c]					
	5	10	15	20	25	≥ 30
18	120	31	42	55	70	84 (89)[d]
20	150	40	53	70	86	110
25	310	74	93	130	150	150
30	540	140	160	200	200	200
35	710	170	200	200	200	200
≥ 40	900	200	200	200	200	200

[a]Screening doses are equivalent doses, to two significant figures, to the organ or tissue in which cancer type occurs that are intended to correspond to an upper 99% credibility limit of PC of 50%. Calculations are described in Section 4.1.1 and the accuracy of screening doses is discussed in Section 4.1.2.

[b]Calculations were performed with Version 5.4 of NIOSH-IREP (NIOSH, 2002). The risk model for this cancer type is described in Section 3.1.2.

[c]Difference between age at diagnosis and age at exposure.

[d]First entry applies at time since exposure of 30 years; second entry in parentheses applies at time since exposure of 32 years or greater (age at diagnosis of 50 years or greater).

Table 4-10. Screening doses (rem) calculated with IREP: Cancer of lung (including trachea and bronchus) – I[a,b]

Smoking status	Age at exposure (y)	Time since exposure when cancer was diagnosed (y)[c]		
		5	10	≥ 15
Never smoker	Any	220	46	44
Former smoker	Any	530	130	130
Current smoker[d]	Any	720	160	150

[a]Screening doses are equivalent doses, to two significant figures, to the organ or tissue in which cancer type occurs that are intended to correspond to an upper 99% credibility limit of PC of 50%. Calculations are described in Section 4.1.1 and the accuracy of screening doses is discussed in Section 4.1.2.

[b]Calculations were performed with Version 5.4 of NIOSH-IREP (NIOSH, 2002). The risk model for this cancer type is described in Sections 3.1.3 and 3.1.4.

[c]Difference between age at diagnosis and age at exposure.

[d]Screening doses apply when the number of cigarettes smoked per day is unknown. IREP also calculates PC for separate smoking categories of < 10, 10-19, 20-40, and ≥ 40 cigarettes per day; screening doses for these smoking categories are similar to values for former smokers and current smokers with an unknown number of cigarettes smoked per day.

Table 4-11. Screening doses (rem) calculated with IREP: Cancer of lung (including trachea and bronchus) – II[a,b,c]

Age at exposure (y)	Time since exposure when cancer was diagnosed (y)[d]					
	5	10	15	20	25	≥ 30
18	58	18	26	35	44	52 (54)[e]
	95	23	32	43	54	63 (66)
	100	23	33	44	54	64 (68)
20	76	24	33	44	55	63
	120	30	41	54	65	76
	140	31	42	54	67	78
25	150	45	60	77	90	90
	250	56	71	89	110	110
	250	57	73	91	110	110
30	270	80	100	120	120	120
	420	95	120	140	140	140
	440	97	120	140	140	140
35	360	100	120	120	120	120
	550	120	140	140	140	140
	570	120	140	140	140	140
≥ 40	450	130	120	120	120	120
	680	150	140	140	140	140
	720	150	140	140	140	140

[a]Screening doses are equivalent doses, to two significant figures, to the organ or tissue in which cancer type occurs that are intended to correspond to an upper 99% credibility limit of PC of 50%. Calculations are described in Section 4.1.1 and the accuracy of screening doses is discussed in Section 4.1.2.

[b]Calculations were performed with Version 5.3 of NIH-IREP (Land et al., 2003). The risk model for this cancer type is described in Sections 3.1.2 and 3.1.4.

[c]For each age at exposure and time since exposure when cancer was diagnosed, first entry gives the screening dose for never smokers, second entry gives the screening dose for former smokers, and third entry gives the screening dose for current smokers that applies when the number of cigarettes smoked per day is unknown. IREP also calculates PC for separate smoking categories of < 10, 10-19, 20-40, and ≥ 40 cigarettes per day; screening doses for these smoking categories are similar to values for former smokers and current smokers with an unknown number of cigarettes smoked per day.

[d]Difference between age at diagnosis and age at exposure.

[e]First entry applies at time since exposure of 30 years; second entry in parentheses applies at time since exposure of 32 years or greater (age at diagnosis of 50 years or greater).

