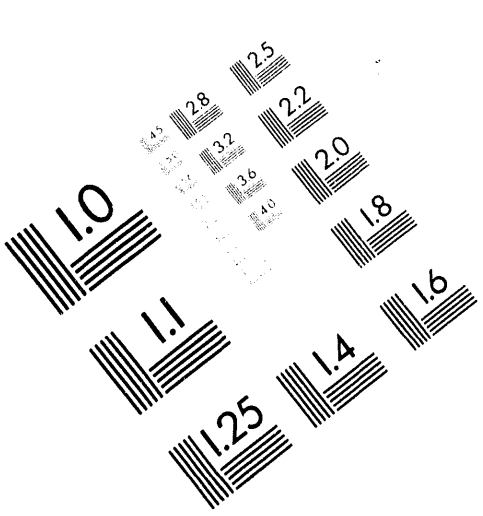

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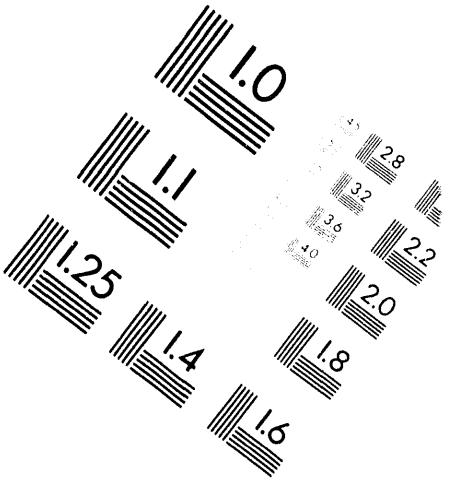

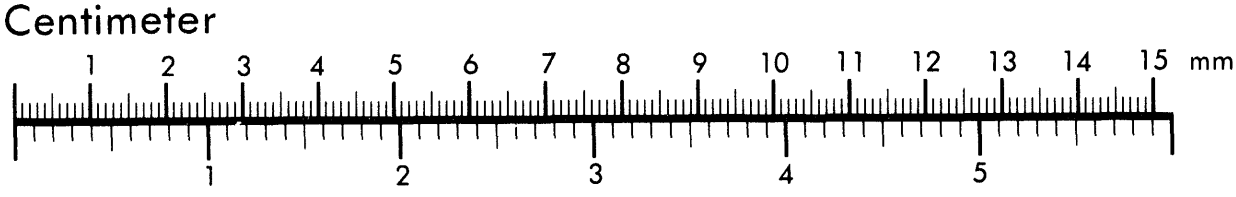

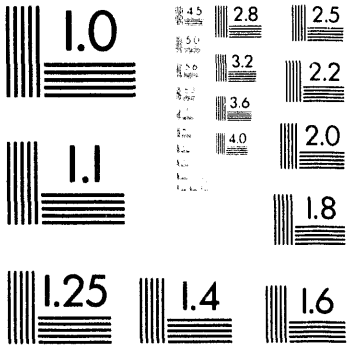

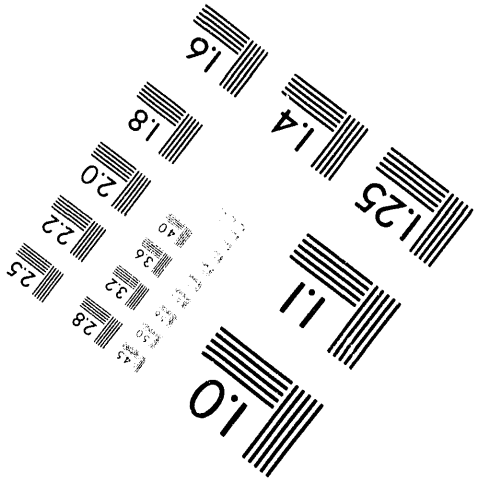

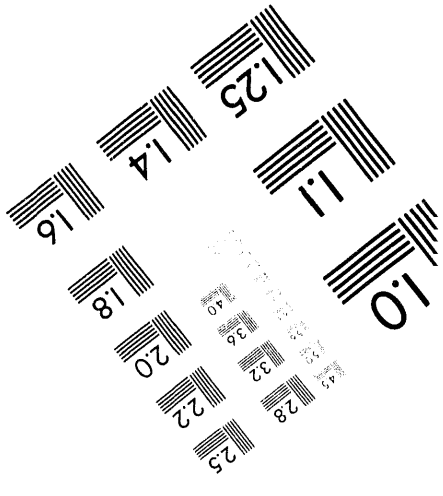

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NUREG/GR–0011

Information Bias and Lifetime Mortality Risks of Radiation-Induced Cancer

Low LET Radiation

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Available from

Superintendent of Documents
U.S. Government Printing Office
Mail Stop SSOP
Washington, DC 20402-9328

and

National Technical Information Service
Springfield, VA 22161

NUREG/GR-0011

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Manuscript Completed: February 1994
Date Published: April 1994

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ABSTRACT

Additive and multiplicative models of relative risk were used to measure the effect of cancer misclassification and DS86 random errors on lifetime risk projections in the Life Span Study (LSS) of Hiroshima and Nagasaki atomic bomb survivors. The true number of cancer deaths in each stratum of the cancer mortality cross-classification was estimated using *sufficient* statistics from the EM algorithm. Average survivor doses in the strata were corrected for DS86 random error (σ=0.45) by use of reduction factors. Poisson regression was used to model the corrected and uncorrected mortality rates with covariates for age at-time-of-bombing, age at-time-of-death and gender. Excess risks were in good agreement with risks in RERF Report 11 (Part 2) and the BEIR-V Report. Bias due to DS86 random error typically ranged from -15% to -30% for both sexes, and all sites and models. The total bias, including diagnostic misclassification, of excess risk of nonleukemia for exposure to 1 Sv from age 18 to 65 under the non-constant relative projection model was -37.1% for males and -23.3% for females. Total excess risks of leukemia under the relative projection model were biased -27.1% for males and -43.4% for females. Thus, nonleukemia risks for 1 Sv from ages 18 to 65 (DREF=2) increased from 1.91%/Sv to 2.68%/Sv among males and from 3.23%/Sv to 4.02%/Sv among females. Leukemia excess risks increased from 0.87%/Sv to 1.10%/Sv among males and from 0.73%/Sv to 1.04%/Sv among females. Bias was dependent on the gender, site, correction method, exposure profile and projection model considered. Future studies that use LSS data for U.S. nuclear workers may be downwardly biased if lifetime risk projections are not adjusted for random and systematic errors. (Supported by U.S. NRC Grant NRC-04-091-92).

This report makes use of data obtained from the Radiation Effects Research Foundation (RERF) in Hiroshima, Japan. RERF is a private foundation funded equally by the Japanese Ministry of Health and Welfare and the U.S. Department of Energy through the U.S. National Academy of Sciences. The conclusions in this report are those of the authors and do not necessarily reflect the scientific judgement of RERF or its funding agencies.

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ACKNOWLEDGEMENTS

The successful completion of this project[1] would not have been possible without the help, suggestions and scientific advice of several individuals. The following individuals contributed, in part, to this study and are gratefully acknowledged:

Ms. Barbara Brooks	Department of Energy
Dr. Sharon Cooper	University of Texas
Dr. Tom Downs	University of Texas
Dr. Mark Durst	Lawrence Berkeley Laboratory
Dr. Edward Frome	Oak Ridge National Laboratory
Dr. Ethel Gilbert	Battelle Pacific Northwest Laboratory
Dr. Charles Land	National Cancer Institute
Dr. Mary McConney	Hirosoft International Corporation
Dr. Colin Muirhead	National Radiological Protection Board(UK)
Dr. Donald Pierce	Radiation Effects Research Foundation
Dr. Dale Preston	Radiation Effects Research Foundation
Dr. Yukiko Shimizu	Radiation Effects Research Foundation
Dr. Mary Ann Smith	University of Texas
Ms. Terry Smith	UT M.D. Anderson Cancer Center
Dr. Shlomo Yaniv	Nuclear Regulatory Commission

[1]This study was a dissertation thesis in the School of Public Health at the The University of Texas–Health Science Center at Houston. The first author's current address is: Kelsey-Seybold Clinic, Mail Code SD23, Lyndon B. Johnson Space Center, Houston, Texas 77058.

APR 2 6 1994

FOREWORD

The Nuclear Regulatory Commission, through its Grant Program has supported several educational institutions. One of the criteria considered in awarding a grant is the benefit to the graduate research program of the institution, e.g., graduate student training.

NUREG/GR-0011 "Information Bias and Lifetime Mortality Risks of Radiation - Induced Cancer" is based on the doctoral dissertation of the senior author. The research was supported by an NRC grant.

NUREG/GR-0011 is published for information only. Publication of this report does not necessarily constitute NRC approval or agreement with the information contained herein.

Donald A. Cool

Donald A. Cool, Chief
Radiation Protection and Health
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Office of Nuclear Regulatory Research

1 EXECUTIVE SUMMARY

The purpose of the present study was to measure the effect of random and systematic errors in the measurement of radiation exposures and cancer-specific mortality misclassification in the Life Span Study (LSS) of Hiroshima and Nagasaki atomic bomb survivors and the Surveillance, Epidemiology, and End Results (SEER) program on lifetime mortality risks of radiation-induced cancer for U.S. nuclear workers. The LSS is a radiation effects cohort study that has been conducted by the Radiation Effects Research Foundation (RERF), formerly known as the Atomic Bomb Casualty Commission (ABCC), since 1947. The RERF is a private non-profit Japanese Foundation, supported equally by the Government of Japan through the Ministry of Health and Welfare, and the U.S. Government through the National Academy of Sciences under contract with the Department of Energy. The SEER program is a nation-wide cancer reporting system run by the National Cancer Institute of the National Institutes of Health.

Although every imaginable aspect of the effect of information bias[1] on radiation-induced cancer in the LSS has been subject to scrutiny over the last decade, the one part that has managed to elude systematic investigation has been the joint analysis of information bias and lifetime risk projections for U.S. nuclear workers. The primary intent of this study was to measure the bias in lifetime mortality risks of radiation-induced cancer that have been generated with and without adjustment for Dosimetry System - 1986 (DS86) random error and diagnostic misclassification of mortality rates in the LSS and SEER program. Adjustments for DS86 random errors and diagnostic misclassification of LSS cancer deaths were made during dose-response analysis with Poisson regression using the AMFIT[2] computer program. Adjustments for diagnostic misclassification of cancer deaths in the SEER data were made during lifetime risk projection using the SURVRAD[3] computer program. Death certificate and confirmation and detection rates for the LSS in the years 1950-1975 were based on results of the RERF Pathology Studies. Confirmation and detection rates for the SEER program were obtained from reports published in the open literature.

