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Estimating the Risks of Cancer Mortality and Genetic Defects Resulting from Exposures to Low Levels of Ionizing Radiation

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Los Alamos National Laboratory
Los Alamos, New Mexico 87545

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Estimating the Risks of Cancer Mortality and Genetic Defects Resulting from Exposures to Low Levels of Ionizing Radiation

Thomas E. Buhl
Wayne R. Hansen

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ESTIMATING THE RISKS OF CANCER MORTALITY AND GENETIC DEFECTS RESULTING FROM EXPOSURES TO LOW LEVELS OF IONIZING RADIATION

by

Thomas E. Buhl and Wayne R. Hansen

ABSTRACT

Estimators for calculating the risk of cancer and genetic disorders induced by exposure to ionizing radiation have been recommended by the U.S. National Academy of Sciences Committee on the Biological Effects of Ionizing Radiations, the U.N. Scientific Committee on the Effects of Atomic Radiation, and the International Committee on Radiological Protection. These groups have also considered the risks of somatic effects other than cancer. The U.S. National Council on Radiation Protection and Measurements has discussed risk estimate procedures for radiation-induced health effects.

The recommendations of these national and international advisory committees are summarized and compared in this report. Based on this review, two procedures for risk estimation are presented for use in radiological assessments performed by the U.S. Department of Energy under the National Environmental Policy Act of 1969 (NEPA). In the first procedure, age- and sex-averaged risk estimators calculated with U.S. average demographic statistics would be used with estimates of radiation dose to calculate the projected risk of cancer and genetic disorders that would result from the operation being reviewed under NEPA. If more site-specific risk estimators are needed, and the demographic information is available, a second procedure is described that would involve direct calculation of the risk estimators using recommended risk-rate factors. The computer program REPCAL has been written to perform this calculation and is described in this report.

We have briefly discussed somatic effects other than cancer, such as developmental effects resulting from irradiation *in utero* and nonstochastic effects that may occur

in the dose ranges considered in NEPA documents. No risk estimation procedures are given in this report for these effects because none have been recommended by any of the national and international committees reviewed here.

I. INTRODUCTION

A. Scope of This Report

Under the National Environmental Policy Act of 1969 (NEPA), the Department of Energy (DOE) identifies and assesses environmental impacts from its proposed major actions. An important consideration in assessments of DOE programs involving the use of ionizing radiation is the potential effect on public health.

In this report we will present a method that estimates impacts on health from projected radiation doses from a particular program or facility. This method will allow the DOE decision maker to determine whether a program has a negligible or a significant associated health risk, and it provides a numerical estimate of the risk. In some NEPA documents, several alternatives involving a proposed action are analyzed. Expressing the results of the radiological analysis of each alternative in terms of health effects would help to clarify differences among the alternatives, which may facilitate decision making.

These estimation procedures are proposed so that DOE health risk estimation can be standardized in NEPA documents. Radiation impacts from different proposed actions can be compared more clearly because one element of variability--use of different risk calculations methods--will have been eliminated.

We have used in this report only the recommendations of well-recognized national or international advisory committees. No attempt was made to derive independent risk evaluations.

B. The NEPA Implementation Process: A Brief Description

The NEPA established a national policy for the environment. It also provided for a Council on Environmental Quality (CEQ), whose function was to set up regulations governing policy implementation.

The purpose and content of DOE-associated NEPA documentation are governed by the CEQ NEPA Regulations (Council on Environmental Quality 1978), DOE NEPA Guidelines (USDOE 1980b), the DOE Environmental Compliance Guide (USDOE 1981a), DOE Order 5440.1B (USDOE 1982a), and various NEPA-directed Executive Orders. Three basic levels of documentation are included in the DOE NEPA-review process: the Action Description Memorandum (ADM), the Environmental Assessment (EA), and the Environmental Impact Statement (EIS). The ADM is prepared for each proposed action not exempted under the DOE Guideline. The ADM identifies potential areas of environmental concern. If a finding of no significant impact is made in the ADM, the DOE prepares a memorandum to this effect as a file record. No further NEPA documentation is necessary. If it is found that the proposed action has a potential for significant impact, an environmental impact statement (EIS) must be prepared.

If, based on the information in the ADM, DOE is uncertain whether the proposed action will result in significant impact, an EA may be required. The EA contains a more complete analysis of environmental impacts than that in the ADM and includes consideration of alternative courses of action. Based on the information in the EA, the DOE decides if the proposed action results in no significant impact or if an EIS is necessary.

The EIS treats environmental impacts more completely than either the ADM or the EA. Although recent CEQ regulations emphasize a concise EIS (150 or fewer pages of text), the analysis underlying the document is extensive and detailed. All significant impacts must be considered, alternatives to a proposed action must be fully analyzed, and the impacts from each alternative must be evaluated.

Under the NEPA review process, then, an EIS is prepared only if either the ADM or the EA indicates that the proposed action may have significant impact. Preparing an EIS is a complex procedure involving a scoping stage (with participation of affected federal, state, and local agencies and other affected parties), publication of a draft EIS, a period for comment by the public and by other government agencies, and publication of a final EIS culminating in a minimum 30-day public review period. The DOE's final decision regarding the proposed action and its alternatives is published as a Record of Decision. That final document states the rationale for the chosen course of action, including the environmental issues, and it identifies necessary mitigating measures.

C. Use of Health Effects Estimates in NEPA Documents

In view of the wide range of detail required for NEPA documents, two alternate methods of estimating health effects are presented in this report. The first method is simple and direct. Risk factors given in this report are used to predict the lifetime risk of dying of cancer and the risk of genetic disorder in offspring in all subsequent generations as a result of exposure to ionizing radiation. These factors are average values calculated using the age and sex distribution of the U.S. population, the U.S. life tables, U.S. cancer mortality rates, and U.S. age-specific birth rates.

In situations where the characteristics of the population differ significantly from the average U.S. population, a somewhat more complex method using the specific characteristics of the local population may be used if these data are available. For this situation a second method of health risk estimation is presented. Risk-rate coefficients are recommended that can be used with local demographic and health statistics to calculate site-specific lifetime risk factors. A computer program was written to perform these calculations and is listed in Appendix B of the report.

D. Contents of the Report

Section II presents terminology and calculational models that are discussed in the report. Section III reviews the work that was considered in developing recommendations for lifetime risk factors and risk-rate coefficients. The lifetime risk factors and the genetic risk factors from the U.S. National Academy of Sciences Committee on the Biological Effects of Ionizing Radiations (the BEIR Committee), the United National Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), and the International Commission on Radiological Protection (ICRP) were reviewed, as well as a risk calculation method proposed by the National Council on Radiation Protection and Measurements (NCRP). Tumorigenic and mutagenic risk factors from these organizations were compiled in a common form so that they could be compared.

In Section IV risk factors and risk-rate coefficients are recommended for use in DOE NEPA documents. The calculational methodologies for estimating cancer risk and genetic risk are described in that section.

The final section, Section V, summarizes the recommendations made in the report.

II. CONSIDERATIONS IN CALCULATING RADIATION RISKS FOR NEPA DOCUMENTS

A. Typical Doses Considered in NEPA Documents

Doses from operation of DOE facilities are limited by DOE radiation standards found in DOE Order 5480.1 (USDOE 1980a). Annual doses to any member of the public are not to exceed 500 mrem to the whole body, gonads, or bone marrow, and 1500 mrem to any other organ. Annual doses to a suitable sample of the exposed population are limited to one-third of these limits. In addition to the dose limits, DOE policy requires that actual doses be kept to as small a fraction of the annual dose limits as is reasonably achievable (this is referred to as the ALARA policy).

When a dose assessment for a NEPA document is performed, some accident scenarios may involve consideration of doses larger than these dose standards. Dose criteria used to evaluate the suitability of facility siting are given in DOE Order 6430, which is now (October 1983) available only in draft form. For a one-time credible accident, the criteria would be 25 rem to the whole body, 300 rem to the thyroid, 300 rem to the bone surface, and 75 rem to the remaining organs. These criteria apply to the maximum exposed individual located either at the site boundary or onsite at the nearest separate facility (USDOE 1981b). Dose estimates for possible accidents for a proposed DOE operation may range up to these dose criteria.

These accident dose criteria are used as reference values for evaluating the suitability of facility siting. They apply only to accidents. The criteria do not imply the acceptability of doses at these levels, but they provide guidance for siting purposes.

B. Health Effects Resulting from Radiation Exposure

Radiation-induced health effects can be somatic, which occur in the individual receiving the radiation exposure, or genetic, which occur in his or her offspring. Early somatic effects, which can follow the exposure by minutes to weeks, result from high doses of ionizing radiation at high dose rates. These levels are usually not encountered in NEPA documents and are not discussed in this report. Late somatic effects, which usually occur years after the exposure, can be either stochastic, where the probability of injury depends on the dose received, or nonstochastic, where the severity of the effect depends on the dose.

The principal stochastic effect resulting from radiation exposure is induction of cancer. In Section IV, a method of estimating the cancer risks due to radiation is presented.

Other somatic effects include teratogenic effects (which are stochastic) and nonstochastic effects. Teratogenic effects may occur as the result of *in utero* irradiation of the fetus. These effects include microcephaly, growth impairment, and mental retardation. Nonstochastic effects can range in severity from very mild effects detectable only by sensitive biological testing to severe effects that can be life threatening. As will be discussed later in this report, at the dose levels resulting from routine facility operations that are assessed in NEPA documents, neither widespread teratogenic effects nor nonstochastic effects are expected to occur. In contrast to routine operations, analysis of some accident scenarios may involve consideration of doses in ranges where teratogenic effects and nonstochastic effects are not precluded. However, even these relatively higher accident doses are at the extreme low end of the range of doses where teratogenic effects and nonstochastic effects may occur, so that the importance of these effects is expected to be minimal.

Genetic effects resulting from radiation exposure are stochastic. These effects appear as a result of gene mutations or chromosomal aberrations. A method for estimating the risk of genetic disorder in the first generation and in all subsequent generations due to radiation exposure is discussed in Section IV.

C. Terminology

In the discussion of risk calculations, several terms are used in this report with specific meanings. These terms are defined in this section.

- The risk factor is the lifetime risk of radiation-induced cancer mortality per unit of absorbed dose. The risk factors have been averaged over the age and sex distribution of the population receiving the radiation exposure. The unit is rad^{-1}.

Sometimes a risk factor for genetic risk is given. In these cases, the risk factor is the risk of genetic disorder in liveborn offspring in the first generation or in all subsequent generations per unit of absorbed dose. In this case the absorbed dose is the gamete dose, defined below. This risk factor is also expressed in rad^{-1}. The context in which the term appears will clarify whether a somatic or genetic risk factor, or both, are discussed.

- The risk-rate factor is the risk of cancer mortality resulting from the radiation exposure per year per unit absorbed dose. The factor is expressed in rad^{-1} $year^{-1}$ and is used in calculating the lifetime risk factor for cancer mortality described above.

- The latent period is the time between the radiation exposure and the appearance of the health effect.

- The expression period or plateau period is the time of an increased relatively uniform risk of cancer mortality resulting from exposure to radiation.

- The relative biological effectiveness (RBE) is the ratio of the absorbed dose of a reference radiation (such as 250 kVp x-rays) needed to produce a given biological effect to the absorbed dose of a particular radiation type (such as alpha or neutron) needed to produce the identical biological effect.

- The quality factor is the quantity used for radiation protection purposes that multiplies the absorbed dose so that radiation of different linear energy transfer (LET) can be expressed in a common term taking into account the different LET-dependent biological effectiveness of each radiation type.

- The genetically significant dose is the gonadal dose from all sources of exposure that, if received by every member of the population, would be expected to produce the same total genetic effect on the population as the sum of the individual doses actually received.

- The gamete dose is the dose accumulated by gametes before conception by the population at risk. The procedure used in BEIR III for calculating the gamete dose is described in Section IV.H.

D. Calculational Assumptions Used in Estimating Radiation Risks

Risk estimates, published by the national and international advisory groups reviewed in Section III, are based on the results of epidemiological studies. Use of these estimates entails several assumptions. These assumptions concern the shape of the dose-response relationship, the method for estimating the risk for times longer than the period spanned in the epidemiological study, the comparability between the studied population and the population that is the immediate concern in the NEPA dose assessment, the value of the RBE used to relate risk from low-LET radiation to risk from high-LET radiation, and the variability of demographic statistics used in estimating risk factors.

1. The Dose-Response Model. Epidemiological studies of the effects of radiation exposure typically are designed to observe the incidence or mortality rate of a health effect such as cancer in exposed and control (non-exposed) human populations. Because of the statistical nature of the appearance of these health effects, the highest quality data will usually be obtained from those population sectors receiving the largest radiation dose. At the low-dose levels of most interest in NEPA-related documents, the risk per unit dose is low, usually resulting in so few health effects that any increased effects are difficult or impossible to observe by epidemiological techniques. Alternatively, the sample size theoretically may be increased to improve statistical power. This is limited, however, by the size of the exposed population. For example, Land and Pierce estimate that a sample size of tens of millions of individuals would be needed to measure the carcinogenic effect of 1 rad of whole body radiation if our current estimates of the risk are accepted (Land 1983).

Consequently, the risk of health effects at doses below 5 to 10 rads has never been conclusively observed. The BEIR Committee in its 1980 report states that it is uncertain "as to whether a total dose of, say, 1 rad would have any effect at all" (BEIR III 1980, p. 139), and "it is by no means clear whether dose rates of gamma or x radiation of about 100 mrads/yr are in any way detrimental to exposed people; any somatic effects would be masked by environmental or other factors that produce the same types of health effects as does ionizing radiation." (BEIR III 1980, p. 139).

Because health effects are difficult to observe when subjects were only exposed at low doses, health risks potentially caused by low levels of ionizing radiation are estimated by extrapolating risks observed at high doses to the low-dose region. A mathematical relationship giving risk in terms of dose is used to perform the extrapolation. None of the mathematical models commonly used contain a threshold dose of radiation, below which the radiation would be expected to have no adverse effect on health. Until the 1980 BEIR report was published, the most commonly used model assumed a linear nonthreshold relationship between the dose D and the response E,

$$E = aD + E_0 \quad ,$$

where "a" is the risk per unit dose, and E_0 is the number of health effects in the absence of any dose. In its 1980 report, the BEIR Committee considered two additional nonthreshold dose-response models for induction of cancer by low-LET radiation: the linear-quadratic model, in which the response is a sum of a linear and a quadratic term,

$$E = aD + bD^2 + E_0 \quad ,$$

and the quadratic model, in which the response is a quadratic function of the dose,

$$E = bD^2 + E_0 \quad ,$$

where b is a constant.

In summary, epidemiological studies provide estimates of increased risk of cancer induction at relatively high doses where this risk can be more easily observed. In order to obtain estimates of risks at low doses, assumptions are made about the shape of the dose-response curve, and the high-dose risks are extrapolated to the low-dose region.

The question of the slope of the dose response curve and the magnitude of the risk factors may be affected by recent work by Loewe and Mendelsohn (1981) revising the dosimetry of the Japanese atomic bomb survivors. The possible effects this work may have on estimating the risk of radiation-induced cancer are discussed in Section IV.J.

We have elected to recommend the linear no-threshold dose-response model for all radiation types, including low-LET radiation (see Section IV.B). Until the uncertainty noted above in the Japanese atomic bomb survivor epidemiological data is resolved, the more conservative linear model is the most appropriate for long-term projections such as made in environmental documents. We do include a correction to the recommended risk estimate for low doses of low-LET radiation.

The national and international organizations whose recommendations are reviewed in Section III were unanimous in considering that linear extrapolation of risk from low-LET radiation exposure (from the high-dose high-dose-rate regions to low-dose low-dose-rate regions) tends to overestimate the cancer risk. As noted above, the BEIR Committee proposed using a linear-quadratic dose-response model to estimate total cancer risk induced by low-LET radiation. The Committee stated that the quadratic and linear model estimates would bracket the radiation risk, which would be more accurately represented by the intermediate estimates from the linear-quadratic model. For example, the linear-quadratic model produces estimates of total cancer approximately 2.4 times lower at a continuous exposure of 1 rad/year than would be those for the linear model (BEIR III 1980, p. 146). The NCRP developed a Dose Rate Effectiveness Factor (DREF) that would lower the linearly extrapolated estimate of total cancer risk resulting from low-LET radiation by a factor of 2 to 10 for low-dose low-dose-rate exposures (NCRP 1980). UNSCEAR lowered its risk estimate for total cancer induction from 250 x 10^{-6}/rad of low-LET radiation to 100 x 10^{-6}/rad of low-LET radiation for low-dose exposures (UNSCEAR 1977). The leukemia risk was similarly reduced. The UNSCEAR Committee notes that such a value is derived essentially from mortalities induced at doses in excess of 100 rad and thus the value appropriate for much lower dose values, and especially for environmental exposures to radiation, may well be substantially less. The ICRP also warns that risk estimates derived from data involving populations exposed at high doses and high-dose rates could overestimate the risk at low doses and low-dose rates, and they consider these possible overestimates in choosing the risk factors used in their report (ICRP 1977a).

For the choice of models to estimate the risk of genetic disorders, the situation is somewhat different. Only very limited evidence of genetic damage from radiation has been observed in human populations. Risk estimates have been obtained principally from laboratory work with several animal species, particularly with mice. These risk estimates were then used with assumptions about the dose-response relationship to estimate the risk of genetic disorders from radiation at low doses. A linear dose-response model has been used consistently by BEIR, UNSCEAR, and ICRP to estimate genetic risk.

2. Projection of Cancer Risk Beyond the Period of Follow-Up. The majority of the epidemiological studies have not yet followed the individuals in their study populations through their entire lifetimes. When the BEIR III report was being written, the data from Japanese atomic bomb survivor study--one of the most important studies for estimating radiation risks--encompassed only 30 years of observation. For some types of cancer, namely leukemia and bone cancer, no elevated cancer incidence had been observed for several years. This was interpreted as the risk returning to zero in about 25-30 years. An estimate of the total lifetime risk of incurring one of these cancers could be calculated straightforwardly. For many other cancers,

however, cancer incidence and mortality had remained elevated above levels found in the control populations. In order to calculate the total lifetime risk of having one of these cancers as a result of radiation exposure, the future risk had to be estimated. The risk was assumed to follow either the absolute risk projection model or the relative risk projection model.

Risk projection using the absolute risk model assumes that absolute risk, which is the difference between the risk of the exposed population and that of the control population, remained constant throughout the expression period. Risk projection with the relative risk model, in contrast, assumes that the ratio of the risk of the exposed population to the control population, as measured during the observation period, was a constant throughout the remaining expression period.

Determining which projection model is preferable may depend on the type of cancer being considered. For example, the BEIR Committee has noted that lung and breast cancer induction may be underestimated by the absolute risk model (BEIR III 1980). However, for many cancers, data are insufficient to indicate which projection model is more appropriate.

3. Comparability Between Populations. The major use of risk estimators in NEPA documents would be to estimate the health impacts of the proposed facility or activity on the surrounding population. This population, which has its own age and sex distribution, would usually be similar to the U.S. population. Even so, populations forming the basis of most epidemiological studies usually differ from the U.S. population in several ways. For example, uranium miner populations have been studied for the effects of radon decay products in inducing lung cancer. This population is composed mainly of males of working age. Exposures occurred while the miners were working in dusty underground mine atmospheres. Cigarette smoking was found to be more widely prevalent among these groups than in the U.S. population as a whole. Thus, there is a question as to what degree the lung cancer risks in this population represent those of a more typical population group.

Similar considerations apply to other groups used in epidemiological studies. The Japanese atomic bomb survivors formed a population group in which males of military age were largely absent, and in which spontaneous incidence rates of many cancers, such as breast cancer or digestive tract cancers, differed significantly from those of the U.S. population. Many epidemiological studies concerned groups that received radiation as a treatment for a specific disease. To what extent the pre-existing disease contributed to elevated cancer rates in many cases is not known.

The BEIR III Committee partially addressed this issue in its relative risk estimate of the number of cancer deaths from a hypothetical radiation exposure in a population group similar to the U.S. population. The Committee used absolute risk-rate coefficients derived from the epidemiological study of these previously exposed populations to calculate relative risk-rate factors. The expected number of cancer deaths (calculated with the absolute risk-rate factors) resulting from radiation exposure that would occur between 10 and 30 years after the exposure was divided by the number of spontaneous cancer deaths during the same time period. (The period of 30 years after the exposure was used because this was the follow-up period for the atomic bomb survivor study, on which the absolute risk-rate factors were based.) Because the risk estimate was for the U.S. population, the spontaneous cancer mortality rate for the U.S. population was used in the relative risk calculation. The calculated ratio was used as the relative risk-rate factor. The number of cancer deaths, then, in the first 30 years after exposure was calculated using the absolute risk-rate factors from the exposed population (the atomic bomb survivors), but the projection was based on the characteristics of the population for whom the risk was calculated. The question remains as to the applicability of the absolute risk-rate factors to populations other than those that were studied.

4. Numerical Value of the RBE. The RBE should be used in converting risk factors for low-LET radiation to those for high-LET radiation. There is no reason why the RBE should be exactly equal to the quality factor. However, at the dose ranges considered in this report, there are very few measurements of the RBE. The quality factor is frequently used as the RBE, and this practice has been followed in this study. Following the ICRP (ICRP 1977a), we have used a quality factor of 20 for alpha radiation. An exception is the RBE for lung cancer, for which a range of values of 8 to 15 was explicitly given in BEIR III report, whose recommendations were used in estimating the risk of radiation-induced lung cancer (see Section IV.F.7). We have also used a maximum value of 10 for the RBE for neutron radiation.

5. Stability of Demographic Data. Age- and sex-averaged risk factors are calculated using demographic data describing the exposed population at a particular time. These data are the population distribution by age and sex, the probability of dying during a particular age interval, cancer mortality rates by age and sex (if the relative risk of cancer is to be calculated), and age-specific birth rates (for estimating the risk of genetic disorders in offspring).

The estimation of the risk factors assumes that the demographic data used in the calculation are relatively constant in time. While this may be true generally, it may not be a particularly good assumption for several parameters. Examples would include increasing lung cancer rates and falling birth rates. Interpretation of estimates of radiation-induced health risks should be made with these uncertainties in mind.

III. RISK ESTIMATION PROCEDURES OF NATIONAL AND INTERNATIONAL ADVISORY GROUPS

A. Risks of Radiation-Induced Cancer and Genetic Disorders

1. U.S. National Academy of Sciences Committee on the Biological Effects of Ionizing Radiations (BEIR Committee)

a. The BEIR I Report. In 1972 the BEIR Committee published their review of the evidence for effects on human health caused by exposure to low levels of ionizing radiation (BEIR I 1972). Because the recommendations of this report have been superseded by the 1980 BEIR report (BEIR III 1980), the BEIR I report will only be briefly discussed here.

Both somatic and genetic effects were considered in the BEIR I report. The linear dose-response model was used for both carcinogenic and mutagenic effects. The principal somatic effect was induction of cancer, but other effects such as the formation of cataracts and impairment of fertility were also included.

The BEIR I report published both absolute and relative risk-rate coefficients for the major cancers induced by radiation. If these rates are used with the estimates of latent period and plateau period given in BEIR I for each cancer type, the total lifetime risk can be calculated that is due to a radiation exposure at any age. The estimate of the annual number of cancer deaths in the United States resulting from continuous exposure to 0.1 rem/year is included in the report (BEIR I 1972, pp. 172-173) and illustrates the calculation procedure.

Four methods of assessing genetic risks were used in BEIR I: comparison with natural background radiation, a doubling dose method, a method based on an estimate of the mutational component in congenital anomalies and constitutional diseases, and a method based on the role of mutations in overall ill health. The BEIR Committee indicated that the above list is in the order of decreasing confidence.

Estimates of genetic disorders were based on a risk relative to the spontaneous mutation rate of 0.005 to 0.05 per rem, or a doubling dose ranging from 20 to 200 rem. Dominant, chromosomal, and recessive genetic disorders would eventually increase in proportion to the mutation rate. Diseases of complex etiology were assumed to have a mutational component between 5% and 50% of the incidence rate. Based on these factors, the BEIR Committee estimated that the equilibrium risk factor for genetic disorder in offspring ranged between 300 and 7500 x 10^{-6} for 5 rem per generation.

b. The BEIR III Report. The BEIR Committee in the BEIR III report published in 1980 reviewed its 1972 report and updated its risk estimates based on the most recent epidemiological results.

Although most features of the BEIR I were retained, several significant procedural changes were made in BEIR III. The most significant change in BEIR III was the recommendation that the linear-quadratic dose-response model be used to calculate cancer risks from exposure to low-LET radiation. The linear and quadratic dose-response models were also presented, and the BEIR Committee concluded that risk estimates using these two models represent upper and lower bounds, respectively, for the risk, which was best represented by the linear-quadratic model. The linear dose-response model continued to be used by the BEIR Committee for calculating cancer risk from high-LET radiation and for calculating the risk of genetic disorders for both high- and low-LET radiation.

These recommendations of the BEIR Committee were based on radiobiological considerations. Because of statistical considerations noted earlier, epidemiological studies are relatively insensitive to the shape of the dose-response model in the low-dose region, the areas where the greatest difference between these models would be expected. The use of one model rather than another has not been decided through epidemiological data, but independently through radiobiological research, which has formed the basis of understanding how radiation interacts with human tissue.

Unfortunately, risk-rate coefficients for low-LET radiation used in the linear-quadratic model were supplied by the BEIR Committee only for combined leukemia and bone cancer, and for all other cancers combined. Only linear risk-rate factors were provided for each cancer type singly.

The BEIR III report used a 3-year latent period and a 24-year expression period for leukemia and bone cancer. Risks from other cancers were calculated using a 10-year latent period and an expression period extending for the full lifetime. For in utero exposures, the latent period was taken to be 0 year, and the expression period was 12 years for hematopoietic tumors and 10 years for solid tumors. Most of these values for latent period and expression period represent only small changes from values in the BEIR I report. One notable exception is that BEIR III no longer uses a 30-year expression period in addition to the lifetime expression period for solid cancers as did BEIR I; it only considers a lifetime expression period.

One final procedural difference between BEIR I and BEIR III concerns the calculation of relative risk. In BEIR III explicit relative risk-rate factors usually are not given as they were in the earlier report. A relative risk calculation was performed using the absolute risk-rate factors for all cancers except leukemia and bone cancer; this will be described in Section IV.C. In addition, for this calculation, relative risks to individuals in the 0- to 9-year age group were found to be unreliable, and the relative risks for the 10- to 19-year age group were substituted for them in BEIR III.

More generally, the BEIR Committee tended to give age-specific absolute risk-rate coefficients rather than relative risk-rate coefficients (breast cancer was an exception in that both were given). The BEIR Somatic Effects Subcommittee stated:

"Review of the current data has led the present Subcommittee to conclude that the relative-risk model does not apply generally, but is applicable to the effect of age on cancer incidence for many sites at which cancer is induced by radiation. Thus, age at exposure and at cancer development has emerged as a major determinant of cancer risk from radiation. For this reason, this subject is also considered in some detail; both projection models have been used." (BEIR III 1980, p. 150)

In giving the lower and upper bounds of the risk estimates from the quadratic and linear models, respectively, as well as the central value of the risk estimate from the linear-quadratic model, the BEIR III Committee provided a measure of the uncertainty of these risk projections. At a single exposure of 10 rads, the estimates made with the linear model were 2.2 times larger than were those made with the linear-quadratic model. The linear-quadratic estimates were eight times larger than were the quadratic estimates. And finally, the estimates made with the relative risk projection model were three times larger than those made with the absolute risk projection model for all three dose-response functions (BEIR III 1980, Table V-2, p. 145).

Estimates of the risk of genetic disorders in BEIR III were calculated using two methods, the indirect relative-mutation-risk method (for equilibrium effects) and a new direct method (for first-generation effects). The relative mutation risk of genetic disorder was revised to 0.004-0.02 per rem, corresponding to a doubling dose of 50 to 250 rem. This method was used for all genetic disorders except chromosomal aberrations. The BEIR Committee estimated the equilibrium rate of chromosomal aberrations from the direct method; the expected number of these aberrations was low and did not appreciably affect the estimate of all genetic disorders at equilibrium. The BEIR III report follows BEIR I in using 5% to 50% for the mutational component in irregularly inherited disorders.

Using the indirect method, the BEIR Committee estimated the total number of genetic disorders at equilibrium from an exposure of 1 rem of low-LET radiation per generation to range from 60 to 1100 per million liveborn offspring. This estimate includes a reduction by a factor of 3 to account for the lesser effectiveness of low-dose-rate low-LET radiation to produce genetic effects (BEIR III 1980, p. 128). This dose-rate effect has not been observed for high-LET radiation, so that the risk of genetic disorder at equilibrium from 1 rem of high-LET radiation per generation would be 180-3300 per million liveborn offspring.

A direct method, based on new data giving the incidence of radiation-induced skeletal abnormalities in mice, allows estimation of first generation genetic disorders in man that are due to gene mutations. The risk of chromosomal aberrations from radiation exposure, which the BEIR Committee felt would be dominated by reciprocal translocations, was derived from human and marmoset data. For an exposure of 1 rem, 5 to 65 serious disorders and irregularly inherited disorders, and 0 to 10 disorders from chromosomal aberrations per million liveborn offspring would be expected in the first generation from an exposure of 1 rem. This risk factor took into account the sensitivity of oocytes to radiation, which was estimated to be from 0 to 0.44 of that of spermatogonia for mature and maturing oocytes, and negligible for resting oocytes (BEIR III 1980, p. 118).

As noted above, corrections for dose-rate effects from low-LET radiation were applied in the BEIR III report in the calculation of the risk of genetic disorders. They considered a dose-rate correction for cancer induction by low-LET radiation but it was not adopted. As stated by the BEIR III Committee, "most members of the Committee conclude that it is not now possible to assign a numerical value to any dose-rate factor by which risk estimates obtained in populations exposed to low-LET radiation at relatively high dose rates can be corrected to apply to exposures at low dose rates" (BEIR III 1980, p. 191). The Committee noted that the linear-quadratic model includes some correction for dose rate because the coefficient of the quadratic term depends on dose fractionation.

For high-LET radiation, the Committee did not apply any reduction for dose rate. Because of the reduced effectiveness of body repair mechanisms for high-LET radiation, they recommended the use of the linear dose-response model for both genetic and tumorigenic effects.

2. United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR Committee)

a. The 1977 UNSCEAR Report. UNSCEAR published a comprehensive report in 1977 entitled Sources and Effects of Ionizing Radiation, which included a discussion of the health effects of low-level ionizing radiation exposure. The report reviewed recent work in radiation-induced carcinogenesis, genetic disorders, and developmental disorders from in utero exposure. Both tumorigenic and mutagenic effects were calculated with a linear dose-response model.

UNSCEAR published total lifetime risk of cancer mortality (or incidence) resulting from exposure to ionizing radiation. Risk factors were given per unit of absorbed dose (in rads), so that identification of the type of radiation--whether high or low LET--should accompany the risk estimate to make it meaningful.

UNSCEAR explicitly reduced its estimate of total lifetime cancer risk per rad of low-LET radiation from 250 to 300 x 10^{-6}/rad at moderately high doses (100 to several hundred rads) to 100 x 10^{-6}/rad at low doses (doses of a few rads) (UNSCEAR 1977, p. 414, paragraph 318). Risk factors for leukemia, from which the above total cancer risks were estimated, were observed to fall from 50 x 10^{-6}/rad at moderately high doses to 20 x 10^{-6}/rad at low doses.

Dose-rate effects, in addition to the dose magnitude effects discussed above, also were considered (for example, see UNSCEAR 1977, p. 413, paragraph 310 and p. 512, paragraph 646). Low-LET radiation delivered at low dose rates would be expected to result in a lower risk of cancer induction per rad, but UNSCEAR indicated that it would be impossible to quantify this effect for tumorogenesis (UNSCEAR 1977, p. 598, paragraph 183). A dose-rate reduction factor of 3 for low-dose-rate low-dose effects was included in the calculation of risk of mutagenesis from low-LET radiation (UNSCEAR 1977, p. 508, paragraph 611).

The risk of genetic disorders was estimated using a direct method based on research on skeletal abnormalities in mice exposed to radiation (work also used in the BEIR III report that appeared later) and an indirect method using a doubling dose of 100 rads. The UNSCEAR report and the BEIR III report are in good agreement in estimating the risk of genetic disorder. UNSCEAR estimates that low-dose-rate irradiation at the rate of 1 rad per generation would result in 63 genetic disorders per million liveborn offspring in the first generation (compared with 5 to 75 per million in BEIR III) and 185 genetic disorders per million liveborn offspring at equilibrium (compared with 60 to 1100 per million in BEIR III).

b. The 1982 UNSCEAR Report. UNSCEAR issued its report Ionizing Radiation: Sources and Biological Effects in 1982. The report

1. did not revise any risk factors for radiation-induced cancer from its 1977 report. UNSCEAR indicated that it is now reviewing models of tumor induction, but that it is postponing publication of its findings until questions concerning the dosimetry of the atomic bomb survivors are settled (UNSCEAR 1982, p. 11, paragraph 52). (See Section IV.J. of this report for a short discussion of the effects the review of this dosimetry may have.)

2. reviewed the evidence for nonstochastic risks from radiation exposure. Nonstochastic risks are discussed in Section III.B.2.

3. reviewed recent data on the risk of radiation-induced genetic disorders. The Committee concluded that no substantial changes in previous estimates of genetic risks were necessary.

As in the 1977 UNSCEAR report, the risk of genetic disorder was calculated using a direct method (risks for first generation only) and an indirect method (risks for first generation and for equilibrium). The direct method included the estimate that was used in the 1977 UNSCEAR report based on skeletal malformations in the mouse, and also included an estimate based on radiation-induced dominant cataract mutations in male mice. The sensitivity of oocytes to radiation, which had been considered low in the 1977 report and not included in the risk estimates, was quantified in the 1982 report. The oocytes were estimated to have from 0 to 0.44 times the sensitivity of spermatogonia. The UNSCEAR Committee estimated that the risk of genetic disorder in the first generation from dominant mutations induced by low-LET radiation at low-dose rates would be 10 to 20 x 10^{-6}/rad for males and 0 to 0.9 x 10^{-6}/rad for females. The genetic risk from structural chromosomal damage was estimated using human, marmoset, and rhesus monkey data. The estimate of 0.30 to 10 x 10^{-6}/rad (low LET) for males was similar to the estimates of 2 to 10 x 10^{-6}/rad (low LET) for males in the 1977 UNSCEAR report. The estimate in the 1982 report of 0 to 3 x 10^{-6}/rad (low LET) for females agrees with the statement in the 1977 report that the risk of structural chromosome damage in females was low.

Using the direct method, the UNSCEAR Committee estimated that the total risk of genetic disorder in the first generation would be 10.3 to 30 x 10^{-6}/rad for males and 0 to 12 x 10^{-6}/rad for females. These risk factors apply to irradiation by low-LET radiation at low-dose rates.

The indirect method calculation in the UNSCEAR 1982 report used a doubling dose of 100 rads (low LET) to estimate the risk of radiation-induced genetic disorders in the first generation after exposure and at equilibrium. The equilibrium estimate is 149 per million liveborn offspring at a dose of 1 rad (low LET) per generation. This is only a slight change in the previous estimate of 185 x 10^{-6}/rad in UNSCEAR 1977.

The risk of genetic disorder in offspring in the first generation using the indirect method was estimated to be 21.9 x 10^{-6}/rad. This slight reduction from the estimate of 63 x 10^{-6}/rad made in the UNSCEAR 1977 report was based primarily on more recent information that was available for the 1982 report. This estimate, as well as the estimates for first-generation effects made with the direct method, is in agreement with the BEIR III estimate of 5 to 75 x 10^{-6}/rad.

3. International Commission on Radiological Protection (ICRP)

In ICRP Publication 26, Recommendations of the International Commission on Radiological Protection (ICRP 1977a), the ICRP presented a method for regulating radiation doses to radiation workers and the public based on limiting risks of somatic and hereditary effects. The dose-limitation procedure was designed to prevent nonstochastic effects (those for which the severity of the effect varies with the dose) and limit stochastic effects (those for which the probability of the effect occurring, rather than its severity, depends on dose). The linear dose-response model for both tumorigenic and mutagenic risks was used in this dose-limitation procedure.

In developing its recommendations for dose limits, the ICRP presented risk estimates for both cancer mortality and genetic disorder resulting from exposure to ionizing radiation. These estimates were chosen for radiation protection purposes and considered to be conservative by the ICRP. The risk factors for cancer mortality are estimates of lifetime risks per unit dose of sufficient accuracy to be applied regardless of age or sex (ICRP 1977a, p. 9).