Table 4-12. Screening doses (rem) calculated with IREP: Cancers of respiratory tract other than lung[a,b]

Age at exposure (y)	Time since exposure when cancer was diagnosed (y)[c]					
	5	10	15	20	25	≥ 30
18	150	34	47	62	79	94 (100)[d]
20	210	45	59	78	95	120
25	360	83	110	130	160	160
30	630	150	170	210	210	210
35	840	190	210	210	210	210
≥ 40	1100	220	210	210	210	210

[a]Screening doses are equivalent doses, to two significant figures, to the organ or tissue in which cancer type occurs that are intended to correspond to an upper 99% credibility limit of PC of 50%. Calculations are described in Section 4.1.1 and the accuracy of screening doses is discussed in Section 4.1.2.

[b]Calculations were performed with Version 5.4 of NIOSH-IREP (NIOSH, 2002). Specific organs and tissues to which this cancer type applies are listed in Table 4 of NIOSH (2002), and the risk model for this cancer type is described in Section 3.1.2.

[c]Difference between age at diagnosis and age at exposure.

[d]First entry applies at time since exposure of 30 years; second entry in parentheses applies at time since exposure of 32 years or greater (age at diagnosis of 50 years or greater).

Table 4-13. Screening doses (rem) calculated with IREP: Cancer of bone[a,b]

Age at exposure (y)	Time since exposure when cancer was diagnosed (y)[c]						
	3	5	10	15	20	25	≥ 30
18	33	10	14	21	30	38	45 (48)[d]
20	47	14	19	28	37	47	55
25	96	32	37	51	64	76	76
30	190	61	66	84	110	110	110
35	270	83	84	110	110	110	110
≥ 40	320	110	110	110	110	110	110

[a]Screening doses are equivalent doses, to two significant figures, to the organ or tissue in which cancer type occurs that are intended to correspond to an upper 99% credibility limit of PC of 50%. Calculations are described in Section 4.1.1 and the accuracy of screening doses is discussed in Section 4.1.2.

[b]Calculations were performed with Version 5.5 of NIOSH-IREP (NIOSH, 2002); see Section 4.1.1, footnote 13. The risk model for this cancer type is described in Section 3.1.2.

[c]Difference between age at diagnosis and age at exposure.

[d]First entry applies at time since exposure of 30 years; second entry in parentheses applies at time since exposure of 32 years or greater (age at diagnosis of 50 years or greater).

Table 4-14. Screening doses (rem) calculated with IREP: Cancers of connective tissue (including other soft tissue not listed)[a,b]

Age at exposure (y)	Time since exposure when cancer was diagnosed (y)[c]					
	5	10	15	20	25	≥ 30
18	48	16	23	31	39	47 (50)[d]
20	69	21	29	39	49	58
25	140	41	53	67	80	80
30	260	72	87	110	110	110
35	330	92	110	110	110	110
≥ 40	410	120	110	110	110	110

[a]Screening doses are equivalent doses, to two significant figures, to the organ or tissue in which cancer types occurs that are intended to correspond to an upper 99% credibility limit of PC of 50%. Calculations are described in Section 4.1.1 and the accuracy of screening doses is discussed in Section 4.1.2.

[b]Calculations were performed with Version 5.4 of NIOSH-IREP (NIOSH, 2002). The risk model for this cancer type is described in Section 3.1.2.

[c]Difference between age at diagnosis and age at exposure.

[d]First entry applies at time since exposure of 30 years; second entry in parentheses applies at time since exposure of 32 years or greater (age at diagnosis of 50 years or greater).

Table 4-15. Screening doses (rem) calculated with IREP: Malignant melanoma of skin[a,b]

Age at exposure (y)	Time since exposure when cancer was diagnosed (y)[c]					
	White, non-hispanic[d]			Black[d]		
	5	10	≥ 15	5	10	≥ 15
18	35	6.3	5.9	28	5.6	5.3
20	49	8.4	7.9	37	7.7	7.3
25	94	17	16	72	15	15
30	190	33	31	140	30	29
35	310	55	51	250	49	47
≥ 40	550	91	86	440	80	77

[a]Screening doses are equivalent doses, to two significant figures, to the organ or tissue in which cancer type occurs that are intended to correspond to an upper 99% credibility limit of PC of 50%. Calculations are described in Section 4.1.1 and the accuracy of screening doses is discussed in Section 4.1.2.

[b]Calculations were performed with Version 5.4 of NIOSH-IREP (NIOSH, 2002). The risk model for this cancer type is described in Section 3.1.5.

