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

by

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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 250×10^{-6}/rad of low-LET radiation to 100×10^{-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.

<u>2. Projection of Cancer Risk Beyond the Period of Follow-Up</u>. 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 x 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 x 10^{-6} per rem.

The ICRP also used a risk factor for genetic disorder of 80 x 10^{-6}/rem in all subsequent generations (40 x 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 x 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.

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*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 50×10^{-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	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]	
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]	
Prenatal Exposure		
Hematopoietic tumors/fetus	280[e]	
Solid tumors/fetus	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	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 x 10^{-6}/rad and 270 x 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 0-9	10-19	20-34	35-49	50+	Latent Period (years)	Expression Period (years)	Observation Period[a] (years)
All cancers									
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.

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*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,

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

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)

	Lung Cancer		Thyroid Cancer		Liver Cancer		Breast Cancer	
Age	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 (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 (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 100×10^{-6}/WLM. We recommend as a conservative procedure that the maximum value of 100×10^{-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	
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 <u>age-averaged</u> 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,lat(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    ,8hlu-hema ,8hlu-solid,8hother   ,8hleu/bone,
     >8hlymphoma,8hbeir 1  ,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              41
c         (48)                   tqx                 5f12.9
c         (40)                   agedis              6f10.0
c           1                    xnum                2f10.0
c           1                    norgan              15
c           1                    korgan,let,model,nfollw 415
c           1                    xnum                2f10.0
c          (8)                   can5y               7f10.4
c           1                    n1nv                15
c         n1nv                   time,dosinv         2f10.2
c           1                    ntable              i3
c           1                    nyear               1415
c
c the array iflag 1s used to 1nsert user-suppl1ed data to the arrays
c tqx and agedis.  1f iflag.ne.1, default values based
c on un1ted states nat1onal average stat1st1cs w1ll be used.  the 1ndex
c 1 for 1flag corresponds to
c   tqx    (proport1on dy1ng 1n each age 1nterval)    for     1=1
c   aged1s (populat1on age d1str1but1on)              for     1=2
      read(50,10)(1flag(i),1=1,4)
   10 format(4i1)
c 1f iwrite(i)=1, the array correspond1ng to the value of 1
c (def1ned above) w1ll be pr1nted.  1f 1write(1).ne.1, no pr1ntout
c w1ll be prov1ded.
      read(50,10)(iwrite(1),1=1,4)
      1f(iflag(1).ne.1) go to 20
      read(50,15)((tqx(1,j),1=1,120),j=1,2)
   20 1f(1wr1te(1).eq.1) wr1te(55,115)((tqx(i,j),1=1,120),j=1,2)
   15 format(5f12.9)
  115 format(/t5,"proport1on dy1ng 1n each age 1nterval",
     > //t5,"male",/12(t5,10f11.9/),//t5,"female",/12(t5,10f11.9/))
      1f (iflag(2).ne.1) go to 30
      read(50,16)((aged1s(i,j),1=1,120),j=1,2)
   30 1f (1wr1te(2).eq.1) wr1te(55,116)((aged1s(1,j),1=1,120),j=1,2)
   16 format(6f10.0)
  116 format(//t5,"age d1str1but1on by sex",
     > //t5,"male",/12(t5,10f11.5/),//t5,"female",/12(t5,10f11.5/))
      do 3 1=1,2
      do 4 j=1,120
      pop(1)=pop(1)+aged1s(j,1)
    4 cont1nue
    3 cont1nue
      do 1 i=1,2
      do 2 j=1,120
      aged1s(j,1)=aged1s(j,1)/pop(i)
    2 cont1nue
    1 cont1nue
      1f (1wr1te(2).eq.1) wr1te(55,600)(pop(1),1=1,2)
  600 format(/tt5,"populat1on totals used to normal1ze age d1str1but1on
     >tables",/t40,"males",t55,f10.2,/t40,"females",t55,f10.2)
c read 1n 1nput 1nformat1on, where
c
c         dose 1s the dose 1n rads,
c         let = 1   for low let rad1at1on
c             = 2   for h1gh let rad1at1on
c         korgan = cancer type (see subrout1ne getrsk for l1st1ng
c                           of cancer types)
c         model = 1 for absolute r1sk model
c                 2 for relat1ve r1sk model
c         xnum(1) = number of males 1n populat1on at r1sk
```

```
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",15)
      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-1
      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(1,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 111 (p.283).
      if (k.eq.1) go to 100
      do 700 1=1,111
      130=1+nfollw(iorg)
      if (130.gt.111) 130=111
      do 705 j=i,130
      jage=j-2
      call getrsk(rc,iage(1),jage,k,let(iorg),model(iorg),ngendr,
     > dosx)
      idif=j-1
      if(idif.lt.latent) go to 705
      if (idif.eq.latent) go to 500
      if (idif.eq.nfollw(iorg)) go to 500
      xrad(1)=xrad(1)+rc*dosx
      xnat(1)=xnat(i)+canrte(j,ngendr,k)
      go to 705
  500 continue
      xrad(1)=xrad(1)+(rc*dosx)/2.0
      xnat(1)=xnat(1)+canrte(j,ngendr,k)/2.0
  705 continue
      if (1.ge.101) go to 772
      if(xnat(i).lt.1.0e-09) write(55,771)1,xnat(1),xrad(1)
  771 format(/1x,"check value of xnat",15.2f20.10)
      if (xnat(i).lt.0.00001) go to 772
      r(1,k)=xrad(1)/xnat(1)
  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 111, p.195)
      riskave=0.0
      do 773 1j=12,21
      riskave=riskave+r(1j,k)
  773 continue
      riskave=riskave/10.
      do 774 1j=1,11
      r(ij,k)=riskave
  774 continue
      write(55,942)gender(ngendr),aname(k),(iage(1),r(1,k),xrad(1),
     > xnat(1),1=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 1=1,111
      jage=200.
      dosx=1.0
      call getrsk(rc,iage(1),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 lexcept 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
```

TABLE C-I (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

----

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
.00397376	.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.	2707.492	51.845	2655.646	51881.	548568.	10.30
359	71	72	.05341402	50527.	2747.977	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)

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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	.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

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TABLE C-I (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	.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)

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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

```
 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     .00023
       .00016     .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


 ****************************************************************************************************************



 ****************************************************************************************************************



  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	1x	tdx	drad	dref	t1x	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	96615.	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	234.478	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.	1245[illegible].	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
303	66	67	.03745423	61599.	2326.099	18.963	2307.136	60436.	763915.	12.40
204	67	68	.04043358	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.	17985.	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.	63112.	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

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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	.6686e-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	.166e+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	.636e-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	.00214385	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	.00523946	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	89610.	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.	78.151	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	98228.	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	27.863	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	.7667e-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)

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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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