The ICRP in Publication 27, Problems Involved in Developing an Index of Harm (ICRP 1977b) further discusses risk calculation using these risk factors. The risk of breast cancer mortality is taken to be 50 x 10^{-6}/rem for females and 0 for males (the average, 25 x 10^{-6}/rem,* is given in ICRP Publication 26). The ICRP sums the various organ risk factors to calculate a total lifetime cancer risk of 100 x 10^{-6}/rem for males and 150 x 10^{-6}/rem for females. The average would then be 125 x 10^{-6}/rem. This sex-averaged risk is reduced to 100 x 10^{-6}/rem when the risk is averaged over the ages of the working population, because in exposed older workers, the cancer expression period is necessarily shortened by deaths from other causes.

The ICRP site-specific cancer risk factors quoted in this report are not age-averaged, but instead, they represent the risk when the "full expression period" is available. We infer this from the use of these risk factors in ICRP Publication 27 (ICRP 1977b). However, age averaging reduced the total cancer risk factor by only 20%, and a similar reduction would occur if age averaging were used for the site-specific cancer risk factors. Because of the uncertainties inherent in these risk factors, the ICRP factors are sufficiently close to the age-averaged factors to compare with risk factors recommended by other advisory groups (see Sec. III.C).

To calculate internal exposure, the ICRP uses the 50-year dose commitment in its system for limitation of dose received by intake of radioactive material during a year. The 50-year dose commitment to an organ is the total dose that an organ receives from radionuclide intake during the 50 years following that intake. The total 50-year dose is thus charged against the year that the intake occurred, even though some fraction of that dose may not be incurred for years after that intake. Multiplication of that organ

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*Really as 2.5 x 10^{-3}/Sievert. The ICRP presents its risk factors in terms of dose equivalent (units of Sievert or rem) rather than absorbed dose (units of greys or rads) as other advisory bodies have done. To compare the recommendations of the ICRP with those of the other groups, we converted the rem values to rad values using a quality factor of 20.

dose by the organ's weighting factor, which is the proportion of the stochastic risk to that organ to the total risk when the whole body is irradiated uniformly, gives a weighted effective dose. Risk of stochastic effects from this effective dose can then be compared directly with the risk from uniform whole-body radiation.

Use of the 50-year dose commitment to calculate stochastic risk is compatible with the ICRP's risk factors. Because their risk factors are not age dependent, the age at which the dose is received does not affect the risk calculation. It is obvious, however, that exposures to older individuals may never result in a 50-year dose because their life expectancies can be much less than 50 years.

The ICRP considered reductions in risk owing to both low doses and low-dose rates in deriving its risk factors. Many of the risk factors were based on data taken at high doses and high-dose rates. For these factors, the ICRP states, "it is likely that the frequency of effects per unit dose will be lower following exposure to low doses or to doses delivered at low-dose rates, and it may be appropriate, therefore, to reduce these estimates by a factor to allow for the probable difference in risk. The risk factors...have therefore been chosen as far as possible to apply in practice for the purposes of radiation protection." (ICRP 1977a, p. 7).

Risks of serious genetic disorder given by the ICRP are 100×10^{-6} per rem (genetically significant dose) in the first two generations and an amount of the same magnitude in later generations (ICRP 1977a, p. 10). The total risk to all subsequent generations was taken to be 200×10^{-6} per rem.

The ICRP also used a risk factor for genetic disorder of 80×10^{-6}/rem in all subsequent generations (40×10^{-6}/rem for the first two generations) (ICRP 1977a, p. 12). This risk factor has been adjusted for the contribution that a uniform dose to a typical population would make to the genetically significant dose (ICRP 1977b); this is the genetic risk in an exposed population in terms of the gonadal dose to that population rather than the genetically significant dose.

For the purposes of comparison with estimates of risk of genetic disorder taken from the BEIR and UNSCEAR reports, the first risk factor, 200 $\times 10^{-6}$/rem, is appropriate, and will be discussed with risk factors from other advisory bodies in Section III.C.

4. National Council on Radiation Protection and Measurements (NCRP)

The NCRP, in its Report No. 64, Influence of Dose and Its Distribution in Time on Dose-Response Relationships for Low-LET Radiations (NCRP 1980), extensively reviewed the influences of dose magnitude and dose rate on carcinogenic and genetic effects in man. Radiation effects on a wide variety of biological systems, including simple cells, plants, animals, and finally humans were considered by the NCRP.

The NCRP noted that linear extrapolation of cancer risk from low-LET radiation exposure based on data for populations exposed at high doses and high-dose rates could lead to overestimation of risk at low doses and low-dose rates because the effect of biological repair mechanisms would not be taken into account. A Dose-Rate Effectiveness Factor (DREF) was developed to correct overestimates of total cancer risk and risk of genetic disorder resulting from exposure to low-LET radiation at doses of 20 rads or less and dose rates of 5 rads/year or less. For this dose magnitude and dose-rate range, the NCRP estimated that the linear hypothesis would overestimate the total number of tumors or genetic disorders in man by a factor of 2 to 10. The NCRP avoided giving DREFs for individual organs, or a single value for the DREF for all tumors, because of our present limited understanding of tumor formation and the widely different tumor responses to radiation in experimental animals.

Risk factors for selected cancers in humans were reviewed by the NCRP, but no specific factors were recommended for calculating the risk from radiation exposure. Similarly, latent periods and plateau periods were discussed, but no values were recommended for risk calculation for specific cancers. Instead, the report focused on correlating dose magnitude and dose-rate effects observed in a wide variety of biological systems so that the effects on man for exposure to ionizing radiation at low doses, or at high doses but at low-dose rates could be assessed, and the validity of the linear dose-response model for low-LET radiation could be examined.

B. Risks of Somatic Effects Other Than Cancer

1. Effects from Irradiation in Utero. *In utero* radiation exposure has been related to an increased risk of death of the conceptus and embryo and of teratogenic effects in animal experiments, and in some cases, in human populations (such as the atomic bomb survivors). The developmental effects include morphological changes (especially microcephaly for humans), functional disabilities (such as mental retardation), and growth impairment. These effects have been principally observed in populations exposed at high-radiation doses, although some effects have also been reported at doses as low as a few rads to the embryo.

Although these effects have been documented, the dose-response relationship has not been well defined. None of the organizations (with the exception of the ICRP) whose work is reviewed in this report have developed a method of quantitatively relating the risk of teratogenic effects to the radiation dose. Many questions remain, such as the biological effectiveness of high-LET radiation relative to low-LET radiation.

In its 1977 report, the UNSCEAR Committee stated that, for somatic effects other than cancer, "data applicable to man can only be derived from human epidemiological studies. These studies are, however, not available at present, at least on the scale required and at the low doses of interest. The Committee believes that this point should be particularly emphasized so as to discourage numerical extrapolations not sufficiently justified by present knowledge." (UNSCEAR 1977, p. 707) Data obtained from animal experiments was qualitatively useful, but should not be used to establish a quantitative dose-effect relationship for man because of "(a) the great specificity of the malformations induced at comparable stages in different species and even among different strains of the same species; (b) the species difference in the duration of the foetal period ...; (c) the extremely variable form of the dose-effect relationships in different species." (UNSCEAR 1977, p. 707)

The UNSCEAR Committee did report an incidence rate for man of mental retardation associated with microcephaly of 10^{-3}/rad when irradiation occurred during the period of major organogenesis (9 to 60 days post conception). This incidence rate was measured at doses greater than 50 rads to the fetus, and the Committee warned against extrapolating this rate to the lower dose region (UNSCEAR 1977, p. 682).

In studies of individuals exposed in utero at Hiroshima and Nagasaki, microcephaly was observed at doses as low as 10 to 19 rad (kerma) at Hiroshima, but only at doses above 150 rad (kerma) at Nagasaki. The difference was presumably due to the larger neutron component to the dose at Hiroshima, although this conclusion may be altered by the recent reexamination of the dosimetry at Hiroshima and Nagasaki (UNSCEAR 1977, p. 682) (see Section IV.J). No dose-response relationship was given in the UNSCEAR report based on this data.

The BEIR Committee felt that, for some teratogenic effects where cell-killing effects could be directly measured, such as oocyte killing, "there do not appear to be any clear threshold doses under some conditions. For morphologic malformations, however, a generalized straight-line extrapolation from the results of acute irradiation at high or moderate doses is probably not valid. Because it is unlikely that any perceived developmental abnormality results from damage to a single target, there are probably threshold doses for all such abnormalities." (BEIR III 1980, p. 489.) The BEIR III report states that, at total exposures less than 1 R delivered at exposure rates of 0.01 R/min or less, widespread teratogenic effects would not occur, even though some effects involving single cells could occur (BEIR III 1980, p. 492). The report also states that natural and manmade background radiation is so low that it is not believed to be a factor in the natural occurrence of teratogenic effects (BEIR III 1980, p. 487).

The report in which the ICRP systematically presented its risk factors, ICRP Publication 26, discussed teratogenic effects (ICRP 1977a, p. 13, paragraph 65) but presented no risk factors for those effects. In contrast to BEIR III and UNSCEAR, the ICRP has used a linear dose-response model in developing an index of harm to estimate effects from in utero irradiation in ICRP Publication 27 (ICRP 1977b). Risk factors for these effects were estimated to be 8 x 10^{-3}/rem for intrauterine death for exposures before implantation of the conceptus on the uterine wall and 5 x 10^{-4}/rem for malformation from exposures occurring during major organogenesis.

2. Nonstochastic Effects. Nonstochastic effects were briefly discussed in BEIR I, BEIR III, the 1977 UNSCEAR report, and in ICRP Publication 26. The most thorough treatment was found in the 1982 UNSCEAR report. No organization whose work is reviewed here has proposed a risk calculation procedure for nonstochastic effects in humans.

Nonstochastic effects in general exhibit an effective dose threshold. For doses below this threshold, no nonstochastic effects are expected to occur. In reviewing the reports described above, we have found that dose thresholds are generally well above the range of doses described in Section II.A that would be encountered in NEPA documents.

According to the ICRP, nonstochastic effects are not expected to occur over a lifetime at annual doses below 5 rem for all tissues (ICRP 1977a, p. 25, paragraph 126 and ICRP 1980).

The BEIR III report considered the effects of radiation exposure on the impairment of fertility, formation of cataracts, and aging. Doses less than 400 rads (low-LET radiation) to spermatogonial stem cells were not expected to cause permanent sterility in males. Doses to the ovary in the range of 300 to 400 rads (low-LET radiation) may cause some impairment of fertility in females, but the effect is somewhat dependent on age (BEIR III 1980, p. 499). Data on cataract formation were reported to be sigmoid in shape, with dose thresholds in the range of 20 to 450 rads (low-LET radiation) (BEIR III 1980, p. 500), but only above a dose threshold of 200 rads do vision-impairing cataracts begin to appear. With regard to aging, the BEIR Commitee concluded that "there is no firm evidence that exposure to ionizing radiation causes premature aging in man or that the associated increased incidence of carcinogenesis is due to a general acceleration of aging." (BEIR III 1980, p. 505)

The 1982 UNSCEAR report reviewed in some detail the evidence for nonstochastic effects induced by radiation. The tissues having the lowest thresholds for induction of nonstochastic effects were the reproductive organs, where acute doses as low as 10 rads (low-LET radiation) could cause temporary sterility in males (permanent sterility in males would not occur until acute doses exceeded 200 to 600 rads, and in females until doses exceeded 300 rads), and blood and blood-forming cells, where acute doses as low as 50 to 100 rads may cause some loss of lymphocytes and stem cells from the bone marrow and circulating blood. The UNSCEAR report discusses nonstochastic effects for many organs, including lung, skin, urinary tract, gastrointestinal system, and eye (UNSCEAR 1982, pp. 625-626).

C. Comparison of Risk Factors

Two different approaches were taken by the organizations reviewed here in presenting their risk estimates for cancer. Both UNSCEAR and the ICRP published age- and sex-averaged risk factors, giving the incremental lifetime risk to an individual of dying from a radiation-induced cancer either per unit absorbed dose (UNSCEAR) or per unit dose equivalent (ICRP). The BEIR Committees, in contrast, tended to publish an age- and sex-specific risk rate, giving the annual risk of dying from cancer in terms of age of exposure and elapsed time since the exposure.

The first approach has the advantage of simplicity because the cumulative organ dose to a population in an assessment area leads directly to the estimated number of health effects resulting from that dose by multiplying the cumulative organ dose by the risk factor for that organ. However, if the population-at-risk differed significantly from the population over which the risk factors had been averaged, the estimate of health effects using an age- and sex-averaged risk factor is unlikely to be representative. For example, if the population consisted of male radiation workers of age 25, the risk factor for total cancers from whole-body low-LET radiation is 40% higher than the age- and sex-averaged risk factor. [However, the uncertainties already associated with risk estimates are probably much larger than this (see Section III.A.1.b)].

This difficulty is remedied by using the second approach, which employs risk-rate coefficients for each sex and age group. The enhanced flexibility in this approach, however, is offset by an increased complexity. Input data required to perform this calculation of health effects include the population distribution by age and sex, life tables for each sex, and, if a relative risk projection model is used, cancer mortality rates by age and sex.

In order to compare the risk estimates from BEIR III with those from UNSCEAR and the ICRP, we calculated age- and sex-averaged lifetime risk factors from the BEIR III risk-rate factors when lifetime risk factors were not given. The risk factors recommended by these three groups are listed in Table I for the most important organs of concern. In obtaining the BEIR III lifetime risk factors, we used a life table calculation based on the 1980

TABLE I

TUMORIGENIC AND MUTAGENIC RISK FACTORS RECOMMENDED BY NATIONAL AND INTERNATIONAL ORGANIZATIONS FOR RADIATION EXPOSURE AT LOW DOSES

	Age- and Sex-Averaged Lifetime Risk of Cancer Mortality (Cancer Deaths/10^6 Person-rad)							
	Low-LET Radiation				High-LET Radiation			
			BEIR III[a]				BEIR III	
	UNSCEAR	ICRP	Absolute Risk	Relative Risk	UNSCEAR	ICRP[b]	Absolute Risk	Relative Risk
All cancers	100	100	167	501 (Linear)	--	--	--	--
(whole-body radiation)	(75-175)	--	77	226 (Linear-Quadratic)	--	--	--	--
		--	10	28 (Quadratic)	--	--	--	--
Bone[c]	2-5	5	1.4[d]		20-50	100	27[d]	
Lung	25-50	20	100	270	200-450	400	800-1500[e]	2200-4000[e]
Breast	25[f]	25[f]	36[f]	23	--	500	--	
Liver	10-15	<10[g]	15	56	100	<200	300	--
Thyroid	5-15	5	26	170	--	100	--	--
Leukemia	15-25	20	55 (Linear)		50-55[h]	400	--	--
(red marrow dose)	--	--	23 (Linear-Quadratic)		--	--	--	--
	--	--	3 (Quadratic)		--	--	--	--

[a]The linear model was used in making these risk estimates, unless otherwise indicated.
[b]A quality factor of 20 has been assumed.
[c]Dose calculated to the bone surface.
[d]The BEIR III report lists a dose-squared exponential function and a linear function to express the dose-response relation for bone cancers. Only the linear function is given here.
[e]The RBE of alpha radiation for lung cancer is 8-15.
[f]The breast cancer risk for women has been reduced by 50% for the general population.
[g]The ICRP risk for liver cancer was calculated from the risk factor for the "other cancers" category (ICRP 1977a).
[h]Calculated from Thorotrast patients.
[i]The first two estimates (10.3-30) x 10^{-6} and (0-12) x 10^{-6} were obtained using the direct method. The third estimate was obtained using the doubling dose method. The quoted risk factors are taken from UNSCEAR (1982), which supersedes UNSCEAR (1977).

TABLE I (cont)

	Risk of Genetic Disorder per 10^6 Liveborn Offspring per rad					
	Low-LET Radiation			High-LET Radiation		
	UNSCEAR	ICRP	BEIR III[a]	UNSCEAR	ICRP[b]	BEIR III
First generation	10.3-30 (males)[i] 0-12 (females)[i] 21.9 (males and females)[i]	--	5-75	--	--	300-4500
First two generations	--	100	--	--	2000	--
Equilibrium	149	200	60-1100	--	4000	3600-66000

[a]The linear model was used in making these risk estimates, unless otherwise indicated.
[b]A quality factor of 20 has been assumed.
[c]Dose calculated to the bone surface.
[d]The BEIR III report lists a dose-squared exponential function and a linear function to express the dose-response relation for bone cancers. Only the linear function is given here.
[e]The RBE of alpha radiation for lung cancer is 8-15.
[f]The breast cancer risk for women has been reduced by 50% for the general population.
[g]The ICRP risk for liver cancer was calculated from the risk factor for the "other cancers" category (ICRP 1977a).
[h]Calculated from Thorotrast patients.
[i]The first two estimates (10.3-30) x 10^{-6} and (0-12) x 10^{-6} were obtained using the direct method. The third estimate was obtained using the doubling dose method. The quoted risk factors are taken from UNSCEAR (1982), which supersedes UNSCEAR (1977).

U.S. population distribution by age and sex (U.S. Bureau of the Census 1982) and the U.S. decennial life tables (USNCHS 1975).

The BEIR III lifetime risk factors were calculated assuming a linear dose-response curve for high-LET radiation, and a linear, linear-quadratic, or quadratic dose-response curve for low-LET radiation. This corresponds to the procedure used in the BEIR III report in which the three models were used to present a range of risk estimates. We note that, because the linear-quadratic and quadratic models are not linear in dose for low-LET radiation, the risk factors for these two models in Table I are average values per rad and not estimates of risk at 1 rad of dose (BEIR III 1980, p. 212).

Because the report of the BEIR III Committee supersedes previous reports, lifetime risk coefficients were not derived for the BEIR I report.

The reports reviewed here give the risk of genetic disorder per million liveborn offspring for either the first or first two generations and for the equilibrium situation (equilibrium corresponds to the case of a number of succeeding generations, each receiving the same additional radiation exposure to the point where the rate of elimination of mutant genes balances the rate of increase of mutant genes). The BEIR III report points out that the risk of genetic disorder at equilibrium in a single generation is numerically equal to the risk of genetic disorder in all succeeding generations due to a radiation exposure in a single generation (BEIR III 1980, p. 128). Accordingly, the equilibrium estimate has been used in Table I to give the number of genetic disorders in all succeeding generations.

As seen in Table I, the lifetime risk factors for low-LET radiation published by the BEIR Committee, UNSCEAR, and ICRP are in fair agreement. The BEIR III estimate of all cancer fatalities per rad of exposure is larger for the linear model than the estimates of UNSCEAR and ICRP; however, those two organizations deliberately tailored their risk factors for use at low doses, whereas BEIR III did not. A more fair comparison would be between the BEIR III estimate using the linear-quadratic model [(77-228) x 10^{-6}/rad] and the UNSCEAR and ICRP risk factors having a range of (75-175) x 10^{-6}/rad, for which there is good agreement (BEIR III 1980, p. 212, Table V-25). (The same consideration applies also to the lifetime risk factor for leukemia.)

Using risk-rate factors from Appendix A of BEIR III, we calculated the BEIR III thyroid risk factor to be about twice as large as the UNSCEAR factor and five times as large as the ICRP factor. This discrepancy may be due to a difference in changing from an incidence to mortality risk. UNSCEAR gives a lifetime thyroid cancer incidence risk factor of 100 and 300 x 10^{-6}/rad (UNSCEAR 1977, p. 385, paragraph 150). A 3% fatality risk per 25 years was then used to calculate the lifetime thyroid cancer mortality risk of (5-15) x 10^{-6}/rad. The BEIR III thyroid cancer risk factor was calculated using a mortality-to-incidence ratio of 0.19 for thyroid cancer (the average of the male and female values) given in Table V-15 (BEIR III 1980). This ratio would yield a mortality risk factor approximately 3 times larger than that used in UNSCEAR. Lowering the BEIR III risk factor of 25 x 10^{-6}/rad by a factor of 3 to 8 x 10^{-6}/rad would place it in the range estimated by UNSCEAR.

The risk factor for lung cancer from low-LET radiation is also higher in BEIR III than in either UNSCEAR or ICRP. The BEIR III estimate was calculated for an entire lifetime using the age-specific risk rate coefficients from Appendix A of BEIR III. The UNSCEAR estimate was based on a 40-year followup period for the uranium miner study and a 27- to 29-year followup period for the Japanese atomic bomb survivor study. Although the basis of the ICRP risk factor was not discussed, the ICRP did indicate that its risk factors were chosen to apply for radiation protection, which may mean they were chosen for the doses and dose rates typically found in operational radiation exposure.

Many of these comments also apply to the high-LET radiation risk factors. The risk of liver cancer mortality is 3 times higher in BEIR III than in UNSCEAR; no explanation is offered for this difference, because these risk factor values were taken directly from each report. The BEIR III Committee indicated that previous estimates of liver cancer risk made by several individual authors were three or four times too low for several reasons, including these authors' not considering future risk to surviving patients (BEIR III 1980, p. 375). The Committee did not indicate whether its revisions would also apply to the UNSCEAR risk factor for liver cancer.

IV. RISK ESTIMATION METHODOLOGY FOR USE IN U.S. DEPARTMENT OF ENERGY NEPA DOCUMENTS

A. Recommendations for Calculating Risk of Cancer and Genetic Disorder from Radiation Exposure

Recommendations for risk estimation methodology and for risk factor values based on the review of the literature presented in Chapter III are discussed in this section. These recommendations are intended to apply to NEPA-related documents published by the U.S. Department of Energy.

The reports reviewed in Section III to some degree present competing estimates of risk (is it better to use a risk factor from one report instead of from another report?). However, in a larger sense each subsequent report represents a cumulative (rather than competing) effort that includes the results of previous reports. The authors of the more recent reports have benefitted from reviewing the earlier reports and had available both the data on which the earlier reports were based and also data published since the appearance of those earlier reports. The later reports, because they incorporate a larger epidemiological and experimental data base than the earlier ones, were used as the basis for the recommendations presented here.

The BEIR III report was relied on heavily in making these recommendations. Several extensions of the BEIR III report were developed so that the risk calculational methodology could be applied in a wide variety of circumstances. These extensions were consistent with the approach found in BEIR III.

As noted in Section II.C.1., the BEIR Committee expressed considerable uncertainty over just what the health effects at low doses (1 rad or less) of radiation are, or even if there are any at all (see, for example, p. 193, BEIR III 1980). Typical doses discussed in NEPA documents are generally in this low-dose range. In spite of these uncertainties, procedures for estimating health effects at low doses are given here because of the need to directly relate dose estimates to their impact on health so that the potential effects of proposed DOE activities can be presented more clearly and concretely to decision makers. This approach agrees with that of the BEIR Committee. In the BEIR I report, the BEIR Committee stated that "such (risk) estimates... are fraught with uncertainty. However, they are needed as a basis for logical decision making and may serve to stimulate the gaining of data for assessment of comparative hazards from technological options and development, at the same time promoting better public understanding of the issues." (BEIR I 1972, p. 7.) Similarly, in BEIR III, "The Committee recognizes that the scientific basis for making such estimates (for cancer risk from low dose, low-LET radiation) is inadequate, but it also recognizes that policy decisions cannot be reached or regulatory authority exercised without someone's taking a position on the probable cancer risk associated with such radiation." (BEIR III 1980, p. 177.)

Under NEPA, radiation exposures to members of the public, which would occur as a result of a proposed federal action, are evaluated. This evaluation may also include doses to personnel, such as office workers, whose tasks are not connected with the exposure-producing activity. To estimate the health risks resulting from these exposures, either a simple or a more detailed approach may be taken, depending on the population exposed.

1. First Method. If the exposed population is similar to the 1980 U.S. population in that it has a similar life table and age distribution, and similar (if relative risk is used) cancer mortality rates, or if this demographic data is not available for the exposed population,* then age- and sex-averaged lifetime cancer risk factors (Table IIa) calculated for the U.S.

*Use of risk factors averaged by age and sex over the U.S. population would lead to differences of up to a factor of 2 to 3 for the exposed populations with more extreme age and sex distributions. The uncertainties associated with risk estimation (see Sec. III.A.1.b.) may make a more detailed risk calculation unnecessary.

TABLE IIa

RISK FACTORS (RISK/ABSORBED DOSE) RECOMMENDED FOR USE IN DOE NEPA DOCUMENTS
(If a population-specific calculation is deemed unnecessary)

A. Age-and Sex-Averaged Lifetime Risk[a] of Cancer Mortality per rad

Cancer Type/Organ Receiving Dose	Risk Factor (x 10^{-6}/rad) Low-LET Radiation Absolute Risk	Low-LET Radiation Relative Risk	High-LET Radiation Absolute Risk	High-LET Radiation Relative Risk
All cancers/whole-body radiation	86[b]	270[b]	1700[c]	5300[c]
Bone cancer/bone surface	1.4[d]		27[d]	
Lung cancer/lung	100	270	1000[e]	2700[e]
Breast cancer/breast	36	23	720	460
Liver cancer/liver	15	56	300	1100
Thyroid cancer/thyroid	26	170	520	3400
Leukemia/red marrow	46[d]		920[d]	
Prenatal Exposure				
Hematopoietic tumors/fetus	280[f]		2800[f]	
Solid tumors/fetus	260[f]		2600[f]	

B. Risk of Genetic Disorder in Offspring per rad

Effects Occurring In	Dose Type	Risk Factor (x 10^{-6}/rad) Low-LET Radiation	High-LET Radiation
First Generation	Gamete	5- 75	300- 4500
All generations subsequent to exposure	Gamete	60-1100	3600-66000
First generation	Gonadal	2- 34[g]	130- 2000[g]
All generations subsequent to exposure	Gonadal	25- 500[g]	1500-30000[g]

[a]Some factors may differ slightly from those given in Table I because of a different population age distribution.

[b]If the dose is greater than or equal to 20 rads from a single exposure, or delivered at a rate greater than or equal to 5 rads/year, these risks should be multiplied by two to become 170 x 10^{-6}/rad (absolute risk) and 530 x 10^{-6} (relative risk).

[c]The factor of two reduction for low-dose, low-dose-rate low-LET radiation was deleted for high-LET radiation. An RBE of 10 was used here in calculating the risk from high-LET radiation, because whole body high-LET radiation would normally involve neutron radiation. If the quality factor of the neutron radiation is known, this should be used as the RBE instead of 10.

[d]No risk projection is necessary for either leukemia or bone cancer. Both absolute and relative risk calculations give the same result.

[e]The risk factor for lung cancer due to exposure to environmental levels of radon and its decay products is taken to be 100 x 10^{-6}/WLM (see Section IV.F.7).

[f]The risk factors for prenatal exposure obviously are not age-averaged. An RBE of 10 was used in calculating the risk from high-LET radiation, since high-LET irradiation of the fetus would normally involve neutron radiation. If the quality factor of the neutron radiation is known, this should be used as the RBE instead of 10. Because the cancer expression periods are short (10-12 years), the absolute and relative risk models give the same result.

[g]These risk factors assume that the exposed population has the same age-specific birth rate as the US population (USNCHS 1982) and the same age and sex distribution as the 1981 US population (US Bureau of the Census 1982).

population can be used. This would be a simple and straightforward approach, involving only multiplication of the absorbed dose by the absolute and relative lifetime cancer risk factors to obtain the lower and upper estimates, respectively, for the incremental lifetime risk of dying of cancer as a result of the exposure.

We recommend that the lifetime risk of cancer incidence also be given. This is obtained from the cancer mortality risk calculated here by using the conversion factors given in Section IV.G.

The risk of genetic disorder in the first generation and in all subsequent generations can be estimated in the same manner. The number of genetic disorders per million liveborn offspring per rad of exposure is presented in Table IIa. This risk factor is expressed in terms of the gamete dose. If the population exposed to the radiation is expected to have the same number of offspring as would the typical U.S. population, then the risk factor of genetic disorder in terms of gonadal dose, also presented in Table IIa, may be used directly.

The risk factors in Table IIb were calculated from those in Table IIa for use with dose equivalent (in rem) instead of absorbed dose (in rads). A quality factor of 20 was used to make this calculation for all risk factors except for whole-body radiation. Because whole-body high-LET radiation normally would result from neutron exposure, we used a quality factor of 10 for whole-body exposure.

Risk factors for all cancers from whole-body low-LET radiation exposure and the risk factors for genetic disorders for low-LET radiation include reductions by factors of 2 and 3, respectively, for application at low dose rates. These reductions are not appropriate for the factors for high-LET radiation, which are given separately in the table.

Lastly, the RBE for lung cancer from alpha radiation was stated to range from 8 to 15 by the BEIR III Committee. A value of 10 is used in this report to obtain the high-LET lung cancer risk factor in Table IIa. If a quality factor of 20 is used in a NEPA dose assessment to calculate lung dose, the appropriate risk factor is 50 x 10^{-6}/rem.

2. Second Method. If the exposed population is significantly different from the U.S. population (for example, a group of males of ages 25 to 30 years), the age- and sex-averaged risk factors for cancer given above may not be appropriate. A more detailed risk calculation may be preferable, using age- and sex-specific risk rates if the required demographic information for the exposed population is available. This calculation can be performed with the computer code REPCAL (Risk Estimation Program for CALculating the risk of radiation-induced cancers), which is described in Appendix A and listed in Appendix B. The code requires site-specific population distribution by age

and sex, the proportion dying from all causes in each age interval for each sex, as well as other input data including mortality rates for each cancer of interest (if relative risk is to be used) and dose distribution by year. The required input data are discussed in Appendix A. A sample calculation is presented in Appendix C.

This computer code utilizes the same risk-rate factors used to calculate the lifetime risk factors in Tables IIa and IIb. Except for the risk factors for bone and liver, which were explicitly given in BEIR III, these risk factors are a special case of the application of the code to a population having the same characteristics as the U.S. population.

The algorithms used in the code are discussed in Section IV.D.

As can be seen in Table IIa, the dose for use with the risk factors is the absorbed dose (in rads). Similarly, absorbed dose is used as input to the computer program REPCAL. Absorbed dose, instead of dose equivalent, is used in these calculations to avoid confusion concerning quality factors. [For convenience in Table IIb we have converted the risk factors for use with dose equivalent (in rems) assuming a quality factor of 20.]

In the rest of this section, we will discuss assumptions and specific features of the risk factors and the risk calculational procedure.

B. Dose-Response Model for Low-LET and High-LET Radiation

The linear hypothesis was used to calculate the lifetime risk of cancer mortality and the risk of genetic disorder in offspring for both low-LET and high-LET radiation. This agrees with the procedure used in BEIR III, except for the case of cancer risk from low-LET radiation.

Chapter V of the BEIR III report states that the linear-quadratic model provides the most realistic estimate of the risk of cancer mortality from low-LET radiation (BEIR III 1980). The BEIR Committee was sufficiently uncertain as to the appropriate model that they discussed three models, with the purely linear model and purely quadratic model providing upper and lower bounds on the estimates made with the linear-quadratic model.

Consequently in Chapter V of BEIR III, parameters for all three models are provided for two groups of cancers: (1) leukemia and bone cancer, and (2) all other cancers taken together. The BEIR Committee did not feel that there was sufficient data to present parameters for the linear-quadratic model for specific cancers. Cancers are discussed individually in Appendix A of BEIR III, but only risk factors for the linear model are given. It is, therefore, not possible to calculate the cancer risk using the linear-quadratic model with BEIR III parameters for each cancer type, because these parameters have only been published for two special cases.

TABLE IIb

RISK FACTORS (RISK/DOSE EQUIVALENT) RECOMMENDED FOR USE IN DOE NEPA DOCUMENTS
ASSUMING A QUALITY FACTOR OF 20
(If a population-specific calculation is deemed unnecessary)

A. Age-and Sex-Averaged Lifetime Risk of Cancer Mortality per rem

Cancer Type/Organ Receiving Dose	Risk Factor ($\times 10^{-6}$/rem) Absolute Risk	Risk Factor ($\times 10^{-6}$/rem) Relative Risk
All cancers/whole-body radiation	86 (low-LET) [a] 170 (high-LET)[b]	270 (low-LET) [a] 530 (high-LET)[b]
Bone cancer/bone surface	1.4[c]	1.4[c]
Lung cancer/lung	100 (low-LET) 50 (high-LET)[d]	270 (low-LET) 130 (high-LET)[d]
Breast cancer/breast	36	23
Liver cancer/liver	15	56
Thyroid cancer/thyroid	26	170
Leukemia/red marrow	46[c]	46[c]
Prenatal Exposure		
Hematopoietic tumors/fetus	280[e]	280[e]
Solid tumors/fetus	260[e]	260[e]

B. Risk of Genetic Disorder in Offspring per rem

Effects Occurring In	Dose Type	Risk Factor ($\times 10^{-6}$/rem) Low-LET Radiation	Risk Factor ($\times 10^{-6}$/rem) High-LET Radiation
First Generation	Gamete	5- 75	15- 225
All generations subsequent to exposure	Gamete	60-1100	180-3300
First generation	Gonadal	2- 34[f]	6- 100[f]
All generations subsequent to exposure	Gonadal	25- 500[f]	75-1500[f]

[a]If the dose is greater than or equal to 20 rads from a single exposure, or delivered at a rate greater than or equal to 5 rads/year, these risks should be multiplied by two.

[b]The factor of two reduction for low-dose low-dose-rate low-LET radiation was deleted for high-LET radiation. A quality factor of 10 was used here in calculating the risk from high-LET radiation, because whole-body high-LET radiation would normally involve neutron radiation.

[c]No risk projection is necessary for either leukemia or bone cancer. Both absolute and relative risk calculations give the same result.

[d]The risk factor for lung cancer due to exposure to environmental levels of radon and its decay products is taken to be 100 x 10^{-6}/WLM (see Section IV.F.7).

[e]The risk factors for prenatal exposure obviously are not age-averaged. An RBE of 10 was used in calculating the risk from high-LET radiation, since high-LET irradiation of the fetus would normally involve neutron radiation. If the quality factor of the neutron radiation is known, this should be used as the RBE instead of 10. Because the cancer expression periods are short (10-12 years), the absolute and relative risk models give the same result.

[f]These risk factors assume that the exposed population has the same age-specific birth rate as the US population (USNCHS 1982), and the same age and sex distribution as the 1981 population (US Bureau of the Census 1982).

On the other hand, linear risk-rate factors are available by cancer site in BEIR III, Appendix A. Therefore, risk factors based on the linear model can be calculated using the BEIR III recommended risk-rate factors from Appendix A.

Several issues were considered in choosing the linear model for carcinogenic risk from low-LET radiation. BEIR III notes that, for breast cancer, the dose-response curve does not require a quadratic term, but is well fit by the linear model. In contrast, the dose-response curve for leukemia at Nagasaki appears to have positive curvature, indicating the need for a quadratic term for leukemia.

An additional complication is that the dosimetry at Hiroshima and Nagasaki is now being revised. Although changes in the estimates of low-LET doses may not be significant, the high-LET neutron doses are expected to be reduced significantly. Several authors have indicated that this will allow the data from Hiroshima and Nagasaki to be combined (Loewe 1981). Whether the leukemia dose-response curve will continue to show positive curvature (especially if the Nagasaki data are pooled with the statistically stronger data at Hiroshima), or whether the breast cancer dose-response curve will continue to be linear, remains uncertain.

These considerations have led us to recommend that the linear model be used to estimate the risk of cancers induced by low-LET radiation. The linear hypothesis will probably overestimate the risk of most cancers, but it will be realistic in estimating the risk of breast cancer. The linear model will provide a conservative estimate of the cancer risk from low-LET radiation, which is appropriate in view of the uncertainties in the dosimetry for the Japanese survivors.

In order to reduce the overestimate in the case of total cancer risk from low-LET whole-body radiation, a DREF, as defined by the NCRP, of two is being recommended. This is a conservative value for the value of the DREF because it is the smallest reduction factor of the range of 2 to 10 recommended by the NCRP. In accordance with the recommendations of the NCRP, this DREF would be applied only to the total cancer risk for a single low-LET whole-body radiation dose less than 20 rads, or any low-LET whole-body dose delivered at a dose rate of less than 5 rad/year. The risk factors for all cancers from low-LET radiation in Table IIa, 86×10^{-6}/rad and 270×10^{-6}/rad, have already been divided by this DREF and are for use for low-dose low-dose-rate radiation. If the dose or dose rate exceeds the values given above, these risk factors should be doubled.

C. Absolute Risk vs Relative Risk in Estimating Incremental Probability of Cancer Mortality

Absolute risk rate factors are given in Chapter V and Appendix A to Chapter V of BEIR III. Most of these factors are age-specific and many are sex-specific. The factors used to calculate radiation-induced cancer risks that are recommended for use in NEPA-related documents are presented in Table III. Values from BEIR III for the latent period and expression period of each cancer type are also given.