[c]Difference between age at diagnosis and age at exposure.

[d] IREP also calculates risks of skin cancers for the following racial or ethnic groups: American Indians or Alaska natives; Asians, native Hawaiians, or other Pacific islanders; and white Hispanics.

Table 4-16. Screening doses (rem) calculated with IREP: Basal cell carcinoma of skin[a,b]

Age at exposure (y)	Time since exposure when cancer was diagnosed (y)[c]					
	White, non-hispanic[d]			Black[d]		
	5	10	≥ 15	5	10	≥ 15
18	36	6.2	5.9	18	3.2	3.1
20	48	8.5	7.9	24	4.3	4.0
25	94	17	16	46	7.9	7.4
30	190	33	31	89	15	15
35	320	54	51	160	26	24
≥ 40	550	89	87	270	44	42

[a]Screening doses are equivalent doses, to two significant figures, to the organ or tissue in which cancer type occurs that are intended to correspond to an upper 99% credibility limit of PC of 50%. Calculations are described in Section 4.1.1 and the accuracy of screening doses is discussed in Section 4.1.2.

[b]Calculations were performed with Version 5.4 of NIOSH-IREP (NIOSH, 2002). The risk model for this cancer type is described in Section 3.1.5.

[c]Difference between age at diagnosis and age at exposure.

[d]IREP also calculates risks of skin cancers for the following racial and ethnic groups: American Indians or Alaska natives; Asians, native Hawaiians, or other Pacific islanders; and white Hispanics.

Table 4-17. Screening doses (rem) calculated with IREP: Squamous cell carcinoma of skin[a,b]

Age at exposure (y)	Time since exposure when cancer was diagnosed (y)[c]					
	White, non-hispanic[d]			Black[d]		
	5	10	≥ 15	5	10	≥ 15
All	2500	310	300	1100	160	150

[a]Screening doses are equivalent doses, to two significant figures, to the organ or tissue in which cancer type occurs that are intended to correspond to an upper 99% credibility limit of PC of 50%. Calculations are described in Section 4.1.1 and the accuracy of screening doses is discussed in Section 4.1.2.

[b]Calculations were performed with Version 5.4 of NIOSH-IREP (NIOSH, 2002). The risk model for this cancer type is described in Section 3.1.5.

[c]Difference between age at diagnosis and age at exposure.

[d]IREP also calculates risks of skin cancers for the following racial and ethnic groups: American Indians or Alaska natives; Asians, native Hawaiians, or other Pacific islanders; and white Hispanics.

Table 4-18. Screening doses (rem) calculated with IREP: Cancer of breast (female)[a,b]

Age at exposure (y)	Time since exposure when cancer was diagnosed (y)[c]					
	5	10	15	20	25	≥ 30
18	49	14	22	33	43	53 (57)[d]
20	64	18	27	39	51	62
25	130	32	45	60	75	75
30	230	51	66	84	84	84
35	300	69	84	84	84	84
≥ 40	380	89	84	84	84	84

[a]Screening doses are equivalent doses, to two significant figures, to the organ or tissue in which cancer type occurs that are intended to correspond to an upper 99% credibility limit of PC of 50%. Calculations are described in Section 4.1.1 and the accuracy of screening doses is discussed in Section 4.1.2.

[b]Calculations were performed with Version 5.4 of NIOSH-IREP (NIOSH, 2002). The risk model for this cancer type is described in Section 3.1.1.

[c]Difference between age at diagnosis and age at exposure.

[d]First entry applies at time since exposure of 30 years; second entry in parentheses applies at time since exposure of 32 years or greater (age at diagnosis of 50 years or greater).

Table 4-19. Screening doses (rem) calculated with IREP: Cancer of breast (male)[a,b]

Age at exposure (y)	Time since exposure when cancer was diagnosed (y)[c]					
	5	10	15	20	25	≥ 30
18	38	12	20	30	41	50 (53)[d]
20	51	16	25	37	49	58
25	94	29	41	56	70	70
30	160	46	61	78	78	78
35	210	63	78	78	78	78
≥ 40	270	80	78	78	78	78

[a]Screening doses are equivalent doses, to two significant figures, to the organ or tissue in which cancer type occurs that are intended to correspond to an upper 99% credibility limit of PC of 50%. Calculations are described in Section 4.1.1 and the accuracy of screening doses is discussed in Section 4.1.2.