The major findings of this investigation were:

(1). As age at death increased a greater proportion of true cancer deaths were attributable to non-cancer deaths because the true number of cancer deaths is equal to the sum of the product of the observed cancer deaths and the probability that the observed cancer deaths are correctly classified and the product of the observed non-cancer deaths and one minus the the probability that the observed non-cancer deaths were correctly classified (see Eq. 5 in §3.2.2).

(2). Poisson regression resulted in fitted maximum likelihood models that were in concordance with the observed data. When the goodness-of-fit of regression models containing time-dependent covariates is reasonable, non-constant lifetime risk projection should be used.

(3). Excess relative risk coefficients for the RERF and BEIR-V models were in good agreement with those published in RERF Report 11 (Part 2) and the BEIR-V report. Small differences existed between regression results for RERF models that contained parameters for age at-time-of-bombing (ATB), age at-time-of-death (ATD), and gender because organ dose estimates were used rather than shielded kerma. Thus, the lifetime

[1]Information bias is the distortion of risk estimates caused by random and systematic *misclassification* of a subject's exposure status or diagnosis of death or disease.

[2]AMFIT is trademark of Hirosoft International Corporation. See §3.3.1.

[3]SURVRAD is neither an abbreviation nor an acronym. See §3.4.1.

based on these models were slightly higher than those that would obtain from the use of coefficients in RERF Report 11.

(4). Statistical modeling with the BEIR-V models provided regression coefficients that were almost exactly identical to those in the BEIR-V report. For leukemia, the linear-quadratic contribution of dose to excess mortality was slightly lower than that in the BEIR-V report. Lifetime risks based on the BEIR-V models were similar to those published in the BEIR-V Report (NRC, 1990). Bias due to DS86 random error for the digestive site was smaller than bias in the RERF non-constant nonleukemia projection models, which was most likely due to truncation of dose equivalent to 4 Sv. The correction of diagnostic misclassification in excess risks for the BEIR-V digestive cancer site had little effect on bias (-2%) because records with an age at death beyond 75, when cancer misclassification rises markedly, were excluded.

(5). Using a Dose-Rate Reduction Effectiveness Factor (DRREF) of two and no correction for DS86 random error or diagnostic misclassification in the non-constant relative projection model, lifetime risks (%/Sv) of nonleukemia among males exposed acutely to 1 Sv at age 25, 45, 65 or continuously from ages 18 to 65 were 2.10%, 2.78%, 1.20% and 1.91%. For females, nonleukemia lifetime risks for the same exposure profiles were 3.49%, 4.32%, 1.97% and 3.23%. Excess leukemia risks for 1 Sv at 25, 45 and 65 and over the years 18 to 65 were 0.35%, 0.46%, 2.46% and 0.87% for males and 0.26%, 0.41%, 1.96% and 0.73% for females. These data were in good agreement with the results of Land and Sinclair (1991). By way of comparison, for exposure from ages 18 to 65, excess nonleukemia risks based on the constant relative projection model were 2.84% for males and 4.75% for females. The risks of leukemia among males was 0.75% and among females was 0.64%. Therefore, lifetime risk estimates based on constant models did not underestimate risks projected by non-constant models.

(6). The correction of differential diagnostic misclassification with leukemia and nonleukemia (and non-cancer) confirmation rates that were stratified on T65DR dose (DS86 shielded kerma was converted to T65DR shielded in order to select T65DR-specific confirmation rates) resulted in bias that was negative. Confirmation rates for leukemia and nonleukemia that were stratified on age ATD did not provide bias that was more negative than that obtained with DS86-specific confirmation rates. Correction of diagnostic misclassification using confirmation rates that were crude or stratified on either gender or city and gender resulted in bias that was negative or positive. The bias of excess risk of nonleukemia due to diagnostic misclassification for 1 Sv at age 25, 45, 65 or continuously from ages 18 to 65 under the non-constant relative projection model was -5.0% (2.13%/Sv vs. 2.24%/Sv), -7.3% (2.78%/Sv vs. 2.99%/Sv), -38.9% (1.20%/Sv vs. 1.67%/Sv) and -11.3% (1.91%/Sv vs. 2.13%/Sv) for males and -1.5% (3.49%/Sv vs. 3.54%/Sv), -3.9% (4.32%/Sv vs. 4.49%/Sv), -26.2% (1.97%/Sv vs. 2.48%/Sv) and -6.3% (3.23%/Sv vs. 3.43%/Sv) for females. For leukemia excess risks under the same dose profiles, the bias due to diagnostic misclassification was -6.0% (0.36%/Sv vs. 0.37%/Sv), -69.7% (0.46%/Sv vs. 0.77%/Sv), -23.3% (2.46%/Sv vs. 3.04%/Sv) and -23.9% (0.87%/Sv vs. 1.09%/Sv) for males and -12.1% (0.26%/Sv vs. 0.30%/Sv), -83.4% (0.41%/Sv vs. 0.75%/Sv), -40.9% (1.96%/Sv vs. 2.77%/Sv), and -42.8% (0.73%/Sv vs. 1.05%/Sv) for females. When the nonleukemia Poisson regression coefficients from Sposto et al. (1992) were used to project lifetime risks under the non-constant relative model, the bias due to diagnostic misclassification for 1 Sv acute at 25, 45, or 65 and over a career (18 to 65) was -1.0% (2.61%/Sv vs. 2.64%/Sv), -4.0% (5.72%/Sv vs. 5.95%/Sv), 1.3% (2.39%/Sv vs. 2.36%/Sv), and -10.0% (4.90%/Sv vs. 5.39%/Sv) for males and 13.3% (3.02%/Sv vs. 2.62%/Sv), 3.2% (6.49%/Sv vs. 6.28%/Sv), 5.2% (2.46%/Sv vs. 2.32%/Sv) and 2.5% (5.92%/Sv vs. 5.77%/Sv) for females.

(7). The use of reduction factors to correct for DS86 random error in survivor doses indicated that lifetime risks were negatively biased 15%-30%. Bias of excess risk (non-constant relative projection and correction for diagnostic misclassification) of nonleukemia due to DS86 random errors for 1 Sv at age 25, 45, 65 or continuously from ages 18 to 65 was -27.1% (2.24%/Sv vs. 2.28%/Sv), -23.5% (2.99%/Sv vs. 3.69%/Sv), -24.6% (1.67%/Sv vs. 2.08%/Sv) and -23.7% (2.13%/Sv vs. 2.63%/Sv) for males and -19.6% (3.54%/Sv vs. 4.24%/Sv), -13.9% (4.49%/Sv vs. 5.12%/Sv), -15.9% (2.48%/Sv vs. 2.88%/Sv) and -14.9% (3.43%/Sv vs. 3.94%/Sv) for females. For leukemia excess risks under the same dose profiles, the bias due to DS86 random error was -17.4% (0.37%/Sv vs. 0.44%/Sv), -14.2% (0.77%/Sv vs. 0.88%/Sv), -13.3% (3.04%/Sv vs. 3.44%/Sv) and -14.0% (1.09%/Sv vs. 1.24%/Sv) for males and -15.1% (0.30%/Sv vs. 0.34%/Sv), -11.6% (0.75%/Sv vs. 0.84%/Sv), -10.9% (2.77%/Sv vs. 3.07%/Sv), and -11.4% (1.05%/Sv vs. 1.17%/Sv) for females.

(8). The correction of mortality misclassification in SEER baseline rates used in lifetime risk projection (non-constant relative model) increased excess risks by 2.1% for nonleukemia and decreased risk by 10.8% for leukemia.

(9). The total bias of excess risk of nonleukemia for exposure from age 18 to 65 under the non-constant relative projection model was -37.1% for males and -23.3% for females. For leukemia excess risks under the relative projection model, the total bias was -27.1% for males and -43.4% for females. Thus, nonleukemia risks increased 37.1% for males (1.91%/Sv to 2.68%/Sv) and 23.3% for females (3.23%/Sv to 4.02%/Sv) and leukemia risks increased 27.1% (0.87%/Sv to 1.10%/Sv) for males and 43.4% (0.73%/Sv to 1.04%/Sv).

(10). In most cases, bias due to diagnostic misclassification for lifetime risk projections using the relative model was more positive and less erratic than bias for the absolute and transported relative models. With regard to risk projection and future studies of information bias, we recommend the relative model because its use, when compared with other models, resulted in biases with lower variation across gender, sites and exposure profiles.

It is patently clear that the effects of diagnostic misclassification and DS86 random errors are dependent on gender, site, correction methods, exposure profiles and projection models. The effects of increased internal validity on the *generalizability* of Japanese radiation risk information to U.S. nuclear workers are only revealed when lifetime risks are projected after adjustments are made for random and systematic errors. Future studies in which LSS data are generalized to U.S. nuclear workers may be biased if lifetime risks are not adjusted for random and systematic errors.

Readers who favor our results should not let their enthusiasm overtake their knowledge of bias and regard our assumptions as fixed verities, rather than empirical hypotheses. The major purpose for undertaking this study was to confirm the impression that there are certain advantages of projecting lifetime risk after performing Poisson regression when studying information bias in the LSS. Since we did not employ logistic regression to estimate cancer misclassification probabilities and did not fully implement the EM algorithm to impute missing data where there was no autopsy information, this study should be regarded as an investigation into the most fundamental assumptions. As a result, new phenomena in the LSS should not force a reevaluation of this study's findings.

2 INTRODUCTION

Recent studies have conclusively demonstrated that diagnostic misclassification and random errors in the Dosimetry System-1986 (DS86) are major components of information bias that can affect lifetime risk projections based on the Life Span Study (LSS) of Hiroshima and Nagasaki atomic bomb survivors (Sposto et al., 1991; Sposto et al., 1992; Pierce and Vaeth, 1989; Pierce et al., 1990, Pierce and Vaeth, 1991; Pierce et al., 1991; Ron et al., 1991). On a simplistic level, the relationship between information bias and lifetime risk is evident to the epidemiologist who would adjust cancer mortality rates used in dose-response analyses with the ratio of the cancer confirmation[4] rate to the cancer detection rate, or to the statistician who would suggest that a single excess relative risk coefficient adjusted for DS86 random error results in an increase in projected lifetime risk. A complete analysis of information bias or lifetime risk projection, however, requires a more thorough understanding of both topics. Yet, few scientists who write on these general areas actually study the effects of information bias on lifetime risk by conducting dose-response analysis and projecting lifetime risks with the results.

The purpose of this study, then, was to quantify changes in excess cancer mortality risks by correcting for 1) random error in individual DS86 dose equivalents; 2) diagnostic misclassification of cancer rates in the LSS used in dose-response analysis; and 3) diagnostic misclassification of cancer mortality in U.S. vital statistics that are used in lifetime risk projection.