As noted earlier, the BEIR III report does not present relative risk-rate factors as the BEIR I report did. Instead, relative risk is calculated using the absolute risk-rate factors.* For example, for all cancers except leukemia and bone that result from a single exposure to 10 rads of low-LET radiation in a cohort of 100 000 persons of a given age, the relative risk was estimated by the following procedure:

1. Calculating the number N_{rad} of fatal cancers (other than bone cancer and leukemia) resulting from the radiation exposure that would occur in the cohort during the first 30 years following the exposure. The absolute risk-rate factors and a 10-year latent period were used in the calculation.

2. Estimating the number N_{spon} of fatal cancers (other than bone cancer and leukemia) occurring spontaneously (that is, not induced by radiation) in the cohort from published cancer mortality rates from the 10th to the 30th year following the exposure.

3. Calculating a relative risk-rate factor R by dividing the number of radiation-induced cancer fatalities by the number of spontaneous cancer fatalities, $R = N_{rad}/N_{spon}$.

4. Using this relative risk rate to calculate the expected number of cancers from the 30th year after exposure to the end of the lifetime of the cohort.

5. Adding the number of radiation-induced cancer fatalities occurring during the first 30 years after the exposure (found in No. 1 above) to the number of fatalities occurring after the first 30 years (found in No. 4), to give the total number of cancer fatalities.

6. For this particular example, BEIR III also used age averaging. This simply involved calculating the number of cancer fatalities assuming 100 000

*We have relied to a great extent on the draft paper presented by Mr. Robert Alexander (1982) and on conversations with Dr. Charles Land for a description of the procedure used by the BEIR Committee to calculate relative risk.

TABLE III

PARAMETERS USED FOR CALCULATING LIFETIME RISK FACTORS FOR CANCER (low-LET radiation)

Cancer Type	Sex	Risk-Rate Factors (Number of fatal cancers/10^6 year-person-rad) Age at Exposure					Latent Period (years)	Expression Period (years)	Observation Period[a] (years)
All cancers		0-9	10-19	20-34	35-49	50+			
Leukemia/bone cancer component	M	3.977	1.849	2.596	1.921	4.319	3	24	--
	F	2.542	1.192	1.666	1.237	2.760			
All cancers (excluding leukemia/bone component)	M	1.920	1.457	4.327	5.291	8.808	10	Lifetime	30
	F	2.576	1.955	5.807	7.102	11.823			
Bone	M&F	0.05 (all ages)					3	24	--
Breast	M	0 (all ages)							
	F	0.0[b]	4.1[b]	2.6[b]	2.6[b]	2.6[b]	10	Lifetime	--
		0.0[c]	8.7[c]	3.4[c]	3.4[c]	3.4[c]			
		0.0[d]	0.4[d]	0.16[d]	0.16[d]	0.16[d]			
		0.0[e]	1.1[e]	0.22[e]	0.22[e]	0.22[e]			
Liver	M&F	0.7 (all ages)					10	Lifetime	45
Thyroid	M	0.40 (all ages)					10	Lifetime	30
	F	1.2 (all ages)							
			(Age at Diagnosis)						
Lung	M&F	0	0-14				25	Lifetime	25
		0	15-34				17.5	Lifetime	
		1.5	35-49				10	Lifetime	
		3.0	50-65				10	Lifetime	
		7.0	>65				10	Lifetime	
In utero exposures									
Hematopoietic tumors	M&F	25	(prenatal exposure)				0	12	
Solid tumors	M&F	28	(prenatal exposure)				0	10	

[a]For use in calculating the relative risk.
[b]Absolute risk, no cell killing.
[c]Absolute risk, with cell killing.
[d]Relative risk (%/rad), no cell killing.
[e]Relative risk, (%/rad) with cell killing.

persons in the cohort were each of age 0 year, then doing a second calculation assuming that all persons were of age 1 year, then another calculation assuming age 2 years, and so on up to age 109 years. The number of cancers calculated for each age was then multiplied by the fraction of the total population that each age group represented, and the resulting numbers were then added.

As a result of this procedure, for a given cancer type each age of exposure will have a different risk-rate factor. Partly, this is because the absolute risk-rate factors change to some extent with age, but mainly it is because the number of spontaneous fatal cancers generally is not the same for different ages.

Cancer risk estimates made with the relative risk projection model are typically several times larger than those made with the absolute risk projection model. This difference has been offset somewhat in BEIR III by using age-specific absolute risk-rate factors, which allows adjustment of risk rates upward or downward for ages of high or low spontaneous cancer mortality. As a result, the absolute and relative risk projection model results have been brought into closer agreement for some cancer types.

D. Calculation of the Risk of Cancer Mortality

We describe in this section the procedure that was used to calculate the incremental risk of dying of cancer as a result of exposure to radiation. In developing this procedure, we relied heavily on the work of Cook, Bunger, and Barrick (Cook 1978, Bunger 1981), who had used a life table approach to calculating risks of mortality from the increased risks of cancer as well as from other hazards. A slightly modified version of their procedure was used by the BEIR Committee (BEIR III 1980, p. 193). The computer program REPCAL, on which many of the risk estimates in this report are based, uses a similar life table calculation as well as risk-rate factors taken from the BEIR III report.

The advantage of a life table approach is that risk estimates are automatically corrected for competing causes of death. The life table method used by Cook, Bunger, and Barrick was an adaptation of a method used by the National Center for Health Statistics (NCHS).* In this method, a hypothetical cohort of 100 000 individuals, all of the same age, is followed throughout its lifetime. The cohort is assumed to have the same age-specific mortality rates as found in a subject population from observations over a short time period.

*The NCHS describes two types of life tables, a generation life table and a current life table. The life table described here corresponds to a current life table.

The proportion of individuals q_x reaching a particular age x that will die before reaching age $x + 1$ is calculated using the mortality rate for that age. This proportion is multiplied by the number of individuals ℓ_x reaching age x to give the expected number of deaths d_x in the cohort at that age, which is then subtracted from ℓ_x to give the number of individuals surviving to the next age group $x+1$, or

$$\ell_{x+1} = \ell_x - \ell_x q_x$$

$$= \ell_x - d_x .$$

The life table can be modified easily to include the risk of cancer mortality resulting from radiation exposure. The radiation cancer mortality risk $R_{rad,x}$, which is estimated for the midpoint of an age interval, needs to be modified to be compatible with q_x, which is estimated for individuals beginning the age interval. Cook et al. describe how this can be done by calculating a reference mortality rate $R_{ref,x}$ from q_x,

$$R_{ref,x} = \frac{q_x}{1 - 0.5 q_x}$$

and calculating a new value q'_x for q_x that includes both the natural mortality risk and the radiation-associated cancer mortality risk

$$q'_x = \frac{R_{ref,x}}{1.0 + 0.5\,(R_{ref,x} + R_{rad,x})} + \frac{R_{rad,x}}{1.0 + 0.5\,(R_{ref,x} + R_{rad,x})} ,$$

$$= q'_{ref,x} + q'_{rad,x} .$$

Multiplying by ℓ_x gives the total number of individuals dying from x to $x + 1$,

$$d_x = q'_x \ell_x = q'_{ref,x} \ell_x + q'_{rad,x} \ell_x$$

$$= d_{ref,x} + d_{rad,x} .$$

The first term ($d_{ref,\chi}$) gives the number in the group surviving to age χ that will die from natural causes during age χ; the second term ($d_{rad,\chi}$) gives the number dying from radiation-induced cancer during that age. The total number of deaths due to radiation-induced cancer occurring in the cohort is given by summing $d_{rad,\chi}$ over all the ages χ.

The computer code REPCAL is written so that the life table calculation is performed at each age from ages 0 through 109 years. The expected number of cancer fatalities from radiation-induced cancer is calculated for 100 000 individuals exposed at age 0 year, followed by a calculation for 100 000 individuals exposed at age 1 year, and so on to age 109 years. The expected number of radiation-induced cancer deaths in a population of a given age distribution is found by multiplying the number of cancer deaths calculated for each age cohort by the fraction of the population that is in that age group and summing the resulting age-weighted cancer mortality estimates.

REPCAL calculates the risk of cancer to a cohort of individuals all of the <u>same age</u> for each age up to 109 years for both acute and continuous exposure. Different doses may be entered for each year of exposure to account for a varying radiation environment and for increased dose from internal emitters from continuous radionuclide intake.

In contrast to the calculation above for a cohort of individuals all of the <u>same age</u>, the expected number of radiation-induced cancer fatalities in an actual population of individuals of <u>different ages</u> is calculated only for acute exposures, or for exposures lasting less than 1 year, and not for continuous exposure over more than 1 year. The dose to an organ may be over many years, as in the case of the dose to bone resulting from the inhalation of a radionuclide with a long effective half-life in bone. The dose supplied as input to the program is then the annual dose from this radionuclide. But the actual time of exposure to the radionuclide, the time during which the radionuclide is being inhaled, must be 1 year or less. This is because the program treats the population as static and does not take into account new individuals being born into the population, immigration, or emigration (please see Appendix A for a discussion of REPCAL).

The radiation risk rates $R_{rad,\chi}$ used in the risk calculation are based on the BEIR III report. Absolute risk rates are taken directly from that report and are listed in Table III. Relative risk rates are calculated from the absolute risk rates as described in Section IV.B. Relative risk rates based primarily on the atomic bomb survivor data are estimated using a 30-year period after the initial exposure to calculate the number of radiation-induced and spontaneously occurring cancers. However, for many cancer sites such as the lung, the risk rates were determined from data other than that of the atomic bomb survivors. In those cases we used the time interval that corresponded to the follow-up time of the principal epidemiological surveys on which the risk rates were based. The time interval used in the relative risk calculation is shown in Table III for each cancer site.

The recommended lifetime risk factors listed in Tables IIa or IIb have been calculated using this method and the demographic statistics of the reference U.S. population. Exceptions are the lifetime risk factors for bone and liver cancer, which, since they were given explicitly in BEIR III, were taken directly from that report.

The reference life table values used in this calculation, which were supplied by NCHS for 1970 (the last year for which life tables that are complete to age 109 years are available) (USNCHS 1975), are given in Table IV. The population age- and sex-distribution for 1981 used in obtaining the age- and sex-averaged lifetime risk factors are in Table V. This distribution was taken from a report by the U.S. Bureau of the Census (1982). Age-specific cancer mortality rates used to calculate relative risk factors are in Table VI. Mortality rates for lung cancer, breast cancer, liver cancer, and thyroid cancer were calculated from the data published by the U.S. National Cancer Institute's Surveillance, Epidemiology, and End Results (SEER) Program (USNCI 1981). The age-specific mortality rates for all cancers except leukemia and bone cancer were taken from Alexander (1982), who had obtained these rates from Dr. Charles Land of the National Cancer Institute.

REPCAL contains the risk-rate coefficients shown in Table III. The U.S. population age distribution (1980 census) and 1969-1971 life table values for q_x are contained in the program in DATA statements. Options are provided as input statements for the user to select the type of risk projection model and the desired dose magnitude and time distribution. The user may also choose to supply his own population age distribution and q_x value for the area surrounding the proposed facility.

E. Specification of Dose for Use in the Risk Calculation

The risk factors and risk-rate factors recommended in Table IIa expressed in terms of risk or risk rate per absorbed dose in rads. Doses used to calculate the risk should consequently be absorbed dose in rads. (For convenience, risk factors in terms of risk-per-dose equivalent are presented in Table IIb, so that dose in rems can be used with these factors.)

The dose to bone should be calculated as the dose to the endosteal tissues, rather than as the dose to the entire skeleton (p. 414, BEIR III 1980). This procedure is in accordance with the practice of the BEIR

TABLE IV

PROPORTION DYING IN EACH AGE INTERVAL

male population

age	tqx	age	tqx	age	tqx	age	tqx	age	tqx	age	tqx	age	tqx	age	tqx
-1	0 00000	13	00059	27	00199	41	00435	55	01534	69	04665	83	12770	97	30135
0	02245	14	00084	28	00198	42	00473	56	01676	70	04991	84	13663	98	31111
1	00133	15	00114	29	00203	43	00518	57	01827	71	05344	85	14730	99	32017
2	00094	16	00142	30	00210	44	00568	58	01987	72	05740	86	15979	100	32857
3	00078	17	00167	31	00218	45	00623	59	02158	73	06193	87	17281	101	33633
4	00064	18	00185	32	00228	46	00681	60	02339	74	06703	88	18521	102	34347
5	00058	19	00198	33	00239	47	00744	61	02532	75	07264	89	19681	103	35004
6	00054	20	00212	34	00252	48	00812	62	02738	76	07856	90	20839	104	35606
7	00051	21	00226	35	00268	49	00887	63	02960	77	08462	91	22122	105	36157
8	00046	22	00235	36	00288	50	00969	64	03200	78	09070	92	23512	106	36661
9	00041	23	00235	37	00312	51	01059	65	03463	79	09688	93	25023	107	37121
10	00036	24	00228	38	00339	52	01161	66	03746	80	10367	94	26546	108	37540
11	00035	25	00217	39	00369	53	01275	67	04044	81	11125	95	27962	109	37922
12	00042	26	00206	40	00401	54	01400	68	04350	82	11929	96	29090	110	0 00000

female population

age	tqx	age	tqx	age	tqx	age	tqx	age	tqx	age	tqx	age	tqx	age	tqx
-1	0 00000	13	00033	27	00086	41	00251	55	00768	69	02407	83	09419	97	26980
0	01746	14	00040	28	00090	42	00273	56	00829	70	02632	84	10275	98	27996
1	00116	15	00049	29	00096	43	00297	57	00894	71	02879	85	11282	99	28949
2	00077	16	00058	30	00102	44	00325	58	.00962	72	03165	86	12462	100	29836
3	00060	17	00066	31	00110	45	00354	59	01035	73	03503	87	13685	101	30659
4	00051	18	00069	32	00119	46	00384	60	01113	74	03893	88	14859	102	31420
5	00043	19	00071	33	00129	47	00416	61	01200	75	04325	89	16006	103	32122
6	00038	20	00072	34	00140	48	00449	62	01298	76	04790	90	17264	104	32768
7	00034	21	00073	35	00152	49	00484	63	01411	77	05295	91	18718	105	33361
8	00031	22	00075	36	00165	50	00523	64	01538	78	05840	92	20243	106	33904
9	00028	23	00077	37	00180	51	00565	65	01678	79	06432	93	21750	107	34401
10	00026	24	00079	38	00197	52	00611	66	01832	80	07097	94	23186	108	34855
11	00025	25	00081	39	00215	53	00660	67	02004	81	07834	95	24584	109	35269
12	00027	26	00083	40	00233	54	00712	68	02195	82	08612	96	25854	110	0 00000

TABLE V

POPULATION DISTRIBUTION BY AGE AND SEX

male population

age	number	age	number	age	number	age	number	age	number	age	number	age	number	age	number
-1	0	13	1808	27	2013	41	1219	55	1112	69	715	83	174	97	0
0	1839	14	1854	28	1971	42	1170	56	1118	70	679	84	155	98	0
1	1815	15	1916	29	1866	43	1146	57	1094	71	631	85	706	99	0
2	1713	16	2039	30	1898	44	1101	58	1075	72	587	86	0	100	0
3	1645	17	2131	31	1852	45	1097	59	1074	73	549	87	0	101	0
4	1654	18	2143	32	1812	46	1079	60	1045	74	499	88	0	102	0
5	1598	19	2134	33	1799	47	1050	61	999	75	463	89	0	103	0
6	1631	20	2235	34	1914	48	1065	62	953	76	421	90	0	104	0
7	1595	21	2208	35	1418	49	1051	63	914	77	379	91	0	105	0
8	1659	22	2178	36	1436	50	1097	64	872	78	341	92	0	106	0
9	1722	23	2153	37	1426	51	1122	65	848	79	292	93	0	107	0
10	1903	24	2139	38	1502	52	1102	66	834	80	287	94	0	108	0
11	1903	25	2080	39	1304	53	1116	67	793	81	244	95	0	109	0
12	1852	26	2066	40	1259	54	1110	68	757	82	204	96	0	110	0

female population

age	number	age	number	age	number	age	number	age	number	age	number	age	number	age	number
-1	0	13	1732	27	2030	41	1268	55	1226	69	929	83	347	97	0
0	1752	14	1778	28	1989	42	1220	56	1242	70	899	84	320	98	0
1	1734	15	1839	29	1886	43	1197	57	1225	71	853	85	1656	99	0
2	1636	16	1962	30	1929	44	1153	58	1213	72	811	86	0	100	0
3	1572	17	2048	31	1884	45	1152	59	1220	73	778	87	0	101	0
4	1579	18	2077	32	1850	46	1134	60	1194	74	727	88	0	102	0
5	1530	19	2090	33	1839	47	1109	61	1149	75	694	89	0	103	0
6	1558	20	2197	34	1962	48	1129	62	1105	76	650	90	0	104	0
7	1524	21	2176	35	1460	49	1118	63	1070	77	605	91	0	105	0
8	1585	22	2155	36	1480	50	1174	64	1035	78	564	92	0	106	0
9	1645	23	2144	37	1474	51	1206	65	1023	79	502	93	0	107	0
10	1817	24	2145	38	1554	52	1191	66	1024	80	510	94	0	108	0
11	1820	25	2090	39	1352	53	1213	67	992	81	451	95	0	109	0
12	1774	26	2077	40	1308	54	1215	68	965	82	392	96	0	110	0

TABLE VI

AGE- AND SEX-SPECIFIC CANCER MORTALITY RATES
(rate per 100 000)

Age	Lung Cancer		Thyroid Cancer		Liver Cancer		Breast Cancer	
	Males	Females	Males	Females	Males	Females	Males	Females
	--	0.0537	--	--	0.258	0.107	--	--
<5 9	0.0457	0.0237	--	--	0.0457	0.0711	--	--
5-14	--	--	--	--	0.0613	0.0424	--	--
10-19	0.0812	0.0621	--	--	0.0406	0.0207	--	--
15-24	0.0893	0.0883	--	0.0221	0.201	0.177	--	0.177
20-29	0.267	0.242	--	--	0.219	0.0970	--	1.41
25-34	1.70	1.11	--	0.0293	0.209	0.205	--	6.01
30-39	5.72	3.39	0.0364	0.105	0.510	0.420	--	13.3
35-44	18.2	10.3	0.114	0.146	0.760	0.475	--	22.9
40-49	47.4	20.1	0.325	0.414	1.95	0.760	--	42.6
45-54	85.5	30.8	0.499	0.372	3.10	1.49	--	61.3
50-59	144.9	51.5	0.414	0.779	6.46	2.22	--	77.7
55-64	232.5	64.7	1.01	1.47	10.4	4.56	--	91.0
60-69	324.8	74.1	1.54	2.05	14.1	5.25	--	102.2
65-74	403.2	71.3	2.07	3.51	18.2	8.82	--	110.0
70-79	455.4	73.6	3.21	4.38	21.9	10.1	--	128.2
75-84	402.8	69.4	3.80	5.07	24.0	14.5	--	143.2
80-	323.5	74.8	4.99	5.51	24.2	16.5	--	180.9
85+								

Committee as well as the ICRP (ICRP 1977a, p. 10) and UNSCEAR (UNSCEAR 1977, p. 400).

Following the ICRP, we recommend that the lung dose from all radionuclides but radon (which is discussed below) be mass-averaged over the trachea, bronchi, pulmonary region, and pulmonary lymph nodes (ICRP 1977a, p. 11). The BEIR III report based its lung risk estimate largely on studies of underground miners, Japanese atomic bomb survivors, and British spondylitics. The question of the treatment of the relatively large doses received by the pulmonary lymph nodes after inhalation of insoluble radioaerosols was not an issue in these studies and was not discussed in the BEIR III report. In the absence of specific recommendation concerning the pulmonary lymph nodes, we have elected to follow the ICRP procedure.

The risk factors from Tables IIa or IIb should be multiplied by the 50-year dose commitment to give the total lifetime risk. Since these risk factors have been averaged over age, the age at which the dose is received would not affect the risk calculation. Caution should be exercised in interpreting this risk, since the life expectancy of an older individual may prevent his receiving the full 50-year dose. Similarly, competing risks of mortality for an older individual that would be accounted for in a life table calculation may significantly reduce the risk of mortality from a radiation-induced cancer.

Doses for the more detailed risk calculation procedure using the computer program REPCAL can be treated in a more realistic manner. The dose can be entered into the program on a year-by-year basis up to age 109. The temporal distribution of the dose used in the calculation can then more closely resemble the actual distribution of the dose in time.

F. Discussion of Risk-Rate Factors

1. All Cancers. The risk-rate factors (Table III) were taken directly from Table V-17 (p. 204) and Table V-20 (p. 207) of the BEIR III report. These factors are used with the linear model to calculate cancer mortality risks. The linear-quadratic and quadratic models were discussed by the BEIR Committee. Until the uncertainty in the dosimetry for the Japanese atomic bomb survivors (see Section IV.J)--on which much of the work in BEIR III has been based--can be resolved, we recommend the more conservative linear model for use in estimating risks for NEPA documents.

2. Bone Cancer. The risk rate of 0.05×10^{-6} sarcoma/year/person-rad for low-LET radiation is taken directly from Table A-27 (p. 417) of BEIR III. To use this risk-rate factor, the absorbed dose should be calculated to the endosteal cells.

The BEIR Committee also discussed use of a dose-response curve in which the incidence risk rate depended on both the square of the dose and an exponential containing the dose. Evidence for the shape of the dose-response curve for alpha radiation was reviewed by the Committee, which reported that out of eleven studies (of both human and animal populations), the shape was linear in seven studies, concave upward in three studies, and concave downward in one study. The Committee concluded that the shape of the dose-response curve was uncertain, although it was difficult to exclude a linear component to the alpha-radiation dose response at low doses.

In order to simplify the calculation of the bone cancer risk factor, only the risk-rate factor for the linear model is given in Table III. This factor is based principally on the studies of the effects of radium-224 in humans. If the dose-squared exponential factor were used, the risk estimated to result from low-level radiation would be considerably less than the risk predicted by this linear risk-rate factor. Thus, because the true dose-response relation is uncertain, we recommend the factor giving the more conservative estimate.

3. Breast Cancer. Four different sets of risk-rate factors were given in BEIR III: absolute risk with and without cell killing, and relative risk with and without cell killing (BEIR III 1980, p. 283). The linear dose-response model was used with all four sets of factors. The factors provide a range of lifetime risk estimates for breast cancer. These factors are incidence risk rates. To obtain mortality risk rates, each incidence risk rate was multiplied by 0.39 (obtained from BEIR III 1980, p. 200, Table V-15). The resulting mortality risk-rate factors are listed in Table III.

The BEIR Committee indicated that the greatest uncertainty concerned the risk due to exposures after menopause. At doses lower than 1 rad, those risks were said to range from 0 (if the risk models did not apply at low doses) to about twice the risk estimated by the relative risk model with cell killing.

The relative risk-rate factors were given explicitly for breast cancer, in contrast to other site-specific cancers discussed in BEIR III. The lifetime risk factors were estimated for this special case by using the quoted relative risk-rate factors directly, rather than by calculating them from the procedure described in Section IV.C.

4. Liver Cancer. The recommended lifetime risk factors (Tables IIa and IIb) and risk-rate factors (Table III) were taken directly from the BEIR III report (BEIR III 1980, pp. 279-280). These factors were based principally on the experience with Thorotrast patients. The BEIR Committee indicated that a linear dose-response relationship was reasonable for alpha-particle radiation, but that for low-LET radiation, the observed relationship has been concave upward. Use of the liver cancer lifetime risk factor and risk-rate factor in Tables IIa or IIb and Table III would then lead to an overestimate of the true risk for low-LET radiation. Because no method of correcting this overestimate was given by the Committee, the factors were taken directly from BEIR III.

5. Thyroid Cancer. Thyroid cancer incidence risk-rate factors were given in Table V-14 of BEIR III (BEIR III 1980, p. 198). Mortality risk-rate factors were not explicitly given in BEIR III (BEIR III 1980, p. 303).

The risk-rate factor for thyroid cancer in males and the factor for thyroid cancer in females have been multiplied by 0.18 and 0.20, respectively, to convert the risks from incidence of thyroid cancer to those of mortality from thyroid cancer. The conversion factors of 0.18 and 0.20 were taken from Table V-15 of BEIR III (BEIR III 1980, p. 200). The resulting risk-rate factors for mortality from thyroid cancer are given in Table III.

The BEIR report discussed the possibility of a lower risk of thyroid cancer from internal radiation from ^{131}I relative to the risk from external radiation, stating that "what little evidence is available from children treated with iodine-131 for hyperthyroidism does not demonstrate the carcinogenic effect seen with external radiation." (BEIR III 1980, p. 301). However, in giving the risk-rate factors the BEIR report did not distinguish between external radiation and internal radiation from ^{131}I. Consequently, the factors given in BEIR III should be used with both external and internal radiation.

6. Leukemia. Table V-17 of BEIR III (p. 203) gives age- and sex-specific risk-rate factors for leukemia and bone cancer induced by low-LET radiation for use in the linear model. Age-specific risk coefficients for leukemia alone for use in the linear model are not given in BEIR III. Using the risk rate for bone cancer of 0.05×10^{-6}/yr/person-rad for low-LET radiation, we calculate that bone cancer is never more than 5% of the total and is usually approximately 2%. This small contribution of bone cancer to the total leukemia and bone cancers is small compared with the uncertainties in the risk-rate factors. Therefore, we have used the Table V-17 risk-rate factors to calculate the risks of leukemia (ignoring the small contribution from bone cancer) from exposure to low-LET radiation.

7. Lung Cancer. The lung cancer risk-rate factors were taken from the table given on p. 327 of BEIR III. These factors are somewhat different from other factors in BEIR III in that they apply to the age when the cancer is diagnosed, rather than the age at exposure. They also are expressed in the BEIR III report in terms of dose equivalent instead of the more usual (for BEIR III) absorbed dose.

The age-specific risk coefficients increase with age at diagnosis. As a result, the absolute lifetime risk factor resembles the relative lifetime risk factor, because for the relative risk calculation the lung cancer risk increases as the spontaneous lung cancer rate increases with age.

For Tables I, II, and III, the lung cancer risk must be presented in units of $(\text{absorbed dose})^{-1}$. The BEIR III report quotes a range of RBE values for alpha radiation of 8 to 15. The BEIR III report gives a conversion of 1 WLM* = 0.4-0.8 rad of alpha radiation, which has a central value of 1 WLM = 0.6 rad. The report also gives 1 WLM = 6 rem for alpha radiation. This would indicate that the RBE would be approximately 10, which is in the range of 8 to 15 quoted above. In view of the uncertainties in arriving at the value of the RBE, an RBE = 10 was felt to be reasonable, and was used to convert the BEIR III risk-rate factors to units of $(\text{absorbed dose})^{-1}$ for alpha radiation (see Section IV.F.8 below).

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*A working level (WL) is any combination of short-lived radon decay product concentrations in one liter of air that will result in the ultimate emission of 1.3×10^5 MeV of potential alpha energy. A working level month (WLM) is exposure to 1 WL for 1 working month (170 h).

Risk of lung cancer resulting from exposure to environmental levels of radon and radon decay products is treated as a special case. This risk was considered by Evans (1981) who concluded that the lifetime risk of mortality from lung cancer was at most 100 x 10^{-6}/WLM. We recommend as a conservative procedure that the maximum value of 100 x 10^{-6}/WLM be used in evaluating environmental radon and radon decay product exposures. Since no risk-rate factor was given by Evans et al., a life table calculation is not possible. However, the relatively large uncertainties already associated with these risk estimates suggest that the uncertainties resulting from not performing a life table calculation would not be significant.

8. Risk Factors for High-LET Radiation. Lifetime risk factors from exposure to high-LET radiation can be estimated by first calculating the corresponding lifetime risk factor for low-LET radiation and then multiplying this number by the RBE. Following the recommendations of the ICRP (ICRP 1977a), we recommend that a quality factor (which is assumed to equal an RBE for this report) of 20 be used to make this modification for high-LET radiation. As discussed above (see Section IV.F.7), an RBE of 10 was used for lung cancer.

Recommended values of RBE to use for obtaining high-LET risk factors are given in Table VII.

TABLE VII

RBE VALUE TO USE FOR OBTAINING LIFETIME RISKS FROM HIGH-LET RADIATION[a]

Cancer Type/Organ Exposed	RBE for Alpha Particles, Multiple-Charged Particles
All cancers/total body	
Bone cancer/bone surface	20
Breast cancer/breast	20
Liver cancer/liver	20
Thyroid cancer/thyroid	20
Leukemia/red marrow	20
Lung cancer/lung	10

[a]For neutrons, the RBE is assumed to equal the energy-dependent value for quality factor given in USDOE (1980a).

G. Relating Cancer Incidence to Cancer Mortality

For some types of cancer, cancer mortality may not provide a complete picture of the impact of the radiation exposure. Relatively high survival rates for some cancers, such as thyroid cancer or breast cancer, would reduce the mortality rates, yet even cancers that are cured would still represent an adverse health impact on the population. As a result, it is recommended that both cancer incidence and mortality be reported in NEPA documents.

Several methods of calculating cancer incidence were reviewed by the BEIR III Committee. The Committee concluded that the most reliable approach to estimating incidence of radiation-induced cancers was to first estimate the mortality risk for a given cancer type and then multiply this risk by the ratio of the spontaneous cancer incidence rate to cancer mortality rate for that cancer type. This method was only used by the BEIR Committee to estimate the risk of incidence of all cancers other than leukemia and bone cancer taken together. However, the method is recommended here for use with individual cancer sites.

Table VIII lists values of the mortality-to-incidence ratio for seven different cancer types. The values for all sites except leukemia and bone cancer were taken from Table V-15 of the BEIR III report. The recommended values for leukemia and bone cancer were inferred to be equal to one from the BEIR III report, which treated incidence of and mortality from these two cancers equivalently (see, for example, Table V-16, p. 203, BEIR III 1980).

H. Risk of Genetic Disorders in Offspring

The risk factors for radiation-induced genetic disorders in offspring are presented in Tables IIa and IIb. As noted earlier, the risk factor taken from BEIR III refers to the gamete dose. Usually the gonadal dose is

TABLE VIII

RATIOS OF THE LIFETIME RISK OF CANCER MORTALITY TO THE LIFETIME RISK OF CANCER INCIDENCE

Cancer Type	Males	Females
All cancers except leukemia and bone cancer	0.65	0.50
Bone	1.00	1.00
Breast	--	0.39
Liver	1.00	1.00
Thyroid	0.18	0.20
Leukemia	1.00	1.00
Lung	0.83	0.75

calculated in dose assessments, so this dose needs to be converted to gamete dose. This can be done using tables published by NCHS giving the average number of children that an individual is expected to have after a given age (USNCHS 1982).

The BEIR III procedure for calculating gamete dose from gonadal dose is to divide the population, by sex, into 5-year age intervals (a finer division is not necessary because the NCHS tables are provided only for 5-year age intervals). The number of each sex in each age interval is then multiplied by the number of children that individuals of each sex in that age interval are expected to have from that age onward. This number, which is the number of gametes that will be passed to the succeeding generation by this group of individuals, is multiplied by the gonadal dose for each age group. This dose is corrected for the relative sensitivities of spermatogonia and immature oocytes by multiplying all doses calculated for males by 0.82 and doses calculated for females by 0.18 (BEIR III 1980, p. 127). The final step is to add the doses that have been calculated for both sexes and all age groups to give the total gamete dose.

This gamete dose is appropriate for use with the risk factors for genetic disorders given in Tables IIa and IIb. For convenience, the conversion from gonadal dose to gamete dose was calculated for a population having the same age-specific birth-rate distribution as given in the NCHS tables. The resulting risk factor, expressed in terms of gonadal dose, is also given in Tables IIa and IIb. If the exposed population has an age-specific birth-rate distribution similar to that in the NCHS tables, this factor may be used directly with the gonadal dose calculated for that population. However, if the population is markedly different, for example, all males 25 to 35 years of age, the gamete dose would have to be calculated from the gonadal dose using the data specific to that population, if available.

We recommend that the risk of serious genetic disorders resulting from a radiation exposure in both the first generation and in all subsequent generations be given in the radiological assessment for a NEPA document. Risk factors from which these risks are calculated are given in Tables IIa or IIb in terms of both gamete dose and gonadal dose.

As noted in Section III.C., the risk of radiation-induced genetic disorders in all subsequent generations from a dose D to a single generation is numerically equal to the genetic risk in a single generation produced by exposing several generations to a dose D per generation until equilibrium has been reached (BEIR III 1980, p. 128). Thus the BEIR III equilibrium genetic risk factor is quoted in Tables IIa and IIb to give the total risk of genetic disorders in all subsequent generations.

The risk factors for genetic disorders from exposure to high-LET radiation are obtained by multiplying those for low-LET radiation by 3 to remove the reduction for dose-rate effect made for low-LET radiation (Section III.A.1) and by 20 to adjust for the relative biological effectiveness.

I. Risk of Somatic Effects Other Than Cancer

1. Effects from Irradiation in Utero. We have elected to use the BEIR III treatment of teratogenic effects rather than the treatment presented in ICRP Publication 27. Both approaches were described in Section III.B.1. The BEIR III approach was intended as a realistic assessment of the risk of radiation-induced effects from irradiation *in utero*. The ICRP developed its approach in order to include these effects into an index of harm. This procedure would not necessarily give the best assessment of the risk of these effects.

For NEPA-related documents, doses from any routine operations that may be considered are well within the dose range in which, according to the BEIR Committee, there would be no widespread teratogenic effects. Doses to the public from operations at DOE facilities are limited to 500 mrem/year to whole body, gonads, and bone marrow, and 1500 mrem/year to other organs (US DOE 1980a). Under the DOE regulations of keeping doses to as low a level as reasonably achievable (ALARA), actual doses from DOE operations are considerably lower than these dose limits, usually only a small fraction not only of the dose standards but also of background radiation (see, for example, US DOE 1982b).

Estimated doses resulting from proposed DOE routine operations being evaluated under NEPA would be subject to the same standards. Normally, the DOE dose limits would have to be exceeded before the embryo would receive a dose corresponding to 1-R exposure at an exposure rate greater than 0.01 R/min, the level below which no widespread effects induced by *in utero* irradiation are expected to appear (BEIR III 1980, p. 492). The ALARA policy would further limit actual doses to levels far below that corresponding to the 1-R level. In addition, the dose resulting from a particular facility's operations is generally distributed over the entire year. The dose received by the embryo during a critical development stage, which is usually during the first trimester of pregnancy, would be proportionately less than the annual dose. Consequently, teratogenic effects would be minimal given the range of doses from routine operations discussed in NEPA documents.

In Section I.D., we noted that assessment in a NEPA document of impacts from a one-time accident may involve consideration of doses above the DOE annual dose limits. These doses could exceed the dose threshold values for teratogenic effects. For these cases, some discussion of these effects in the assessment would be necessary. However, in publications of the national and international advisory bodies reviewed in this report, no recommendations have been made for any dose-response model for these effects, so no procedure to quantify these effects is given here. [The ICRP has proposed a model to use in developing an index of harm, but not for use with their other risk factors (see Section III.B.1).]

2. Nonstochastic Effects. We recommend using the 1982 UNSCEAR report in evaluating the occurrence of nonstochastic effects in an exposed population. This report presents a comprehensive review of these effects on an organ-by-organ basis.

Routine doses, which are limited by the DOE standards discussed above, from operations of facilities reviewed in NEPA documents are well below the dose thresholds at which nonstochastic effects may begin to occur. Doses calculated for some accident scenarios may slightly exceed the lowest of the thresholds. In particular, the UNSCEAR Committee reports temporary sterility in males at doses as low as 10 rads. While these effects may not be significant, they should be discussed for the sake of completeness using information presented in the 1982 UNSCEAR report (UNSCEAR 1982).

J. Effect of Current Research on Risk Assessment Procedures

Most of the risk factors and risk rate coefficients recommended in this report are the result of ongoing epidemiological studies. As more data become available with time, estimates of these factors will improve so that there will be a need to continually update the factors given here.

The recalculation of the doses at Hiroshima and Nagasaki could result in a significant revision of the risk factors. This recalculation has resulted in larger gamma-dose values at Hiroshima and slightly lower gamma-dose values at Nagasaki, and lower neutron doses calculated for both cities. Preliminary results suggest the new dosimetry may show that the neutron component at both cities was not significant, and the data from both cities may be combined to yield pooled estimates of risk and risk-rate factors (Loewe 1981). However, although the free-in-air doses have been recalculated, the impact on the epidemiological results of the atomic bomb survivor study cannot be entirely gauged until several issues have been resolved. In a recent review of the atomic bomb survivor dosimetry, Kerr (1982) concluded that these epidemiological results should be considered tentative until organ dose factors, house-shielding factors, and the energy yield and neutron output of the weapons are revised.