[b]Calculations were performed with Version 5.4 of NIOSH-IREP (NIOSH, 2002). The risk model for this cancer type is described in Section 3.1.1.

[c]Difference between age at diagnosis and age at exposure.

[d]First entry applies at time since exposure of 30 years; second entry in parentheses applies at time since exposure of 32 years or greater (age at diagnosis of 50 years or greater).

Table 4-20. Screening doses (rem) calculated with IREP: Cancer of ovary[a,b]

Age at exposure (y)	Time since exposure when cancer was diagnosed (y)[c]					
	5	10	15	20	25	≥ 30
18	42	14	19	25	32	38 (41)[d]
20	60	17	23	32	39	46
25	120	33	42	53	63	63
30	220	57	69	82	82	82
35	290	73	82	82	82	82
≥ 40	350	87	82	82	82	82

[a]Screening doses are equivalent doses, to two significant figures, to the organ or tissue in which cancer type occurs that are intended to correspond to an upper 99% credibility limit of PC of 50%. Calculations are described in Section 4.1.1 and the accuracy of screening doses is discussed in Section 4.1.2.

[b]Calculations were performed with Version 5.4 of NIOSH-IREP (NIOSH, 2002). The risk model for this cancer type is described in Section 3.1.2.

[c]Difference between age at diagnosis and age at exposure.

[d]First entry applies at time since exposure of 30 years; second entry in parentheses applies at time since exposure of 32 years or greater (age at diagnosis of 50 years or greater).

Table 4-21. Screening doses (rem) calculated with IREP: Cancers of all female genitalia other than ovary[a,b]

Age at exposure (y)	Time since exposure when cancer was diagnosed (y)[c]		
	5	10	≥ 15
All	26000	1600	1500

[a]Screening doses are equivalent doses, to two significant figures, to the organ or tissue in which cancer type occurs that are intended to correspond to an upper 99% credibility limit of PC of 50%. Calculations are described in Section 4.1.1 and the accuracy of screening doses is discussed in Section 4.1.2.

[b]Calculations were performed with Version 5.4 of NIOSH-IREP (NIOSH, 2002). The risk model for this cancer type is described in Section 3.1.3.

[c]Difference between age at diagnosis and age at exposure.

Table 4-22. Screening doses (rem) calculated with IREP: Cancers of all male genitalia (including prostate)[a,b]

Age at exposure (y)	Time since exposure when cancer was diagnosed (y)[c]					
	5	10	15	20	25	≥ 30
18	89	21	28	38	47	56 (60)[d]
20	120	27	36	47	57	68
25	250	50	61	77	91	91
30	420	85	99	120	120	120
35	490	110	120	120	120	120
≥ 40	650	130	120	120	120	120

[a]Screening doses are equivalent doses, to two significant figures, to the organ or tissue in which cancer type occurs that are intended to correspond to an upper 99% credibility limit of PC of 50%. Calculations are described in Section 4.1.1 and the accuracy of screening doses is discussed in Section 4.1.2.

[b]Calculations were performed with Version 5.4 of NIOSH-IREP (NIOSH, 2002). The risk model for this cancer type is described in Section 3.1.2.

[c]Difference between age at diagnosis and age at exposure.

[d]First entry applies at time since exposure of 30 years; second entry in parentheses applies at time since exposure of 32 years or greater (age at diagnosis of 50 years or greater).

Table 4-23. Screening doses (rem) calculated with IREP: Cancer of bladder[a,b]

Age at exposure (y)	Time since exposure when cancer was diagnosed (y)[c]					
	5	10	15	20	25	≥ 30
18	48	16	22	31	38	46 (49)[d]
20	64	21	29	38	47	56
25	140	40	51	64	77	77
30	260	69	84	100	100	100
35	330	88	100	100	100	100
≥ 40	400	110	100	100	100	100

[a]Screening doses are equivalent doses, to two significant figures, to the organ or tissue in which cancer type occurs that are intended to correspond to an upper 99% credibility limit of PC of 50%. Calculations are described in Section 4.1.1 and the accuracy of screening doses is discussed in Section 4.1.2.

[b]Calculations were performed with Version 5.4 of NIOSH-IREP (NIOSH, 2002). The risk model for this cancer type is described in Section 3.1.2.

[c]Difference between age at diagnosis and age at exposure.