2.1 Precision, Validity, Generalizability and Bias

Random error is a *precision* issue in epidemiologic research that is related to statistical variation of estimates. It is based mainly on sampling variation and is not generally considered to be of the same importance as systematic error (*validity*). One should not sacrifice validity for the sake of precision, at least under the stultifying conditions that an increasing number of epidemiologists work in today. Figure 1 shows the relationship between precision (random error) and validity (systematic error) in epidemiologic research.

Kleinbaum et al. (1982) suggest that there are four populations (Figure 2) typically involved in an epidemiologic investigation of disease etiology. Under the present study, the *external population* is the group of U.S. nuclear workers for which inclusion into the LSS has been restricted but to which results are *generalized.* Because risk information from the LSS is generalized to U.S. working populations, one must ensure that the *external validity* is hinged on several criteria related to biologic plausibility, strength of association, dose-response gradients, temporality, disease specificity and consistency with other findings which, collectively, act to discredit the *null* or biological hypothesis. The *study population* is comprised of LSS subjects from which the effect estimator, $\hat{\theta}$, is measured. The effect estimate, θ°, for the *actual population*, is represented by $\hat{\theta}$ in the sampled study population. The true effect measure, θ, is for the *target population* through which *internal validity* and to which statistical (random) and methodological (systematic) issues apply. Figure 3 shows schematically the hierarchy of populations in the LSS.

The effect measure, $\hat{\theta}$, is an *asymptotically unbiased* estimator of θ if random and systematic errors are corrected and

$$\lim_{n \to \infty} E(\hat{\theta}) = \theta \tag{1}$$

[4] Confirmation and detection rates are defined in §3.2.1.

where $E(\hat{\theta})$ is the expectation of θ. The *bias* of θ relative to $\hat{\theta}$ when $\hat{\theta}$ is uncorrected for random and/or systematic error is functionally composed as

$$BIAS(\hat{\theta},\theta) = (\hat{\theta} - \theta) / \theta \tag{2}$$

and serves as the underlying construct for comparing lifetime risks that are estimated with and without adjustments for DS86 random error and diagnostic misclassification. When the effect estimate, $\hat{\theta}$, is greater than the true association, θ, bias is *positive*, however, if the effect estimate, $\hat{\theta}$, is less than the true association, θ, then bias is *negative*. If $\hat{\theta}$ and θ are both on either side of the null value and $\hat{\theta}$ is closer to the null value than θ, then bias is defined as being *toward the null*. If, on the contrary, $\hat{\theta}$ is further away from the null than θ, provided they are both on the same side of the null value, then the bias is said to be *away from the null*. As an example, if the lifetime mortality risk of radiation-induced cancer, $\hat{\theta}$, is 3%/Sv when no correction for random and systematic error is made and the true estimate, θ, is 5%/Sv (after error is adjusted), the bias is negative and is toward the null. Likewise, if the uncorrected lifetime risk is 3%/Sv and the corrected estimate is 2%/Sv, then the bias is positive and is away from the null. A simple point to remember is that if excess risks are increased after making an adjustment for random and systematic error, the bias is negative and towards the null.

2.2 Effects of Random Error on Dose-Response

Random error in, say, the DS86 system is attributable to the methodology used for estimating DS86 doses and survivor response (Thiessen and Kaul, 1991). As a paradigm, Sposto et al. (1991) recently sampled 1028 subjects from the Adult Health Study (AHS) population (which is a sample of the LSS population) to estimate random error in the DS86 by modeling the dose-response of the combined effects of severe epilation and chromosome aberrations (CA). Figure 4 shows the proportion of cells with CA as a function of corrected and uncorrected DS86 dose for the 1028 survivors. While the two straight lines represent the fitted regression lines for the per cent CA of the no epilation and epilation groups, respectively, the two curvilinear lines represent the fitted dose-response functions (same groups) assuming a 45% coefficient of variation (CV) in random error. This finding by Sposto et al. should not be surprising because recent analyses in the LSS have shown that the average survivor true dose, Avg($x|z$), is less than the estimated dose, z, at any level of z because the deviations (x-z) tend more toward the negative rather than the positive (Pierce et al., 1990; Pierce and Vaeth, 1991; Pierce et al., 1991). In addition, the ratio of Avg($x|z$) to the average estimated dose, Avg($z|x$), decreases from unity as z increases because, for increasing z, there are fewer survivors. The effect of random error on the dose-response in the previous example suggests that a majority of individuals with severe epilation and notable CA have been assigned DS86 doses which are equal to AHS participants without severe epilation and CA. Thus, to correct for the random errors in DS86, one would most likely increase the slope of the no epilation group by a factor, which according to Pierce and Vaeth (1989) is called the Linear Extrapolation Overestimation Factor or Dose Rate Reduction Effectiveness Factor. Figure 5 illustrates the the relationship between Avg($z|x$) and Avg($x|z$) as a function of CV for the two cities.

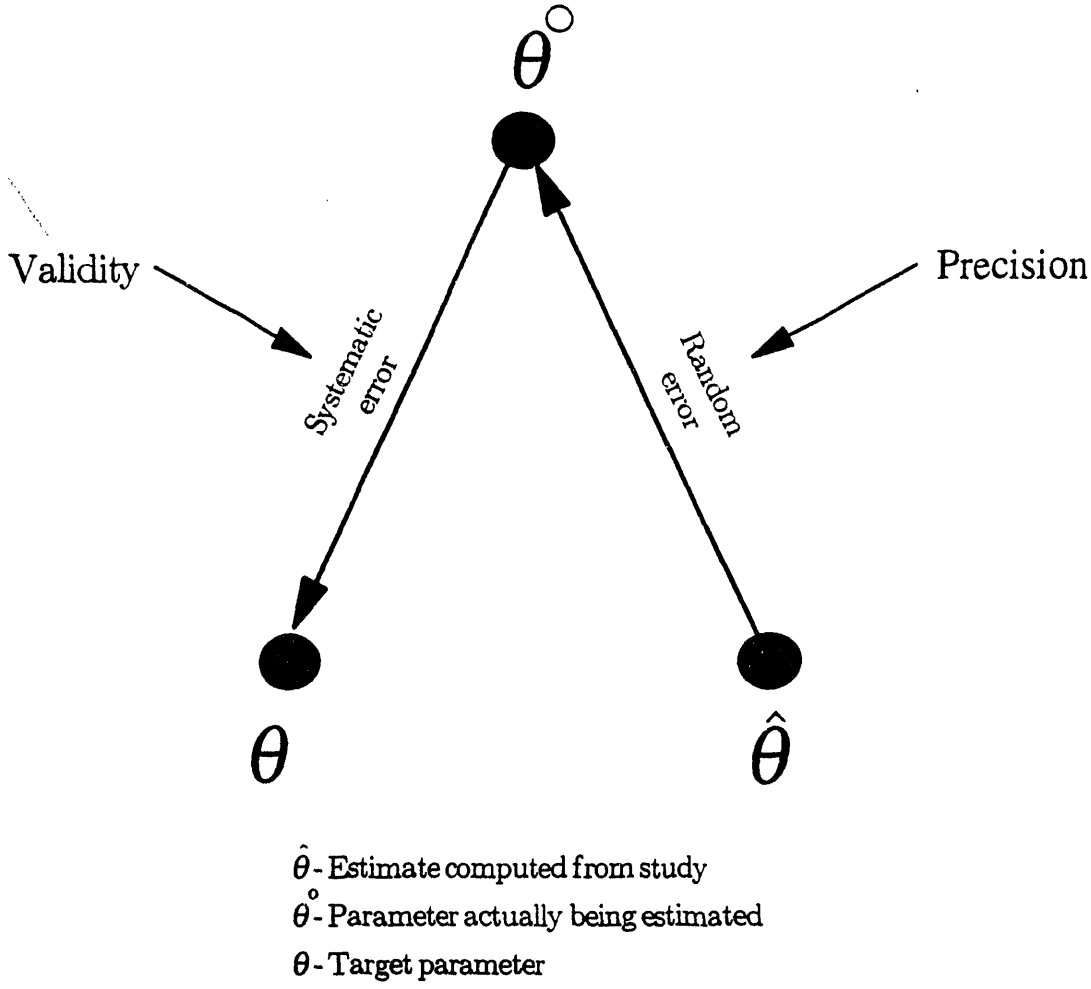


Figure 1: Random and systematic error in epidemiologic research. (With permission, ©1982 Van Nostrand Reinhold)

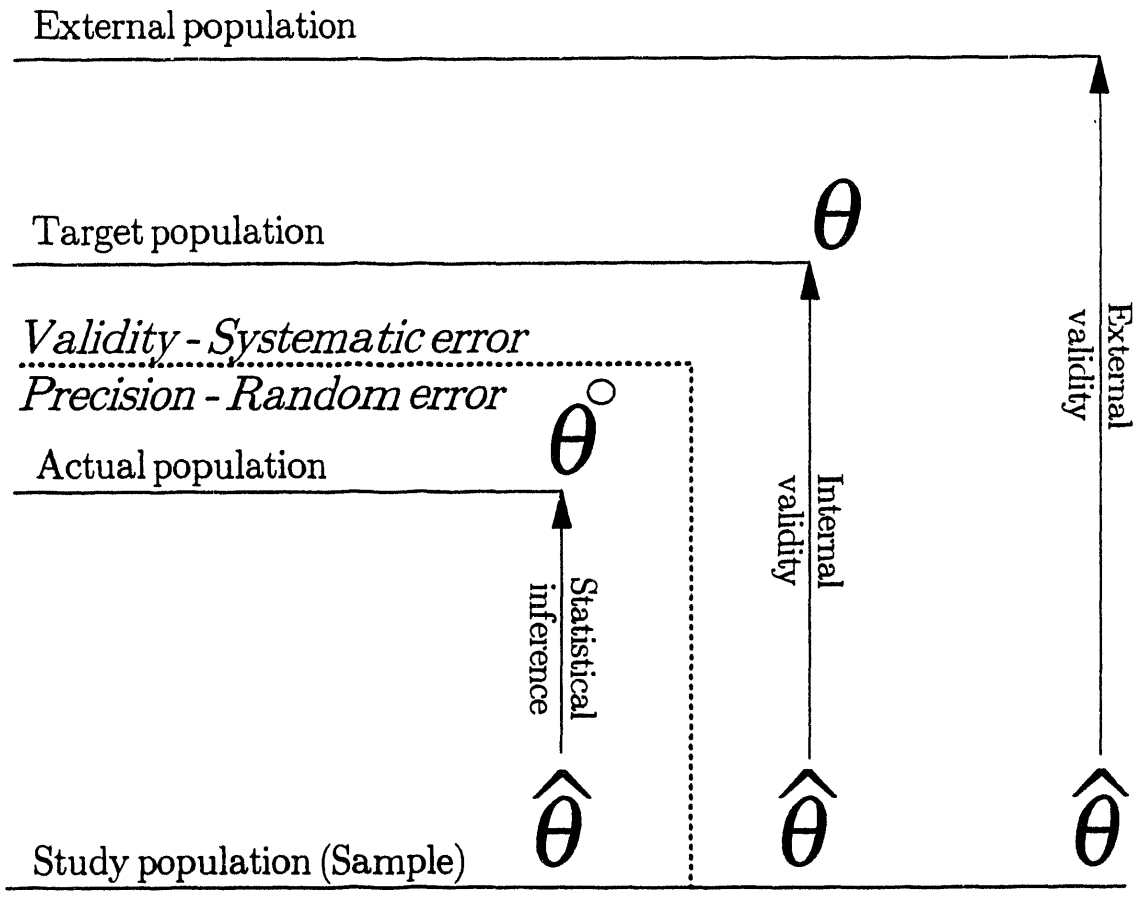


Figure 2: Hierarchy of populations in epidemiologic research. (With permission, ©1982 Van Nostrand Reinhold)