Future epidemiological surveys and the revised dose estimates at Hiroshima and Nagasaki would give improved estimates of the risk and risk-rate factors. In addition, with improved statistical accuracy, the shape of the dose-response curve may become better defined. This would improve risk estimation by more clearly identifying models that correlate closely with the epidemiological data.

V. SUMMARY

Factors are recommended that give the risk of genetic disorders in offspring and lifetime risk of cancer mortality averaged over a population with the age and sex distribution of the U.S. population. These recommendations are for populations of similar demographic composition where a detailed risk calculation would not be necessary. This could apply to ADMs, EAs, and even EISs. These recommended risk factors are listed in Tables IIa or IIb.

If demographic data are available, the mutagenic risk and lifetime tumorigenic risk may be calculated individually for situations where the population is significantly different from the U.S. population. Recommended risk-rate factors and genetic risk factors are provided for the cancer mortality and genetic disorder calculations, respectively. These factors are given in Table III. A computer program was written that calculates lifetime risk of mortality from radiation-induced cancer by use of site-specific demographic and population health data. A program listing, description of the required input data, and a sample problem are given in the appendixes.

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APPENDIX A

THE COMPUTER PROGRAM REPCAL

I. GENERAL INFORMATION

The computer code REPCAL has been written in FORTRAN IV. It currently runs on a Control Data 7600 computer. A simple problem, such as the calculation of the relative risk coefficients for total cancer (running NORGAN = 2, KORGAN = 22,23) will use approximately 14 seconds CPU time and 100 000 octal words of memory. The CDC 7600 has a 60-bit word size; if the program is to be run on another type of computer, some consideration may have to be given to using double precision variables to reach comparable precision. A listing of the program is provided in Appendix B.

II. INPUT REQUIREMENTS

The structure of the input file is described below in Table A-I. Input variables and parameters appearing in this input file are defined in Table A-II.

TABLE A-I

STRUCTURE OF INPUT FILE

	Parameter	Number of Cards	Format
	Title	1	10A8
	IFLAG(I),I=1,4	1	4I1
	IWRITE(I),I=1,4	1	4I1
	[(TQX[I,J],I=1,120), J=1,2]*	48	5F12.9
	[(AGEDIS[I,J],I=1,120),J=1,2]*	40	6F10.0
	NUM(I),I=1,2	1	2F10.0
	NORGAN	1	I5
	KORGAN,LET,MODEL,NFOLLW	1	4I5
NORGAN	[(CAN5Y[I,J],I=1,28)J=1,2]	8	7F10.4
TIMES	NINV	1	I5
	TIME(I),DOSINV(I),I=1,NINV	NINV	2F10.2
	NTABLE	1	I3
	NYEAR(I),I=1,NTABLE	1	14I5

*Array included in the input deck only if the corresponding value of IFLAG=1.

TABLE A-II

DEFINITION OF INPUT PARAMETERS

Variable	Definition
Title	Any descriptive title up to 80 characters in length.
IFLAG(I)	Parameter indicating which set of input data should be used by the program for I=1 and 2. IFLAG=0 means use the input data given in DATA statements in SUBROUTINE START. IFLAG=1 means use data sets supplied by the user. I=1 proportion dying in each age interval for reference life table I=2 population age distribution
TQX(I,J)	Proportion dying in each age interval i[from age i= -1 (prenatal) to age i=109] for males (j=1) and females (j=2).
AGEDIS(I,J)	Population distribution by age [from age i=-1 (prenatal) to age i=109] and sex [for males (j=1) and females (j=2)]. The entries for AGEDIS do not have to be normalized; the program adds up to entries for both males and females and normalizes AGEDIS automatically.
KORGAN	The number identifying the organ at risk.

KORGAN	Organ/Cancer Type	KORGAN	Organ/Cancer Type
1	Breast	15	
2	Thyroid	16	Bone
3	Lung	17	
4	Leukemia	18	
5		19	
6		20	Hematopoietic cancer from prenatal exposure
7		21	Solid cancer from prenatal exposure
8	Liver	22	All cancers except leukemia and bone cancer, linear model
9		23	Leukemia and bone cancer, linear model
10		24	

TABLE A-II (cont)

Variable	Definition
KORGAN (cont)	

KORGAN	Organ/Cancer Type	KORGAN	Organ/Cancer Type
11		25	Leukemia risk from BEIR I
12		26	All cancers except leukemia and bone cancer, linear-quadratic model
13		27	Leukemia and bone cancer, linear-quadratic model
14		28	

Variable	Definition
LET	Radiation type, low linear-energy-transfer (LET=1) or high linear-energy-transfer (LET=2).
MODEL	Risk projection model, absolute risk model (MODEL=1) or relative risk model (MODEL=2).
NFOLLW	Number of years for which there has been adequate epidemiological followup. Used to calculate the relative risk-rate coefficients.
NINV	Number of dose intervals.
CAN5Y(I,J)	Cancer mortality rates in 5-year intervals for age intervals i=1 (0-4 years) up to i=22 (105-109 years) for males (j=1) and females (j=2). This array must be supplied for all relative risk calculations. Units are deaths per million individuals.
XNUM(I)	Number of males (j=1) and females (j=2) in population receiving the dose.
NORGAN	Number of organs for which cancer risk is calculated.
TIME(I)	Number of years in dose interval i.
DOSINV(I)	Dose in rads received in dose interval i.
NTABLE	Number of ages for which life tables are to be printed.
NYEAR(I)	Starting age for the printing of life table i.

A listing of the input file for the first example problem discussed in Appendix C is presented in Table A-III. This problem calculates the total risk of dying of cancer as a result of 10 rads of whole body, low-LET radiation (a calculation also performed in BEIR III, p. 204 and p. 207). We have used the linear dose-response model and a relative risk projection model for all cancers except leukemia and bone.

TABLE A-III

INPUT FILES FOR A SAMPLE PROBLEM: CALCULATING THE TOTAL NUMBER OF CANCER DEATHS INDUCED BY A DOSE OF 10 Rads OF LOW-LET RADIATION

```
 single dose of 10 rads using relative risk (except for leukemia/bone)
1110
1110
0.000000000  .022450000  .001330000  .000940000  .000780000
 .000640000  .000580000  .000540000  .000510000  .000460000
 .000410000  .000360000  .000350000  .000420000  .000590000
 .000840000  .001140000  .001420000  .001670000  .001850000
 .001980000  .002120000  .002260000  .002350000  .002350000
 .002280000  .002170000  .002060000  .001990000  .001980000
 .002030000  .002100000  .002180000  .002280000  .002390000
 .002520000  .002680000  .002880000  .003120000  .003390000
 .003690000  .004010000  .004350000  .004730000  .005180000
 .005680000  .006230000  .006810000  .007440000  .008120000
 .008870000  .009690000  .010590000  .011610000  .012750000
 .014000000  .015340000  .016760000  .018270000  .019870000
 .021580000  .023390000  .025320000  .027380000  .029600000
 .032000000  .034630000  .037460000  .040440000  .043500000
 .046650000  .049910000  .053440000  .057400000  .061930000
 .067030000  .072640000  .078560000  .084620000  .090700000
 .096880000  .103670000  .111250000  .119290000  .127700000
 .136630000  .147300000  .159790000  .172810000  .185210000
 .196810000  .208390000  .221220000  .235120000  .250230000
 .265460000  .279620000  .290900000  .301350000  .311110000
 .320170000  .328570000  .336330000  .343470000  .350040000
 .356060000  .361570000  .366610000  .371210000  .375400000
 .379220000 0.000000000 0.000000000 0.000000000 0.000000000
0.000000000 0.000000000 0.000000000 0.000000000 0.000000000
0.000000000  .017460000  .001160000  .000770000  .000600000
 .000510000  .000430000  .000380000  .000340000  .000310000
 .000280000  .000260000  .000250000  .000270000  .000330000
 .000400000  .000490000  .000580000  .000660000  .000690000
 .000710000  .000720000  .000730000  .000750000  .000770000
 .000790000  .000810000  .000830000  .000860000  .000900000
 .000960000  .001020000  .001100000  .001190000  .001290000
 .001400000  .001520000  .001650000  .001800000  .001970000
 .002150000  .002330000  .002510000  .002730000  .002970000
 .003250000  .003540000  .003840000  .004160000  .004490000
 .004840000  .005230000  .005650000  .006110000  .006600000
 .007120000  .007680000  .008290000  .008940000  .009620000
 .010350000  .011130000  .012000000  .012980000  .014110000
 .015380000  .016780000  .018320000  .020040000  .021950000
 .024070000  .026320000  .028790000  .031650000  .035030000
 .038930000  .043250000  .047900000  .052950000  .058400000
 .064320000  .070970000  .078340000  .086120000  .094190000
 .102750000  .112820000  .124620000  .136850000  .148590000
 .160060000  .172640000  .187180000  .202430000  .217500000
 .231860000  .245840000  .258540000  .269800000  .279960000
 .289490000  .298360000  .306590000  .314200000  .321220000
 .327680000  .333610000  .339040000  .344010000  .348550000
 .352690000 0.000000000 0.000000000 0.000000000 0.000000000
0.000000000 0.000000000 0.000000000 0.000000000 0.000000000
  0.00000     .01463     .01457     .01455     .01454     .01453
   .01452     .01451     .01451     .01450     .01449     .01449
   .01448     .01448     .01447     .01446     .01445     .01443
   .01440     .01438     .01435     .01432     .01429     .01426
   .01422     .01419     .01416     .01413     .01410     .01407
   .01405     .01402     .01399     .01396     .01392     .01389
   .01385     .01381     .01377     .01373     .01368     .01363
   .01357     .01351     .01344     .01337     .01329     .01320
   .01311     .01301     .01290     .01277     .01265     .01251
   .01235     .01218     .01201     .01182     .01161     .01139
   .01115     .01090     .01064     .01036     .01006     .00975
   .00943     .00909     .00873     .00838     .00799     .00760
   .00721     .00681     .00641     .00599     .00558     .00516
```

TABLE A-III (cont).

65	.00474	.00432	.00392	.00352	.00315	.00278	
66	.00244	.00212	.00182	.00154	.00129	.00106	
67	.00086	.00068	.00054	.00041	.00031	.00023	
68	.00017	.00012	.00009	.00006	.00004	.00003	
69	.00002	.00001	.00001	.00001	.00000	.00000	
70	.00000	.00000	.00000	0.00000	0.00000	0.00000	
71	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	
72	0.00000	.01320	.01316	.01314	.01313	.01313	
73	.01312	.01311	.01311	.01310	.01310	.01310	
74	.01309	.01309	.01309	.01308	.01308	.01307	
75	.01306	.01305	.01304	.01304	.01303	.01301	
76	.01300	.01299	.01299	.01297	.01296	.01295	
77	.01294	.01293	.01291	.01290	.01288	.01287	
78	.01285	.01283	.01280	.01278	.01275	.01273	
79	.01269	.01266	.01263	.01259	.01254	.01250	
80	.01245	.01239	.01234	.01227	.01221	.01214	
81	.01206	.01197	.01189	.01179	.01169	.01158	
82	.01147	.01134	.01121	.01107	.01092	.01076	
83	.01059	.01040	.01020	.00999	.00976	.00951	
84	.00925	.00897	.00867	.00835	.00800	.00764	
85	.00726	.00686	.00644	.00600	.00555	.00510	
86	.00464	.00418	.00373	.00329	.00286	.00246	
87	.00208	.00173	.00142	.00115	.00091	.00070	
88	.00054	.00040	.00030	.00021	.00015	.00011	
89	.00008	.00005	.00004	.00002	.00002	.00001	
90	.00001	.00001	.00000	0.00000	0.00000	0.00000	
91	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	
92	1000000.	1000000.					
93	2						
94	22 1	2 30					
95	33.87205	28.82773	24.16823	40.09863	61.77780	90.26943	140.0339
96	260.7323	570.3040	1229.845	2237.891	3669.446	5817.599	8173.591
97	10481.97	13112.09	13112.09	14115.99	14115.99	14115.99	14115.99
98	14115.99						
99	26.55585	21.89922	18.58769	28.64152	39.20196	80.95097	170.5309
100	355.5241	732.9593	1328.616	2046.024	2973.764	3954.441	4858.459
101	6190.020	8392.462	8392.462	10608.92	10608.92	10608.92	10608.92
102	10608.92						
103	2						
104	1.0	10.0					
105	110.0	0.0					
106	23 1	1 30					
107	2						
108	1.0	10.0					
109	110.0	0.0					
110	2						
111	0 10						

In line 2 of the example, IFLAG(1) = 1 and IFLAG(2) = 1. This signals the program to look for the arrays TQX and AGEDIS in the input file. From line 3, IWRITE(1) = 1 and IWRITE(2) = 1, signifying that these arrays should be printed. TQX appears as lines 4-51, and AGEDIS as lines 52-91, in the Input File.

Line 92 tells the program that there are one million males and one million females in the population at risk. These individuals are distributed in age according to the proportions given in AGEDIS.

Line 93 indicates that two cancer types are being considered in this calculation. These are all cancers except leukemia and bone cancer (K = 22) and leukemia and bone cancer (K = 23). Lines 94 and 106 identify these two cancer types and indicate that the risks are to be calculated for low-LET radiation (LET = 1) using the relative risk model (MODEL = 2) for K = 22 and the absolute risk model (MODEL = 1) for K = 23. Age- and sex-specific cancer mortality rates for K = 22 are in lines 95-102.

For K = 22, two dose intervals are to be considered (line 103). They are a 1-year dose of 10 rads (line 104) and a 110-year dose of 0 rad (line 105). Similar dose distribution in time is indicated for K = 23 in lines 107, 108, and 109.

Two life tables are to be printed (line 110), for beginning ages 0 and 10 (line 111).

III. INTERPRETATION OF CALCULATED RESULTS

The computer program REPCAL estimates the lifetime risk of radiation-induced cancer mortality by sex for each age of exposure up to age 109. This is the lifetime risk that a hypothetical cohort of individuals all of the same age would incur if they all simultaneously received the stated radiation dose.

The program also calculates the total number of fatal cancers for all age groups for each sex in a given population resulting from exposure to ionizing radiation. Dividing this estimate by the number of individuals in each population gives the age-averaged lifetime risk of cancer mortality for males and for females. Taking the weighted average by sex of these two risks will then give the age- and sex-averaged lifetime risk of cancer mortality.

Caution should be exercised in interpreting the age-averaged risk calculated by REPCAL. This risk estimate should only apply to 1-year exposures. For external radiation the 1-year exposure also corresponds to a 1-year dose. For internal radiation, the 1-year exposure to radioactive material could result in doses occurring beyond 1 year. For example, inhalation of a radioactive material of class Y lung solubility would result in a lung dose for several years after inhalation. These doses are properly accounted for by entering the dose for each year in DOSINV(I). But the exposure time during which the material was inhaled should not exceed 1 year.

The reason for this limitation is that the changing age structure of the population at risk may invalidate the age-averaging procedure. It is assumed that changes in the population for periods shorter than a year would not be significant. For longer periods, the population would be aging and new members would be born. Immigration and emigration could also change the age distribution. These population dynamics are not taken into account in the program. Consequently, the period when the individual receives the external radiation or is exposed to radioactive material is limited to 1 year for the calculation of the age-averaged risk.

This limitation applies only to the age-averaged risk. The lifetime risk to a cohort of individuals all of the same age can be estimated for exposure periods larger than 1 year. This is the age-specific risk, estimated for each age from birth to the age of 109. It is in contrast to the age-averaged risk, which is the age-weighted average of these age-specific risks. See the two sample problems in Appendix C for an illustration.

APPENDIX B

LISTING OF THE COMPUTER PROGRAM REPCAL

```
      program repcal (input,output,tape50=input,tape55=output)
      real latent,iat(7,27)
      dimension surviv(120,2),radxr(120,2),tqxprm(120,2),
     > drisk(120),rskpop(120,2),totmor(27),plt(7,27),rsk(7,27),
     > ageint(7),drad(27),hleff(120,27),radrsk(27)
      dimension dtot(120),dref(120),tx(120),ex(120),tlx(120)
      dimension dplat(120),dlat(120),dhaz(120)
      common/acom/ xrad(120),xnat(120),r(120,27)
      common/wind/iage(120)
      common/sea/rskrad,latent,plteau,nfollw(27)
      common/indata/agedis(120,2),tqx(120,2),canrte(120,2,27),
     > alet(2),amodel(2),aname(27),gender(2),let(30),korgan(30),
     > model(30),xnum(2),dose(120,27),norgan
      common/liftab/ntable,nage(27),nyear(120)
      data itable/0/
      data (gender(i),i=1,2)/8hmale    ,8hfemale  /
      data (ageint(i),i=1,7)/8h  <0    ,8h 0 - 9  ,8h10 - 19 ,8h20 - 34
     > ,8h35 - 49 ,8h50 - 65 ,8h  >65   /
      data (aname(i),i=1,27)/8hbreast  ,8hthyroid ,8hlung    ,8hleukemia
     > ,8hesophag ,
     >8hstomach ,8hintestin,8hliver   ,8hpancreas,8hpharynx ,8hsal glnd,
     >8hparathyr,8hurin org,8hovary   ,8huterus  ,8hbone    ,8hsinuess ,
     >8hbrain   ,8hskin    ,8hiu-hema ,8hiu-solid,8hother   ,8hleu/bone,
     >8hlymphoma,8hbeir i  ,8hother   ,8hleu/bone/
      call start
      do 950 i=1,120
      iage(i)=i-2
  950 continue
      do 502 ngendr=1,2
      write(55,360)
      write(55,305)
      write(55,350) gender(ngendr)
  350 format(1h0,t34,"calculation of cancer risks for ",a8,"population")
      write(55,305)
      do 805 iexps=1,111
      do 240 k=1,27
      hleff(iexps,k)=0.0
      totmor(k)=0.0
  240 continue
  805 continue
c calculate the risk rate factors for the relative risk model
      do 770 iorg=1,norgan
      k=korgan(iorg)
      if (model(iorg).eq 1) go to 770
      if (iexps.ne 1) go to 1000
      if (k ne 20.and.k.ne 21) go to 770
      call relfac(iorg,k,ngendr)
      go to 770
 1000 continue
      call relfac(iorg,k,ngendr)
  770 continue
c loop over iexps, the age when the radiation exposure begins
      do 800 iexps=1,111
cdb   if (iexps.ge.4) stop                                          cdb
      rskcon=0.0
      surviv(iexps,ngendr)=100000.
      do 210 j=iexps,111
      jage=j-2
      radtot=0.0
      do 201 iorg=1,norgan
      k=korgan(iorg)
      radrsk(k)=0.0
  201 continue
      do 220 iorg=1,norgan
```

```
      k=korgan(iorg)
      if (iexps ne 1.and.k eq.20) go to 220
      if (iexps ne 1 and.k.eq 21) go to 220
      if (model(iorg) eq 2) go to 701
c-----------------------------------------------------------------------
c
c          start calculations for the absolute risk model
c
c-----------------------------------------------------------------------
      do 200 i=iexps,j
      if (iexps.eq.1.and.k.eq.20) go to 1020
      if (iexps.eq 1.and.k.eq.21) go to 1020
      if (iexps.eq.1) go to 200
 1020 continue
      idjust=i-iexps+1
      call getrsk(rc,iage(i),jage,k,let(iorg),model(iorg),ngendr,
     > dose(idjust,k))
      radrsk(k)=radrsk(k)+dose(idjust,k)*rc
      radtot=radtot+dose(idjust,k)*rc
  200 continue
      go to 220
  701 continue
c-----------------------------------------------------------------------
c
c          start calculations for the relative risk model
c
c-----------------------------------------------------------------------
      do 725 i=iexps,j
      if (iexps.eq.1.and.k.eq.20) go to 1030
      if (iexps.eq.1.and.k.eq.21) go to 1030
      if (iexps.eq.1) go to 725
 1030 continue
      idjust=i-iexps+1
      if (k.ne.1) go to 760
      riske6=r(i,k)*canrte(j,ngendr,k)*dose(idjust,k)
      if (i le.9) latent=20.0
      if (i ge.10.and.i.le.14) latent=20.0
      if (i.ge.15.and.i.le.19) latent=15.0
      if (i.ge.20) latent=10.0
      delta=j-i
      if (delta.lt.latent) riske6=0.0
      if (delta.eq.latent) riske6=riske6/2.0
      go to 735
  760 continue
      jdif=j-i
      if(jdif.lt.nfollw(iorg)) go to 730
      if (jdif.eq.nfollw(iorg)) go to 850
      riske6=r(i,k)*canrte(j,ngendr,k)*dose(idjust,k)
      go to 735
  850 continue
      call getrsk(rc,iage(i),jage,k,let(iorg),model(iorg),ngendr,
     > dose(idjust,k))
      riske6=(dose(idjust,k)*rc/2.0)+(r(i,k)*canrte(j,ngendr,k)
     > *dose(idjust,k)/2.0)
      go to 735
  730 continue
      call getrsk(rc,iage(i),jage,k,let(iorg),model(iorg),ngendr,
     > dose(idjust,k))
      riske6=dose(idjust,k)*rc
  735 continue
      radrsk(k)=radrsk(k)+riske6
      radtot=radtot+riske6
  725 continue
  220 continue
```

```
c-----------------------------------------------------------------------
c
c          use the calculated risks to generate a new life table
c
c-----------------------------------------------------------------------
      agemor=tqx(j,ngendr)/(1.0-0.5*tqx(j,ngendr))
      tqxprm(j,ngendr)=agemor/(1.0+0.5*(agemor+radtot))
      dref(j)=tqxprm(j,ngendr)*surviv(j,ngendr)
      dtot(j)=dref(j)
      do 230 iorg=1,norgan
      k=korgan(iorg)
      radxr(j,ngendr)=radrsk(k)/(1.0+0.5*(agemor+radtot))
      drad(k)=radxr(j,ngendr)*surviv(j,ngendr)
      dtot(j)=dtot(j)+drad(k)
      hleff(iexps,k)=hleff(iexps,k)+drad(k)
  230 continue
      j1=j+1
      surviv(j1,ngendr)=surviv(j,ngendr)-dtot(j)
      tlx(j)=(surviv(j1,ngendr)+surviv(j,ngendr))/2.
  905 format(/t33,27("-"),
     >/"     age ",t15,"tqx",t26,"lx",t36,"tdx",t45,"drad",t55,
     > "dref",t65,"tlx",t75,"tx",t85,"ex")
  902 format(1x,2i4,f10.8,f10.0,3f10.3,2f10.0,f10.2)
cdb   jage=j-2                                                      cdb
cdb   jage1=jage+1                                                  cdb
cdb   write(55,911)jage,jage1,tqxprm(j,ngendr),surviv(j,ngendr),dtot(j),cdb
cdb  > dref(j),drad(22),drad(23),agemor,radtot,radrsk(22),radrsk(23)   cdb
c 911 format(1x,2i4,f10.8,f10.0,4f10.3,4(1x,e11.3))                  cdb
  210 continue
c-------------------------------------------------------------------
c
c          print out the life tables if requested...
c
c-------------------------------------------------------------------
      do 650 itable=1,ntable
      if (iage(iexps).ne.nyear(itable)) go to 650
      if (itable.gt.1) write(55,360)
      write(55,900)iage(iexps),gender(ngendr)
  900 format(1h0,"life table calculation",//t10,"starting age",t40,i3,
     > //t10,"population",t40,a8,//)
      write(55,901)(aname(korgan(iorg)),iorg=1,norgan)
  901 format(t10,"cancer types",(t40,a8,//))
      write(55,905)
      tx(111)=tlx(111)
      do 652 l=iexps,110
      linv=111-l
      linv1=linv+1
      tx(linv)=tlx(linv)+tx(linv1)
      ex(linv)=tx(linv)/surviv(linv,ngendr)
  652 continue
      do 654 j=iexps,111
      dradt=dtot(j)-dref(j)
      jage=j-2
      jage1=jage+1
      write(55,902)jage,jage1,tqxprm(j,ngendr),surviv(j,ngendr),dtot(j),
     > dradt,dref(j),tlx(j),tx(j),ex(j)
  654 continue
  650 continue
  800 continue
      do 810 iexps=1,111
      do 235 iorg=1,norgan
      k=korgan(iorg)
      hleff(iexps,k)=hleff(iexps,k)/100000.
  235 continue
```

```
810 continue
305 format(//1x,120("-"),//)
    do 250 iorg=1,norgan
    k=korgan(iorg)
    write(55,360)
360 format(1h1)
    write(55,305)
    write(55,361)aname(k),gender(ngendr)
361 format(1x,"cancer type",t20,a8,//1x,"population",t20,a8)
    write(55,340)((iage(iexps),hleff(iexps,k),iexps=j,112,14),j=1,14)
340 format(//1h0,"lifetime risk to individual from exposure by age",
   > //8("  age   lifetime"),/8(" group   risk  "),
   > 14(/8(1x,i4,1x,e10.4)))
    do 815 iexps=1,111
    hleff(iexps,k)=hleff(iexps,k)*agedis(iexps,ngendr)*xnum(ngendr)
    totmor(k)=totmor(k)+hleff(iexps,k)
815 continue
    write(55,306)gender(ngendr),alet(let(iorg))
306 format(//1x,"number of health effects in ",a8,"population "
   >"distributed by age (",a4,"let radiation)")
    write(55,307)
307 format(/1x,8("  age    health"),/8(" group  effects"))
    write(55,330)((iage(i),hleff(i,k),i=j,112,14),j=1,14)
330 format(14(1x,/8(i5,e10.3)))
    write(55,308)
308 format(t112,9("_"))
    write(55,320)gender(ngendr),totmor(k)
320 format(1x,/t53,"total number of health effects to the ",a8,
   >"population",e12.4)
    write(55,305)
250 continue
502 continue
    end
    subroutine start
    dimension time(120),dosinv(120)
    common/indata/agedis(120,2),tqx(120,2),canrte(120,2,27),
   > alet(2),amodel(2),aname(27),gender(2),let(30),korgan(30),
   > model(30),xnum(2),dose(120,27),norgan
    common/liftab/ntable,nage(27),nyear(120)
    common/sea/rskrad,latent,plteau,nfollw(27)
    dimension pop(2),iflag(4),iwrite(4),title(8),disnam(2),ipr(4)
    dimension can5y(28,2)
    data ((agedis(i,j),i=1,120),j=1,2)/
   >   0.,1839.,1815.,1713.,1645.,1654.,1598.,1631.,1595.,1659.,
   >1722.,1903.,1903.,1852.,1808.,1854.,1916 ,2039.,2131.,2143.,
   >2134.,2235.,2208.,2178.,2153.,2139.,2080.,2066.,2013.,1971.,
   >1866.,1898.,1852.,1812.,1799.,1914.,1418.,1436.,1426.,1502.,
   >1304.,1259.,1219.,1170.,1146.,1101.,1097.,1079.,1050.,1065.,
   >1051.,1097.,1122.,1102.,1116.,1110.,1112.,1118 ,1094.,1075.,
   >1074.,1045., 999., 953., 914., 872., 848., 834., 793., 757.,
   > 715., 679., 631., 587., 549., 499., 463., 421., 379., 341.,
   > 292., 287., 244., 204., 174., 155., 706.,   0.,   0 ,   0 ,
   >   0.,   0.,   0.,   0.,   0.,   0.,   0 ,   0.,   0.,   0.,
   >   0.,   0.,   0.,   0.,   0.,   0.,   0.,   0.,   0.,   0.,
   >   0.,   0.,   0.,   0.,   0.,   0.,   0.,   0.,   0.,   0.,
   >   0.,1752.,1734.,1636.,1572.,1579.,1530.,1558 ,1524.,1585.,
   >1645.,1817.,1820.,1774.,1732.,1778.,1839.,1962.,2048.,2077.,
   >2090.,2197.,2176.,2155.,2144.,2145.,2090.,2077 ,2030.,1989.,
   >1886.,1929.,1884.,1850.,1839.,1962.,1460.,1480.,1474.,1554.,
   >1352.,1308.,1268.,1220.,1197.,1153.,1152.,1134.,1109.,1129.,
   >1118.,1174.,1206.,1191.,1213.,1215.,1226.,1242.,1225.,1213.,
   >1220.,1194.,1149.,1105.,1070.,1035.,1023.,1024., 992., 965.,
   > 929., 899., 853., 811., 778., 727., 694., 650., 605., 564.,
   > 502., 510., 451., 392., 347., 320.,1656.,   0 ,   0.,   0.,
```

```
     >   0     0 ,  0 ,  0 ,  0 ,  0 ,  0     0     0     0 ,
     >   0 ,   0 ,  0 ,  0 ,  0 .  0    0     0     0     0 ,
     >   0 ,   0 ,  0 ,  0 ,  0    0 ,  0     0 ,   0 ,   0 /
      data (alet(i),i=1,2)/4hlow ,4hhigh/
      data (amodel(i) i=1,2)/8habsolute,8hrelative/
      data (disnam(i),i=1,2)/8hprogram ,8huser    /
      data (tqx(i,1),i=1,120)/
     >    0 00000,     02245,      00133,      00094       00078,
     >      00064,     00058,      00054,      00051,      00046,
     >      00041,     00036,      00035,      00042,      00059,
     >      00084,     00114,      00142,      00167,      00185,
     >      00198,     00212,      00226,      00235,      00235,
     >      00228,     00217,      00206       00199,      00198,
     >      00203,     00210,      00218       00228,      00239,
     >      00252,     00268       00288,      00312,      00339,
     >      00369,     00401,      00435,      00473,      00518,
     >      00568,     00623,      00681,      00744,      00812,
     >      00887,     00969,      01059,      01161,      01275,
     >      01400,     01534,      01676,      01827,      01987,
     >      02158,     02339,      02532,      02738,      02960,
     >      03200,     03463,      03746,      04044,      04350,
     >      04665,     04991,      05344,      05740,      06193
     >      06703,     07264,      07856,      08462,      09070,
     >      09688,     10367,      11125,      11929,      12770,
     >      13663,     14730,      15979,      17281,      18521,
     >      19681,     20839,      22122,      23512,      25023,
     >      26546,     27962,      29090,      30135,      31111,
     >      32017,     32857,      33633,      34347,      35004,
     >      35606,     36157,      36661,      37121,      37540,
     >      37922,   0 00000,    0 00000,    0 00000,    0 00000,
     >    0 00000,   0 00000,    0 00000,    0 00000,    0 00000/
      data (tqx(i,2),i=1,120)/
     >    0 00000,     01746,      00116,      00077,      00060,
     >      00051,     00043,      00038,      00034,      00031,
     >      00028,     00026,      00025,      00027,      00033,
     >      00040,     00049,      00058,      00066,      00069,
     >      00071,     00072,      00073,      00075,      00077,
     >      00079,     00081,      00083,      00086,      00090,
     >      00096,     00102,      00110,      00119,      00129,
     >      00140,     00152,      00165,      00180,      00197,
     >      00215,     00233,      00251,      00273,      00297,
     >      00325,     00354,      00384,      00416,      00449,
     >      00484,     00523,      00565,      00611,      00660,
     >      00712,     00768,      00829,      00894,      00962,
     >      01035,     01113,      01200,      01298,      01411,
     >      01538,     01678,      01832,      02004,      02195,
     >      02407,     02632,      02879,      03165,      03503,
     >      03893,     04325,      04790,      05295,      05840,
     >      06432,     07097,      07834,      08612,      09419,
     >      10275,     11282,      12462,      13685,      14859,
     >      16006,     17264,      18718,      20243,      21750,
     >      23186,     24584,      25854,      26980,      27996,
     >      28949,     29836,      30659,      31420,      32122,
     >      32768,     33361,      33904,      34401,      34855,
     >      35269,   0 00000,    0 00000,    0 00000     0 00000,
     >    0 00000,   0 00000,    0 00000,    0 00000,    0 00000/
      data (((canrte(i,j,k),i=1,120),j=1,2),k=1,27)/
     > 6480*0 0/
      data (pop(i),i=1,2)/ 0 0,0 0/
      read(50,9)(title(i),i=1,8)
      write(55,9)(title(i),i=1,8)
    9 format(10a8)
c
c set up of the input deck
```

```
c
c     number of cards           parameter           format
c
c           1                     iflag               4i
c           1                     iwrite              4i
c         (48)                    tqx                 5f12 9
c         (40)                    agedis              6f10 0
c           1                     xnum                2f10 0
c           1                     norgan              i5
c           1                     korgan,let,model,nfollw 4i5
c           1                     xnum                2f10 0
c          (8)                    can5y               7f10.4
c           1                     ninv                i5
c         ninv                    time,dosinv         2f10.2
c           1                     ntable              i3
c           1                     nyear               14i5
c
c the array iflag is used to insert user-supplied data to the arrays
c tqx and agedis.  if iflag.ne 1, default values based
c on united states national average statistics will be used.  the index
c i for iflag corresponds to
c   tqx    (proportion dying in each age interval)    for     i=1
c   agedis (population age distribution)              for     i=2
      read(50,10)(iflag(i),i=1,4)
   10 format(4i1)
c if iwrite(i)=1, the array corresponding to the value of i
c (defined above) will be printed.  if iwrite(i) ne.1, no printout
c will be provided
      read(50,10)(iwrite(i),i=1,4)
      if(iflag(1).ne 1) go to 20
      read(50,15)((tqx(i,j),i=1,120),j=1,2)
   20 if(iwrite(1) eq.1) write(55,115)((tqx(i,j),i=1,120),j=1,2)
   15 format(5f12.9)
  115 format(/t5,"proportion dying in each age interval",
     > //t5,"male",/12(t5,10f11 9/),//t5,"female",/12(t5,10f11 9/))
      if (iflag(2).ne.1) go to 30
      read(50,16)((agedis(i,j),i=1,120),j=1,2)
   30 if (iwrite(2) eq.1) write(55,116)((agedis(i,j),i=1,120),j=1,2)
   16 format(6f10.0)
  116 format(//t5,"age distribution by sex",
     > //t5,"male",/12(t5,10f11.5/),//t5,"female",/12(t5,10f11.5/))
      do 3 i=1,2
      do 4 j=1,120
      pop(i)=pop(i)+agedis(j,i)
    4 continue
    3 continue
      do 1 i=1,2
      do 2 j=1,120
      agedis(j,i)=agedis(j,i)/pop(i)
    2 continue
    1 continue
      if (iwrite(2).eq 1) write(55,600)(pop(i),i=1,2)
  600 format(/t15,"population totals used to normalize age distribution
     >tables",/t40,"males",t55,f10 2,/t40,"females",t55,f10.2)
c read in input information, where
c
c          dose is the dose in rads,
c          let = 1   for low let radiation
c              = 2   for high let radiation
c          korgan = cancer type (see subroutine getrsk for listing
c                               of cancer types)
c          model = 1 for absolute risk model
c                  2 for relative risk model
c          xnum(1) = number of males in population at risk
```

```
c          xnum(2) = number of females in population at risk
c
      write(55,402)
  402 format(//120("-"),////120("-"),//)
      read(50,501)(xnum(i),i=1,2)
  501 format(2f10.0)
      read(50,602) norgan
      write(55,25)
   25 format(1x,/t5,"health effects calculated for . ")
      write(55,502) norgan
  502 format(1x,/t15,"number of target organs",t55,i2/)
      do 606 iorg=1,norgan
      read(50,19) korgan(iorg),let(iorg),model(iorg),nfollw(iorg)
   19 format(4i5)
      write(55,22) iorg,alet(let(iorg)),aname(korgan(iorg)),
     > amodel(model(iorg))
   22 format(/11x,i5,".)",t20,"let",t55,a4,/t20,"cancer type",t55,a8,
     > /t20,"risk model",t55,a8/)
      if (model(iorg) ne 2) go to 750
      read(50,17)((can5y(i,j),i=1,28),j=1,2)
   17 format(7f10.4)
      do 700 j=1,2
    . canrte(1,j,korgan(iorg))=0.0
      do 701 i=1,22
      k1=5*(i-1)+2
      k2=5*i+1
      do 702 k=k1,k2
      canrte(k,j,korgan(iorg))=can5y(i,j)*0.000001
  702 continue
  701 continue
  700 continue
  750 continue
      read(50,602)ninv
  602 format(i5)
      read(50,603)(time(i),dosinv(i),i=1,ninv)
  603 format(2f10.2)
      nstart=1
      do 604 i=1,ninv
      ntime=time(i)
      nstop=nstart+ntime-1
      do 605 ij=nstart,nstop
      dose(ij,korgan(iorg))=dosinv(i)
  605 continue
      nstart=nstart+ntime
  604 continue
      write(55,35)
   35 format(1x,t20,"dose by time interval ")
      write(55,21)(dosinv(i),time(i),i=1,ninv)
   21 format(1x,t55,f8.5," rads for ",f5.1," years")
   40 if (model(iorg).eq 2.and.iwrite(3) eq 1) write(55,117)
     > ((canrte(i,j,korgan(iorg)),i=1,120),j=1,2)
  117 format(/t5,"cancer mortality rates",
     > //t5,"male",/12(t5,10f11.8/),//t5,"female",/12(t5,10f11 8/))
cdb   write(55,610)(i,korgan(iorg),dose(i,korgan(iorg)),i=1,120)          cdb
cd610 format(/1x,"listing of dose"//,120(2i5,f10.4/))                    cdb
  606 continue
      do 5 i=1,4
      ipr(i)=iflag(i)+1
    5 continue
      write(55,400)
  400 format(/t5,"summary of population characteristics ..",/)
      write(55,401)xnum(1),xnum(2),disnam(ipr(1)),disnam(ipr(2))
  401 format(/t15,"number of persons in population ",/t40,"males",t55,
     >f8.0,/t40,"females",t55,f8.0,/t15,"population table.",t45,"supplie
```

```
     >d by ",/t30,"life table",t55,a8,/t30,"age distribution",t55,a8)
c read the number of life tables to be printed and the beginning age for each table.
c a maximum of 25 life tables can be printed.
      read(50,601) ntable
  601 format(i3)
      read(50,608)(nyear(iyear),iyear=1,ntable)
  608 format(14i5)
      return
      end
      subroutine getrsk(rc,i,j,k,let,m,n,dose)
      real latent
      common/sea/rskrad,latent,plteau,nfollw(27)
c this subroutine calculates the risk rate at age "j" for cancer type "k"
c due to exposure at age "i" to low let radiation (l=1) or high let radiation
c (l=2), for the absolute risk model (m=1) or relative risk model (m=2),
c for males (n=1) or females (n=2)   the cancer types are
c
c            k     cancer type          k    cancer type
c
c            1      breast             13      urinary organs
c            2      thyroid            14      ovary
c            3      lung               15      uterus and cervix uteri
c            4      leukemia           16      bone
c            5      esophagus          17      paranasal sinuses
c                                               and mastoid air cells
c            6      stomach            18      brain
c            7      intestine          19      skin
c                    and rectum
c            8      liver              20      hematopoietic cancer from
c                                               prenatal exposure
c            9      pancreas           21      solid tumors from
c                                               prenatal exposure
c           10      pharynx, hypo-     22      all cancers except leukemia
c                    pharnx,larynx              and bone cancer, l-l model
c           11      salivary glands    23      leukemia and bone, l-l model
c           12      parathyroid        24      lymphoma
c
c other risk coefficients presented for convenience. .
c
c           25      leukemia risk from beir i
c           26      all cancers except leukemia and bone cancer,
c                    lq-l `model
c           27      leukemia and bone cancer, lq-l model
      rskrad=0 0
      if (k.eq.1) go to 1
      if (k.eq.2) go to 2
      if (k.eq.3) go to 3
      if (k.eq.16) go to 16
      if (k.eq.8) go to 8
      if (k eq.20) go to 20
      if (k.eq.21) go to 21
      if (k eq 23) go to 23
      if (k eq 22) go to 22
      if (k eq 25) go to 25
      if (k.eq.26) go to 26
      if (k.eq 27) go to 27
      rc=0.0
      return
    1 continue
c breast cancer  .     (p 283, beir iii)
c only uses the model for linear risk with no cell killing   to use the
c model with cell killing, just substitute the appropriate values of
c rskrad from page 283 of beir iii   all risk rate factors have been
c multiplied by 0 39 (table v-15, beir iii)to give the mortality risk rate
```

```
      if (let.ne.1) write(55,902) let
  902 format(1x,"value for let incorrect",i5)
      if (let.ne.1) stop
      if (n.eq.1) rskrad=0 0
      if (n.eq.1) go to 100
      if (m.eq.2) go to 101
      if (i.le.9) rskrad=0.0
      if (i.ge.10.and.i.le.19) rskrad=4.1e-06
      if (i.ge.20) rskrad=2.6e-06
      if (i.le.9) latent=20.0
      if (i.ge.10.and.i.le.14) latent=20.0
      if (i.ge.15.and.i.le.19) latent=15.0
      if (i.ge.20) latent=10.0
      plteau=200.0
      go to 100
  101 continue
c this section supplies the relative risk coefficients given in beir iii
c (p. 283) directly to subroutine relfac
      if (i.le.9) rskrad=0.0
      if (i.ge.10.and.i.le.19) rskrad=0.4e-02
      if (i.ge.20) rskrad=0.16e-02
      rc=rskrad
      return
    2 continue
c thyroid cancer...     (pp. 303-304, beir iii)
      if (let.ne.1) write(55,902) let
      if (let.ne.1) stop
      if (n.eq.1) rskrad=0.4e-06
      if (n.eq.2) rskrad=1.2e-06
      latent=10.0
      plteau=200.0
      go to 100
    3 continue
c lung cancer...     (p. 327, beir iii)
c cancer risk is referenced to the age at diagnosis, here taken to be j.
      if (j.lt.35) rskrad=0.0
      if (j.ge.35.and.j.le.49) rskrad=1.5e-06
      if (j.ge.50.and.j.le.65) rskrad=3.0e-06
      if (j.gt.65) rskrad=7.0e-06
      plteau=200.0
      if (i.lt.15) latent=25.0
      if (i.ge.15.and.i.le.34) latent=17.5
      if (i.ge.35) latent=10.0
      go to 100
   20 continue
c hematopoietic cancers from intrauterine exposure(p.452, beir iii)
      latent=0.0
      plteau=12.0
      if (i.ne.-1) rskrad=0.0
      if (i.ne.-1) go to 100
      if (let.eq.1) rskrad=25.0e-06
      if (let.eq.2) rskrad=500.0e-06
      go to 100
   21 continue
c solid cancers from intrauterine exposure (p.452, beir iii)
      latent=0.0
      plteau=10.0
      if (i.ne.-1) rskrad=0.0
      if (i.ne.-1) go to 100
      if (let.eq.1) rskrad=28.0e-06
      if (let.eq.2) rskrad=560.0e-06
      go to 100
   16 continue
c bone cancer...     (p. 417, beir iii)
```

```
      if (let eq 1) rskrad=0 05e-06
      if (let eq 2) rskrad=1 0e-06
      latent=4 0
      plteau=27 0
      go to 100
    8 continue
c liver cancer        (pp 379-380,beir iii)
      if (let eq 1) rskrad=0 7e-06
      if (let eq 2) rskrad=13 0e-06
      latent=10 0
      plteau=200 0
      go to 100
   27 continue
c calculate the combined risk from leukemia and bone cancer using
c the linear-quadratic model (low let radiation and absolute risk model
c only )
      if (let ne 1) write(55,900) let
  900 format(/1x,"the linear-quadratic model has been called for non-low
     > let radiation  ",/1x,"let = ",i5,"  program stopped ")
      if (let ne 1) stop
cdb   if (m ne 1) write(55,901) m
cd901 format(/1x,"the leukemia/bone cancer risk model has been called fo
cdb  >r non-absolute risk ",1x,"model = ",i5, 'program stopped ")
cdb   if (m ne 1) stop
      latent=3 0
      plteau=24 0
      if(n eq 2) go to 600
      if (i le 9) a=1 829
      if (i le 9) b=0 01575
      if (i ge 10 and i le 19) a=0 7855
      if (i ge 10 and i le 19) b=0 006766
      if (i ge 20 and i le 34) a=1 1380
      if (i ge 20 and i le 34) b=0 009798
      if (i ge 35 and i le 49) a=0 8511
      if (i ge 35 and i le 49) b=0 007331
      if (i ge 50) a=1 937
      if (i ge 50) b=0 01669
      if (dose lt 1 1) b=0 0
      rskrad=a*dose + b*(dose**2)
      if (dose lt 0 000000001) rskrad=0 0
      if (dose lt 0 000000001) go to 215
      rskrad=rskrad/dose
  215 continue
      rskrad=rskrad*1 0e-06
      go to 100
  600 continue
      if (i le 9) a=1 169
      if (i le 9) b=0 01007
      if (i ge 10 and i le 19) a=0 5067
      if (i ge 10 and i le 19) b=0 004364
      if (i ge 20 and i le 34) a=0 7301
      if (i ge 20 and i le 34) b=0 006289
      if (i ge 35 and i le 49) a=0 5483
      if (i ge 35 and i le 49) b=0 004723
      if (i ge 50) a=1 238
      if (i ge 50) b=0 01047
      if (dose lt 1 1) b=0 0
      rskrad=a*dose + b*(dose**2)
      if (dose lt 0 000000001) rskrad=0 0
      if (dose lt 0 000000001) go to 210
      rskrad=rskrad/dose
  210 continue
      rskrad-rskrad*1 0e-06
      go to 100
```

```
   26 continue
c calculate the risk of all cancers except leukemia and bone cancer
c using the linear-quadratic model.  low let radiation only.
      latent=10
      plteau=200.
      if (n eq 2) go to 601
      if (i le.9) a=0 89720
      if (i.le.9) b=0 007728
      if (i.ge 10.and i.le.19) a=0.6095
      if (i.ge.10.and.i.le.19) b=0.005250
      if (i.ge.20.and.i.le.34) a=1.774
      if (i ge.20.and.i.le.34) b=0.01528
      if (i.ge.35.and.i.le.49) a=2.278
      if (i.ge.35.and.i.le 49) b=0.01962
      if (i.ge.50) a=3.446
      if (i.ge.50) b=0 02968
      if (dose lt 1.1) b=0.0
      rskrad=a*dose + b*(dose**2)
      if (dose lt.0.000000001) rskrad=0.0
      if (dose.lt.0.000000001) go to 205
      rskrad=rskrad/dose
  205 continue
      rskrad=rskrad*1.0e-06
      go to 100
  601 continue
      if (i.le.9) a=1.1690
      if (i.le.9) b=0.01007
      if (i.ge.10.and.i.le.19) a=0.7940
      if (i.ge.10.and.i.le.19) b=0.006839
      if (i.ge.20.and.i.le.34) a=2.311
      if (i.ge 20.and.i.le.34) b=0.01990
      if (i.ge.35.and.i.le.49) a=2.968
      if (i.ge.35.and.i.le.49) b=0.02556
      if (i ge.50) a=4.489
      if (i.ge.50) b=0.03867
      if (dose.lt.1.1) b=0.0
      rskrad=a*dose + b*(dose**2)
      if (dose.lt.0.000000001) rskrad=0.0
      if (dose.lt.0.000000001) go to 200
      rskrad=rskrad/dose
  200 continue
      rskrad=rskrad*1.0e-06
      go to 100
   25 continue
c this section gives the leukemia risk as calculated from beir i.  it is
c used for comparing program results with those of other authors.
      latent=2.0
      plteau=25.0
      if (i.ge.10) rskrad=1.0e-06
      if (i.le.9) rskrad=2.0e-06
      go to 100
   22 continue
c calculate the risk of all cancers except leukemia and bone cancer
c using the linear model.  low let radiation only. (beir iii, p. 207)
      latent=10.0
      plteau=200.0
      if (n.eq.2) go to 605
      if (i.le.9) a=1.92000
      if (i.ge.10.and.i.le.19) a=1.4570
      if (i ge.20.and.i.le.34) a=4.327
      if (i.ge.35.and.i.le.49) a=5.291
      if (i.ge.50) a=8.808
      rskrad=a
      rskrad=rskrad*1.0e-06
```

```
      go to 100
  605 continue
      if (i.le.9) a=2.57600
      if (i.ge.10.and.i.le.19) a=1.9550
      if (i.ge.20.and.i.le.34) a=5.807
      if (i.ge.35.and.i.le.49) a=7.102
      if (i.ge.50) a=11.823
      rskrad=a
      rskrad=rskrad*1.0e-06
      go to 100
   23 continue
c calculate the risk of leukemia and bone cancer
c using the linear model.  low let radiation only. (beir iii, p. 204)
      latent=3.0
      plteau=24.0
      if (n.eq.2) go to 606
      if (i.le.9) a=3.97700
      if (i ge.10.and.i.le.19) a=1.8490
      if (i.ge.20.and.i.le.34) a=2.596
      if (i.ge.35.and.i.le.49) a=1.921
      if (i ge.50) a=4.319
      rskrad=a
      rskrad=rskrad*1.0e-06
      go to 100
  606 continue
      if (i.le.9) a=2.54200
      if (i.ge.10.and.i.le.19) a=1.1920
      if (i.ge.20.and.i.le.34) a=1.666
      if (i.ge.35.and.i.le.49) a=1.237
      if (i.ge.50) a=2.7600
      rskrad=a
      rskrad=rskrad*1.0e-06
      go to 100
  100 continue
      delta=j-i
      if (delta.lt.latent) rc=0.0
      if (delta.eq.latent) rc=rskrad/2.0
c     we have to fake this for intrauterine exposures since
c     no fatal cancers are expected to occur before birth...
      if (k.eq.20.and.delta.eq.latent) rc=0.0
      if (k.eq.21.and.delta.eq.latent) rc=0.0
      if (delta.gt.latent) rc=rskrad
      span=latent + plteau
      if (delta.eq.span) rc=rskrad/2.0
      if (delta.gt.span) rc=0.0
      return
      end
      subroutine relfac(iorg,k,ngendr)
      real latent
      common/sea/rskrad,latent,plteau,nfollw(27)
      common/acom/xrad(120),xnat(120),r(120,27)
      common/wind/iage(120)
      common/indata/agedis(120,2),tqx(120,2),canrte(120,2,27),
     > alet(2),amodel(2),aname(27),gender(2),let(30),korgan(30),
     > model(30),xnum(2),dose(120,27),norgan
c  do initial calculations for the relative risk model
c  first generate the relative risk factors as a function of age.  calculate
c  xrad(i),the number of cancer deaths in the fraction of the expression period
c  that has been observed following
c  exposure to "dose" rads of radiation at age i.  then calculate xnat(i), the number
c  of cancer deaths in the nfollw(iorg) years between i+latent
c  and i+nfollw(iorg) years from natural causes.
c  the risk factor r(i) is the ratio of these two numbers, i.e., r(i)=xrad(i)/xnat(i).
      do 710 i=1,111
```

```
      xrad(i)=0.0
      xnat(i)=0.0
      r(i,k)=0.0
  710 continue
      dosx=1.0
c treat breast cancer as a special case since the relative risk factors
c are explicitly given in beir iii (p 283).
      if (k eq 1) go to 100
      do 700 i=1,111
      i30=i+nfollw(iorg)
      if (i30 gt.111) i30=111
      do 705 j=1,i30
      jage=j-2
      call getrsk(rc,iage(i),jage,k,let(iorg),model(iorg),ngendr,
     > dosx)
      idif=j-i
      if(idif.lt.latent) go to 705
      if (idif.eq.latent) go to 500
      if (idif.eq.nfollw(iorg)) go to 500
      xrad(i)=xrad(i)+rc*dosx
      xnat(i)=xnat(i)+canrte(j,ngendr,k)
      go to 705
  500 continue
      xrad(i)=xrad(i)+(rc*dosx)/2.0
      xnat(i)=xnat(i)+canrte(j,ngendr,k)/2.0
  705 continue
      if (i.ge.101) go to 772
      if(xnat(i).lt.1.0e-09) write(55,771)i,xnat(i),xrad(i)
  771 format(/1x,"check value of xnat",i5,2f20.10)
      if (xnat(i).lt.0.00001) go to 772
      r(i,k)=xrad(i)/xnat(i)
  772 continue
  700 continue
c the risk factors for ages 0-9 next are set equal to the average
c risk factor for 10-19 (beir iii, p.195)
      riskave=0.0
      do 773 ij=12,21
      riskave=riskave+r(ij,k)
  773 continue
      riskave=riskave/10.
      do 774 ij=1,11
      r(ij,k)=riskave
  774 continue
      write(55,942)gender(ngendr),aname(k),(iage(i),r(i,k),xrad(i),
     > xnat(i),i=1,120)
  942 format(/1x,"risk factors for relative risk model, ",
     > a8,"population",/t10,"for exposure to ",a8,/" age ",
     > "                  risk                    xrad                    xnat",/
     > 120(i5,3f20.8/))
      return
  100 continue
      do 110 i=1,111
      jage=200.
      dosx=1.0
      call getrsk(rc,iage(i),jage,k,let(iorg),model(iorg),
     > ngendr,dosx)
      r(i,k)=rc
  110 continue
      end
```