[d]First entry applies at time since exposure of 30 years; second entry in parentheses applies at time since exposure of 32 years or greater (age at diagnosis of 50 years or greater).

Table 4-24. Screening doses (rem) calculated with IREP: Cancers of kidney and other urinary organs except bladder[a,b]

Age at exposure (y)	Time since exposure when cancer was diagnosed (y)[c]					
	5	10	15	20	25	≥ 30
18	41	14	21	29	36	44 (46)[d]
20	57	19	27	36	45	53
25	120	38	49	63	75	75
30	220	67	83	100	100	100
35	290	87	100	100	100	100
≥ 40	370	110	100	100	100	100

[a]Screening doses are equivalent doses, to two significant figures, to the organ or tissue in which cancer type occurs that are intended to correspond to an upper 99% credibility limit of PC of 50%. Calculations are described in Section 4.1.1 and the accuracy of screening doses is discussed in Section 4.1.2.

[b]Calculations were performed with Version 5.4 of NIOSH-IREP (NIOSH, 2002). Specific organs and tissues to which this cancer type applies are listed in Table 4 of NIOSH (2002), and the risk model for this cancer type is described in Section 3.1.2.

[c]Difference between age at diagnosis and age at exposure.

[d]First entry applies at time since exposure of 30 years; second entry in parentheses applies at time since exposure of 32 years or greater (age at diagnosis of 50 years or greater).

Table 4-25. Screening doses (rem) calculated with IREP: Cancer of eye[a,b]

Age at exposure (y)	Time since exposure when cancer was diagnosed (y)[c]					
	5	10	15	20	25	≥ 30
18	51	16	23	30	39	47 (49)[d]
20	71	21	29	39	48	57
25	150	41	52	67	78	78
30	270	73	87	110	110	110
35	360	92	110	110	110	110
≥ 40	430	120	110	110	110	110

[a]Screening doses are equivalent doses, to two significant figures, to the organ or tissue in which cancer type occurs that are intended to correspond to an upper 99% credibility limit of PC of 50%. Calculations are described in Section 4.1.1 and the accuracy of screening doses is discussed in Section 4.1.2.

[b]Calculations were performed with Version 5.4 of NIOSH-IREP (NIOSH, 2002). The risk model for this cancer type is described in Section 3.1.2.

[c]Difference between age at diagnosis and age at exposure.

[d]First entry applies at time since exposure of 30 years; second entry in parentheses applies at time since exposure of 32 years or greater (age at diagnosis of 50 years or greater).

Table 4-26. Screening doses (rem) calculated with IREP: Cancers of nervous system (including brain)[a,b]

Age at exposure (y)	Time since exposure when cancer was diagnosed (y)[c]					
	5	10	15	20	25	≥ 30
18	120	32	44	60	74	89 (95)[d]
20	170	42	57	73	92	110
25	350	78	100	130	150	150
30	570	140	160	190	190	190
35	760	170	190	190	190	190
≥ 40	960	200	190	190	190	190

[a]Screening doses are equivalent doses, to two significant figures, to the organ or tissue in which cancer type occurs that are intended to correspond to an upper 99% credibility limit of PC of 50%. Calculations are described in Section 4.1.1 and the accuracy of screening doses is discussed in Section 4.1.2.

[b]Calculations were performed with Version 5.4 of NIOSH-IREP (NIOSH, 2002). Specific organs and tissues to which this cancer type applies are listed in Table 4 of NIOSH (2002), and the risk model for this cancer type is described in Section 3.1.2.

[c]Difference between age at diagnosis and age at exposure.

[d]First entry applies at time since exposure of 30 years; second entry in parentheses applies at time since exposure of 32 years or greater (age at diagnosis of 50 years or greater).

Table 4-27. Screening doses (rem) calculated with IREP: Cancer of thyroid[a,b]

Age at exposure (y)	Time since exposure when cancer was diagnosed (y)[c]		
	3	5	≥ 10
18	44	9.4	7.5
20	51	11	8.3
25	71	15	12
30	110	23	18
35	160	34	26
40	180	36	29
45	220	39	31
≥ 50	250	43	34

[a]Screening doses are equivalent doses, to two significant figures, to the organ or tissue in which cancer type occurs that are intended to correspond to an upper 99% credibility limit of PC of 50%. Calculations are described in Section 4.1.1 and the accuracy of screening doses is discussed in Section 4.1.2.