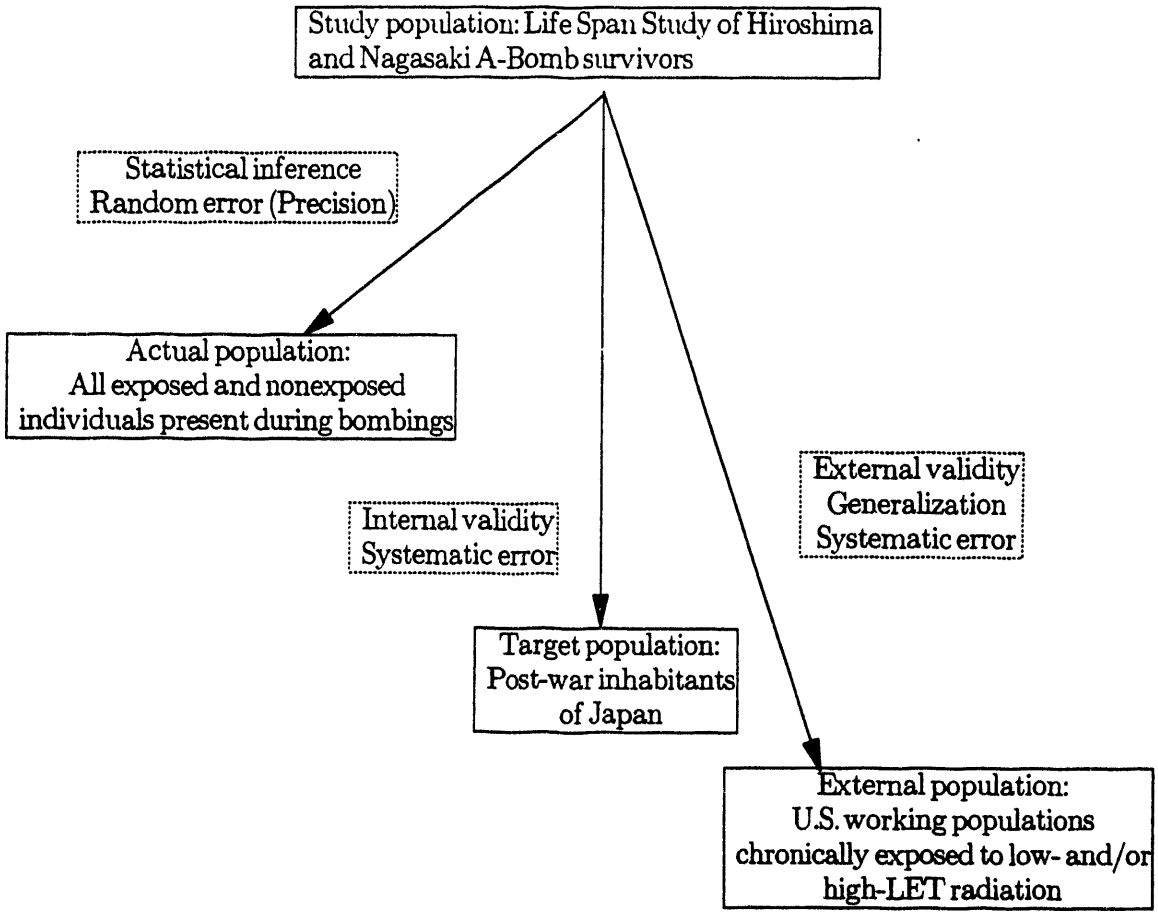


Figure 3: Hierarchy of populations in the Life Span Study.

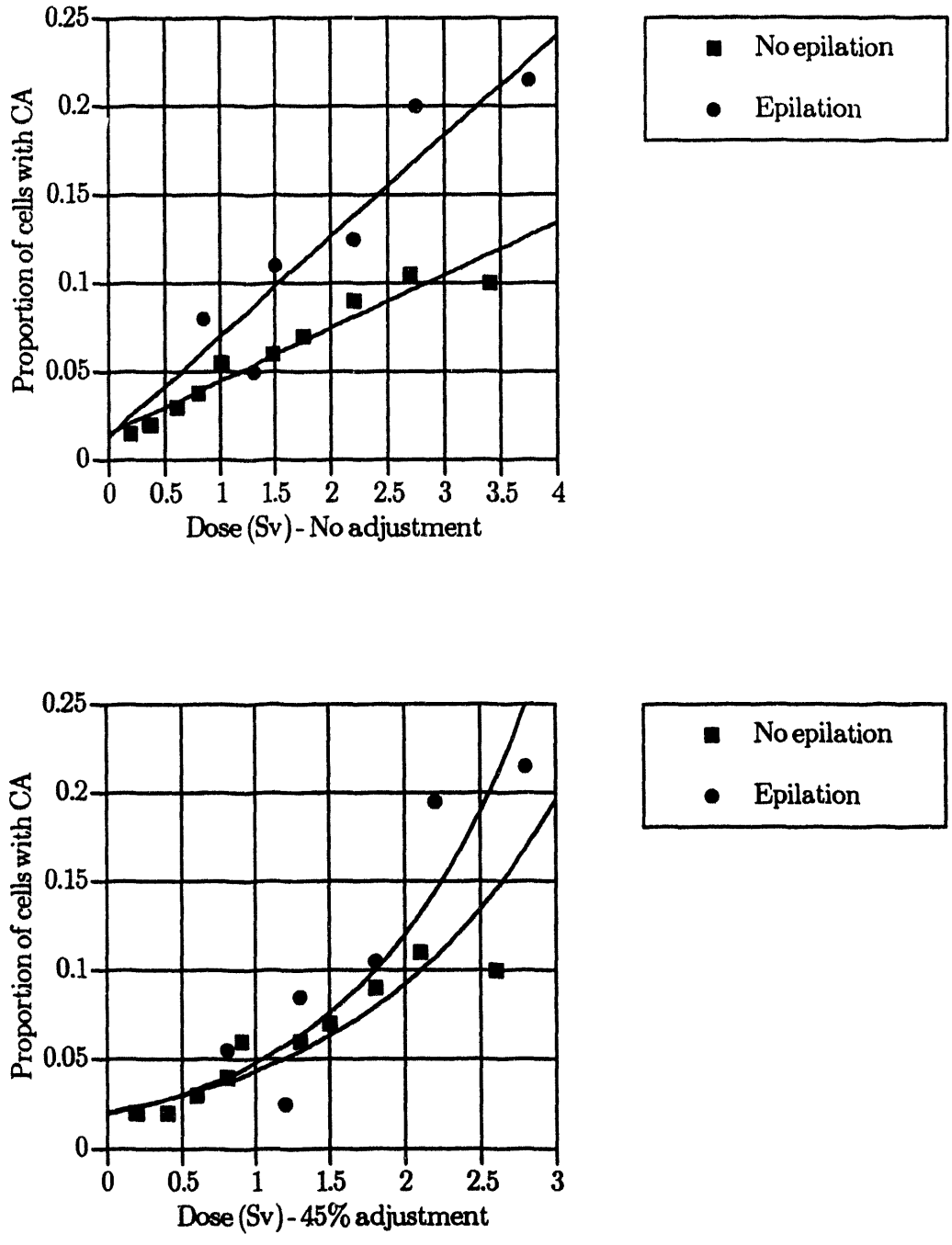


Figure 4: Chromosome aberration (CA) dose-response within epilation groups. Doses adjusted for 45% random error. Adapted from Sposto et al. (1991).