APPENDIX C

SAMPLE PROBLEMS AND COMPARISON OF REPCAL RISK ESTIMATES WITH THOSE OF BEIR III

The program REPCAL was used to calculate risk estimates for several dose scenarios that were also presented in the BEIR III report. The REPCAL input and output files for two of these scenarios are presented here. These two scenarios are

- the calculation of the total number of cancer mortalities from a single exposure of 10 rads using the relative risk model for all cancers except leukemia and bone cancer, and

- the calculation of the total number of cancer mortalities from continuous exposure from birth to 1 rad/year using the absolute risk model for all cancers except leukemia and bone cancer.

The linear no-threshold model was used for both calculations. We followed the BEIR III Committee in using age averaging in the first calculation and in estimating the cancer mortality risk in a cohort of individuals all of the same age in the second calculation.

The input file for the first calculation has been presented in Table A-III. The U.S. age distribution used by the BEIR Committee has been taken from Alexander (1982). The REPCAL output file is shown in Table C-I. The calculated number of cancer deaths (and the line in the output file where this average is found) for a population of 1 000 000 males is

3910 cancers other than leukemia and bone cancer (line 450), and
535 leukemia and bone cancer (line 508),

and for a population of 1 000 000 females

4560 cancers other than leukemia and bone cancer (line 821), and
and 363 leukemia and bone cancer (line 879).

The input file for the second calculation is given in Table C-II, and the output file in Table C-III. For this problem the lifetime risk of cancer mortality for a 1-rad/year exposure from birth is calculated. These risks are the entries for age 0 in the table labeled "lifetime risks to individuals from exposure by age" in the output file. The risks expressed as cancer deaths per million individuals and the lines in the output file on which these risks are found are for males

6126 cancers other than leukemia and bone cancer (line 380), and
3587 leukemia and bone cancer (line 438),

and for females,

10 920 cancers other than leukemia and bone cancer (line 751), and
2706 leukemia and bone cancer (line 809).

The other entries in these tables in the output file are the lifetime risks of cancer mortality for the other age cohorts. As noted earlier, the age-averaged risk factors given here (lines 416, 474, 787, and 845) should not be used if age-averaged risk factors involve exposure times greater than 1 year, because population dynamics have not been accounted for in the program.

In addition to these two calculations, two other calculations were performed using REPCAL that were also presented in BEIR III. The results of these calculations are in Table C-IV for comparison with the BEIR III results. As can be seen in the table, the two sets of calculations are in good agreement and are well within the uncertainty associated with these estimates.

TABLE C-I

OUTPUT FILE FOR THE FIRST SAMPLE PROBLEM

```
single dose of 10 rads using relative risk (except for leukemia

   proportion dying in each age interval

   male
   0 000000000  022450000  001330000  000940000  000780000  000640000  000580000  000540000  000510000  000460000
     000410000  000360000  000350000  000420000  000590000  000840000  001140000  001420000  001670000  001850000
     001980000  002120000  002260000  002350000  002350000  002280000  002170000  002060000  001990000  001980000
     002030000  002100000  002180000  002280000  002390000  002520000  002680000  002880000  003120000  003390000
     003690000  004010000  004350000  004730000  005180000  005680000  006230000  006810000  007440000  008120000
     008870000  009690000  010590000  011610000  012750000  014000000  015340000  016760000  018270000  019870000
     021580000  023390000  025320000  027380000  029600000  032000000  034630000  037460000  040440000  043500000
     046650000  049910000  053440000  057400000  061930000  067030000  072640000  078560000  084620000  090700000
     096880000  103670000  111250000  119290000  127700000  136630000  147300000  159790000  172810000  185210000
     196810000  208390000  221220000  235120000  250230000  265460000  279620000  290900000  301350000  311110000
     320170000  328570000  336330000  343470000  350040000  356060000  361570000  366610000  371210000  375400000
     3792200000 0000000000 0000000000 0000000000 0000000000 0000000000 0000000000 0000000000 0000000000 000000000


   female
   0 000000000  017460000  001160000  000770000  000600000  000510000  000430000  000380000  000340000  000310000
     000280000  000260000  000250000  000270000  000330000  000400000  000490000  000580000  000660000  000690000
     000710000  000720000  000730000  000750000  000770000  000790000  000810000  000830000  000860000  000900000
     000960000  001020000  001100000  001190000  001290000  001400000  001520000  001650000  001800000  001970000
     002150000  002330000  002510000  002730000  002970000  003250000  003540000  003840000  004160000  004490000
     004840000  005230000  005650000  006110000  006600000  007120000  007680000  008290000  008940000  009620000
     010350000  011130000  012000000  012980000  014110000  015380000  016780000  018320000  020040000  021950000
     024070000  026320000  028790000  031650000  035030000  038930000  043250000  047900000  052950000  058400000
     064320000  070970000  078340000  086120000  094190000  102750000  112820000  124620000  136850000  148590000
     160060000  172640000  187180000  202430000  217500000  231860000  245840000  258540000  269800000  279960000
     289490000  298360000  306590000  314200000  321220000  327680000  333610000  339040000  344010000  348550000
     3526900000 0000000000 0000000000 0000000000 0000000000 0000000000 0000000000 0000000000 0000000000 000000000



   age distribution by sex

   male
        0 00000      01463      01457      01455      01454      01453      01452      01451      01451      01450
          01449      01449      01448      01448      01447      01446      01445      01443      01440      01438
          01435      01432      01429      01426      01422      01419      01416      01413      01410      01407
          01405      01402      01399      01396      01392      01389      01385      01381      01377      01373
          01368      01363      01357      01351      01344      01337      01329      01320      01311      01301
          01290      01277      01265      01251      01235      01218      01201      01182      01161      01139
          01115      01090      01064      01036      01006      00975      00943      00909      00873      00838
          00799      00760      00721      00681      00641      00599      00558      00516      00474      00432
          00392      00352      00315      00278      00244      00212      00182      00154      00129      00106
          00086      00068      00054      00041      00031      00023      00017      00012      00009      00006
          00004      00003      00002      00001      00001      00001    0 00000    0 00000    0 00000    0 00000
        0 00000    0 00000    0 00000    0 00000    0 00000    0 00000    0 00000    0 00000    0 00000    0 00000


   female
        0 00000      01320      01316      01314      01313      01313      01312      01311      01311      01310
          01310      01310      01309      01309      01309      01308      01308      01307      01306      01305
          01304      01304      01303      01301      01300      01299      01299      01297      01296      01295
          01294      01293      01291      01290      01288      01287      01285      01283      01280      01278
          01275      01273      01269      01266      01263      01259      01254      01250      01245      01239
          01234      01227      01221      01214      01206      01197      01189      01179      01169      01158
          01147      01134      01121      01107      01092      01076      01059      01040      01020      00999
          00976      00951      00925      00897      00867      00835      00800      00764      00726      00686
          00644      00600      00555      00510      00464      00418      00373      00329      00286      00246
          00208      00173      00142      00115      00091      00070      00054      00040      00030      00021
          00015      00011      00008      00005      00004      00002      00002      00001      00001      00001
```

```
      0 00000     0 00000     0 00000     0 00000     0 00000     0 00000     0 00000     0 00000     0 00000     0 00000


              population totals used to normalize age distribution tables
                                     males                  1 00
                                     females                1 00



---------------------------------------------------------------------------------------------------------------------




--------------------------------------------------------------------------------------------------------------------------



  health effects calculated for

              number of target organs                 2


                1 ) let                             low
                    cancer type                     other
                    risk model                      relative

                    dose by time interval
                                                    10 00000 rads for   1 0 years
                                                     0 00000 rads for 110 0 years

  cancer mortality rates

  male
   0 00000000    00003387    00003387    00003387    00003387    00003387    00002883    00002883    00002883    00002883
     00002883    00002417    00002417    00002417    00002417    00002417    00004010    00004010    00004010    00004010
     00004010    00006178    00006178    00006178    00006178    00006178    00009027    00009027    00009027    00009027
     00009027    00014003    00014003    00014003    00014003    00014003    00026073    00026073    00026073    00026073
     00026073    00057030    00057030    00057030    00057030    00057030    00122985    00122985    00122985    00122985
     00122985    00223789    00223789    00223789    00223789    00223789    00366945    00366945    00366945    00366945
     00366945    00581760    00581760    00581760    00581760    00581760    00817359    00817359    00817359    00817359
     00817359    01048197    01048197    01048197    01048197    01048197    01311209    01311209    01311209    01311209
     01311209    01311209    01311209    01311209    01311209    01311209    01411599    01411599    01411599    01411599
     01411599    01411599    01411599    01411599    01411599    01411599    01411599    01411599    01411599    01411599
     01411599    01411599    01411599    01411599    01411599    01411599    01411599    01411599    01411599    01411599
     01411599 0 00000000 0 00000000 0 00000000 0 00000000 0 00000000 0 00000000 0 00000000 0 00000000 0 00000000


  female
   0 00000000    00002656    00002656    00002656    00002656    00002656    00002190    00002190    00002190    00002190
     00002190    00001859    00001859    00001859    00001859    00001859    00002864    00002864    00002864    00002864
     00002864    00003920    00003920    00003920    00003920    00003920    00008095    00008095    00008095    00008095
     00008095    00017053    00017053    00017053    00017053    00017053    00035552    00035552    00035552    00035552
     00035552    00073296    00073296    00073296    00073296    00073296    00132862    00132862    00132862    00132862
     00132862    00204602    00204602    00204602    00204602    00204602    00297376    00297376    00297376    00297376
     00297376    00395444    00395444    00395444    00395444    00395444    00485846    00485846    00485846    00485846
     00485846    00619002    00619002    00619002    00619002    00619002    00839246    00839246    00839246    00839246
     00839246    00839246    00839246    00839246    00839246    00839246    01060892    01060892    01060892    01060892
     01060892    01060892    01060892    01060892    01060892    01060892    01060892    01060892    01060892    01060892
     01060892    01060892    01060892    01060892    01060892    01060892    01060892    01060892    01060892    01060892
     01060892 0 00000000 0 00000000 0 00000000 0 00000000 0 00000000 0 00000000 0 00000000 0 00000000 0 00000000
```

TABLE C-I (cont)

```

          2 ) let                                  low
              cancer type                          leu/bone
              risk model                           absolute

              dose by time interval
                                                   10 00000 rads for   1 0 years
                                                    0 00000 rads for 110 0 years

 summary of population characteristics


          number of persons in population
                                   males           1000000
                                   females         1000000
          population table              supplied by
                        life table                 user
                        age distribution           user
```

TABLE C-I (cont)

calculation of cancer risks for male population

life table calculation

starting age 0

population male

cancer types other

leu/bone

age		tqx	lx	tdx	drad	dref	tlx	tx	ex
0	1	02245000	100000	2245 000	0 000	2245 000	98878	6688551	66 89
1	2	00133000	97755.	130 014	0 000	130 014	97690	6589673	67 41
2	3	00094000	97625	91 767	0 000	91 767	97579	6491983	66 50
3	4	00077999	97533	78 014	1 939	76 075	97494	6394404	65 56
4	5	00063999	97455	66 245	3 874	62 370	97422	6296910	64 61
5	6	00057999	97389	60 356	3 872	56 484	97359	6199488	63 66
6	7	00053999	97329	56 426	3 870	52 556	97300	6102129.	62 70
7	8	00050999	97272	53 475	3 867	49 608	97245	6004829	61 73
8	9	.00045999	97219	48 585	3 865	44 720	97194	5907583.	60 77
9	10	00040999	97170	43 703	3 864	39 839	97148	5810389	59 80
10	11	00035999	97126	39 759	4 794	34 965	97107	5713241	58 82
11	12	00034999	97087	39 703	5 724	33 979	97067	5616134	57 85
12	13	00041999	97047	46 480	5 721	40 759	97024	5519067	56 87
13	14	00058998	97000	62 947	5 718	57 229	96969	5422043	55 90
14	15	00083998	96938	87 139	5 714	81 425	96894	5325074	54 93
15	16	00113997	96850	116 114	5 708	110 406	96792	5228181	53 98
16	17	00141996	96734	143 059	5 700	137 359	96663	5131388	53 05
17	18	00166995	96591	166 994	5 691	161 303	96508	5034725	52 12
18	19	00184995	96424	184 060	5 681	178 380	96332	4938218	51 21
19	20	00197994	96240	196 219	5 669	190 550	96142	4841886	50 31
20	21	00211994	96044	209 265	5 658	203 607	95939	4745743	49 41
21	22	00225993	95835.	222 225	5 645	216 580	95724	4649804	48 52
22	23	00234993	95612	230 314	5 631	224 683	95497	4554081	47 63
23	24	.00234993	95382	229 759	5 618	224 141	95267	4458583	46 74
24	25	00227993	95152	222 546	5 605	216 941	95041	4363316	45 86
25	26	00216994	94930	211 583	5 592	205 992	94824	4268275	44 96
26	27	00205994	94718	200 693	5 580	195 114	94618	4173451	44 06
27	28	00198996	94518	191 777	3 690	188 086	94422	4078833	43 15
28	29	00197998	94326	188 572	1 809	186 763	94231	3984411	42 24
29	30	00202998	94137	192 902	1 806	191 097	94041	3890180	41 32
30	31	00209999	93944	198 546	1 264	197 282	93845	3796139	40 41
31	32	00217999	93746	205 089	724	204 365	93643	3702294	39 49
32	33	00227999	93541	213 995	723	213 272	93434	3608651	38 58
33	34	00238999	93327	223 771	721	223 050	93215	3515217	37 67

TABLE C-I (cont)

205	34	35	00251999	93103	235 338	719	234 618	92985	3422002	36 76
206	35	36	00267998	92868	250 219	1 336	248 883	92742	3329017	35 85
207	36	37	00287998	92617	268 068	1 332	266 736	92483	3236275	34 94
208	37	38	00311998	92349	289 455	1 328	288 128	92205	3143791	34 04
209	38	39	00338998	92060	313 404	1 323	312 081	91903	3051587	33 15
210	39	40	00368997	91746	339 861	1 319	338 542	91576	2959684	32 26
211	40	41	00400994	91407	369 408	2 873	366 535	91222	2868107	31 38
212	41	42	00434993	91037	398 867	2 861	396 005	90838	2776885	30 50
213	42	43	00472993	90638	431 561	2 848	428 712	90423	2686048	29 63
214	43	44	00517992	90207	470 097	2 834	467 263	89972	2595625	28 77
215	44	45	00567991	89737	512 515	2 819	509 696	89480	2505653	27 92
216	45	46	00622979	89224	561 889	6 042	555 847	88943	2416173	27 08
217	46	47	00680977	88662	609 771	6 002	603 769	88357	2327230	26 25
218	47	48	00743975	88052	661 047	5 959	655 088	87722	2238873	25 43
219	48	49	00811973	87391	715 506	5 912	709 594	87034	2151151	24 62
220	49	50	00886970	86676	774 651	5 861	768 789	86289	2064117	23 81
221	50	51	00968940	85901	842 897	10 566	832 332	85480	1977828	23 02
222	51	52	01058935	85058	911 170	10 457	900 713	84603	1892349	22 25
223	52	53	01160929	84147	987 229	10 340	976 889	83654	1807746	21 48
224	53	54	01274922	83160	1070 437	10 213	1060 224	82625	1724092	20 73
225	54	55	01399914	82090	1159 258	10 075	1149 183	81510	1641468	20 00
226	55	56	01533846	80930	1257 620	16 275	1241 345	80301	1559958	19 28
227	56	57	01675832	79673	1351 190	16 010	1335 179	78997	1479656	18 57
228	57	58	01826817	78321	1446 516	15 727	1430 789	77598	1400659	17 88
229	58	59	01986801	76875	1542 776	15 424	1527 352	76104	1323061	17 21
230	59	60	02157784	75332	1640 606	15 101	1625 505	74512	1246957	16 55
231	60	61	02338629	73692	1746 769	23 398	1723 372	72818	1172446	15 91
232	61	62	02531598	71945	1844 174	22 821	1821 353	71023	1099627	15 28
233	62	63	02737566	70101	1941 263	22 213	1919 051	69130	1028605	14 67
234	63	64	02959532	68159	2038 770	21 573	2017 197	67140	959475	14 08
235	64	65	03199494	66121	2136 426	20 902	2115 524	65052	892335	13 50
236	65	66	03462232	63984	2243 658	28 379	2215 280	62862	827282	12 93
237	66	67	03745170	61740	2339 631	27 344	2312 287	60571	764420	12 38
238	67	68	04043106	59401	2427 908	26 268	2401 640	58187	703849	11 85
239	68	69	04349040	56973	2502 931	25 155	2477 776	55721	645663	11 33
240	69	70	04663972	54470	2564 478	24 011	2540 466	53188	589941	10 83
241	70	71	04989592	51906	2619 167	29 292	2589 875	50596	536753	10 34
242	71	72	05342495	49286	2660 886	27 763	2633 122	47956	486157	9 86
243	72	73	05738387	46625	2701 762	26 211	2675 551	45275	438201	9 40
244	73	74	06191263	43924	2744 068	24 635	2719 434	42552	392927	8 95
245	74	75	06701125	41180	2782 536	23 035	2759 501	39788	350375	8 51
246	75	76	07261466	38397	2814 982	26 788	2788 194	36990	310587	8 09
247	76	77	07853268	35582	2819 109	24 748	2794 361	34173	273597	7 69
248	77	78	08459067	32763	2794 162	22 715	2771 447	31366	239424	7 31
249	78	79	09066866	29969	2737 949	20 712	2717 237	28600	208059	6 94
250	79	80	09684663	27231	2655 982	18 759	2637 223	25903	179459	6 59
251	80	81	10363442	24575	2563 679	16 869	2546 810	23293	153556	6 25
252	81	82	11121197	22011	2462 964	15 049	2447 916	20780	130263	5 92
253	82	83	11924940	19548	2344 431	13 308	2331 123	18376	109483	5 60
254	83	84	12765673	17204	2207 849	11 660	2196 189	16100	91107	5 30
255	84	85	13658392	14996	2058 330	10 115	2048 215	13967	75007	5 00
256	85	86	14724683	12938	1914 374	9 341	1905 033	11981	61040	4 72
257	86	87	15973271	11023	1768 689	7 905	1760 784	10139	49059	4 45
258	87	88	17274848	9255	1605 312	6 590	1598 722	8452	38920	4 21
259	88	89	18514451	7649	1421 638	5 410	1416 228	6938	30469	3 98
260	89	90	19674085	6228	1229 614	4 376	1225 238	5613	23530	3 78
261	90	91	20831725	4998	1044 672	3 490	1041 182	4476	17917	3 58
262	91	92	22114333	3953	877 006	2 740	874 266	3515	13441	3 40
263	92	93	23503915	3076	725 186	2 116	723 070	2714	9927	3 23
264	93	94	25014469	2351	589 743	1 603	588 139	2056	7213	3 07
265	94	95	26537028	1761	468 628	1 191	467 438	1527	5156	2 93
266	95	96	27952627	1293	362 246	867	361 379	1112	3629	2 81
267	96	97	29080313	931	271 235	620	270 616	795	2518	2 71
268	97	98	30125026	659	199 064	436	198 628	560	1723	2 61

TABLE C-I (cont)

269	98	99	31100762	460	143 454	303	143 151	389	1163	2 53
270	99	100	32006520	317.	101 613	207	101 405	266	774	2 44
271	100	101	32846299	215	70 830	140	70 690	180	508	2 36
272	101	102	33622097	144	48 639	094	48 545	120	328	2 27
273	102	103	34335914	96	32 937	062	32 875	79	208	2 18
274	103	104	34992746	63	22 019	040	21 978	52	129	2 06
275	104	105	35594595	41	14 545	026	14 519	34	77	1 90
276	105	106	36145457	26	9 503	017	9 486	21	44	1 67
277	106	107	36649332	17	6 146	011	6 136	14	22	1 33
278	107	108	.37109219	11	3 939	007	3 932	9	9	81
279	108	109	37528117	7	2 502	004	2 498	5	0	0 00
280	109	110	37910024	4	1 578	003	1 575	3	3	0 00