[b]Calculations were performed with Version 5.5 of NIOSH-IREP (NIOSH, 2002); see Section 4.1.1, footnote 13. The risk model for this cancer type is described in Section 3.1.5.

[c]Difference between age at diagnosis and age at exposure.

Table 4-28. Screening doses (rem) calculated with IREP: Cancers of endocrine glands other than thyroid[a,b]

Age at exposure (y)	Time since exposure when cancer was diagnosed (y)[c]					
	5	10	15	20	25	≥ 30
18	42	14	20	28	36	42 (45)[d]
20	58	19	27	35	44	51
25	130	37	47	61	74	74
30	230	66	81	96	96	96
35	290	83	96	96	96	96
≥ 40	360	99	96	96	96	96

[a]Screening doses are equivalent doses, to two significant figures, to the organ or tissue in which cancer type occurs that are intended to correspond to an upper 99% credibility limit of PC of 50%. Calculations are described in Section 4.1.1 and the accuracy of screening doses is discussed in Section 4.1.2.

[b]Calculations were performed with Version 5.4 of NIOSH-IREP (NIOSH, 2002). The risk model for this cancer type is described in Section 3.1.2.

[c]Difference between age at diagnosis and age at exposure.

[d]First entry applies at time since exposure of 30 years; second entry in parentheses applies at time since exposure of 32 years or greater (age at diagnosis of 50 years or greater).

Table 4-29. Screening doses (rem) calculated with IREP: Cancers of other and ill-defined sites[a,b]

Age at exposure (y)	Time since exposure when cancer was diagnosed (y)[c]					
	5	10	15	20	25	≥ 30
18	52	16	23	31	40	48 (50)[d]
20	72	21	29	39	49	58
25	150	42	53	68	81	81
30	280	74	88	110	110	110
35	360	93	110	110	110	110
≥ 40	430	120	110	110	110	110

[a]Screening doses are equivalent doses, to two significant figures, to the organ or tissue in which cancer type occurs that are intended to correspond to an upper 99% credibility limit of PC of 50%. Calculations are described in Section 4.1.1 and the accuracy of screening doses is discussed in Section 4.1.2.

[b]Calculations were performed with Version 5.4 of NIOSH-IREP (NIOSH, 2002). The risk model for this cancer type is described in Section 3.1.2.

[c]Difference between age at diagnosis and age at exposure.

[d]First entry applies at time since exposure of 30 years; second entry in parentheses applies at time since exposure of 32 years or greater (age at diagnosis of 50 years or greater).

Table 4-30. Screening doses (rem) calculated with IREP: Lymphoma and multiple myeloma[a,b,c]

Age at exposure (y)	Time since exposure when cancer was diagnosed (y)[d]					
	5	10	15	20	25	≥ 30
18	96	22	30	38	48	57 (61)[e]
20	120	29	37	47	59	70
25	230	50	64	78	93	93
30	420	88	110	130	130	130
35	520	110	130	130	130	130
≥ 40	690	140	130	130	130	130

[a]Screening doses are equivalent doses, to two significant figures, to the organ or tissue in which cancer type occurs that are intended to correspond to an upper 99% credibility limit of PC of 50%. Calculations are described in Section 4.1.1 and the accuracy of screening doses is discussed in Section 4.1.2.

[b]Calculations were performed with Version 5.4 of NIOSH-IREP (NIOSH, 2002). Specific diseases to which this cancer type applies are listed in Table 4 of NIOSH (2002), and the risk model for this cancer type is described in Section 3.1.2.

[c]VA assumes that chronic lymphocytic leukemia (CLL) is a form of non-Hodgkin's lymphoma.

[d]Difference between age at diagnosis and age at exposure.

[e]First entry applies at time since exposure of 30 years; second entry in parentheses applies at time since exposure of 32 years or greater (age at diagnosis of 50 years or greater).