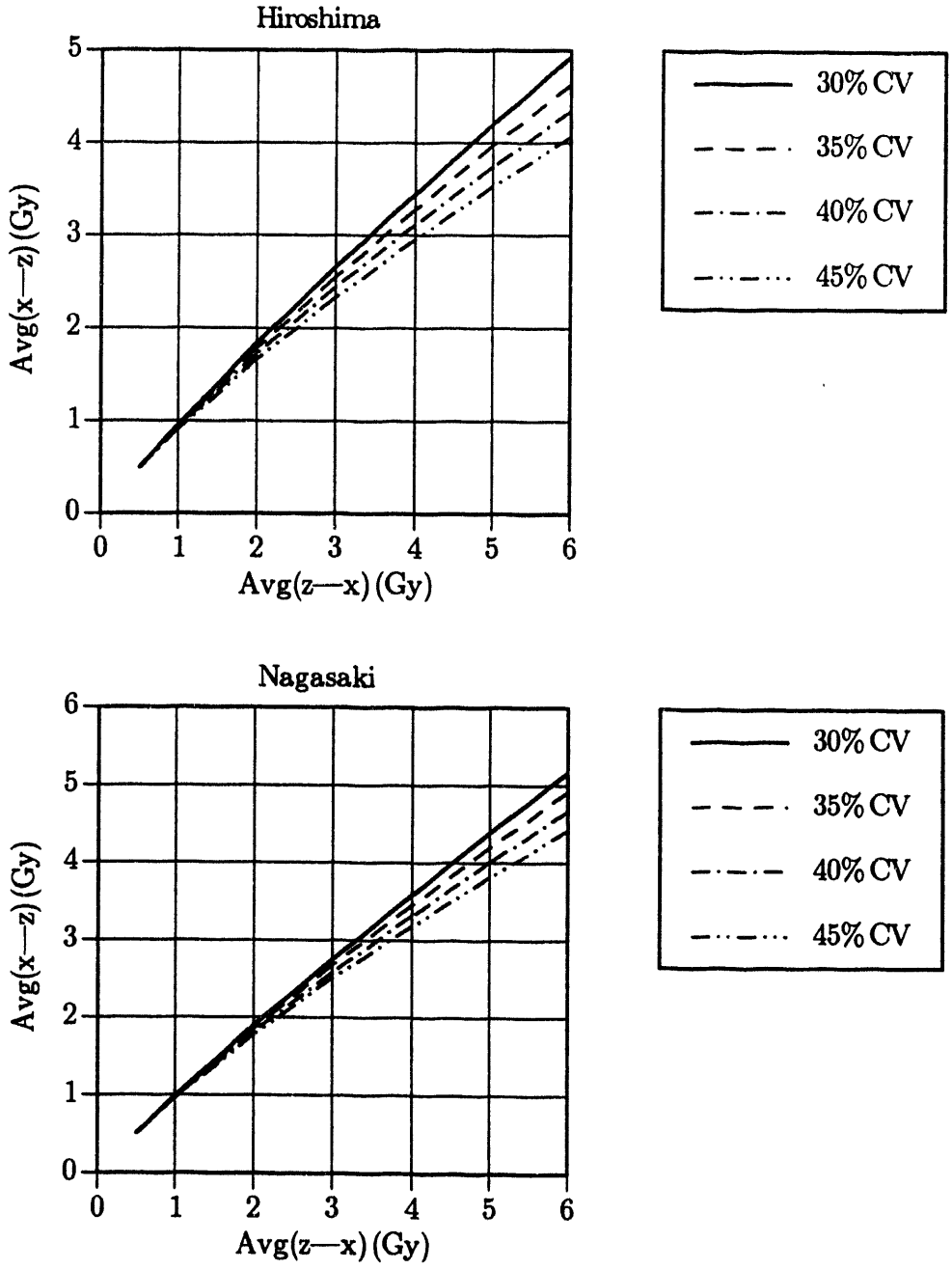


Figure 5: Plot of survivor true dose, Avg($x|z$), as a function of estimated dose, Avg($z|x$), for four levels of random error. Adapted from Pierce and Vaeth (1991).

Thiessen and Kaul (1991) reported that random uncertainties in DS86 range from 15% to 40% and are mainly attributable to survivor location and shielding parameters (DS86 input) and the choice of shielding factors and an appropriate model (DS86 methodology). Jablon (1971) has suggested that a survivor's reported location on the questionnaires used for dosimetry could have been affected by simple errors due to postconcussion amnesia or to deliberate mistatements hinged on beneficial welfare laws that were dependent on distance from the hypocenter. Random errors in T65DR doses were also analyzed by Gilbert (1982). Her results indicated that by truncating shielded kerma to 600 Gy, bias was reduced but at the expense of a substantial loss of power. Moreover, if the standard errors of the estimates are large, then moderate bias due to random error in doses may be moot.

The overall effect of DS86 random error on dose-response is a downward bias of the risk coefficients in either the linear (L) or linear-quadratic (LQ) models. If we model with cancer rates held constant and use doses that are not underestimated, then there will be a downward bias of the regression (risk) coefficients. On the contrary, if dose is underestimated, then the regression coefficients in the L and LQ models must make up for the difference between the logarithms of baseline and fitted excess rates, thus, risks become increased. It warrants noting that increases in neutron relative biological effectiveness (RBE) can increase dose equivalent and result in decreased risk coefficients. However, if the neutron component of dose equivalent is reduced, then there will be a increase of risk (*regression*) coefficients. This is what happened with the reduction of the neutron component in Hiroshima during DS86: the risk coefficients increased because shielded kerma (gamma and neutron) decreased. It should be pointed out that the risk coefficients for DS86 when considering kerma are about 40% higher than T65DR, but when organ doses and new transmission factors are considered, the coefficients are similar (Shimizu et al., 1988).

2.3 Effects of Systematic Error on Dose-Response

Loss of validity in the LSS is attributable to information bias caused by 1) systematic errors in analytic and numerical calculations in DS86 and subsequent misclassification of exposure; 2) misclassification of disease in LSS subjects and 3) selection bias caused by using the 1950 census for cohort construction.

For dosimetry, Thiessen and Kaul (1991) cite sources of systematic error in DS86 arising from the spectral yield, burst altitude, megaton yield and efficiency, and cross sections to determine when the devices went critical and how much the air and shielding materials attenuated and scattered the incident radiation. Systematic errors in DS86 range from 10% to 15%.

Systematic error in the LSS is also attributable to a selection bias brought about by not sampling the Hiroshima and Nagasaki populations for subjects before the 1950 city censuses were available. The most recent study of systematic error and its effect on the dose-response curve in the LSS was carried out by Sposto et al. (1992). In their analysis, they estimated misclassification probabilities for cancer and non-cancer and discovered that, when adjusting for a 22% cancer misclassification probability, 839 non-cancer deaths needed to be reclassified as cancer deaths. In addition, after the correction was made for the 22% misclassification rate, they found that (for males at age ATB 25) the cancer excess relative risk increased from 0.494 to 0.553 (12%) and the number of excess deaths increased from 274 to 317 (16%). Their findings indicated that a downward bias of risk existed as a result of the underreporting of cancer as the underlying cause of death on

death certificates. More importantly, they demonstrated how to employ the results of the RERF Autopsy Program to increase the validity and generalizability of LSS results to other populations.

Another correction of a downward bias of excess relative and absolute risks occurred with the implementation of the new DS86 shielded kerma values, which resulted in an upward correction of a downward bias in shielded kerma and a subtle upward correction of a downward bias of organ doses. For the reader who is interested in comparisons of sex- and site-specific excess relative risks and absolute risks for the T65DR and DS86, see Report 11, Part. 1 (Shimizu et al., 1987).

2.4 Studies of Death Certificate Misclassification

The first extensive evaluation of death certificate validity in the Atomic Bomb Casualty Commission (ABCC) pathology studies was done by Stone and Anderson (1960) on 1165 Hiroshima autopsy cases obtained from 1949 through 1959. In their analysis, they tried to answer several questions generally related to death certificate validity: how representative of the target population was the sample of cases?; what was the accuracy of autopsy in terms of specifying a single underlying cause of death?; how accurately was the coding performed?; and finally, how comparable were the autopsy diagnoses and underlying cause of death reported on death certificates?

First, they found that the underlying cause of death on the death certificate affected the likelihood of being autopsied and that there was a higher proportion of deaths due to malignancy that were autopsied, rather than non-neoplastic diseases, as indicated by the high correspondence between necropsy and death due to neoplasm. This led them to believe that the population for whom the cases represented was simply unknown. Second, the requirement for a single cause of death caused more difficulty in terms of assigning a *correct* cause. They also discovered that anatomical findings may be variously interpreted. For example, when clinical information was not available at the time of post mortem evaluation, it was difficult to discern renal insufficiency from diabetes mellitus, hypertension, atherosclerosis, or the combination thereof. Third, it was known that from a sample of 1000 deaths in the ABCC study, there was a 97% agreement between autopsy diagnoses and underlying cause of death on death certificates. Coding in the present analysis was done by two trained coders and was therefore believed to be very accurate. Finally, the correspondence of underlying cause of disease and autopsy diagnoses for all neoplasms and leukemia were 92% and 86%, respectively. This showed that the International Statistical Classification (WHO,1959) worked quite well when comparing underlying cause of disease and autopsy diagnoses in this study.

In 1962, a joint pathology study of the A-bomb survivors was instituted among the ABCC, Japanese National Institutes of Health (JNIH), Hiroshima and Nagasaki City Medical Associations, Departments of Pathology of Hiroshima and Nagasaki University Medical Schools, the Hiroshima Red Cross Hospital, Atomic Bomb Hospitals of both cities, and Hiroshima University Research Institute for Nuclear Medicine and Biology (Zeldis and Matsumoto, 1962)[5]. This effort was largely due to the *Unified Study Plan* which called for the mutual support of well-controlled studies to combine clinical, pathologic and vital statistics investigations on 100,000 individuals who were either present in these cities and received large doses of radiation, present in these cities but suffered no radiation injury, or not in the cities at all; this sample of 100,000 persons was called the *Life Span Study*.

[5]ABCC Technical Report 12-62 was based on a draft report by L.J. Zeldis and Y.S. Matsumoto and, in part, on previous suggestions by T. Francis, Jr., S. Jablon, and F.E. Moore.

The plan also called for a new autopsy procurement plan in the LSS since previous work showed strong evidence for selection (Stone and Anderson, 1960). In the ensuing pathology studies, factors influencing autopsy selection were analyzed objectively to determine how the autopsy series might be used for epidemiologic investigations. Immediately, systematic coverage of both cities was begun to collect information on recent deaths. Screening was implemented to determine status within the LSS sample and permission to conduct autopsy was sought from families and others who were concerned. The results of this work were published in Reports 1 through 4 of the ABCC-JNIH Pathology Studies in Hiroshima and Nagasaki (Angevine et al., 1963; Beebe et al., 1967; Steer et al., 1973; Yamamoto et al., 1978).

The latest report of the LSS Pathology Studies, Report 4, suggested that a peak autopsy rate of 45% was reached in 1963 after which time the rate dropped to 15% in 1975 (Yamamoto et al., 1978). The rate averaged 19% from 1971 to 1975. An unusual finding in the report was that from 1961-75, there was a 25.5% autopsy rate on individuals dying at home; this was a direct result of implementing the autopsy procurement plan. Confirmation and detection rates for neoplasms were higher than those for cerebrovascular and cardiovascular disease, however, there was often disagreement between death certificate and autopsy diagnosis. Nonetheless, it must be kept in mind that the purpose of these analyses was to verify death certificate accuracy in the context of specifying radiation effects. The use of autopsy information alone is limited by the amount and selective nature of such data. In 1975, it was recommended that the autopsy program be terminated. Since then, approximately 8 autopsies have been performed each year, thus leaving Japanese vital statistics as the primary source of information concerning death certificate validity.

Jablon and colleagues (1966) conducted another study of death certificate validity in the LSS and stated that vital statistics for all malignancies were 14% too low. Specifically, mortality rates for malignant neoplasms of digestive organs were 13% too low (stomach cancer was 21% too low, cancer of other digestive organs was 3% too high); cancer of the respiratory system was 40% too low; and uterus 4% too high. It follows that in this setting the true mortality rates for malignant neoplasms were underestimated by Japanese vital statistics.

More recently, in an RERF study on cancer mortality among A-bomb survivors, it was recognized that a wide variation existed for confirmation and detection rates for various causes of death, however, the authors went on to say that there was no evidence to suggest that inaccuracies of death certificates were consistently related to A-bomb exposure (Preston et al., 1986). Two years later, in RERF Report 11 (Shimizu et al., 1988), the investigators recognized that risk projection was affected to some degree by death certificate inaccuracies and recommended the site-specific correction of these insufficiencies, however, they used a crude correction of 1.23, which was identical to that used by the BEIR-III committee (NRC, 1980). In BEIR-V, although no correction for death certificate misclassification was made, the problem of diagnostic misclassification was circumvented by restricting analyses to survivors whose attained age was less than 75, since it was known that misclassification increases dramatically after an attained age of 75 or thereabout.