TABLE C-I (cont)

life table calculation

starting age 10

population male

cancer types other

leu/bone

age		tqx	lx	tdx	drad	dref	tlx	tx	ex
10	11	00036000	100000	36 000	0 000	36 000	99982	5878019	58 78
11	12	00035000	99964	34 987	0 000	34 987	99947	5778037	57 80
12	13	00042000	99929	41 970	0 000	41 970	99908	5678091	56 82
13	14	00059000	99887	59 856	923	58 933	99857	5578183	55 84
14	15	00083999	99827	85 699	1 845	83 854	99784	5478326	54 88
15	16	00113999	99741	115 547	1 843	113 704	99684	5378541	53 92
16	17	00141999	99626	143 308	1 841	141 468	99554	5278858	52 99
17	18	00166998	99483	167 972	1 838	166 134	99399	5179303	52 06
18	19	00184998	99315	185 565	1 835	183 730	99222	5079905	51 15
19	20	00197998	99129	198 105	1 831	196 274	99030	4980683	50 24
20	21	00211997	98931	212 278	2 547	209 731	98825	4881653	49 34
21	22	00225996	98719	226 361	3 260	223 101	98606	4782828	48 45
22	23	00234996	98492	234 705	3 252	231 453	98375	4684222	47 56
23	24	00234996	98258	234 146	3 245	230 902	98141	4585847	46 67
24	25	00227996	98023	226 727	3 237	223 490	97910	4487707	45 78
25	26	00216996	97797	215 445	3 230	212 215	97689	4389797	44 89
26	27	00205997	97581	204 237	3 223	201 014	97479	4292108	43 98
27	28	00198997	97377	196 993	3 216	193 777	97279	4194628	43 08
28	29	00197997	97180	195 623	3 210	192 413	97082	4097350	42 16
29	30	00202997	96984	200 078	3 203	196 875	96884	4000268	41 25
30	31	00209997	96784	206 440	3 196	203 244	96681	3903383	40 33
31	32	00217996	96578	213 726	3 189	210 536	96471	3806702	39 42
32	33	00227996	96364	222 889	3 182	219 707	96253	3710231	38 50
33	34	00238996	96141	232 949	3 175	229 774	96025	3613978	37 59
34	35	00251996	95908	244 852	3 167	241 685	95786	3517953	36 68
35	36	00267996	95664	259 532	3 158	256 374	95534	3422167	35 77
36	37	00287995	95404	277 908	3 149	274 759	95265	3326633	34 87
37	38	00311996	95126	299 052	2 262	296 790	94977	3231368	33 97
38	39	00338998	94827	322 841	1 379	321 461	94666	3136392	33 07
39	40	00368997	94504	350 092	1 374	348 718	94329	3041726	32 19
40	41	00400993	94154	380 790	3 239	377 552	93964	2947397	31 30
41	42	00434988	93773	412 990	5 087	407 903	93567	2853433	30 43
42	43	00472987	93360	446 646	5 064	441 582	93137	2759867	29 56
43	44	00517986	92914	486 318	5 039	481 280	92671	2666730	28 70
44	45	00567985	92427	529 984	5 011	524 973	92162	2574059	27 85
45	46	00622964	91897	583 228	10 741	572 487	91606	2481897	27 01
46	47	00680960	91314	632 483	10 669	621 813	90998	2390291	26 18
47	48	00743957	90682	685 224	10 592	674 632	90339	2299293	25 36
48	49	00811953	89996	741 237	10 509	730 729	89626	2208954	24 54
49	50	00886948	89255	802 066	10 418	791 648	88854	2119328	23 74
50	51	00968897	88453	875 798	18 778	857 020	88015	2030474	22 96
51	52	01058888	87577	945 930	18 584	927 346	87104	1942459	22 18
52	53	01160877	86631	1024 058	18 374	1005 684	86119	1855354	21 42
53	54	01274865	85607	1109 524	18 146	1091 378	85053	1769235	20 67
54	55	01399852	84498	1200 744	17 900	1182 844	83897	1684182	19 93
55	56	01533734	83297	1306 467	28 912	1277 556	82644	1600285	19 21

TABLE C-I (cont)

344	56	57	01675709	81991	1402 362	28 438	1373 925	81289	1517641	18 51
345	57	58	01826683	80588	1500 022	27 930	1472 092	79838	1436351	17 82
346	58	59	01986656	79088	1598 599	27 388	1571 211	78289	1356513	17 15
347	59	60	02157627	77490	1698 748	26 811	1671 937	76640	1278224	16 50
348	60	61	02338359	75791	1813 796	41 533	1772 263	74884	1201584	15 85
349	61	62	02531307	73977	1913 087	40 499	1872 587	73021	1126700	15 23
350	62	63	02737251	72064	2011 984	39 411	1972 573	71058	1053679	14 62
351	63	64	02959192	70052	2111 241	38 268	2072 974	68996	982621	14 03
352	64	65	03199127	67941	2210 581	37 069	2173 512	66835	913625	13 45
353	65	66	03461675	65730	2325 679	50 314	2275 366	64567	846790	12 88
354	66	67	03744568	63405	2422 689	48 464	2374 226	62193	782222	12 34
355	67	68	04042457	60982	2511 705	46 541	2465 164	59726	720029	11 81
356	68	69	04348343	58470	2587 036	44 554	2542 482	57177	660303	11 29
357	69	70	04663225	55883	2648 469	42 515	2605 955	54559	603126	10 79
358	70	71	04988570	53235	2 07 492	51 845	2655 646	51881	548568	10 30
359	71	72	05341402	50527	2 47 977	49 120	2698 858	49153	496687	9 83
360	72	73	05737216	47779	2787 547	46 354	2741 193	46385	447534	9 37
361	73	74	06190003	44992	2828 529	43 548	2784 982	43577	401148	8 92
362	74	75	06699765	42163	2865 530	40 702	2824 827	40730	357571	8 48
363	75	76	07259627	39298	2900 167	47 312	2852 856	37847	316840	8 06
364	76	77	07851285	36397	2901 348	43 686	2857 662	34947	278993	7 67
365	77	78	08456938	33496	2872 815	40 077	2832 739	32060	244046	7 29
366	78	79	09064591	30623	2812 393	36 523	2775 870	29217	211987	6 92
367	79	80	09682241	27811	2725 773	33 062	2692 711	26448	182770	6 57
368	80	81	10360860	25085	2628 742	29 715	2599 027	23771	156322	6 23
369	81	82	11118437	22456	2523 286	26 495	2496 791	21195	132551	5 90
370	82	83	11921993	19933	2399 831	23 418	2376 414	18733	111356	5 59
371	83	84	12762532	17533	2258 186	20 506	2237 680	16404	92623	5 28
372	84	85	13655048	15275	2103 590	17 780	2085 810	14223	76219	4 99
373	85	86	14720824	13171	1955 351	16 410	1938 941	12194	61996	4 71
374	86	87	15969113	11216	1804 986	13 880	1791 107	10314	49802	4 44
375	87	88	17270383	9411	1636 894	11 564	1625 330	8593	39489	4 20
376	88	89	18509698	7774	1448 466	9 488	1438 979	7050	30896	3 97
377	89	90	19669067	6326	1251 881	7 671	1244 210	5700	23846	3 77
378	90	91	20826446	5074	1062 814	6 113	1056 701	4542	18146	3 58
379	91	92	22108769	4011	891 587	4 798	886 789	3565	13604	3 39
380	92	93	23498047	3119	736 710	3 702	733 008	2751	10039	3 22
381	93	94	25008278	2383	598 684	2 804	595 880	2083	7287	3 06
382	94	95	26530517	1784	475 398	2 081	473 317	1546	5204	2 92
383	95	96	27945825	1309	367 227	1 514	365 713	1125	3658	2 80
384	96	97	29073282	941	274 784	1 082	273 702	804	2533	2 69
385	97	98	30117788	667	201 538	762	200 777	566	1729	2 59
386	98	99	31093332	465	145 143	528	144 615	393	1163	2 53
387	99	100	31998915	320	102 744	361	102 383	269	774	2 44
388	100	101	32838534	217	71 574	244	71 329	181	508	2 36
389	101	102	33614185	146	49 118	163	48 955	121	328	2 27
390	102	103	34327868	97	33 241	108	33 133	80	208	2 18
391	103	104	34984579	63	22 208	070	22 138	52	129	2 06
392	104	105	35586318	41	14 661	045	14 616	34	77	1 90
393	105	106	36137080	26	9 573	029	9 544	22	44	1 67
394	106	107	36640864	17	6 188	018	6 169	14	22	1 33
395	107	108	37100669	11	3 963	012	3 951	9	9	81
396	108	109	37519492	7	2 516	007	2 509	5	0	0 00
397	109	110	37901332	4	1 585	005	1 581	3	3	0 00

TABLE C-I (cont)

cancer type other

population male

lifetime risk to individual from exposure by age

age group	lifetime risk	age group	lifetime risk	age group	lifetime risk	age group	lifetime risk	age group	lifetime risk	age group	lifetime risk	age group	lifetime risk	age group	lifetime risk
-1	0	13	9323e-02	27	4295e-02	41	1401e-02	55	8855e-03	69	2718e-03	83	3201e-04	97	1763e-05
0	8222e-02	14	8393e-02	28	3864e-02	42	1297e-02	56	8266e-03	70	2431e-03	84	2610e-04	98	1171e-05
1	8403e-02	15	7227e-02	29	3512e-02	43	1206e-02	57	7706e-03	71	2163e-03	85	2119e-04	99	4717e-06
2	8406e-02	16	6064e-02	30	3147e-02	44	1125e-02	58	7172e-03	72	1913e-03	86	1717e-04	100	0
3	8406e-02	17	5226e-02	31	2795e-02	45	1047e-02	59	6663e-03	73	1682e-03	87	1395e-04	101	0
4	8404e-02	18	4594e-02	32	2514e-02	46	9724e-03	60	6177e-03	74	1469e-03	88	1136e-04	102	0
5	8398e-02	19	4100e-02	33	2284e-02	47	9054e-03	61	5714e-03	75	1275e-03	89	9281e-05	103	0
6	8389e-02	20	1050e-01	34	2093e-02	48	8447e-03	62	5270e-03	76	1100e-03	90	7598e-05	104	0
7	.8379e-02	21	8973e-02	35	2330e-02	49	7892e-03	63	4846e-03	77	9420e-04	91	6234e-05	105	0
8	8369e-02	22	7838e-02	36	2112e 02	50	1229e 02	64	4442e-03	78	8015e-04	92	5130e-05	106	0
9	8358e-02	23	6961e-02	37	.1931e-02	51	1152e-02	65	4057e-03	79	6771e-04	93	4234e-05	107	0
10	1398e-01	24	6262e-02	38	1778e-02	52	1080e 02	66	3693e-03	80	5677e-04	94	3498e 05	108	0
11	1198e-01	25	5533e-02	39	1646e-02	53	1011e-02	67	3348e-03	81	4724e-04	95	2875e-05	109	0
12	1049e-01	26	4836e-02	40	1520e-02	54	9470e-03	68	3023e-03	82	3902e-04	96	2314e-05	110	0

number of health effects in male population distributed by age (low let radiation)

age group	health effects	age group	health effects	age group	health effects	age group	health effects	age group	health effects	age group	health effects	age group	health effects	age group	health effects
-1	0	13	135e+03	27	606e+02	41	190e+02	55	106e+02	69	217e+01	83	781e-01	97	159e 03
0	120e+03	14	.121e+03	28	544e+02	42	175e+02	56	977e+01	70	185e+01	84	553e-01	98	703e-04
1	122e+03	15	104e+03	29	493e+02	43	162e+02	57	895e+01	71	156e+01	85	386e-01	99	189e 04
2	122e+03	16	875e+02	30	441e+02	44	150e+02	58	817e+01	72	130e+01	86	264e-01	100	0
3	122e+03	17	.753e+02	31	391e+02	45	139e+02	59	743e+01	73	108e+01	87	180e-01	101	0
4	122e+03	18	.661e+02	32	351e+02	46	128e+02	60	673e+01	74	880e+00	88	120e-01	102	0
5	122e+03	19	588e+02	33	318e+02	47	119e+02	61	608e+01	75	712e+00	89	798e-02	103	0
6	122e+03	20	.150e+03	34	291e+02	48	110e+02	62	546e+01	76	567e+00	90	517e-02	104	0
7	122e+03	21	128e+03	35	323e+02	49	102e+02	63	.488e+01	77	447e+00	91	337e-02	105	0
8	121e+03	22	112e+03	36	292e+02	50	157e+02	64	433e+01	78	346e+00	92	210e-02	106	0
9	121e+03	23	.990e+02	37	266e+02	51	146e+02	65	383e+01	79	265e+00	93	131e-02	107	0
10	203e+03	24	889e+02	38	244e+02	52	135e+02	66	336e+01	80	200e+00	94	805e-03	108	0
11	174e+03	25	783e+02	39	225e+02	53	125e+02	67	292e+01	81	149e+00	95	489e-03	109	0
12	152e+03	26	683e+02	40	207e+02	54	115e+02	68	253e+01	82	108e+00	96	278e-03	110	0

total number of health effects to the male population 3910e+04

TABLE C-I (cont)

cancer type leu/bone

population male

lifetime risk to individual from exposure by age

age group	lifetime risk	age group	lifetime risk	age group	lifetime risk	age group	lifetime risk	age group	lifetime risk	age group	lifetime risk	age group	lifetime risk	age group	lifetime risk
-1	0	13	4311e-03	27	5900e-03	41	3894e 03	55	6346e-03	69	3298e 03	83	1110e-03	97	2810e 04
0	9203e-03	14	4303e 03	28	5877e-03	42	3838e-03	56	6132e 03	70	3099e-03	84	1005e 03	98	2612e 04
1	9402e-03	15	4296e 03	29	5850e-03	43	3778e 03	57	5914e 03	71	2905e 03	85	9063e-04	99	2430e 04
2	9402e-03	16	4289e-03	30	5821e 03	44	3716e-03	58	5694e-03	72	2716e 03	86	8164e-04	100	2256e 04
3	9397e-03	17	4283e-03	31	5789e-03	45	3650e 03	59	5472e 03	73	2533e-03	87	7358e 04	101	2082e 04
4	9391e-03	18	4278e-03	32	5753e-03	46	3581e 03	60	5249e-03	74	2358e-03	88	6634e 04	102	1893e-04
5	9382e-03	19	4273e 03	33	5714e-03	47	3509e-03	61	5025e 03	75	2191e-03	89	5978e 04	103	1672e 04
6	9372e-03	20	5989e-03	34	5671e 03	48	3433e-03	62	4800e-03	76	2032e 03	90	5377e-04	104	1390e 04
7	9361e-03	21	5981e 03	35	4163e-03	49	3354e 03	63	4577e 03	77	1881e-03	91	4831e-04	105	1002e 04
8	9349e-03	22	5973e-03	36	4125e-03	50	7355e 03	64	4355e-03	78	1737e 03	92	4347e-04	106	4353e 05
9	9336e-03	23	5963e-03	37	4085e 03	51	7164e-03	65	4136e-03	79	1599e 03	93	3928e-04	107	0
10	4335e-03	24	5951e 03	38	4042e 03	52	6967e-03	66	3920e-03	80	1468e-03	94	3575e 04	108	0
11	4327e-03	25	5937e 03	39	3996e 03	53	6764e-03	67	3708e-03	81	1342e 03	95	3280e-04	109	0
12	4319e-03	26	5920e-03	40	3946e-03	54	6557e-03	68	3501e 03	82	1223e-03	96	3030e 04	110	0

number of health effects in male population distributed by age (low let radiation)

age group	health effects	age group	health effects	age group	health effects	age group	health effects	age group	health effects	age group	health effects	age group	health effects	age group	health effects
-1	0	13	624e+01	27	832e+01	41	528e+01	55	762e+01	69	263e+01	83	271e+00	97	253e 02
0	135e+02	14	622e+01	28	827e+01	42	518e+01	56	725e+01	70	236e+01	84	213e+00	98	157e-02
1	137e+02	15	621e+01	29	822e+01	43	508e+01	57	687e+01	71	209e+01	85	165e+00	99	972e 03
2	137e+02	16	619e+01	30	816e+01	44	497e+01	58	649e+01	72	185e+01	86	126e+00	100	677e 03
3	137e+02	17	617e+01	31	810e+01	45	485e+01	59	610e+01	73	162e+01	87	949e 01	101	416e 03
4	136e+02	18	615e+01	32	803e+01	46	473e+01	60	572e+01	74	141e+01	88	703e 01	102	189e 03
5	136e+02	19	613e+01	33	795e+01	47	460e+01	61	535e+01	75	122e+01	89	514e 01	103	167e 03
6	136e+02	20	858e+01	34	788e+01	48	447e+01	62	497e+01	76	105e+01	90	366e 01	104	139e 03
7	136e+02	21	855e+01	35	577e+01	49	433e+01	63	460e+01	77	891e+00	91	261e 01	105	0
8	136e+02	22	852e+01	36	570e+01	50	939e+01	64	425e+01	78	750e+00	92	178e 01	106	0
9	135e+02	23	848e+01	37	563e+01	51	906e+01	65	390e+01	79	627e+00	93	122e 01	107	0
10	628e+01	24	844e+01	38	555e+01	52	872e+01	66	356e+01	80	517e+00	94	822e 02	108	0
11	627e+01	25	841e+01	39	547e+01	53	835e+01	67	324e+01	81	423e+00	95	558e 02	109	0
12	625e+01	26	837e+01	40	538e+01	54	799e+01	68	293e+01	82	340e+00	96	364e 02	110	0

total number of health effects to the male population 5346e+03

TABLE C-I (cont)

calculation of cancer risks for female population

life table calculation

starting age 0

population female

cancer types other

leu/bone

age		tqx	lx	tdx	drad	dref	tlx	tx	ex
0	1	01746000	100000	1746 000	0 000	1746 000	99127	7445406	74 45
1	2	00116000	98254	113 975	0 000	113 975	98197	7346279	74 77
2	3	00077000	98140	75 568	0 000	75 568	98102	7248082	73 85
3	4	00060000	98064	60 084	1 246	58 838	98034	7149980	72 91
4	5	00050999	98004	52 472	2 491	49 982	97978	7051945	71 96
5	6	00042999	97952	44 608	2 489	42 119	97930	6953967	70 99
6	7	00038000	97907	39 693	2 488	37 204	97887	6856038	70 03
7	8	00034000	97868	35 762	2 487	33 275	97850	6758150	69 05
8	9	00031000	97832	32 814	2 486	30 327	97815	6660301	68 08
9	10	00028000	97799	29 869	2 486	27 383	97784	6562485	67 10
10	11	00026000	97769	29 163	3 744	25 419	97755	6464701	66 12
11	12	00024999	97740	29 436	5 002	24 434	97725	6366946	65 14
12	13	00026999	97711	31 381	5 000	26 381	97695	6269221	64 16
13	14	00032999	97679	37 232	4 998	32 233	97661	6171526	63 18
14	15	00039999	97642	44 052	4 996	39 056	97620	6073866	62 21
15	16	00048999	97598	52 815	4 994	47 822	97571	5976246	61 23
16	17	00057999	97545	61 565	4 991	56 575	97514	5878674	60 27
17	18	00065998	97484	69 325	4 987	64 337	97449	5781160	59 30
18	19	00068998	97414	72 198	4 984	67 214	97378	5683711	58 35
19	20	00070998	97342	74 091	4 980	69 111	97305	5586333	57 39
20	21	00071998	97268	75 007	4 976	70 031	97230	5489028	56 43
21	22	00072998	97193	75 921	4 972	70 949	97155	5391798	55 48
22	23	00074998	97117	77 804	4 968	72 836	97078	5294643	54 52
23	24	00076998	97039	79 683	4 964	74 718	96999	5197565	53 56
24	25	00078998	96959	81 556	4 960	76 596	96919	5100565	52 61
25	26	00080998	96878	83 425	4 956	78 469	96836	5003647	51 65
26	27	00082998	96794	85 289	4 952	80 337	96752	4906811	50 69
27	28	00085998	96709	86 887	3 719	83 168	96666	4810059	49 74
28	29	00089999	96622	89 447	2 488	86 959	96578	4713393	48 78
29	30	00095999	96533	95 156	2 485	92 670	96485	4616815	47 83
30	31	00101999	96438	100 107	1 741	98 366	96388	4520330	46 87
31	32	00109999	96338	106 970	999	105 971	96284	4423942	45 92
32	33	00118999	96231	115 512	998	114 514	96173	4327658	44 97
33	34	00128999	96115	124 984	997	123 988	96053.	4231485	44 03

TABLE C-I (cont)

576	34	35	00139999	95990	135 381	995	134 386	95922	4135433	43 08
577	35	36	00151998	95855	147 769	2 072	145 698	95781	4039510	42 14
578	36	37	00164998	95707	159 983	2 068	157 915	95627	3943729	41 21
579	37	38	00179998	95547	174 048	2 065	171 983	95460	3848102	40 27
580	38	39	00196998	95373	189 944	2 061	187 883	95278	3752642	39 35
581	39	40	00214998	95183	206 698	2 057	204 641	95080	3657364	38 42
582	40	41	00232995	94976	225 520	4 230	221 290	94864	3562285	37 51
583	41	42	00250994	94751	242 039	4 220	237 819	94630	3467421	36 60
584	42	43	00272994	94509	262 212	4 209	258 003	94378	3372791	35 69
585	43	44	00296993	94247	284 102	4 196	279 906	94105	3278414	34 79
586	44	45	00324993	93962	309 554	4 183	305 371	93808	3184309	33 89
587	45	46	00353986	93653	339 074	7 557	331 518	93483	3090502	33 00
588	46	47	00383985	93314	365 839	7 528	358 311	93131	2997018	32 12
589	47	48	00415983	92948	394 145	7 497	386 648	92751	2903887	31 24
590	48	49	00448982	92554	423 014	7 464	415 550	92342	2811136	30 37
591	49	50	00483980	92131	453 324	7 429	445 895	91904	2718794	29 51
592	50	51	00522968	91677	490 825	11 382	479 444	91432	2626890	28 65
593	51	52	00564965	91187	526 491	11 318	515 173	90923	2535458	27 81
594	52	53	00610962	90660	565 150	11 250	553 899	90378	2444534	26 96
595	53	54	00659959	90095	605 768	11 177	594 590	89792	2354157	26 13
596	54	55	00711956	89489	648 223	11 099	637 124	89165	2264365	25 30
597	55	56	00767931	88841	698 248	16 010	682 238	88492	2175199	24 48
598	56	57	00828925	88143	746 518	15 880	730 638	87770	2086708	23 67
599	57	58	00893919	87396	796 992	15 740	781 252	86998	1998938	22 87
600	58	59	00961913	86599	848 601	15 591	833 010	86175	1911940	22 08
601	59	60	01034907	85751	902 872	15 433	887 440	85299	1825765	21 29
602	60	61	01112867	84848	964 541	20 298	944 243	84366	1740466	20 51
603	61	62	01199857	83883	1026 537	20 058	1006 479	83370	1656100	19 74
604	62	63	01297845	82857	1095 155	19 803	1075 352	82309	1572730	18 98
605	63	64	01410831	81762	1173 048	19 530	1153 518	81175	1490421	18 23
606	64	65	01537816	80589	1258 541	19 237	1239 304	79959	1409246	17 49
607	65	66	01677754	79330	1354 211	23 249	1330 962	78653	1329287	16 76
608	66	67	01831732	77976	1451 142	22 834	1428 307	77250	1250634	16 04
609	67	68	02003707	76525	1555 719	22 390	1533 329	75747	1173384	15 33
610	68	69	02194679	74969	1667 241	21 914	1645 327	74135	1097637	14 64
611	69	70	02406649	73302	1785 517	21 403	1764 114	72409	1023502	13 96
612	70	71	02631511	71516	1908 529	26 574	1881 956	70562	951093	13 30
613	71	72	02878466	69608	2029 464	25 832	2003 632	68593	880531	12 65
614	72	73	03164414	67578	2163 495	25 043	2138 453	66496	811938	12 01
615	73	74	03502352	65415	2315 251	24 199	2291 052	64257	745442	11 40
616	74	75	03892281	63099	2479 304	23 297	2456 007	61860	681185	10 80
617	75	76	04323920	60620	2651 441	30 276	2621 165	59294	619325	10 22
618	76	77	04788807	57969	2804 891	28 883	2776 008	56566	560030	9 66
619	77	78	05293684	55164	2947 611	27 414	2920 197	53690	503464	9 13
620	78	79	05838553	52216	3074 546	25 877	3048 669	50679	449774	8 61
621	79	80	06430411	49142	3184 287	24 279	3160 009	47549	399095	8 12
622	80	81	07095253	45957	3283 417	22 628	3260 789	44316	351546	7 65
623	81	82	07832079	42674	3363 186	20 931	3342 255	40992	307230	7 20
624	82	83	08609897	39311	3403 817	19 203	3384 614	37609	266238	6 77
625	83	84	09416709	35907	3398 717	17 466	3381 250	34208	228629	6 37
626	84	85	10272512	32508	3355 151	15 742	3339 409	30831	194422	5 98
627	85	86	11278565	29153	3305 796	17 750	3288 046	27500	163591	5 61
628	86	87	12458230	25847	3235 749	15 639	3220 111	24229	136091	5 27
629	87	88	13680887	22612	3107 047	13 592	3093 455	21058	111861	4 95
630	88	89	14854562	19504	2908 953	11 650	2897 302	18050	90803	4 66
631	89	90	16001249	16596	2665 340	9 851	2655 488	15263	72753	4 38
632	90	91	17258911	13930	2412 408	8 213	2404 195	12724	57491	4 13
633	91	92	18712526	11518	2162 000	6 736	2155 264	10437	44767	3 89
634	92	93	20237130	9356	1898 763	5 426	1893 337	8406	34330	3 67
635	93	94	21743746	7457	1625 719	4 288	1621 430	6644	25923	3 48
636	94	95	23179387	5831	1354 981	3 327	1351 654	5154	19279	3 31
637	95	96	24577043	4476	1102 675	2 533	1100 141	3925	14126	3 16
638	96	97	25846737	3374	873 867	1 895	871 971	2937	10201	3 02
639	97	98	26972470	2500	675 641	1 395	674 246	2162	7264	2 91

TABLE C-I (cont)

640	98	99	27988232	1824	511 550	1 012	510 537	1568	5102	2 80
641	99	100	28941012	1313	380 594	724	379 869	1122	3534	2 69
642	100	101	29827810	932	278 498	512	277 986	793	2411	2 59
643	101	102	30650625	653	200 650	357	200 293	553	1619	2 48
644	102	103	31411455	453	142 484	246	142 238	382	1065	2 35
645	103	104	32113301	310	99 828	168	99 660	260	684	2 20
646	104	105	32759160	211	69 075	114	68 961	176	423	2 01
647	105	106	33352032	141	47 248	076	47 171	118	248	1 75
648	106	107	33894916	94	31 975	050	31 925	78	130	1 38
649	107	108	34391810	62	21 429	033	21 396	51	51	83
650	108	109	34845714	41	14 233	022	14 211	34	0	0 00
651	109	110	35259627	27	9 376	014	9 362	22	22	0 00

TABLE C-I (cont)

life table calculation

starting age 10

population female

cancer types other

leu/bone

age		tqx	lx	tdx	drad	dref	tlx	tx	ex
10	11	00026000	100000	26 000	0 000	26 000	99987	6605273	66 05
11	12	00025000	99974	24 994	0 000	24 994	99962	6505286	65 07
12	13	00027000	99949	26 986	0 000	26 986	99936	6405324	64 09
13	14	00033000	99322	33 570	595	32 974	99905	6305389	63 10
14	15	00040000	99888	41 146	1 190	39 955	99868	6205484	62 12
15	16	00049000	99847	50 115	1 190	48 925	99822	6105616	61 15
16	17	00058000	99797	59 071	1 189	57 882	99768	6005793	60 18
17	18	00066000	99738	67 015	1 188	65 827	99705	5906026	59 22
18	19	00069000	99671	69 960	1 188	68 773	99636	5806321	58 25
19	20	00071000	99601	71 903	1 187	70 716	99565	5706685	57 30
20	21	00071999	99529	73 819	2 158	71 660	99492	5607120	56 34
21	22	00072999	99455	75 730	3 129	72 601	99418	5507627	55 38
22	23	00074999	99380	77 660	3 126	74 534	99341	5408210	54 42
23	24	00076999	99302	79 585	3 124	76 461	99262	5308869	53 46
24	25	00078999	99222	81 506	3 121	78 384	99182	5209607	52 50
25	26	00080999	99141	83 422	3 119	80 303	99099	5110425	51 55
26	27	00082999	99058	85 332	3 116	82 216	99015	5011326	50 59
27	28	00085999	98972	88 228	3 113	85 115	98928	4912311	49 63
28	29	00089999	98884	92 105	3 110	88 994	98838	4813383	48 68
29	30	00095998	98792	97 946	3 107	94 839	98743	4714545	47 72
30	31	00101998	98694	103 770	3 104	100 666	98642	4615802	46 77
31	32	00109998	98590	111 548	3 101	108 447	98534	4517160	45 82
32	33	00118998	98479	120 285	3 097	117 188	98418	4418626	44 87
33	34	00128998	98358	129 974	3 093	126 880	98293	4320207	43 92
34	35	00139998	98228	140 607	3 089	137 518	98158	4221914	42 98
35	36	00151998	98088	152 175	3 084	149 091	98012	4123756	42 04
36	37	00164997	97936	164 671	3 079	161 591	97853	4025744	41 11
37	38	00179998	97771	178 477	2 492	175 985	97682	3927891	40 17
38	39	00196998	97592	194 161	1 906	192 255	97495	3830210	39 25
39	40	00214998	97398	211 306	1 902	209 404	97293	3732714	38 32
40	41	00232994	97187	231 228	4 788	226 440	97071	3635422	37 41
41	42	00250990	96956	251 008	7 659	243 349	96830	3538350	36 49
42	43	.00272989	96705	271 632	7 638	263 993	96569	3441520	35 59
43	44	00296988	96433	294 011	7 616	286 395	96286	3344951	34 69
44	45	00324987	96139	320 031	7 592	312 440	95979	3248665	33 79
45	46	00353975	95819	352 888	13 713	339 175	95643	3152686	32 90
46	47	00383973	95466	380 224	13 660	366 564	95276	3057044	32 02
47	48	00415970	95086	409 133	13 604	395 529	94881	2961767	31 15
48	49	00448968	94677	438 611	13 543	425 068	94457	2866886	30 28
49	50	00483965	94238	469.558	13 478	456 080	94003	2772429	29 42
50	51	00522942	93769	511 003	20 647	490 356	93513	2678425	28 56
51	52	00564938	93258	547 378	20 531	526 847	92984	2584912	27 72
52	53	00610933	92710	586 803	20 405	566 397	92417	2491928	26 88
53	54	00659927	92123	628 219	20 271	607 948	91809	2399511	26 05
54	55	00711922	91495	671 502	20 128	651 374	91159	2307702	25 22
55	56	00767877	90824	726 445	29 030	697 415	90460	2216543	24 40

TABLE C-I (cont)

715	56	57	00828868	90097	775 576	28 789	746 787	89709	2126082	23 60
716	57	58	00893857	89322	826 940	28 532	798 408	88908	2036373	22 80
717	58	59	00961846	88495	879 442	28 258	851 184	88055	1947465	22 01
718	59	60	01034835	87615	934 641	27 967	906 674	87148	1859409	21 22
719	60	61	01112764	86681	1001 328	36 777	964 551	86180	1772261	20 45
720	61	62	01199746	85679	1064 270	36 336	1027 934	85147	1686082	19 68
721	62	63	01297725	84615	1133 938	35 867	1098 071	84048	1600934	18 92
722	63	64	01410701	83481	1213 035	35 366	1177 669	82875	1516886	18 17
723	64	65	01537674	82268	1299 846	34 830	1265 015	81618	1434012	17 43
724	65	66	01677564	80968	1400 379	42 085	1358 294	80268	1352393	16 70
725	66	67	01831524	79568	1498 630	41 325	1457 305	78819	1272125	15 99
726	67	68	02003480	78069	1604 613	40 511	1564 102	77267	1193307	15 29
727	68	69	02194431	76465	1717 604	39 640	1677 963	75606	1116040	14 60
728	69	70	02406377	74747	1837 403	38 708	1798 695	73828	1040434	13 92
729	70	71	02631133	72910	1966 396	48 047	1918 349	71926	966606	13 26
730	71	72	02878053	70943	2088 476	46 692	2041 783	69899	894679	12 61
731	72	73	03163960	68855	2223 789	45 252	2178 537	67743	824780	11 98
732	73	74	03501851	66631	2377 032	43 715	2333 317	65442	757038	11 36
733	74	75	03891725	64254	2542 659	42 072	2500 586	62983	691595	10 76
734	75	76	04323085	61711	2722 488	54 658	2667 830	60350	628612	10 19
735	76	77	04787884	58989	2876 436	52 122	2824 314	57551	568262	9 63
736	77	78	05292667	56112	3019 292	49 452	2969 839	54603	510712	9 10
737	78	79	05837434	53093	3145 932	46 660	3099 272	51520	456109	8 59
738	79	80	06429182	49947	3254 953	43 762	3211 191	48320	404589	8 10
739	80	81	07093902	46692	3353 066	40 770	3312 296	45016	356269	7 63
740	81	82	07830593	43339	3431 406	37 697	3393 708	41623	311254	7 18
741	82	83	08608270	39908	3469 934	34 572	3435 362	38173	269630	6 76
742	83	84	09414937	36438	3462 025	31 433	3430 592	34707	231458	6 35
743	84	85	10270588	32976	3415 121	28 319	3386 802	31268	196751	5 97
744	85	86	11275909	29561	3365 145	31 917	3333 228	27878	165483	5 60
745	86	87	12455314	26195	3290 834	28 107	3262 728	24550	137605	5 25
746	87	88	13677706	22905	3157 244	24 415	3132 829	21326	113055	4 94
747	88	89	14851130	19747	2953 628	20 917	2932 711	18271	91729	4 65
748	89	90	15997575	16794	2704 273	17 679	2686 595	15442	73458	4 37
749	90	91	17254975	14089	2445 868	14 730	2431 138	12867	58017	4 12
750	91	92	18708293	11644	2190 399	12 077	2178 323	10548	45150	3 88
751	92	93	20232590	9453	1922 354	9 722	1912 632	8492	34602	3 66
752	93	94	21738909	7531	1644 809	7 680	1637 128	6708	26109	3 47
753	94	95	23174272	5886	1370 006	5 955	1364 051	5201	19401	3 30
754	95	96	24571663	4516	1114 202	4 532	1109 669	3959	14200	3 14
755	96	97	25841120	3402	882 466	3 390	879 076	2961	10241	3 01
756	97	98	26966646	2519	681 888	2 494	679 394	2178	7280	2 89
757	98	99	27982224	1837	515 981	1 808	514 173	1580	5102	2 80
758	99	100	28934834	1322	383 672	1 293	382 379	1130	3534	2 69
759	100	101	29821476	938	280 592	913	279 679	798	2411	2 59
760	101	102	30644147	657	202 046	637	201 409	556	1619	2 48
761	102	103	31404847	455	143 396	439	142 957	384	1065	2 35
762	103	104	32106573	312	100 411	300	100 112	262	684	2 20
763	104	105	32752323	211	69 440	202	69 238	177	423	2 01
764	105	106	33345096	142	47 472	135	47 336	118	248	1 75
765	106	107	33887890	94	32 109	090	32 020	78	130	1 38
766	107	108	34384703	62	21 507	059	21 448	52	51	83
767	108	109	34838533	41	14 277	039	14 239	34	0	0 00
768	109	110	35252379	27	9 400	025	9 375	22	22	0 00

TABLE C-I (cont)