Table 4-31. Screening doses (rem) calculated with IREP:
All leukemia excluding chronic lymphocytic leukemia (CLL)[a,b,c]

Age at exposure (y)	Time since exposure when cancer was diagnosed (y)[d]										
	3	5	10	15	20	25	30	35	40	45	≥ 50
18	2.2	1.9	4.4	9.1	17	28	41	58	78	110	140
20	2.5	2.2	4.8	9.8	18	29	42	59	79	110	140
25	3.4	3.0	6.1	12	20	31	44	59	78	100	130
30	4.5	3.9	7.4	14	22	32	44	57	73	92	120
35	5.7	5.0	8.8	15	23	32	42	53	65	78	94
40	6.9	6.0	11	16	24	31	38	46	53	61	69
45	8.0	7.0	12	17	23	29	34	37	40	43	46
50	9.2	8.0	12	18	23	26	28	29	29	28	27
≥ 55	11	8.8	13	19	22	24	23	21	19	17	15

[a]Screening doses are equivalent doses, to two significant figures, to the organ or tissue in which cancer type occurs that are intended to correspond to an upper 99% credibility limit of PC of 50%. Calculations are described in Section 4.1.1 and the accuracy of screening doses is discussed in Section 4.1.2.

[b]The corresponding cancer type in the CIRRPC table (Table 2-1) is leukemia (excluding chronic lymphatic).

[c]Calculations were performed with Version 5.4 of NIOSH-IREP (NIOSH, 2002). Specific diseases to which this cancer type applies are listed in Table 4 of NIOSH (2002), and the risk model for this cancer type is described in Section 3.1.5.

[d]Difference between age at diagnosis and age at exposure.

Table 4-32. Screening doses (rem) calculated with IREP: Chronic myeloid leukemia (CML)[a,b,c]

Age at exposure (y)	Time since exposure when cancer was diagnosed (y)[d]										
	3	5	10	15	20	25	30	35	40	45	50
All	1.6	1.4	5.0	12	22	37	57	86	130	180	240

[a]Screening doses are equivalent doses, to two significant figures, to the organ or tissue in which cancer type occurs that are intended to correspond to an upper 99% credibility limit of PC of 50%. Calculations are described in Section 4.1.1 and the accuracy of screening doses is discussed in Section 4.1.2.

[b]The corresponding cancer type in the CIRRPC table (Table 2-1) is chronic granulocytic leukemia.

[c]Calculations were performed with Version 5.4 of NIOSH-IREP (NIOSH, 2002). Specific diseases to which this cancer type applies are listed in Table 4 of NIOSH (2002), and the risk model for this cancer type is described in Section 3.1.5.

[d]Difference between age at diagnosis and age at exposure.

Table 4-33. Screening doses (rem) calculated with IREP: Acute lymphocytic leukemia (ALL)[a,b,c]

Age at exposure (y)	Time since exposure when cancer was diagnosed (y)[d]										
	3	5	10	15	20	25	30	35	40	45	50
18	0.28	0.24	0.91	2.7	6.5	13	24	40	64	110	160
≥ 20	19	16[e]									

[a]Screening doses are equivalent doses, to two significant figures, to the organ or tissue in which cancer type occurs that are intended to correspond to an upper 99% credibility limit of PC of 50%. Calculations are described in Section 4.1.1 and the accuracy of screening doses is discussed in Section 4.1.2.

[b]Acute leukemia of unspecified type is included in the CIRRPC table (Table 2-1).

[c]Calculations were performed with Version 5.4 of NIOSH-IREP (NIOSH, 2002). Specific diseases to which this cancer type applies are listed in Table 4 of NIOSH (2002), and the risk model for this cancer type is described in Section 3.1.5.

[d]Difference between age at diagnosis and age at exposure.

[e]Entry applies at all times since exposure when cancer was diagnosed of 5 years or greater.

Table 4-34. Screening doses (rem) calculated with IREP: Acute myeloid leukemia (AML)[a,b,c]

Age at exposure (y)	Time since exposure when cancer was diagnosed (y)[d]										
	3	5	10	15	20	25	30	35	40	45	50
All	6.7	5.8	9.1	14	19	25	29	33	35	38	39

[a]Screening doses are equivalent doses, to two significant figures, to the organ or tissue in which cancer type occurs that are intended to correspond to an upper 99% credibility limit of PC of 50%. Calculations are described in Section 4.1.1 and the accuracy of screening doses is discussed in Section 4.1.2.

[b]Acute leukemia of unspecified type is included in the CIRRPC table (Table 2-1).

[c]Calculations were performed with Version 5.4 of NIOSH-IREP (NIOSH, 2002). Specific diseases to which this cancer type applies are listed in Table 4 of NIOSH (2002), and the risk model for this cancer type is described in Section 3.1.5.

[d]Difference between age at diagnosis and age at exposure.