Although much work has been done by the RERF in the way of providing insight about death certificate validity and the selective nature of autopsy in the LSS, little has been done to use these site-specific data for risk estimation (NRC, 1990).

A recent study of the LSS autopsy data revealed that, overall, cancer mortality is underestimated by about 18% (Ron et al., 1991). In addition, for *Cancers of Interest* (lymphoma, breast, brain, multiple myeloma and melanoma) they found a 40% increase

in mortality rates between 1962 and 1982. Their results, as reported, do not really lend themselves well for use in this analysis because they did not provide cancer misclassification probabilities that were stratified by site, sex, city, age ATB, age ATD and follow-up period, since the study only addressed cancer mortality trends. Sposto et al. (1992) recently performed a dose-response analysis using LSS nonleukemia data corrected for a 22% cancer misclassification probability and observed a 12% increase in excess relative risk and a 16% increase in absolute risk for Hiroshima males exposed at age 25. Although they modeled and used nonleukemia misclassification probabilities as a function of city, sex, age ATB, age ATD and dose in the EM algorithm to impute missing data, they did not project lifetime risks to reveal the full effect of misclassification since the main focus was on the possibility that an apparent increase in the non-cancer death rate was attributable to cancer deaths being misclassified as non-cancer deaths.

In the United States, studies of death certificate misclassification for malignant disease have been conducted since 1941 (Dorn and Horn, 1941). Some involved a small number of cases and were limited in scope (Moriyama et al., 1958; James et al., 1955). Among the large-scale studies are Dorn and Horn's on the First National Cancer Survey, Dorn and Cutler's on the Second National Cancer Survey, and the Pan American Health Association's study (Dorn and Cutler, 1958; Puffer and Griffith, 1967). More recent studies by Percy et al. showed that according to the underlying cause of death, 65% of the death certificates were accurate (Percy et al., 1981; Percy et al., 1990). Ron et al. (1991) report on a historical review of cancer mortality misclassification in the U.S.

2.5 Studies of Lifetime Risk

Several studies reflect the state-of-the-art in lifetime risk projection. With the exception of female breast cancer, the BEIR-V study relied solely on the LSS data to project lifetime risk of developing cancer in various sites (NRC,1990). While detailed descriptions on risk projection and respective uncertainties were well documented throughout the report, no effort was made to correct for site-specific death certificate misclassification. However, the BEIR-V analyses only included data for which survivor attained age was less than 75 — an age at which misclassification starts to increase. The BEIR-III committee corrected for death certificate incompleteness, but instead of taking a site-specific approach, they used a crude correction factor of 1.23 (NRC,1980). The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) report "Sources, Effects and Risks of Ionizing Radiation" also relied to a large extent on the A-bomb data for the purpose of making lifetime risk estimates (UN, 1988). Here again, the authors recognized the uncertainties due to death certificate misclassification and underscored the need to account for such variation. Unfortunately, this comprehensive evaluation of lifetime risk from radiation exposure followed the already suffering method of providing risk estimates without correcting for random and systematic error.

Gilbert's classic health effects studies reported on radiation-induced late effects for an exposed working population (Gilbert, 1989a; Gilbert 1989b; Gilbert 1991). She used the life table approach and combined U.S. vital statistics and LSS data to obtain risk estimates constrained by lower, middle, and upper boundary conditions. However, a correction for site-specific misclassification was not made. Stather and his colleagues (Stather et al., 1988) conducted a health effects study using radiation risk data published in the 1988 UNSCEAR report. Their results indicated that risk estimates for human exposure to radiation are three times higher than risk estimates introduced by the International Commission on Radiological Protection in 1977 (ICRP, 1977). This is in good agreement with

the findings of the BEIR-V committee, who suggested a 4- to 5-fold increase in risk since the BEIR-III committee published its findings in 1980. These apparent increases in risk caused much concern in the area of radiation risk assessment and warranted a reappraisal of current radiation protection guidelines by the International Commission on Radiological Protection (ICRP, 1991). In ICRP Report 60, however, there is no discussion about the effects of diagnostic misclassification on lifetime risk estimates. In another ICRP study, Land and Sinclair (1991) used risk coefficients from Tables 5A and 5B of RERF Report 11 (Shimizu et al., 1988) to project risk for a number of Western populations, but did not adjust their lifetime risk estimates for DS86 random error or diagnostic misclassification. Within this framework, it was propitious to pursue this investigation in view of such findings.

The NIH study to develop radioepidemiological tables also deserves mention (Rall et al., 1985). Multiplicative and additive risk data were used to determine age- and sex-specific risk at a point in time from a previous exposure. No mention was made for the correction of site-specific misclassification and its effect on radiation risk estimates.

What these and other studies lack is an analytic evaluation of the degree to which site-specific diagnostic misclassification and DS86 random error jointly affect lifetime mortality risks. This investigation has the distinct advantage of complementing the above studies in order to increase internal validity in the LSS (by correcting estimates of lifetime risk) to therefore understand changes in the generalizability of results to U.S. nuclear workers.

2.6 Research Objectives

The following is a list of specific objectives for this investigation:

(1). Obtain for the years 1950-75, confirmation and detection rates for the leukemia and nonleukemia sites published in RERF Pathology Reports.

(2). Estimate cancer and non-cancer confirmation rates for the BEIR-V digestive cancer site by combining data for rubrics such as the stomach and colon.

(3). Estimate the true number of cancer deaths in each subpopulation of the LSS cancer mortality data by using sufficient statistics of the expectation-maximization (EM) algorithm [6].

(4). Calculate organ radiation absorbed doses[7] from shielded kerma[8] using body self-shielding transmission factors for the marrow, stomach, and colon.

(5). Model the excess relative risk (ERR) of radiation-induced cancer mortality for the leukemia, nonleukemia and BEIR-V digestive cancer sites with and without use of sufficient statistics and adjustment for DS86 random error using non-linear Poisson regression. Variables to be used in the analysis are organ radiation dose equivalent and covariates (effect modifiers) such as age ATB, age ATD, sex, and city (Hiroshima or Nagasaki). The L and LQ dose-response models will be used and the Pearson chi-square, deviance and Freeman-Tukey goodness-of-fit residuals determined for each model.

(6). Determine a *Death Certificate Correction Factor* (DCCF) for baseline rates of leukemia, nonleukemia and BEIR-V digestive cancers by dividing each site's confirmation rate by its detection rate obtained from the SEER data.

(7). Use a life-table method to combine ERR and absolute risk (AR) coefficients with

[6]The expectation-maximization (EM) algorithm is a generic statistical method based on *sufficient* statistics to impute missing data. See Sposto et al. (1992) and Dempster et al. (1977).

[7]Radiation absorbed dose is the amount of energy deposited in tissue.

[8]Kinetic Energy Released in Matter, *KERMA*, is the total amount of kinetic energy released by charged particles created from the interaction of radiation in tissue.

SEER baseline rates to obtain lifetime risk coefficients for a working U.S. population with and without using SEER-based DCCFs. Generate 90% confidence intervals of lifetime risk coefficients based on "model" and "non-model" geometric standard deviations, DRREFs and linear or linear-quadratic models. Use a DRREF of two to generate sex-specific lifetime risks (excess deaths/Sv/100,000 population) for the following exposure profiles: 1 Sv at age 25, 1 Sv at age 45, 1 Sv at age 65, and 0.02128 Sv/y from age 18 to 65 (1 Sv total).

(8). Ascertain the effect of nondifferential and differential misclassification of cancer mortality on point estimates of lifetime risk.

3 MATERIALS AND METHODS

The following sections outline the various methods employed in the study. Figure 6 shows the typical methodology used for risk assessment in radioepidemiologic studies and Figure 7 illustrates the method used in the present study.

3.1 Sources of Data

3.1.1 RERF Autopsy Program

Between January 1961 and December 1975, the RERF performed 4,920 autopsies during the Autopsy Progam. Results of the Autopsy Program are reported in RERF Pathology Reports 1-4 and contain autopsy characteristics as a function of city (Hiroshima or Nagasaki), place (RERF or other), exposure (T65D shielded kerma), sex and age ATD (Angevine et al., 1963; Beebe et al., 1967; Steer et al., 1973; Yamamoto et al., 1978). Although Reports 1-4 list confirmation and detection rates (discussed below) for leukemia and nonleukemia, there were no data for the BEIR-V digestive cancer site. Section 3.2 describes confirmation and detection rates, estimation of confirmation rates for the BEIR-V leukemia and digestive models, and the use of cancer and non-cancer confirmation rates to determine the true number of cancer deaths in each subpopulation (stratum).

3.1.2 RERF Cancer Mortality Data

The RERF continually maintains a computer data base which contains the status of LSS subjects at the time of each 5-year follow-up. The mortality status of each survivor at follow-up is determined by searching for LSS study subjects in the obligatory household registries (*koseki*) throughout Japan. Death certificate information, namely, underlying cause of death, for any survivor is obtained from the Vital Statistics Death Schedules and appended to the computer data base. At present, the LSS listing contains information on 5,936 cancer deaths for the years 1950-85.

As of 1985, there were 120,128 survivors in the extended cohort of the Life Span Study (LSS-E85) of which 75,991 have been assigned radiation doses from the Dosimetry System 1986 (DS86) (Beebe and Usagawa, 1968; Shimizu et al., 1988). Survivors for which DS86 dose estimates do not exist include 26,517 who were not in the cities (NIC) at time of the bombings, 2,383 with insufficient shielding information and 15,237 who had doses from the Tentative Dosimetry System 1965 Revised (TD65R) (Milton and Shohoji, 1968) but for which DS86 doses could not be calculated. The LSS mortality data are cross-classified into several age-, sex-, age ATB-, age ATD-, and dose-specific categories as shown in Table 1. Since confirmation and detection rates are proportions (discussed later), site-specific sample sizes were based on the higher of the two sample size estimates for each proportion (Cochran, 1977). The site-specific precisions expected from using all of the data were less than 0.05, except for the colon (0.074) and breast (0.066). In addition to the categorical covariates in Table 1, there are several person-year weighted continuous variables for the mean age ATB, mean age ATD, and the gamma and neutron components of shielded kerma (See Appendix A).