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cancer type other

population female

lifetime risk to individual from exposure by age

age group	lifetime risk	age group	lifetime risk	age group	lifetime risk	age group	lifetime risk	age group	lifetime risk	age group	lifetime risk	age group	lifetime risk	age group	lifetime risk
-1	0	13	1017e-01	27	5934e-02	41	.2611e-02	55	1820e-02	69	6097e-03	83	7519e-04	97	3872e-05
0	9323e-02	14	9068e-02	28	5436e-02	42	2451e-02	56	1704e-02	70	5485e-03	84	6143e-04	98	2526e-05
1	9478e-02	15	7873e-02	29	5015e-02	43	2306e-02	57	1594e-02	71	4905e-03	85	4995e-04	99	9913e-06
2	9478e-02	16	6734e-02	30	4612e-02	44	2174e-02	58	1491e-02	72	4360e-03	86	4052e-04	100	0
3	9475e-02	17	5883e-02	31	4231e-02	45	2038e-02	59	1393e-02	73	3851e-03	87	3288e-04	101	0
4	9470e-02	18	5224e-02	32	3906e-02	46	1899e-02	60	1300e-02	74	3379e-03	88	2672e-04	102	0
5	9459e-02	19	4698e-02	33	3626e-02	47	1775e-02	61	1211e-02	75	2945e-03	89	2174e-04	103	0
6	9442e 02	20	1232e-01	34	3383e-02	48	1663e 02	62	1125e-02	76	2548e-03	90	1771e-04	104	0
7	9424e-02	21	1086e 01	35	3856e-02	49	1561e-02	63	1042e-02	77	2189e-03	91	1446e-04	105	0
8	9406e-02	22	9715e-02	36	3594e-02	50	2444e-02	64	9626e-03	78	1867e-03	92	1185e 04	106	0
9	9387e-02	23	8786e-02	37	3363e-02	51	2305e-02	65	8861e-03	79	1580e-03	93	9734e-05	107	0
10	1602e-01	24	8019e-02	38	3157e-02	52	2175e-02	66	8125e 03	80	1327e-03	94	7989e-05	108	0
11	1344e-01	25	7256e-02	39	2973e-02	53	2053e-02	67	7419e-03	81	1106e-03	95	6497e-05	109	0
12	1158e-01	26	6529e-02	40	2790e-02	54	1937e-02	68	6742e-03	82	9148e-04	96	5159e-05	110	0

number of health effects in female population distributed by age (low let radiation)

age group	health effects	age group	health effects	age group	health effects	age group	health effects	age group	health effects	age group	health effects	age group	health effects	age group	health effects
-1	0	13	133e+03	27	769e+02	41	331e+02	55	216e+02	69	595e+01	83	349e+00	97	116e-02
0	123e+03	14	119e+03	28	704e+02	42	310e+02	56	201e+02	70	522e+01	84	257e+00	98	530e-03
1	125e+03	15	103e+03	29	649e+02	43	291e+02	57	186e+02	71	454e+01	85	186e+00	99	149e-03
2	125e+03	16	880e+02	30	596e+02	44	274e+02	58	173e+02	72	391e+01	86	133e+00	100	0
3	124e+03	17	768e+02	31	546e+02	45	256e+02	59	160e+02	73	334e+01	87	940e-01	101	0
4	124e+03	18	682e+02	32	504e+02	46	237e+02	60	147e+02	74	282e+01	88	657e-01	102	0
5	124e+03	19	613e+02	33	467e+02	47	221e+02	61	136e+02	75	236e+01	89	452e-01	103	0
6	124e+03	20	161e+03	34	435e+02	48	206e+02	62	125e+02	76	195e+01	90	306e-01	104	0
7	124e+03	21	142e+03	35	495e+02	49	193e+02	63	114e+02	77	159e+01	91	205e-01	105	0
8	123e+03	22	126e+03	36	461e+02	50	300e+02	64	104e+02	78	.128e+01	92	136e-01	106	0
9	123e+03	23	114e+03	37	430e+02	51	281e+02	65	938e+01	79	102e+01	93	886e 02	107	0
10	210e+03	24	104e+03	38	404e+02	52	264e+02	66	845e+01	80	796e+00	94	559e 02	108	0
11	176e+03	25	943e+02	39	379e+02	53	248e+02	67	757e+01	81	614e+00	95	351e-02	109	0
12	152e+03	26	847e+02	40	355e+02	54	232e+02	68	674e+01	82	467e+00	96	206e-02	110	0

total number of health effects to the female population 4560e+04

TABLE C-I (cont)

cancer type leu/bone

population female

lifetime risk to individual from exposure by age

age group	lifetime risk	age group	lifetime risk	age group	lifetime risk	age group	lifetime risk	age group	lifetime risk	age group	lifetime risk	age group	lifetime risk	age group	lifetime risk
-1	0	13	2826e-03	27	3880e-03	41	2714e-03	55	5051e-03	69	2912e-03	83	9576e-04	97	2295e-04
0	5946e-03	14	2824e-03	28	3871e-03	42	2695e-03	56	4936e-03	70	2741e-03	84	8647e-04	98	2122e 04
1	6049e 03	15	2822e-03	29	3860e-03	43	2674e 03	57	4813e-03	71	2573e-03	85	7782e-04	99	1963e-04
2	6052e-03	16	2819e-03	30	3849e-03	44	2652e-03	58	4683e-03	72	2407e-03	86	6990e-04	100	1810e 04
3	6053e-03	17	2817e-03	31	3837e-03	45	2628e-03	59	4546e-03	73	2245e-03	87	6275e-04	101	1657e-04
4	6053e-03	18	2815e-03	32	3824e-03	46	2602e-03	60	4402e 03	74	2089e-03	88	5628e-04	102	1493e 04
5	6053e-03	19	2812e-03	33	3810e-03	47	2575e 03	61	4252e-03	75	1938e-03	89	5040e 04	103	1304e-04
6	6051e-03	20	3925e-03	34	3795e-03	48	2545e-03	62	4095e-03	76	1793e-03	90	4507e-04	104	1069e-04
7	6049e-03	21	3920e-03	35	2806e-03	49	2513e-03	63	3934e-03	77	1654e-03	91	4032e-04	105	7571e-05
8	6046e-03	22	3915e-03	36	2793e-03	50	5528e 03	64	3768e-03	78	1521e-03	92	3619e-04	106	3211e-05
9	6043e-03	23	3910e-03	37	2780e-03	51	5446e-03	65	3600e-03	79	1395e-03	93	3265e-04	107	0
10	2833e-03	24	3903e-03	38	2765e-03	52	5357e-03	66	3429e-03	80	1276e-03	94	2964e-04	108	0
11	2831e-03	25	3896e-03	39	2749e-03	53	5262e-03	67	3257e-03	81	1163e-03	95	2707e-04	109	0
12	2829e-03	26	3888e-03	40	2732e-03	54	5160e-03	68	3084e 03	82	1057e-03	96	2487e-04	110	0

number of health effects in female population distributed by age (low let radiation)

age group	health effects	age group	health effects	age group	health effects	age group	health effects	age group	health effects	age group	health effects	age group	health effects	age group	health effects
-1	0	13	370e+01	27	503e+01	41	344e+01	55	601e+01	69	.284e+01	83	444e+00	97	688e-02
0	785e+01	14	369e+01	28	501e+01	42	341e+01	56	582e+01	70	261e+01	84	361e+00	98	446e-02
1	796e+01	15	369e+01	29	500e+01	43	338e+01	57	563e+01	71	238e+01	85	290e+00	99	294e 02
2	795e+01	16.	369e+01	30	498e+01	44	334e+01	58	542e+01	72	216e+01	86	230e+00	100	199e-02
3	795e+01	17	.368e+01	31	495e+01	45	330e+01	59	521e+01	73	195e+01	87	179e+00	101	133e-02
4	795e+01	18	.367e+01	32	493e+01	46	325e+01	60	499e+01	74	174e+01	88	138e+00	102	746e-03
5	794e+01	19	367e+01	33	491e+01	47	321e+01	61	477e+01	75	155e+01	89	105e+00	103	521e-03
6	793e+01	20	512e+01	34	488e+01	48	315e+01	62	453e+01	76	137e+01	90	780e-01	104	214e-03
7	793e+01	21	511e+01	35	361e+01	49	310e+01	63	430e+01	77	120e+01	91	573e-01	105	151e-03
8	792e+01	22	509e+01	36	358e+01	50	678e+01	64	405e+01	78	104e+01	92	416e-01	106	321e-04
9	792e+01	23	508e+01	37	356e+01	51	665e+01	65	381e+01	79	899e+00	93	297e-01	107	0
10	371e+01	24	507e+01	38	353e+01	52	650e+01	66	357e+01	80	766e+00	94	207e-01	108	0
11	371e+01	25	506e+01	39	351e+01	53	635e+01	67	332e+01	81	645e+00	95	146e-01	109	0
12	370e+01	26	504e+01	40	348e+01	54	618e+01	68	308e+01	82	539e+00	96	995e-02	110	0

total number of health effects to the female population 3630e+03

TABLE C-II

INPUT FILE FOR THE SECOND SAMPLE PROBLEM: CALCULATION OF THE TOTAL NUMBER OF CANCER DEATHS INDUCED BY CONTINUOUS EXPOSURE OF 1 Rad/Year OF LOW-LET RADIATION

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 calculation of total cancer risk for 1 rad/year using absolute risk
1100
1100
0.000000000  .022450000  .001330000  .000940000  .000780000
  .000640000  .000580000  .000540000  .000510000  .000460000
  .000410000  .000360000  .000350000  .000420000  .000590000
  .000840000  .001140000  .001420000  .001670000  .001850000
  .001980000  .002120000  .002260000  .002350000  .002350000
  .002280000  .002170000  .002060000  .001990000  .001980000
  .002030000  .002100000  .002180000  .002280000  .002390000
  .002520000  .002680000  .002880000  .003120000  .003390000
  .003690000  .004010000  .004350000  .004730000  .005180000
  .005680000  .006230000  .006810000  .007440000  .008120000
  .008870000  .009690000  .010590000  .011610000  .012750000
  .014000000  .015340000  .016760000  .018270000  .019870000
  .021580000  .023390000  .025320000  .027380000  .029600000
  .032000000  .034630000  .037460000  .040440000  .043500000
  .046650000  .049910000  .053440000  .057400000  .061930000
  .067030000  .072640000  .078560000  .084620000  .090700000
  .096880000  .103670000  .111250000  .119290000  .127700000
  .136630000  .147300000  .159790000  .172810000  .185210000
  .196810000  .208390000  .221220000  .235120000  .250230000
  .265460000  .279620000  .290900000  .301350000  .311110000
  .320170000  .328570000  .336330000  .343470000  .350040000
  .356060000  .361570000  .366610000  .371210000  .375400000
  .379220000 0.000000000 0.000000000 0.000000000 0.000000000
0.000000000 0.000000000 0.000000000 0.000000000 0.000000000
0.000000000  .017460000  .001160000  .000770000  .000600000
  .000510000  .000430000  .000380000  .000340000  .000310000
  .000280000  .000260000  .000250000  .000270000  .000330000
  .000400000  .000490000  .000580000  .000660000  .000690000
  .000710000  .000720000  .000730000  .000750000  .000770000
  .000790000  .000810000  .000830000  .000860000  .000900000
  .000960000  .001020000  .001100000  .001190000  .001290000
  .001400000  .001520000  .001650000  .001800000  .001970000
  .002150000  .002330000  .002510000  .002730000  .002970000
  .003250000  .003540000  .003840000  .004160000  .004490000
  .004840000  .005230000  .005650000  .006110000  .006600000
  .007120000  .007680000  .008290000  .008940000  .009620000
  .010350000  .011130000  .012000000  .012980000  .014110000
  .015380000  .016780000  .018320000  .020040000  .021950000
  .024070000  .026320000  .028790000  .031650000  .035030000
  .038930000  .043250000  .047900000  .052950000  .058400000
  .064320000  .070970000  .078340000  .086120000  .094190000
  .102750000  .112820000  .124620000  .136850000  .148590000
  .160060000  .172640000  .187180000  .202430000  .217500000
  .231860000  .245840000  .258540000  .269800000  .279960000
  .289490000  .298360000  .306590000  .314200000  .321220000
  .327680000  .333610000  .339040000  .344010000  .348550000
  .352690000 0.000000000 0.000000000 0.000000000 0.000000000
0.000000000 0.000000000 0.000000000 0.000000000 0.000000000
   0.00000     .01463     .01457     .01455     .01454     .01453
    .01452     .01451     .01451     .01450     .01449     .01449
    .01448     .01448     .01447     .01446     .01445     .01443
    .01440     .01438     .01435     .01432     .01429     .01426
    .01422     .01419     .01416     .01413     .01410     .01407
    .01405     .01402     .01399     .01396     .01392     .01389
    .01385     .01381     .01377     .01373     .01368     .01363
    .01357     .01351     .01344     .01337     .01329     .01320
    .01311     .01301     .01290     .01277     .01265     .01251
    .01235     .01218     .01201     .01182     .01161     .01139
    .01115     .01090     .01064     .01036     .01006     .00975
    .00943     .00909     .00873     .00838     .00799     .00760
    .00721     .00681     .00641     .00599     .00558     .00516
```

TABLE C-II (cont)

65	.00474	.00432	.00392	.00352	.00315	.00278
66	.00244	.00212	.00182	.00154	.00129	.00106
67	.00086	.00068	.00054	.00041	.00031	.00023
68	.00017	.00012	.00009	.00006	.00004	.00003
69	.00002	.00001	.00001	.00001	.00000	.00000
70	.00000	.00000	.00000	0.00000	0.00000	0.00000
71	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
72	0.00000	.01320	.01316	.01314	.01313	.01313
73	.01312	.01311	.01311	.01310	.01310	.01310
74	.01309	.01309	.01309	.01308	.01308	.01307
75	.01306	.01305	.01304	.01304	.01303	.01301
76	.01300	.01299	.01299	.01297	.01296	.01295
77	.01294	.01293	.01291	.01290	.01288	.01287
78	.01285	.01283	.01280	.01278	.01275	.01273
79	.01269	.01266	.01263	.01259	.01254	.01250
80	.01245	.01239	.01234	.01227	.01221	.01214
81	.01206	.01197	.01189	.01179	.01169	.01158
82	.01147	.01134	.01121	.01107	.01092	.01076
83	.01059	.01040	.01020	.00999	.00976	.00951
84	.00925	.00897	.00867	.00835	.00800	.00764
85	.00726	.00686	.00644	.00600	.00555	.00510
86	.00464	.00418	.00373	.00329	.00286	.00246
87	.00208	.00173	.00142	.00115	.00091	.00070
88	.00054	.00040	.00030	.00021	.00015	.00011
89	.00008	.00005	.00004	.00002	.00002	.00001
90	.00001	.00001	.00000	0.00000	0.00000	0.00000
91	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
92	1000000.	1000000.				
93	2					
94	22 1	1 30				
95	1					
96	110.0	1.0				
97	23 1	1 30				
98	1					
99	110.0	1.0				
100	2					
101	0 10					

TABLE C-III

OUTPUT FILE FOR THE SECOND SAMPLE PROBLEM

```
calculation of total cancer risk for 1 rad/year using absolute

   proportion dying in each age interval

   male
   0 000000000  022450000  001330000  000940000  000780000  000640000  000580000  000540000  000510000  000460000
     000410000  000360000  000350000  000420000  000590000  000840000  001140000  001420000  001670000  001850000
     001980000  002120000  002260000  002350000  002350000  002280000  002170000  002060000  001990000  001980000
     002030000  002100000  002180000  002280000  002390000  002520000  002680000  002880000  003120000  003390000
     003690000  004010000  004350000  004730000  005180000  005680000  006230000  006810000  007440000  008120000
     008870000  009690000  010590000  011610000  012750000  014000000  015340000  016760000  018270000  019870000
     021580000  023390000  025320000  027380000  029600000  032000000  034630000  037460000  040440000  043500000
     046650000  049910000  053440000  057400000  061930000  067030000  072640000  078560000  084620000  090700000
     096880000  103670000  111250000  119290000  127700000  136630000  147300000  159790000  172810000  185210000
     196810000  208390000  221220000  235120000  250230000  265460000  279620000  290900000  301350000  311110000
     320170000  328570000  336330000  343470000  350040000  356060000  361570000  366610000  371210000  375400000
     3792200000 0000000000 0000000000 0000000000 0000000000 0000000000 0000000000 0000000000 0000000000 000000000


   female
   0 000000000  017460000  001160000  000770000  000600000  000510000  000430000  000380000  000340000  000310000
     000280000  000260000  000250000  000270000  000330000  000400000  000490000  000580000  000660000  000690000
     000710000  000720000  000730000  000750000  000770000  000790000  000810000  000830000  000860000  000900000
     000960000  001020000  001100000  001190000  001290000  001400000  001520000  001650000  001800000  001970000
     002150000  002330000  002510000  002730000  002970000  003250000  003540000  003840000  004160000  004490000
     004840000  005230000  005650000  006110000  006600000  007120000  007680000  008290000  008940000  009620000
     010350000  011130000  012000000  012980000  014110000  015380000  016780000  018320000  020040000  021950000
     024070000  026320000  028790000  031650000  035030000  038930000  043250000  047900000  052950000  058400000
     064320000  070970000  078340000  086120000  094190000  102750000  112820000  124620000  136850000  148590000
     160060000  172640000  187180000  202430000  217500000  231860000  245840000  258540000  269800000  279960000
     289490000  298360000  306590000  314200000  321220000  327680000  333610000  339040000  344010000  348550000
     3526900000 0000000000 0000000000 0000000000 0000000000 0000000000 0000000000 0000000000 0000000000 000000000



   age distribution by sex

   male
       0 00000      01463      01457      01455      01454      01453      01452      01451      01451      01450
         01449      01449      01448      01448      01447      01446      01445      01443      01440      01438
         01435      01432      01429      01426      01422      01419      01416      01413      01410      01407
         01405      01402      01399      01396      01392      01389      01385      01381      01377      01373
         01368      01363      01357      01351      01344      01337      01329      01320      01311      01301
         01290      01277      01265      01251      01235      01218      01201      01182      01161      01139
         01115      01090      01064      01036      01006      00975      00943      00909      00873      00838
         00799      00760      00721      00681      00641      00599      00558      00516      00474      00432
         00392      00352      00315      00278      00244      00212      00182      00154      00129      00106
         00086      00068      00054      00041      00031      00023      00017      00012      00009      00006
         00004      00003      00002      00001      00001      00001    0 00000    0 00000    0 00000    0 00000
       0 00000    0 00000    0 00000    0 00000    0 00000    0 00000    0 00000    0 00000    0 00000    0 00000


   female
       0 00000      01320      01316      01314      01313      01313      01312      01311      01311      01310
         01310      01310      01309      01309      01309      01308      01308      01307      01306      01305
         01304      01304      01303      01301      01300      01299      01299      01297      01296      01295
         01294      01293      01291      01290      01288      01287      01285      01283      01280      01278
         01275      01273      01269      01266      01263      01259      01254      01250      01245      01239
         01234      01227      01221      01214      01206      01197      01189      01179      01169      01158
         01147      01134      01121      01107      01092      01076      01059      01040      01020      00999
         00976      00951      00925      00897      00867      00835      00800      00764      00726      00686
         00644      00600      00555      00510      00464      00418      00373      00329      00286      00246
         00208      00173      00142      00115      00091      00070      00054      00040      00030      00021
         00015      00011      00008      00005      00004      00002      00002      00001      00001      00001
```

TABLE C-III (cont)

```
     0.00000    0.00000    0.00000    0.00000    0.00000    0.00000    0.00000    0.00000    0.00000    0.00000


          population totals used to normalize age distribution tables
                                   males                1.00
                                   females              1.00


-----------------------------------------------------------------------------------------------------------------------




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 health effects calculated for...

          number of target organs                2


           1.) let                              low
               cancer type                      other
               risk model                       absolute

               dose by time interval:
                                                 1.00000 rads for 110.0 years

           2.) let                              low
               cancer type                      leu/bone
               risk model                       absolute

               dose by time interval:
                                                 1.00000 rads for 110.0 years

 summary of population characteristics...