Table 4-35. Lowest screening doses for any age at exposure and time since exposure when cancer was diagnosed for all cancer types calculated with IREP[a]

Cancer type	Screening dose (rem)	Cancer type	Screening dose (rem)
Oral cavity and pharynx (including lip)	32	Non-melanoma basal cell carcinoma of skin	3.1 (5.9)[c]
Esophagus	12	Non-melanoma squamous cell carcinoma of skin	150 (300)[c]
Stomach	9.0	Breast (female)	14
Colon	12	Breast (male)	12
Rectum (including anus and anal canal)	36	Ovary	14
Digestive tract other than stomach, colon, and rectum	22	All female genitalia other than ovary	1500
Liver (including biliary system)	4.0	All male genitalia (including prostate)	21
Gallbladder (including bile ducts)	6.0	Bladder	16
Pancreas	31	Kidney and other urinary organs except bladder	14
Lung (including trachea and bronchus)[b]	18	Eye	16
Respiratory tract other than lung	34	Nervous system (including brain)	32
Bone	10	Thyroid	7.5
Connective tissue (including other soft tissues not listed)	16	Endocrine glands other than thyroid	14
Malignant melanoma of skin	5.3 (5.9)[c]	Other and ill-defined sites	16

Table is continued on following page.

Table 4-35. (continued)

Cancer type	Screening dose (rem)	Cancer type	Screening dose (rem)
Lymphoma and multiple myeloma	22	Acute lymphocytic leukemia (ALL)	0.24
Leukemia excluding chronic lymphocytic leukemia (CLL)	1.9	Acute myeloid leukemia (AML)	5.8
Chronic myeloid leukemia (CML)	1.4		

[a]Lowest screening dose for each cancer type is obtained from Tables 4-1 through 4-34. Values apply to age at exposure of 18 and shortest time since exposure when cancer was diagnosed at which assumption about minimum latency period does not have significant effect on estimated risk (see Section 3.2).

[b]Lowest screening dose for never smokers calculated with NIH-IREP (Land et al., 2003) and obtained from Table 4-11. Lowest screening dose calculated with NIOSH-IREP (NIOSH, 2002) and given in Table 4-12 is higher.

[c]First entry applies to blacks; second entry in parentheses applies to white, non-Hispanics.

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Department of Veterans Affairs
Chief, Public Health & Environmental Hazards
VA Central Office (13)
810 Vermont Ave., NW
Washington, DC 20420

Department of Veterans Affairs
Director, Compensation and Pension Service
VA Central Office (210A)
810 Vermont Ave., NW
Washington, DC 20420

DEPARTMENT OF HEALTH AND HUMAN SERVICES

National Institute of Occupational Safety and Health
Director, Compensation Analysis and Support
Robert A. Taft Laboratories
4676 Columbia Parkway
Cincinnati, OH 45226-1998

DEPARTMENT OF LABOR

U. S. Department of Labor, DEEOIC
200 Constitution Avenue NW, Room C-3321
Washington, DC 20210

DEPARTMENT OF JUSTICE

Department of Justice
Civil Division - Radiation Exposure Compensation Program
Ben Franklin Station
PO Box 146
Washington, DC 20044-0146

FEDERAL AGENCY ADVISORY BOARDS

Veterans' Advisory Board on Dose Reconstruction
7910 Woodmont Avenue, Suite 400
Bethesda, MD 20814-3095

Veterans' Advisory Committee on Environmental Hazards
Department of Veterans Affairs
Compensation and Pension Service
VA Central Office (210A)
810 Vermont Ave., NW
Washington, DC 20420

Advisory Board on Radiation and Worker Health
4676 Columbia Parkway, MS: C-46
Cincinnati, OH 45226

DEPARTMENT OF DEFENSE CONTRACTORS

ITT Industries
ITT Systems Corporation
1680 Texas Street, SE
Kirtland AFB, NM 87117-5669
2 CYS ATTN: DTRIAC
ATTN: DARE

L3 Communications
11410 Isaac Newton Square North, Suite 103
Reston, VA 20190-5005

Senes Oak Ridge, Inc.
102 Donner Drive
Oak Ridge, TN 37830

SAIC
8301 Greensboro Drive, M/S E-5-5
McLean, VA 22102

Oak Ridge Associated Universities
4850 Smith Road, Suite 200
Cincinnati, OH 45212

S. Cohen and Associates
6858 Old Dominion Drive, Suite 301
McLean, VA 22101