3.1.3 RERF Average Body Transmission Factors

The RERF has maintained dosimetry information for all of the study subjects in the LSS. These data include DS86 estimates of the shielded kerma from gamma rays and neutrons

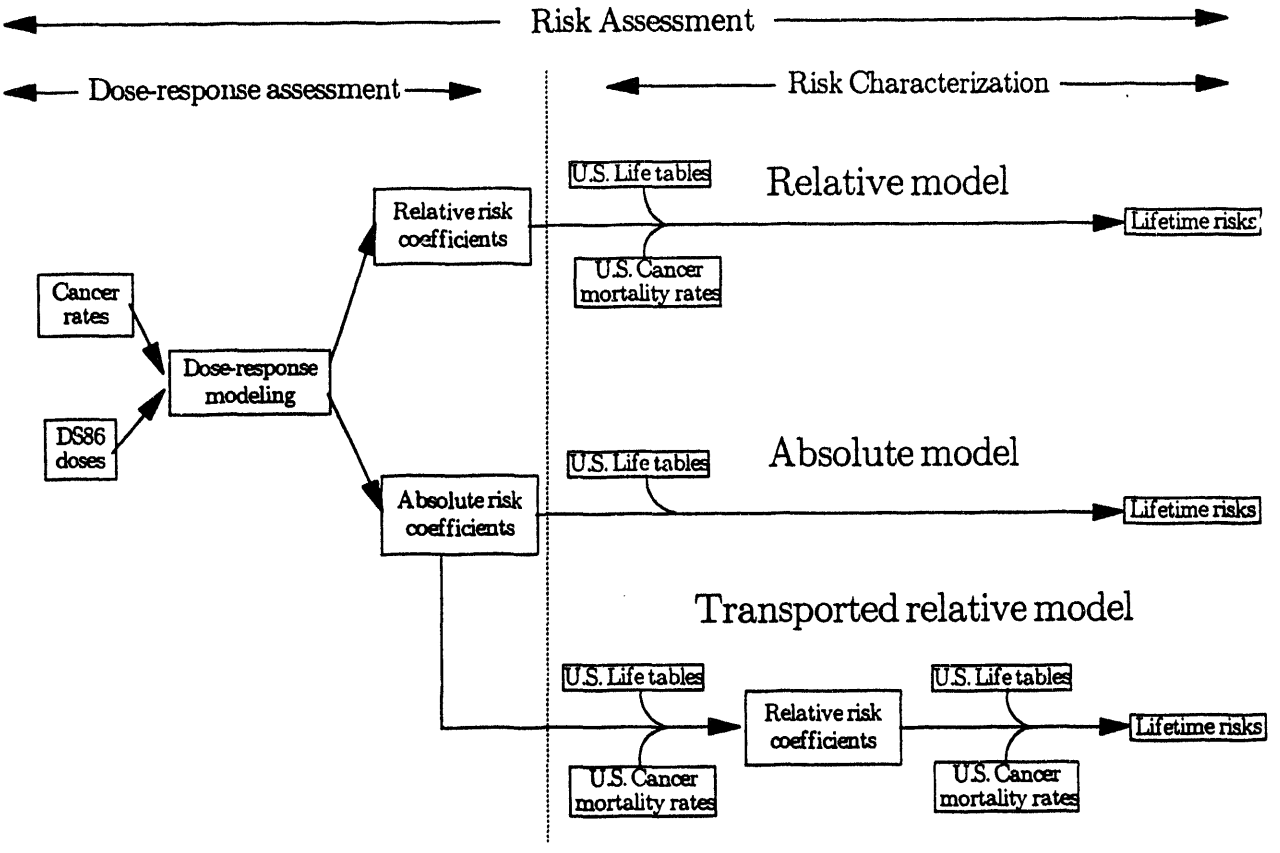


Figure 6: Typical methodology for estimating lifetime mortality risk of radiation-induced cancer.

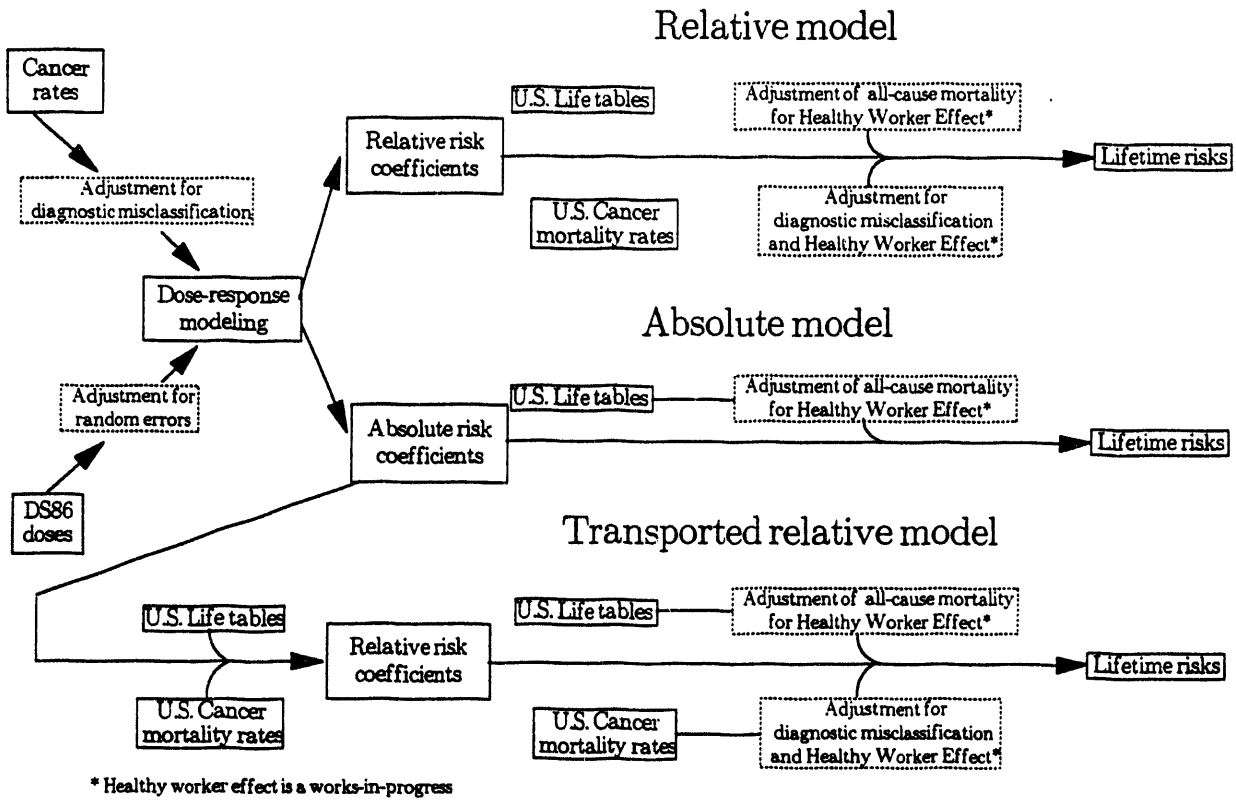


Figure 7: Methodology for estimating lifetime mortality risk of radiation-induced cancer in this investigation.

Table 1: Cross-classification of LSS cancer mortality data.

Category	Levels	Description
City	2	Hiroshima, Nagasaki
Sex	2	Males, Females
Age at exposure	13	0-4, 5-9, 10-14, 15-19, 20-24, 25-29, 30-34, 35-39, 40-44, 45-49, 50-54, 55-59, 60+
Follow-up period	7	1 Oct 1950 to 31 Dec 1955 1 Jan 1956 to 31 Dec 1960 1 Jan 1961 to 31 Dec 1965 1 Jan 1966 to 31 Dec 1970 1 Jan 1971 to 31 Dec 1975 1 Jan 1976 to 31 Dec 1980 1 Jan 1981 to 31 Dec 1985

in units of mGy, the location and radiation shielding at age ATB, sex, city, and distance in meters from the hypocenter of the blast. Information on the organ-, city-, age ATB-, and radiation-specific body transmission factors are also available to convert kerma to organ dose. The average body transmission factors are also cross-classified into several organ-, age ATB-, and city-specific categories and were used for converting whole-body shielded kerma into organ absorbed doses (see Appendix A). For the neutron portion of dose equivalent, an RBE factor of 10 was used for the RERF models. In the BEIR-V relative risk models, a neutron RBE of 20 was used.

3.1.4 Reduction Factors for DS86 Random Error

City-specific reduction factors used to adjust DS86 survivor doses were adapted from previous work on DS86 random errors (Pierce and Vaeth, 1991). Reduction factors were multiplied by organ dose equivalents which were used in the dose-response analysis described in the next section (see Appendix A).

3.2 Use of Confirmation Rates to Adjust Cancer Deaths

3.2.1 Diagnostic Screening

Comparisons of mortality between death certificates and autopsy records reported in the RERF Autopsy Program (Yamamoto et al., 1978) are identical to the results of screening tests (Lilienfeld and Lilienfeld, 1980; Fleiss, 1981; Kramer, 1988). Data arrangement for results of the LSS Autopsy Program are arranged in Table 2.

As one notices in Table 2, the *sensitivity*, which is equivalent to the *cancer detection rate* and the ratio $a/(a+c)$, is defined as the probability of correctly assigning cancer X as the underlying cause of death on a death certificate given that the principal autopsy finding was cancer X. The *specificity*, which is equivalent to the *non-cancer detection rate* and the ratio $d/(b+d)$, is defined as the probability of correctly assigning non-cancer as the underlying cause of death on a death certificate given that the decedent's principal autopsy finding was non-cancer. The *predictive value positive* (PV^+), which is equivalent to the *cancer confirmation rate* and the ratio $a/(a+b)$, is defined as the probability that

Table 2: Data arrangement of screening results in the RERF.

	Autopsy diagnosis		
Death Certificate	*Cancer X*	*Non-cancer*	
Cancer X	a-confirmed	b-false positives	$a+b=d_c$
Non-cancer	c-false negatives	d-absence of Cancer X	$c+d=d_{nc}$
	$a+c=D_c$	$b+d=D_{nc}$	$a+b+c+d=d_T$

Table 3: Probabilities of misclassification of disease.

	Autopsy diagnosis		
Death Certificate	*Cancer X*	*Non-cancer*	
Cancer X	ϕ	$(1-\psi)$	
Non-cancer	$(1-\phi)$	ψ	
	D_c	D_{nc}	D_T

an individual with cancer X as the underlying cause on their death certificate actually died of cancer. Lastly, the *predictive value negative* (PV^-), which is equivalent to the *non-cancer confirmation rate* and the ratio $d/(c+d)$, is defined as the probability that an individual with non-cancer as the underlying cause on their death certificate actually did not die of cancer X. The observed number of cancer deaths on death certificates of a sample of LSS survivors is d_c and the observed number of non-cancer deaths is d_{nc}. The total number of deaths due to cancer and non-cancer is d_T. When sensitivity and specificity differ across exposure levels, misclassification is termed *differential*. However, when sensitivity and specificity are equal across exposure levels, the misclassification is called *non-differential*.