          number of persons in population:
                                   males        1000000.
                                   females      1000000.
          population table·             supplied by:
                         life table             user
                         age distribution       user
```

TABLE C-III (cont)

---

calculation of cancer risks for male population

---

life table calculation

starting age 0

population male

cancer types other

leu/bone

age		tqx	lx	tdx	drad	dref	tlx	tx	ex
0	1	02245000	100000	2245 000	0 000	2245 000	98878	6683193	66 83
1	2	00133000	97755	130 014	0 000	130 014	97690	6584315	67 36
2	3	00094000	97625	91 767	0 000	91 767	97579	6486625	66 44
3	4	00078000	97533	76 270	194	76 076	97495	6389046	65 51
4	5	00064000	97457	62 953	581	62 372	97425	6291551	64 56
5	6	00058000	97394	57 456	968	56 488	97365	6194125	63 60
6	7	00054000	97337	53 916	1 355	52 561	97310	6096760	62 64
7	8	00051000	97283	51 354	1 741	49 614	97257	5999451	61 67
8	9	00045999	97231	46 852	2 126	44 726	97208	5902194	60 70
9	10	00040999	97184	42 357	2 512	39 845	97163	5804986	59 73
10	11	00035999	97142	37 961	2 990	34 971	97123	5707823	58 76
11	12	00034999	97104	37 547	3 562	33 986	97085	5610699	57 78
12	13	00041999	97067	44 899	4 132	40 767	97044	5513614	56 80
13	14	00058999	97022	61 840	4 599	57 241	96991	5416570	55 83
14	15	00083998	96960	86 405	4 961	81 444	96917	5319579	54 86
15	16	00113997	96873	115 753	5 320	110 433	96816	5222663	53 91
16	17	00141996	96758	143 069	5 678	137 392	96686	5125847	52 98
17	18	00166995	96515	167 374	6 032	161 341	96531	5029161	52 05
18	19	00184994	96447	184 806	6 384	178 421	96355	4932630	51 14
19	20	00197993	96262	197 327	6 734	190 593	96164	4836275	50 24
20	21	00211992	96065	210 710	7 059	203 650	95960	4740112	49 34
21	22	00225991	95854	223 982	7 360	216 623	95742	4644152	48 45
22	23	00234991	95630	232 381	7 658	224 722	95514	4548410	47 56
23	24	00234990	95398	232 166	7 990	224 176	95282	4452895	46 68
24	25	00227990	95166	225 325	8 356	216 969	95053	4357613	45 79
25	26	00216990	94941	214 733	8 721	206 011	94833	4262560	44 90
26	27	00205990	94726	204 211	9 085	195 126	94624	4167727	44 00
27	28	00198990	94522	197 350	9 261	188 089	94423	4073103	43 09
28	29	00197990	94324	196 002	9 249	186 753	94226	3978681	42 18
29	30	00202990	94128	200 308	9 237	191 071	94028	3884454	41 27
30	31	00209990	93928	206 597	9 358	197 239	93825	3790426	40 35
31	32	00217989	93721	213 915	9 613	204 302	93614	3696602	39 44
32	33	00227988	93507	223 052	9 866	213 186	93396	3602987	38 53
33	34	00238987	93284	233 054	10 116	222 938	93168	3509591	37 62

TABLE C-III (cont)

171	34	35	00251986	93051	244 840	10 364	234 476	92929	3416424	36 72
172	35	36	00267985	92806	259 316	10 609	248 707	92677	3323495	35 81
173	36	37	00287983	92547	277 371	10 851	266 520	92408	3230818	34 91
174	37	38	00311981	92270	299 050	11 186	287 864	92120	3138409	34 01
175	38	39	00338979	91971	323 344	11 583	311 761	91809	3046289	33 12
176	39	40	00368976	91647	350 100	11 943	338 157	91472	2954480	32 24
177	40	41	00400973	91297	378 374	12 296	366 077	91108	2863008	31 36
178	41	42	00434970	90919	408 112	12 642	395 470	90715	2771900	30 49
179	42	43	00472966	90511	441 066	12 980	428 085	90290	2681185	29 62
180	43	44	00517962	90070	479 836	13 309	466 527	89830	2590895	28 77
181	44	45	00567957	89590	522 460	13 628	508 832	89329	2501065	27 92
182	45	46	00622951	89067	568 825	13 978	554 847	88783	2411736	27 08
183	46	47	00680945	88499	616 984	14 358	602 627	88190	2322953	26 25
184	47	48	00743938	87882	668 475	14 690	653 785	87547	2234763	25 43
185	48	49	00811930	87213	723 084	14 974	708 110	86852	2147216	24 62
186	49	50	00886922	86490	782 341	15 242	767 099	86099	2060364	23 82
187	50	51	00968912	85708	845 924	15 491	830 433	85285	1974265	23 03
188	51	52	01058902	84862	914 324	15 721	898 603	84405	1888980	22 26
189	52	53	01160890	83947	990 467	15 929	974 538	83452	1804576	21 50
190	53	54	01274875	82957	1073 810	16 211	1057 598	82420	1721124	20 75
191	54	55	01399858	81883	1162 810	16 561	1146 249	81302	1638703	20 01
192	55	56	01533840	80720	1254 998	16 877	1238 121	80093	1557402	19 29
193	56	57	01675819	79465	1348 851	17 155	1331 696	78791	1477309	18 59
194	57	58	01826797	78117	1444 424	17 394	1427 030	77394	1398518	17 90
195	58	59	01986772	76672	1540 891	17 591	1523 300	75902	1321124	17 23
196	59	60	02157745	75131	1638 884	17 744	1621 140	74312	124522	16 57
197	60	61	02338714	73492	1736 753	17 978	1718 775	72624	1170910	15 93
198	61	62	02531677	71756	1834 902	18 282	1816 620	70838	1098286	15 31
199	62	63	02737637	69921	1932 719	18 545	1914 174	68954	1027448	14 69
200	63	64	02959592	67988	2030 928	18 762	2012 166	66972	958494	14 10
201	64	65	03199541	65957	2129 229	18 907	2110 322	64892	891521	13 52
202	65	66	03462485	63828	2229 003	18 975	2210 028	62713	826629	12 95
203	66	67	03745423	61599	2326 099	18 963	2307 136	60436	763915	12 40
204	67	68	04043356	59273	2415 476	18 870	2396 606	58065	703480	11 87
205	68	69	04349285	56857	2491 578	18 696	2472 883	55611	645415	11 35
206	69	70	04664209	54366	2554 170	18 442	2535 727	53089	589803	10 85
207	70	71	04990128	51811	2603 571	18 112	2585 459	50510	536715	10 36
208	71	72	05343038	49208	2646 905	17 708	2629 197	47884	486205	9 88
209	72	73	05738938	46561	2689 335	17 228	2672 107	45216	438321	9 41
210	73	74	06191823	43872	2733 127	16 671	2716 456	42505	393104	8 96
211	74	75	06701694	41139	2773 015	16 037	2756 979	39752	350599	8 52
212	75	76	07262549	38366	2801 641	15 326	2786 315	36965	310847	8 10
213	76	77	07854393	35564	2807 873	14 546	2793 327	34160	273882	7 70
214	77	78	08460234	32756	2784 904	13 669	2771 235	31364	239723	7 32
215	78	79	09068075	29971	2730 522	12 719	2717 802	28606	208359	6 95
216	79	80	09685910	27241	2650 250	11 751	2638 498	25915	179753	6 60
217	80	81	10364729	24590	2559 497	10 776	2548 721	23311	153838	6 26
218	81	82	11122526	22031	2460 184	9 799	2450 385	20801	130527	5 92
219	82	83	11926309	19571	2342 886	8 829	2334 056	18399	109726	5 61
220	83	84	12767080	17228	2207 362	7 880	2199 483	16124	91327	5 30
221	84	85	13659834	15020	2058 723	6 960	2051 762	13991	75203	5 01
222	85	86	14726547	12962	1914 886	6 078	1908 808	12004	61212	4 72
223	86	87	15975214	11047	1769 984	5 234	1764 749	10162	49208	4 45
224	87	88	17276865	9277	1607 182	4 439	1602 742	8473	39046	4 21
225	88	89	18516525	7670	1423 855	3 707	1420 149	6958	30573	3 99
226	89	90	19676197	6246	1231 980	3 049	1228 931	5630	23615	3 78
227	90	91	20833864	5014	1047 038	2 471	1044 567	4490	17995	3 59
228	91	92	22116501	3967	879 280	1 972	877 308	3527	13495	3 40
229	92	93	23506110	3087	727 293	1 547	725 746	2724	9968	3 23
230	93	94	25016688	2360	591 631	1 191	590 440	2064	7244	3 07
231	94	95	26539261	1769	470 259	898	469 361	1533	5180	2 93
232	95	96	27954854	1298	363 600	664	362 936	1116	3646	2 81
233	96	97	29082505	935	272 314	482	271 833	799	2530	2 71
234	97	98	30127170	662	199 901	344	199 556	562	1731	2 61

TABLE C-III (cont)

235	98	99	31102847	462	144 087	242	143 844	390	1169	2 53
236	99	100	32008537	318	102 081	168	101 913	267	778	2 44
237	100	101	32848237	216	71 170	115	71 055	181	511	2 36
238	101	102	33623949	145	48 881	078	48 802	121	330	2 28
239	102	103	34337671	96	33 106	052	33 054	80	210	2 18
240	103	104	34994403	63	22 135	035	22 101	52	130	2 06
241	104	105	35596145	41	14 624	023	14 601	34	78	1 90
242	105	106	36146895	26	9 556	015	9 541	22	44	1 67
243	106	107	36650654	17	6 181	010	6 172	14	22	1 33
244	107	108	37110421	11	3 961	006	3 955	9	9	81
245	108	109	37529195	7	2 517	004	2 513	5	0	0 00
246	109	110	37910975	4	1 587	002	1 585	3	3	0 00

TABLE C-III (cont)

life table calculation

starting age 10

population male

cancer types other

leu/bone

age		tqx	lx	tdx	drad	dref	tlx	tx	ex
10	11	00036000	100000	36 000	0 000	36 000	99982	5882813	58 83
11	12	00035000	99964	34 987	0 000	34 987	99947	5782831	57 85
12	13	00042000	99929	41 970	0 000	41 970	99908	5682884	56 87
13	14	00059000	99887	59 026	092	58 933	99858	5582976	55 89
14	15	00084000	99828	84 132	277	83 855	99786	5483118	54 93
15	16	00114000	99744	114 169	461	113 708	99687	5383333	53 97
16	17	00142000	99630	142 118	644	141 474	99559	5283646	53 03
17	18	00166999	99488	166 971	827	166 144	99404	5184087	52 11
18	19	00184999	99321	184 751	1 009	183 742	99228	5084683	51 19
19	20	00197999	99136	197 478	1 190	196 288	99037	4985455	50 29
20	21	00211998	98938	211 190	1 443	209 748	98833	4886418	49 39
21	22	00225998	98727	224 887	1 765	223 121	98615	4787585	48 49
22	23	00234998	98502	233 565	2 087	231 478	98386	4688970	47 60
23	24	00234997	98269	233 371	2 443	230 929	98152	4590584	46 71
24	25	00227997	98035	226 351	2 834	223 517	97922	4492432	45 82
25	26	00216996	97809	215 466	3 224	212 242	97701	4394510	44 93
26	27	00205996	97594	204 651	3 612	201 039	97491	4296809	44 03
27	28	00198996	97389	197 799	3 999	193 800	97290	4199318	43 12
28	29	00197996	97191	196 818	4 384	192 434	97093	4102028	42 21
29	30	00202995	96994	201 661	4 768	196 894	96893	4004935	41 29
30	31	00209994	96793	208 547	5 288	203 259	96688	3908041	40 38
31	32	00217993	96584	216 491	5 945	210 547	96476	3811353	39 46
32	33	00227992	96368	226 308	6 597	219 711	96254	3714877	38 55
33	34	00238991	96141	237 015	7 246	229 769	96023	3618623	37 64
34	35	00251990	95904	249 560	7 891	241 669	95779	3522600	36 73
35	36	00267988	95655	264 874	8 531	256 343	95522	3426820	35 82
36	37	00287986	95390	283 875	9 166	274 710	95248	3331298	34 92
37	38	00311984	95106	306 422	9 707	296 715	94953	3236050	34 03
38	39	00338982	94800	331 476	10 123	321 353	94634	3141098	33 13
39	40	00368979	94468	359 068	10 500	348 568	94289	3046464	32 25
40	41	00400977	94109	388 227	10 872	377 355	93915	2952175	31 37
41	42	00434974	93721	418 898	11 237	407 661	93511	2858260	30 50
42	43	00472971	93302	452 884	11 594	441 290	93075	2764749	29 63
43	44	00517967	92849	492 869	11 942	480 927	92603	2671674	28 77
44	45	00567962	92356	536 829	12 281	524 548	92088	2579071	27 93
45	46	00622957	91819	584 648	12 653	571 995	91527	2486983	27 09
46	47	00680951	91235	634 320	13 056	621 263	90917	2395456	26 26
47	48	00743945	90600	687 428	13 412	674 017	90257	2304539	25 44
48	49	00811938	89913	743 756	13 719	730 037	89541	2214282	24 63
49	50	00886930	89169	804 878	14 010	790 868	88767	2124741	23 83
50	51	00968922	88364	870 464	14 283	856 181	87929	2035974	23 04
51	52	01058912	87494	941 020	14 538	926 482	87023	1948045	22 26
52	53	01160901	86553	1019 563	14 771	1004 792	86043	1861022	21 50
53	54	01274888	85533	1105 535	15 083	1090 452	84980	1774979	20 75
54	55	01399872	84428	1197 346	15 467	1181 879	83829	1689999	20 02
55	56	01533854	83230	1292 448	15 816	1276 632	82584	1606170	19 30

TABLE C-III (cont)

310	56	57	01675835	81938	1389 273	16 129	1373 144	81243	1523586	18 59
311	57	58	01826814	80549	1487 877	16 403	1471 473	79805	1442342	17 91
312	58	59	01986791	79061	1587 408	16 636	1570 772	78267	1362538	17 23
313	59	60	02157766	77473	1688 519	16 826	1671 693	76629	1284271	16 58
314	60	61	02338736	75785	1789 508	17 101	1772 407	74890	1207642	15 94
315	61	62	02531701	73995	1890 790	17 450	1873 340	73050	1132752	15 31
316	62	63	02737663	72105	1991 738	17 759	1973 978	71109	1059702	14 70
317	63	64	02959620	70113	2093 094	18 023	2075 071	69066	988593	14 10
318	64	65	03199572	68020	2194 552	18 213	2176 338	66922	919527	13 52
319	65	66	03462518	65825	2297 534	18 327	2279 207	64676	852604	12 95
320	66	67	03745459	63528	2397 760	18 360	2379 400	62329	787928	12 40
321	67	68	04043394	61130	2490 032	18 311	2471 720	59885	725599	11 87
322	68	69	04349326	58640	2568 617	18 181	2550 436	57355	665714	11 35
323	69	70	04664252	56071	2633 272	17 970	2615 302	54755	608359	10 85
324	70	71	04990174	53438	2684 326	17 681	2666 645	52096	553604	10 36
325	71	72	05343088	50754	2729 125	17 316	2711 809	49389	501509	9 88
326	72	73	05738992	48024	2772 994	16 874	2756 120	46638	452120	9 41
327	73	74	06191881	45251	2818 271	16 354	2801 917	43842	405482	8 96
328	74	75	06701756	42433	2859 524	15 754	2843 769	41003	361639	8 52
329	75	76	07262616	39574	2889 161	15 077	2874 084	38129	320636	8 10
330	76	77	07854466	36685	2895 701	14 328	2881 373	35237	282507	7 70
331	77	78	08460312	33789	2872 119	13 479	2858 639	32353	247270	7 32
332	78	79	09068158	30917	2816 129	12 554	2803 575	29509	214917	6 95
333	79	80	09685999	28101	2733 430	11 609	2721 821	26734	185409	6 60
334	80	81	10364823	25367	2639 913	10 654	2629 259	24047	158675	6 26
335	81	82	11122627	22727	2537 561	9 696	2527 864	21458	134628	5 92
336	82	83	11926417	20190	2416 648	8 744	2407 903	18981	113169	5 61
337	83	84	12767194	17773	2276 925	7 810	2269 115	16635	94188	5 30
338	84	85	13659956	15496	2123 663	6 904	2116 759	14434	77553	5 00
339	85	86	14726677	13372	1975 347	6 033	1969 314	12385	[illegible]	4 72
340	86	87	15975355	11397	1825 923	5 199	1820 724	10484	50734	4 45
341	87	88	17277017	9571	1658 023	4 412	1653 610	8742	40250	4 21
342	88	89	18516686	7913	1468 937	3 686	1465 250	7179	31508	3 98
343	89	90	19676367	6444	1271 018	3 034	1267 984	5809	24329	3 78
344	90	91	20834044	5173	1080 243	2 461	1077 783	4633	18521	3 58
345	91	92	22116690	4093	907 187	1 965	905 222	3639	13888	3 39
346	92	93	23506309	3186	750 394	1 542	748 852	2811	10248	3 22
347	93	94	25016898	2435	610 438	1 188	609 250	2130	7438	3 05
348	94	95	26539482	1825	485 220	896	484 324	1582	5308	2 91
349	95	96	27955084	1340	375 176	663	374 514	1152	3725	2 78
350	96	97	29082743	965	280 990	481	280 509	824	2573	2 67
351	97	98	30127416	684	206 274	344	205 930	580	1749	2 56
352	98	99	31103099	477	148 684	242	148 442	403	1169	2 53
353	99	100	32008795	329	105 341	168	105 172	276	778	2 44
354	100	101	32848501	223	73 444	115	73 328	187	511	2 36
355	101	102	33624217	150	50 443	078	50 365	125	330	2 28
356	102	103	34337944	99	34 165	052	34 113	82	210	2 18
357	103	104	34994680	65	22 844	035	22 809	54	130	2 06
358	104	105	35596426	42	15 093	023	15 070	35	78	1 90
359	105	106	36147180	27	9 862	015	9 847	22	44	1 67
360	106	107	36650942	17	6 380	010	6 370	14	22	1 33
361	107	108	37110711	11	4 089	006	4 082	9	9	81
362	108	109	37529487	7	2 598	004	2 594	6	0	0 00
363	109	110	37911270	4	1 638	002	1 636	3	3	0 00

TABLE C-III (cont)

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cancer type other

population male

lifetime risk to individual from exposure by age

age group	lifetime risk	age group	lifetime risk	age group	lifetime risk	age group	lifetime risk	age group	lifetime risk	age group	lifetime risk	age group	lifetime risk	age group	lifetime risk
-1 0		13	5084e-02	27	3665e-02	41	2002e-02	55	8081e-03	69	1501e 03	83	1037e-04	97	2809e 06
0	6126e-02	14	5021e-02	28	3531e-02	42	1902e-02	56	7323e-03	70	1289e-03	84	8222e 05	98	1496e 06
1	6157e-02	15	4961e-02	29	3400e-02	43	1808e-02	57	6618e-03	71	1101e-03	85	6499e-05	99	4718e-07
2	6057e-02	16	4903e-02	30	3273e-02	44	1718e-02	58	5964e-03	72	9345e-04	86	5137e-05	100 0	
3	5956e-02	17	4848e-02	31	3150e 02	45	1632e-02	59	5359e-03	73	7885e-04	87	4069e-05	101 0	
4	5856e-02	18	4796e-02	32	3031e-02	46	1552e-02	60	4799e-03	74	6612e-04	88	3233e-05	102 0	
5	5757e-02	19	4746e-02	33	2916e-02	47	1476e-02	61	4284e-03	75	5513e 04	89	2574e-05	103 0	
6	5659e-02	20	4697e-02	34	2805e-02	48	1404e-02	62	3811e-03	76	4569e-04	90	2049e-05	104 0	
7	5563e-02	21	4539e-02	35	2698e-02	49	1337e-02	63	3377e-03	77	3765e-04	91	1628e-05	105 0	
8	5468e-02	22	4385e-02	36	2570e-02	50	1274e-02	64	2982e-03	78	3084e-04	92	1290e-05	106 0	
9	5375e-02	23	4234e-02	37	2446e-02	51	1169e-02	65	2622e-03	79	2510e-04	93	1015e 05	107 0	
10	5283e-02	24	4087e-02	38	2328e 02	52	1070e-02	66	2296e-03	80	2030e-04	94	7890e-06	108 0	
11	5215e-02	25	3943e-02	39	2214e-02	53	9766e-03	67	2002e-03	81	1631e-04	95	5978e-06	109 0	
12	5149e-02	26	3803e-02	40	2106e-02	54	8895e-03	68	1737e-03	82	1304e-04	96	4307e-06	110 0	

number of health effects in male population distributed by age (low let radiation)

age group	health effects	age group	health effects	age group	health effects	age group	health effects	age group	health effects	age group	health effects	age group	health effects	age group	health effects
-1 0		13	736e+02	27	517e+02	41	272e+02	55	971e+01	69	120e+01	83	253e-01	97	253e 04
0	896e+02	14	726e+02	28	497e+02	42	257e+02	56	866e+01	70	980e+00	84	174e 01	98	898e 05
1	897e+02	15	717e+02	29	478e+02	43	243e+02	57	768e+01	71	794e+00	85	118e 01	99	189e 05
2	881e+02	16	708e+02	30	459e+02	44	230e+02	58	679e+01	72	636e+00	86	791e 02	100 0	
3	866e+02	17	698e+02	31	441e+02	45	217e+02	59	598e+01	73	505e+00	87	525e-02	101 0	
4	851e+02	18	690e+02	32	423e+02	46	205e+02	60	523e+01	74	396e+00	88	343e 02	102 0	
5	836e+02	19	681e+02	33	406e+02	47	193e+02	61	456e+01	75	308e+00	89	221e 02	103 0	
6	821e+02	20	673e+02	34	390e+02	48	183e+02	62	395e+01	76	236e+00	90	139e 02	104 0	
7	807e+02	21	649e+02	35	374e+02	49	172e+02	63	340e+01	77	178e+00	91	879e-03	105 0	
8	793e+02	22	625e+02	36	355e+02	50	163e+02	64	291e+01	78	133e+00	92	529e 03	106 0	
9	779e+02	23	.602e+02	37	337e+02	51	148e+02	65	247e+01	79	984e 01	93	315e-03	107 0	
10	766e+02	24	580e+02	38	320e+02	52	134e+02	66	209e+01	80	715e-01	94	181e 03	108 0	
11	755e+02	25	558e+02	39	303e+02	53	121e+02	67	175e+01	81	514e-01	95	102e 03	109 0	
12	746e+02	26	537e+02	40	287e+02	54	108e+02	68	146e+01	82	362e 01	96	517e-04	110 0	

total number of health effects to the male population 2883e+04

TABLE C-III (cont)

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cancer type leu/bone

population *male*

lifetime risk to individual from exposure by age

age group	lifetime risk	age group	lifetime risk	age group	lifetime risk	age group	lifetime risk	age group	lifetime risk	age group	lifetime risk	age group	lifetime risk	age group	lifetime risk
-1 0		13	2630e-02	27	1973e-02	41	1327e 02	55	7709e-03	69	2395e-03	83	4613e-04	97	7574e-05
0	3587e 02	14	2589e-02	28	1918e-02	42	1294e-02	56	7185e-03	70	2167e-03	84	4015e-04	98	6819e-05
1	3576e-02	15	2548e-02	29	1863e-02	43	1261e-02	57	6685e-03	71	1954e-03	85	3487e-04	99	6107e 05
2	3487e-02	16	2508e-02	30	1809e 02	44	1230e-02	58	6208e 03	72	1758e-03	86	3027e-04	100	5409e-05
3	3397e 02	17	2469e-02	31	1755e-02	45	1200e 02	59	5753e 03	73	1577e-03	87	2631e 04	101	4695e 05
4	3306e-02	18	2430e-02	32	1701e-02	46	1171e-02	60	5321e 03	74	1411e-03	88	2291e-04	102	3937e-05
5	3215e-02	19	2392e-02	33	.1647e-02	47	1143e-02	61	4912e 03	75	1260e-03	89	1997e-04	103	3112e 05
6	3123e 02	20	2354e 02	34	1594e-02	48	1116e-02	62	4525e 03	76	1122e 03	90	1742e 04	104	2214e 05
7	3032e-02	21	2300e-02	35	1541e 02	49	1091e 02	63	4159e-03	77	9974e-04	91	1521e-04	105	1280e 05
8	2940e-02	22	2245e-02	36	1504e-02	50	1067e-02	64	3814e-03	78	8842e-04	92	1333e-04	106	4353e-06
9	2848e-02	23	2191e-02	37	1467e-02	51	1003e-02	65	3491e-03	79	7814e-04	93	1175e-04	107 0	
10	2756e-02	24	2137e 02	38	1431e-02	52	9418e-03	66	3188e-03	80	6881e-04	94	1043e-04	108 0	
11	2714e-02	25	2083e-02	39	1396e-02	53	8825e-03	67	2905e-03	81	6039e-04	95	9332e 05	109 0	
12	2672e-02	26	2028e-02	40	1361e-02	54	8255e 03	68	2641e-03	82	5286e-04	96	8401e-05	110 0	

number of health effects in male population distributed by age (low let radiation)

age group	health effects	age group	health effects	age group	health effects	age group	health effects	age group	health effects	age group	health effects	age group	health effects	age group	health effects
-1 0		13	381e+02	27	278e+02	41	180e+02	55	926e+01	69	191e+01	83	113e+00	97	682e-03
0	525e+02	14	374e+02	28	270e+02	42	175e+02	56	849e+01	70	165e+01	84	851e 01	98	409e 03
1	521e+02	15	368e+02	29	262e+02	43	170e+02	57	776e+01	71	141e+01	85	635e 01	99	244e-03
2	507e+02	16	362e+02	30	254e+02	44	164e+02	58	707e+01	72	120e+01	86	466e-01	100	162e 03
3	494e+02	17	356e+02	31	245e+02	45	159e+02	59	641e+01	73	101e+01	87	339e 01	101	939e 04
4	480e+02	18	349e+02	32	237e+02	46	155e+02	60	580e+01	74	845e+00	88	243e-01	102	394e-04
5	467e+02	19	343e+02	33	229e+02	47	150e+02	61	523e+01	75	703e+00	89	172e 01	103	311e-04
6	453e+02	20	337e+02	34	221e+02	48	145e+02	62	469e+01	76	579e+00	90	118e 01	104	221e 04
7	440e+02	21	329e+02	35	213e+02	49	141e+02	63	418e+01	77	473e+00	91	822e-02	105 0	
8	426e+02	22	320e+02	36	208e+02	50	136e+02	64	372e+01	78	382e+00	92	547e-02	106 0	
9	413e+02	23	312e+02	37	202e+02	51	127e+02	65	323e+01	79	306e+00	93	364e 02	107 0	
10	399e+02	24	303e+02	38	196e+02	52	118e+02	66	290e+01	80	242e+00	94	240e-02	108 0	
11	393e+02	25	295e+02	39	191e+02	53	109e+02	67	254e+01	81	190e+00	95	159e-02	109 0	
12	387e+02	26	287e+02	40	185e+02	54	101e+02	68	221e+01	82	147e+00	96	101e-02	110 0	

total number of health effects to the male population 1669e+04

TABLE C-III (cont)

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calculation of cancer risks for female population

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life table calculation

starting age 0

population female

cancer types other

leu/bone

age		tqx	lx	tdx	drad	dref	tlx	tx	ex
0	1	01746000	100000	1746 000	0 000	1746 000	99127	7434906	74 35
1	2	00116000	98254	113 975	0 000	113 975	98197	7335779	74 66
2	3	00077000	98140	75 568	0 000	75 568	98102	7237582	73 75
3	4	00060000	98064	58 963	125	58 839	98035	7139479	72 80
4	5	00051000	98005	50 356	374	49 983	97980	7041444	71 85
5	6	00043000	97955	42 743	622	42 121	97934	6943464	70 88
6	7	00038000	97912	38 078	871	37 207	97893	6845530	69 91
7	8	00034000	97874	34 396	1 119	33 277	97857	6747637	68 94
8	9	00031000	97840	31 698	1 368	30 330	97824	6649780	67 97
9	10	00028000	97808	29 002	1 616	27 386	97794	6551956	66 99
10	11	00026000	97779	27 412	1 990	25 422	97766	6454162	66 01
11	12	00025000	97752	26 927	2 489	24 438	97738	6356397	65 03
12	13	00027000	97725	29 374	2 989	26 385	97710	6258658	64 04
13	14	00032999	97696	35 661	3 422	32 239	97678	6160948	63 06
14	15	00039999	97660	42 852	3 788	39 063	97638	6063270	62 09
15	16	00048999	97617	51 986	4 154	47 831	97591	5965632	61 11
16	17	00057999	97565	61 106	4 519	56 586	97534	5868041	60 14
17	18	00065998	97504	69 235	4 884	64 351	97469	5770506	59 18
18	19	00068998	97435	72 475	5 247	67 228	97398	5673037	58 22
19	20	00070998	97362	74 735	5 610	69 125	97325	5575639	57 27
20	21	00071998	97287	75 987	5 942	70 045	97249	5478314	56 31
21	22	00072998	97211	77 205	6 243	70 962	97173	5381064	55 35
22	23	00074997	97134	79 392	6 543	72 848	97095	5283892	54 40
23	24	00076997	97055	81 596	6 866	74 730	97014	5186797	53 44
24	25	00078997	96973	83 817	7 211	76 606	96931	5089783	52 49
25	26	00080997	96889	86 033	7 556	78 477	96846	4992852	51 53
26	27	00082997	96803	88 243	7 899	80 344	96759	4896005	50 58
27	28	00085996	96715	91 291	8 119	83 172	96670	4799246	49 62
28	29	00089996	96624	95 173	8 216	86 958	96576	4702576	48 67
29	30	00095996	96529	100 975	8 311	92 664	96478	4606000	47 72
30	31	00101995	96428	106 944	8 592	98 352	96374	4509522	46 77
31	32	00109995	96321	115 005	9 057	105 948	96263	4413147	45 82
32	33	00118994	96206	123 999	9 520	114 479	96144	4316884	44 87
33	34	00128993	96082	133 919	9 980	123 939	96015	4220740	43 93

TABLE C-III (cont)

542	34	35	00139992	95948	144 758	10 438	134 320	95876	4124726	42 99
543	35	36	00151991	95803	156 507	10 894	145 612	95725	4028850	42 05
544	36	37	00164990	95647	169 154	11 347	157 808	95562	3933125	41 12
545	37	38	00179989	95477	183 709	11 861	171 849	95386	3837563	40 19
546	38	39	00196987	95294	200 131	12 414	187 716	95194	3742177	39 27
547	39	40	00214985	95094	217 380	12 943	204 437	94985	3646984	38 35
548	40	41	00232983	94876	234 513	13 467	221 046	94759	3551999	37 44
549	41	42	00250981	94642	251 518	13 985	237 533	94516	3457240	36 53
550	42	43	00272979	94390	272 163	14 498	257 665	94254	3362724	35 63
551	43	44	00296976	94118	294 513	15 004	279 508	93971	3268470	34 73
552	44	45	00324973	93824	320 405	15 503	304 901	93663	3174499	33 83
553	45	46	00353970	93503	347 027	16 055	330 973	93330	3080836	32 95
554	46	47	00383966	93156	374 345	16 657	357 687	92969	2987506	32 07
555	47	48	00415961	92782	403 163	17 227	385 936	92580	2894537	31 20
556	48	49	00448957	92379	432 504	17 764	414 740	92162	2801957	30 33
557	49	50	00483952	91946	463 265	18 290	444 975	91714	2709795	29 47
558	50	51	00522946	91483	497 209	18 803	478 406	91234	2618080	28 62
559	51	52	00564940	90986	533 317	19 302	514 014	90719	2526846	27 77
560	52	53	00610933	90452	572 389	19 786	552 603	90166	2436127	26 93
561	53	54	00659925	89880	613 463	20 322	593 140	89573	2345961	26 10
562	54	55	00711917	89266	656 410	20 907	635 503	88938	2256388	25 28
563	55	56	00767907	88610	701 913	21 471	680 443	88259	2167449	24 46
564	56	57	00828896	87908	750 679	22 012	728 667	87533	2079190	23 65
565	57	58	00893884	87157	801 614	22 527	779 087	86757	1991658	22 85
566	58	59	00961872	86356	853 649	23 017	830 632	85929	1904901	22 06
567	59	60	01034858	85502	908 304	23 478	884 826	85048	1818972	21 27
568	60	61	01112841	84594	965 503	24 107	941 396	84111	1733924	20 50
569	61	62	01199821	83628	1028 286	24 895	1003 391	83114	1649813	19 73
570	62	63	01297798	82600	1097 637	25 654	1071 983	82051	1566699	18 97
571	63	64	01410772	81502	1176 192	26 378	1149 814	80914	1484647	18 22
572	64	65	01537741	80326	1262 255	27 045	1235 210	79695	1403733	17 48
573	65	66	01677707	79064	1354 109	27 647	1326 462	78387	1324038	16 75
574	66	67	01831668	77710	1451 567	28 179	1423 387	76984	1245651	16 03
575	67	68	02003624	76258	1556 566	28 636	1527 930	75480	1168667	15 33
576	68	69	02194574	74702	1668 396	29 010	1639 385	73868	1093187	14 63
577	69	70	02406517	73033	1786 855	29 295	1757 561	72140	1019319	13 96
578	70	71	02631455	71247	1904 304	29 483	1874 820	70294	947179	13 29
579	71	72	02878386	69342	2025 508	29 571	1995 937	68329	876885	12 65
580	72	73	03164305	67317	2159 656	29 550	2130 106	66237	808555	12 01
581	73	74	03502210	65157	2311 343	29 406	2281 936	64001	742318	11 39
582	74	75	03892098	62846	2475 145	29 129	2446 016	61608	678317	10 79
583	75	76	04323972	60371	2639 114	28 708	2610 406	59051	616709	10 22
584	76	77	04788833	57731	2792 802	28 140	2764 662	56335	557658	9 66
585	77	78	05293680	54939	2935 658	27 382	2908 276	53471	501323	9 13
586	78	79	05838515	52003	3062 645	26 443	3036 202	50472	447852	8 61
587	79	80	06430333	48940	3172 396	25 369	3147 027	47354	397380	8 12
588	80	81	07095126	45768	3271 458	24 165	3247 294	44132	350026	7 65
589	81	82	07831895	42496	3351 115	22 834	3328 280	40821	305894	7 20
590	82	83	08609647	39145	3391 670	21 391	3370 278	37450	265073	6 77
591	83	84	09416384	35754	3386 564	19 858	3366 706	34060	227624	6 37
592	84	85	10272102	32367	3343 045	18 259	3324 785	30696	193563	5 98
593	85	86	11278772	29024	3290 171	16 610	3273 561	27379	162868	5 61
594	86	87	12458387	25734	3220 952	14 920	3206 032	24123	135489	5 26
595	87	88	13680983	22513	3093 211	13 215	3079 996	20966	111365	4 95
596	88	89	14854585	19420	2896 265	11 540	2884 725	17972	90399	4 65
597	89	90	16001187	16523	2653 893	9 938	2643 955	15197	72427	4 38
598	90	91	17258751	13870	2402 154	8 435	2393 720	12669	57231	4 13
599	91	92	18712254	11467	2152 859	7 041	2145 818	10391	44562	3 89
600	92	93	20236730	9315	1890 738	5 770	1884 968	8369	34171	3 67
601	93	94	21743205	7424	1618 821	4 638	1614 183	6614	25802	3 48
602	94	95	23178694	5805	1349 188	3 658	1345 530	5130	19187	3 31
603	95	96	24576187	4456	1097 908	2 832	1095 076	3907	14057	3 15
604	96	97	25845710	3358	870 035	2 153	867 882	2923	10150	3 02
605	97	98	26971267	2488	672 628	1 611	671 018	2152	7227	2 90

TABLE C-III (cont)

606	98	99	27986849	1815	509 223	1 187	508 037	1561	5076	2 80
607	99	100	28939444	1306	378 825	862	377 962	1117	3515	2 69
608	100	101	29826052	927	277 172	618	276 554	789	2398	2 59
609	101	102	30648674	650	199 669	438	199 232	550	1610	2 48
610	102	103	31409309	450	141 768	307	141 461	379	1059	2 35
611	103	104	32110956	309	99 311	212	99 098	259	680	2 20
612	104	105	32756615	209	68 706	145	68 560	175	421	2 01
613	105	106	33349286	141	46 987	099	46 888	117	246	1 75
614	106	107	33891968	94	31 793	066	31 726	78	129	1 38
615	107	108	34388660	62	21 302	044	21 258	51	51	83
616	108	109	34842361	41	14 146	029	14 116	33	0	0 00
617	109	110	35256072	26	9 316	019	9 297	22	22	0 00

TABLE C-III (cont)

life table calculation

starting age 10

population female

cancer types other

leu/bone

age		tqx	lx	tdx	drad	dref	tlx	tx	ex
10	11	00026000	100000	26 000	0 000	26 000	99987	6608713	66 09
11	12	00025000	99974	24 994	0 000	24 994	99962	6508726	65 10
12	13	00027000	99949	26 986	0 000	26 986	99936	6408765	64 12
13	14	00033000	99922	33 034	060	32 974	99906	6308829	63 14
14	15	00040000	99889	40 134	179	39 956	99869	6208924	62 16
15	16	00049000	99849	49 223	297	48 926	99824	6109055	61 18
16	17	00058000	99800	58 300	416	57 884	99770	6009230	60 21
17	18	00066000	99741	66 364	535	65 829	99708	5909460	59 25
18	19	00069000	99675	69 429	653	68 776	99640	5809752	58 29
19	20	00071000	99606	71 491	771	70 720	99570	5710112	57 33
20	21	00072000	99534	72 651	987	71 664	99498	5610542	56 37
21	22	00073000	99461	73 905	1 299	72 606	99424	5511044	55 41
22	23	00074999	99387	76 151	1 611	74 540	99349	5411620	54 45
23	24	00076999	99311	78 414	1 945	76 469	99272	5312270	53 49
24	25	00078999	99233	80 696	2 303	78 393	99193	5212998	52 53
25	26	00080999	99152	82 972	2 660	80 312	99111	5113806	51 58
26	27	00082999	99069	85 242	3 016	82 226	99027	5014695	50 62
27	28	00085999	98984	88 497	3 372	85 125	98940	4915668	49 66
28	29	00089998	98896	92 731	3 727	89 004	98849	4816728	48 71
29	30	00095998	98803	98 929	4 081	94 849	98753	4717879	47 75
30	31	00101998	98704	105 299	4 624	100 676	98651	4619126	46 80
31	32	00109997	98599	113 810	5 355	108 455	98542	4520475	45 85
32	33	00118996	98485	123 277	6 084	117 193	98423	4421933	44 90
33	34	00128996	98361	133 692	6 811	126 882	98295	4323510	43 96
34	35	00139995	98278	145 048	7 534	137 514	98155	4225215	43 01
35	36	00151994	98083	157 335	8 255	149 079	98004	4127060	42 08
36	37	00164992	97925	170 542	8 973	161 569	97840	4029056	41 14
37	38	00179991	97755	185 578	9 628	175 950	97662	3931216	40 22
38	39	00196990	97569	202 401	10 200	192 201	97468	3833554	39 29
39	40	00214988	97367	220 074	10 747	209 327	97257	3736086	38 37
40	41	00232986	97147	237 628	11 290	226 339	97028	3638829	37 46
41	42	00250985	96909	255 054	11 827	243 227	96782	3541801	36 55
42	43	00272983	96654	276 209	12 360	263 849	96516	3445019	35 64
43	44	00296980	96378	299 109	12 886	286 223	96228	3348503	34 74
44	45	00324977	96079	325 640	13 405	312 234	95916	3252275	33 85
45	46	00353974	95753	352 921	13 979	338 941	95577	3156359	32 96
46	47	00383971	95400	380 915	14 606	366 309	95210	3060782	32 08
47	48	00415967	95019	410 449	15 200	395 249	94814	2965572	31 21
48	49	00448963	94609	440 521	15 762	424 758	94389	2870758	30 34
49	50	00483958	94168	472 048	16 313	455 735	93932	2776370	29 48
50	51	00522953	93696	506 839	16 851	489 988	93443	2682437	28 63
51	52	00564947	93189	543 848	17 377	526 471	92918	2588995	27 78
52	53	00610941	92646	583 897	17 887	566 010	92354	2496077	26 94
53	54	00659934	92062	625 999	18 452	607 546	91749	2403723	26 11
54	55	00711926	91436	670 023	19 069	650 954	91101	2311975	25 29
55	56	00767917	90766	716 670	19 665	697 005	90407	2220874	24 47

TABLE C-III (cont)

681	56	57	00828907	90049	766 661	20 238	746 423	89666	2130467	23 66
682	57	58	00893896	89282	818 879	20 788	798 091	88873	2040801	22 86
683	58	59	00961884	88463	872 228	21 311	850 916	88027	1951928	22 06
684	59	60	01034871	87591	928 264	21 807	906 457	87127	1863901	21 28
685	60	61	01112856	86663	986 911	22 477	964 434	86170	1776773	20 50
686	61	62	01199837	85676	1051 285	23 311	1027 973	85150	1690604	19 73
687	62	63	01297815	84625	1122 391	24 118	1098 273	84064	1605453	18 97
688	63	64	01410790	83502	1202 934	24 891	1178 043	82901	1521390	18 22
689	64	65	01537761	82299	1291 175	25 606	1265 569	81654	1438489	17 48
690	65	66	01677728	81008	1385 357	26 258	1359 099	80316	1356835	16 75
691	66	67	01831691	79623	1485 288	26 842	1458 446	78880	1276519	16 03
692	67	68	02003649	78138	1592 955	27 350	1565 605	77341	1197639	15 33
693	68	69	02194602	76545	1707 628	27 777	1679 851	75691	1120298	14 64
694	69	70	02406548	74837	1829 104	28 114	1800 990	73923	1044607	13 96
695	70	71	02631489	73008	1949 554	28 357	1921 197	72033	970684	13 30
696	71	72	02878423	71058	2073 861	28 500	2045 362	70021	898651	12 65
697	72	73	03164345	68985	2211 443	28 533	2182 910	67879	828630	12 01
698	73	74	03502254	66773	2367 010	28 447	2338 564	65590	760751	11 39
699	74	75	03892147	64406	2535 006	28 226	2506 780	63139	695161	10 79
700	75	76	04324026	61871	2703 185	2' 863	2675 322	60520	632023	10 22
701	76	77	04788893	59168	2860 841	27 353	2833 488	57737	571503	9 66
702	77	78	05293747	56307	3007 406	26 652	2980 754	54803	513766	9 12
703	78	79	05838588	53300	3137 718	25 770	3111 948	51731	458962	8 61
704	79	80	06430413	50162	3250 373	24 752	3225 620	48537	407232	8 12
705	80	81	07095215	46912	3352 080	23 604	3328 477	45236	358695	7 65
706	81	82	07831992	43559	3433 904	22 328	3411 576	41843	313459	7 20
707	82	83	08609753	40126	3475 652	20 938	3454 714	38388	271617	6 77
708	83	84	09416500	36650	3470 598	19 457	3451 141	34915	233229	6 36
709	84	85	10272227	33179	3426 164	17 907	3408 257	31466	198314	5 98
710	85	86	11278909	29753	3372 138	16 305	3355 833	28067	166848	5 61
711	86	87	12458538	26381	3301 350	14 659	3286 691	24730	138781	5 26
712	87	88	13681147	23080	3170 561	12 995	3157 566	21494	114051	4 94
713	88	89	14854762	19909	2968 810	11 357	2957 453	18425	92556	4 65
714	89	90	16001376	16940	2720 471	9 787	2710 684	15580	74131	4 38
715	90	91	17258954	14220	2462 509	8 313	2454 196	12989	58551	4 12
716	91	92	18712472	11757	2207 033	6 945	2200 088	10654	45563	3 88
717	92	93	20236964	9550	1938 386	5 695	1932 691	8581	34909	3 66
718	93	94	21743455	7612	1659 675	4 581	1655 094	6782	26328	3 46
719	94	95	23178958	5952	1383 283	3 616	1379 668	5261	19546	3 28
720	95	96	24576465	4569	1125 689	2 801	1122 888	4006	14285	3 13
721	96	97	25846000	3443	892 078	2 131	889 947	2997	10279	2 99
722	97	98	26971568	2551	689 691	1 595	688 096	2206	7282	2 85
723	98	99	27987159	1861	522 157	1 176	520 981	1600	5076	2 80
724	99	100	28939763	1339	388 458	855	387 603	1145	3515	2 69
725	100	101	29826379	951	284 228	613	283 615	809	2398	2 59
726	101	102	30649008	667	204 759	435	204 324	564	1610	2 48
727	102	103	31409649	462	145 385	304	145 081	389	1059	2 35
728	103	104	32111303	317	101 848	211	101 637	266	680	2 20
729	104	105	32756968	215	70 463	145	70 318	179	421	2 01
730	105	106	33349644	144	48 190	098	48 091	120	246	1 75
731	106	107	33892330	96	32 608	066	32 541	80	129	1 38
732	107	108	34389026	63	21 849	044	21 805	52	51	83
733	108	109	34842732	42	14 509	029	14 480	34	0	0 00
734	109	110	35256445	27	9 556	019	9 536	22	22	0 00

TABLE C-III (cont)

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cancer type other

population female

lifetime risk to individual from exposure by age

age group	lifetime risk	age group	lifetime risk	age group	lifetime risk	age group	lifetime risk	age group	lifetime risk	age group	lifetime risk	age group	lifetime risk	age group	lifetime risk
-1 0		13	9300e-02	27	6962e 02	41	4152e 02	55	1870e-02	69	3828e-03	83	2658e-04	97	6239e 06
0	1092e-01	14	9201e-02	28	6741e-02	42	3976e-02	56	1711e-02	70	3298e-03	84	2104e-04	98	3240e-06
1	1094e-01	15	9104e 02	29	6526e-02	43	3806e-02	57	1561e-02	71	2824e-03	85	1661e 04	99	9914e 07
2	1079e-01	16	9011e 02	30	6316e 02	44	3643e-02	58	1420e-02	72	2403e-03	86	1309e 04	100 0	
3	1064e 01	17	8920e-02	31	6112e-02	45	3487e-02	59	1287e-02	73	2031e-03	87	1032e 04	101 0	
4	1049e-01	18	8831e-02	32	5913e 02	46	3337e-02	60	1162e-02	74	1706e-03	88	8149e 05	102 0	
5	1034e-01	19	8744e-02	33	5720e-02	47	3194e-02	61	1046e 02	75	1424e-03	89	6433e-05	103 0	
6	1019e-01	20	8660e-02	34	5533e 02	48	3057e 02	62	9371e 03	76	1180e-03	90	5070e-05	104 0	
7	1004e-01	21	8401e-02	35	5352e-02	49	2927e 02	63	8363e-03	77	9720e-04	91	3986e-05	105 0	
8	9894e 02	22	8148e-02	36	5135e 02	50	2803e-02	64	7432e-03	78	7951e-04	92	3125e-05	106 0	
9	9751e-02	23	7900e-02	37	4925e 02	51	2598e 02	65	6574e-03	79	6462e-04	93	2433e 05	107 0	
10	9610e-02	24	7657e-02	38	4721e-02	52	2402e-02	66	5787e-03	80	5218e-04	94	1865e-05	108 0	
11	9505e 02	25	7420e 02	39	4525e 02	53	2215e-02	67	5069e-03	81	4188e-04	95	1388e-05	109 0	
12	9401e-02	26	7188e-02	40	4335e-02	54	2038e-02	68	4417e-03	82	3344e-04	96	9786e-06	110 0	

number of health effects in female population distributed by age (low let radiation)

age group	health effects	age group	health effects	age group	health effects	age group	health effects	age group	health effects	age group	health effects	age group	health effects	age group	health effects
-1 0		13	122e+03	27	902e+02	41	527e+02	55	222e+02	69	374e+01	83	123e+00	97	187e-03
0	144e+03	14	120e+03	28	873e+02	42	503e+02	56	202e+02	70	314e+01	84	880e 01	98	680e 04
1	144e+03	15	119e+03	29	844e+02	43	481e+02	57	182e+02	71	261e+01	85	619e-01	99	149e 04
2	142e+03	16	118e+03	30	817e+02	44	459e+02	58	164e+02	72	216e+01	86	431e 01	100 0	
3	140e+03	17	116e+03	31	789e+02	45	437e+02	59	148e+02	73	176e+01	87	295e 01	101 0	
4	138e+03	18	115e+03	32	763e+02	46	417e+02	60	132e+02	74	142e+01	88	200e 01	102 0	
5	136e+03	19	114e+03	33	737e+02	47	398e+02	61	117e+02	75	114e+01	89	134e 01	103 0	
6	134e+03	20	113e+03	34	712e+02	48	379e+02	62	104e+02	76	902e+00	90	877e 02	104 0	
7	132e+03	21	109e+03	35	688e+02	49	361e+02	63	913e+01	77	706e+00	91	566e 02	105 0	
8	130e+03	22	106e+03	36	659e+02	50	344e+02	64	800e+01	78	545e+00	92	359e 02	106 0	
9	128e+03	23	103e+03	37	630e+02	51	317e+02	65	696e+01	79	416e+00	93	221e-02	107 0	
10	126e+03	24	995e+02	38	603e+02	52	292e+02	66	602e+01	80	313e+00	94	131e 02	108 0	
11	124e+03	25	964e+02	39	577e+02	53	267e+02	67	517e+01	81	232e+00	95	749e 03	109 0	
12	123e+03	26	932e+02	40	552e+02	54	244e+02	68	441e+01	82	171e+00	96	391e 03	110 0	

total number of health effects to the female population 5028e+04

TABLE C-III (cont)

cancer type leu/bone

population female

lifetime risk to individual from exposure by age

age group	lifetime risk	age group	lifetime risk	age group	lifetime risk	age group	lifetime risk	age group	lifetime risk	age group	lifetime risk	age group	lifetime risk	age group	lifetime risk
-1	0	13	2082e-02	27	1631e-02	41	1188e 02	55	7469e-03	69	2460e-03	83	4435e-04	97	6567e-05
0	2706e 02	14	2054e-02	28	1594e-02	42	1164e-02	56	7019e-03	70	2222e-03	84	3839e-04	98	5851e 05
1	2694e-02	15	2027e-02	29	1557e-02	43	1141e-02	57	6581e-03	71	2001e-03	85	3314e-04	99	5178e-05
2	2637e-02	16	.2000e-02	30	1520e-02	44	.1117e-02	58	6156e-03	72	1795e-03	86	2859e-04	100	4525e-05
3	2579e-02	17	1973e-02	31	1484e-02	45	1095e-02	59	5744e-03	73	1606e-03	87	2467e-04	101	3868e 05
4	.2520e-02	18	.1946e-02	32	1447e-02	46	.1072e-02	60	5345e-03	74	1431e-03	88	2131e-04	102	3188e-05
5	2461e-02	19	1920e-02	33	1411e-02	47	.1050e-02	61	4961e-03	75	1272e-03	89	1842e-04	103	2472e-05
6	2402e-02	20	.1893e-02	34	1375e-02	48	1029e-02	62	4591e-03	76	1127e-03	90	1593e-04	104	1722e-05
7	2343e-02	21	1856e-02	35	1339e-02	49	1008e-02	63	4237e-03	77	9955e-04	91	1381e-04	105	9711e-06
8	2283e-02	22	1818e-02	36	1313e-02	50	9880e-03	64	3899e-03	78	8765e-04	92	1203e-04	106	3211e-06
9	2224e-02	23	1781e-02	37	1288e-02	51	9379e-03	65	3578e-03	79	7693e-04	93	1055e-04	107	0
10	2164e-02	24	1743e-02	38	1262e-02	52	8886e-03	66	3273e-03	80	6731e-04	94	9305e-05	108	0
11	2137e-02	25	1706e-02	39	1237e-02	53	8403e-03	67	2985e-03	81	5872e-04	95	8254e-05	109	0
12	2109e-02	26	1669e-02	40	1213e-02	54	7931e-03	68	2714e-03	82	5110e-04	96	7356e-05	110	0

number of health effects in female population distributed by age (low let radiation)

age group	health effects	age group	health effects	age group	health effects	age group	health effects	age group	health effects	age group	health effects	age group	health effects	age group	health effects
-1	0	13	272e+02	27	211e+02	41	151e+02	55	888e+01	69	240e+01	83	206e+00	97	197e-02
0	357e+02	14	269e+02	28	206e+02	42	147e+02	56	828e+01	70	211e+01	84	160e+00	98	123e-02
1	355e+02	15	265e+02	29	202e+02	43	144e+02	57	769e+01	71	185e+01	85	124e+00	99	777e-03
2	346e+02	16	261e+02	30	197e+02	44	141e+02	58	713e+01	72	161e+01	86	941e-01	100	498e-03
3	339e+02	17	258e+02	31	192e+02	45	137e+02	59	659e+01	73	139e+01	87	706e-01	101	309e-03
4	331e+02	18	254e+02	32	187e+02	46	134e+02	60	606e+01	74	120e+01	88	524e-01	102	159e-03
5	323e+02	19	250e+02	33	182e+02	47	131e+02	61	556e+01	75	102e+01	89	383e-01	103	989e 04
6	315e+02	20	247e+02	34	177e+02	48	128e+02	62	508e+01	76	861e+00	90	276e-01	104	344e 04
7	307e+02	21	242e+02	35	172e+02	49	124e+02	63	463e+01	77	723e+00	91	196e-01	105	194e-04
8	299e+02	22	237e+02	36	168e+02	50	121e+02	64	420e+01	78	601e+00	92	138e-01	106	321e-05
9	291e+02	23	231e+02	37	165e+02	51	115e+02	65	379e+01	79	495e+00	93	960e-02	107	0
10	284e+02	24	226e+02	38	161e+02	52	108e+02	66	340e+01	80	404e+00	94	651e-02	108	0
11	280e+02	25	222e+02	39	158e+02	53	101e+02	67	304e+01	81	326e+00	95	446e-02	109	0
12	276e+02	26	216e+02	40	154e+02	54	949e+01	68	271e+01	82	261e+00	96	294e-02	110	0

total number of health effects to the female population 1279e+04

TABLE C-IV

COMPARISON OF REPCAL AND BEIR III ESTIMATES USING THE LINEAR DOSE-RESPONSE MODEL: CANCERS PER ONE MILLION PERSONS

	Male		Female	
	REPCAL	BEIR III	REPCAL	BEIR III
I. 10 rad, single exposure				
A. Leukemia/Bone Cancer	535	566	363	384
B. All Other Cancers				
Absolute risk	917	919	1472	1473
Relative risk	3910	4226	4560	4852
II. 1 Rad/Year Continuous Exposure				
A. Leukemia/Bone Cancer	3587	3568	2706	2709
B. All Other Cancers				
Absolute risk	6126	5827	10920	10400
Relative risk	25760	22080	33390	29030

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