Confirmation rates for the BEIR-V digestive (ICD 150-159) cancer sites were estimated as the ratio of the total number confirmed (a) to the total number of death certificates sampled ($a+b=d_c$) within each rubric.

3.2.2 Estimation of True Cancer Deaths

In order to adjust the observed number of cancer deaths in a given subpopulation, d_c, for diagnostic misclassification, it was necessary to estimate the true number of cancer deaths, D_c, and the true number of non-cancer deaths, D_{nc}. If we denote the sensitivity as ϕ, specificity as ψ, cancer confirmation rate as θ_c, non-cancer confirmation rate as θ_{nc}, true cancer rate, π_c, as D_c/d_T and the true non-cancer rate, π_{nc}, as D_{nc}/d_T, then one can see that Tables 2 and 3 can be combined to determining the relationships between each of the above parameters.

Arithmetically, the cancer confirmation rate θ_c is related to ϕ and ψ by the relationship

$$\theta_c = \frac{\phi\pi_c}{\phi\pi_c + (1-\psi)\pi_{nc}} \tag{3}$$

and the relationship between the non-cancer confirmation rate, θ_{nc}, and ϕ and ψ is

$$\theta_{nc} = \frac{\phi\pi_{nc}}{\phi\pi_{nc} + (1-\psi)\pi_c} \tag{4}$$

The *sufficient* statistics for estimating D_c and D_{nc} in each cell of the cross-tabulated LSS person-year table are

$$D_c = \theta_c d_c + (1-\theta_{nc})d_{nc} \tag{5}$$

Table 4: Crude confirmation rates for cancer, θ_c, and non-cancer, θ_{nc}, in the Life Span Study Pathology Report 4.

Cancer site	θ_c	θ_{nc}
Leukemia	0.857	0.999
Nonleukemia	0.657	0.800
Digestive	0.782	0.914

and

$$D_{nc} = \theta_{nc} d_{nc} + (1 - \theta_c) d_c \tag{6}$$

Confirmation rates for cancer and non-cancer estimated from RERF Pathology Report 4 (Yamamoto et al., 1978) were used in Eq. 5 to estimate the true number of cancer deaths for each stratum of the LSS cancer mortality data before modeling dose-response. Minimum latency periods of 2 years for leukemia and 10 years for solid cancers were used so that the estimation affected only deaths that were likely to be radiation-induced. Tables 4-8 list the cancer and non-cancer confirmation rates from RERF Pathology Report 4 for all covariables jointly (crude), and as a function of gender, city, age ATD and T65DR shielded kerma that were used in Eq. 5 for adjusting mortality for diagnostic misclassification. In order to use the confirmation rates in Pathology Report 4 that were stratified on T65DR shielded kerma (Table 8) with cancer mortality data hinged on the DS86 doses (Table 1), it was necessary to convert DS86 kerma into T65DR kerma.

Using average house transmission factors from Table 1 of the Appendix of Shimizu et al. (1987), we estimated the city-specific T65DR neutron organ dose equivalents as

$$D^*_{ij,n,65,city} = \frac{D^*_{ij,n,86,city}}{\Omega_{n,86,city}/\Omega_{n,65,city}} \tag{7}$$

where $D^*_{ij,n,86,city}$ is the city-specific DS86 organ dose equivalent from neutrons corrected for random error and $\Omega_{n,86,city}$ and $\Omega_{n,65,city}$ are city-specific average house transmission factors for the DS86 and T65DR systems from Table 1 of the Appendix in Shimizu et al. (1987). The T65DR γ-ray organ dose equivalents were functionally composed as

$$D^*_{ij,\gamma,65,city} = \frac{D^*_{ij,\gamma,86,city}}{\Omega_{\gamma,86,city}/\Omega_{\gamma,65,city}} \tag{8}$$

where $D^*_{ij,\gamma,86,city}$ is the city-specific DS86 organ dose equivalent for γ-rays corrected for random error and $\Omega_{\gamma,86,city}$ and $\Omega_{\gamma,65,city}$ are city-specific average house transmission factors from Table 1 of the Appendix in Shimizu et al. (1987). The city-specific neutron, $D^*_{ij,n,65,city}$, and γ-ray organ doses, $D^*_{ij,\gamma,65,city}$, were summed to provide the total organ dose equivalent for selecting a confirmation rate in Table 8 based on a given T65DR dose range. (Appendix A provides a thorough explanation of the methods used for estimating organ dose equivalents).

3.3 Dose-Response Analysis

3.3.1 Excess Relative Risks

Additive and multiplicative models of relative risk were used to estimate cancer risk coefficients for each sex, age ATB and age ATD category (Brown and Chu, 1989; Kodell and

Gaylor, 1989; Kodell et al., 1991). The ERR risk model used in this investigation followed that used in RERF Report 11 (Shimizu et al., 1988). For the reader who is interested in further study, Muirhead and Darby (1987) provide an extensive evaluation of estimating radiation risks with additive and multiplicative maximum likelihood (ML) methods. Using the mortality data described in the previous section, we define the mortality rate, λ_{ij}, in the ith stratum of city, sex and age ATB categories and jth exposure category as

$$\lambda_{ij} = \lambda_{i0}\Phi_{RR}(a) \tag{9}$$

where λ_{i0} is the mortality rate (D_c/person-years $\times$ 10,000) in the 0 dose category of the ith stratum of city, sex and ATB cross-classification and $\Phi_{RR}(a)$ is the relative risk coefficient for exposure at age ATB a. Since the relative risk is related to the excess relative risk as

$$\Phi_{RR}(a) = [1 + \Phi_{ERR}(a)] \tag{10}$$

we can obtain maximum likelihood (ML) estimates of $\Phi_{ERR}(a)$ by first fitting a model of the form

$$\lambda_{ij} = \alpha_s e^{\beta_0}[1 + \{\beta_1 D^*_{ij} e^{(\beta^T z)}\}] \tag{11}$$

where α_s is an unknown nuisance parameter for the stratification of background rates (λ_{i0}) on sex (2 levels), city (2 levels), age ATB (13 levels) and follow-up period (7 levels) resulting in i=364 strata, $\exp(\beta_0)$ is a constant term, β_1 is the contribution of dose equivalent to excess relative risk, D^*_{ij} is the organ dose equivalent and z is a row vector of covariates representing age ATB, age ATD or gender.

Once the model has been fit and ML estimates of nuisance parameters and regression coefficients are known, then the excess relative risk at the 1 Sv level for exposure at age a under the *constant* model, $\Phi_{ERR}(a)$, can be determined as

$$\Phi_{ERR}(a) = \beta_1 e^{(\beta^T z)} \tag{12}$$

where β_1 is a ML estimate of the linear contribution of dose equivalent to the outcome effect, β^T is the transform of row vector β of coefficients and z is a row vector of covariates representing age ATB, age ATD and gender. When covariates for age ATD are included in the regression model of Eq. 11, we can obtain the excess relative risk, $\Phi_{ERR}(a,t)$, for the *non-constant* model, which changes with attained age t. To fit the model in Eq. 11, the computer program AMFIT was used for grouped Poisson regression with a stratified excess relative risk model (Preston and Pierce, 1993). Appendix A provides a detailed description of model formulation, coding methods and matrix operations used for estimating sex-, age ATB- and age ATD-specific $\Phi_{ERR}(a)$ and $\Phi_{ERR}(a,t)$.

Age ATB-, age ATD-, and sex-specific non-constant excess relative risk coefficients, $\Phi_{ERR}(a,t)$, in units of %/Sv were estimated for the leukemia and nonleukemia sites with neutron RBEs of 10.[9]

The BEIR-V ERR model for estimating $\Phi_{ERR}(a,t)$ in each LSS subpopulation exposed at age a at t years since exposure (NRC, 1990) was

$$\Phi_{ERR}(a,t) = f(d)g(\beta) \tag{13}$$

[9]Although other RERF regression models for the stomach, breast, lung, bladder and liver were fitted in this investigation, the results are not provided in the text because the tabular output tables were so voluminous. However, the coding schemes for all Poisson regression runs are provided in Appendix A. Results of all modeling sessions are available on request by writing to the address on the bottom of page v (acknowledgement page).

Table 5: Sex-specific confirmation rates for cancer, θ_c, and non-cancer, θ_{nc}, in the Life Span Study Pathology Report 4.

	θ_c		θ_{nc}	
Cancer site	Males	Female	Males	Female
Leukemia	0.850	0.863	1.000	0.998
Nonleukemia	0.688	0.638	0.792	0.810
Digestive	0.787	0.764	0.900	0.927

where *f(d)* is a function of either the linear ($\alpha_1 D^*_{ij}$) or linear-quadratic ($\alpha_1 D^*_{ij} + \alpha_2 D^{*2}_{ij}$) contribution of radiation dose and g(β) is a link function equal to $\exp(\beta^T; z)$ dependent on sex, age ATB, and time since exposure (see Appendix A). Absolute risks (excess deaths/10^4PYSv) were not estimated from regression coefficients of the BEIR-V models. When fitting the model for digestive cancer, records were dropped if the time since exposure was $\leq$ 10 years, attained age exceeded 75 years or organ dose equivalents (neutron RBE=20) exceeded 4 Sv. However, when fitting the leukemia model, records were dropped if the bone marrow dose equivalent (neutron RBE=20) exceeded 4 Sv or attained age exceeded 75 years.[10]

3.3.2 Absolute Risks

Absolute risks, or the number of excess deaths per 10^4 person-years at the 1 Sv level were estimated by use of the formula

$$\Phi_{AR}(a) = (\sum_i \sum_k (PY_{ij} \lambda_{i0} \Phi_{ERR}(a) D^*_{ij}) / \sum_i \sum_j (PY_{ij} D^*_{ij})) \times 10^4 \qquad (14)$$

where PY_{ij} is the person-years of follow-up in each subpopulation and the other parameters are defined above. Age ATB-, age ATD-, and sex-specific AR coefficients, $\Phi_{AR}(a,t)$, in units of deaths/10^4PYSv were estimated for the leukemia and nonleukemia sites with neutron RBEs of 10 when $\Phi_{ERR}(a,t)$ was used in the above equation. Absolute risks were not estimated from regression coefficients of the BEIR-V models.

3.3.3 Goodness-of-Fit (GOF) Statistics

Regression residuals, defined as the *squared difference* between the observed cancer deaths, y_i, and the predicted deaths, $\hat{\mu}_i$, were determined to ascertain how well each model fitted the observed data (Rayner and Best, 1989). Cressie and Read (1984) introduced the power divergence family of test statistics, which were used in the present study for assessing goodness-of-fit (GOF). When $\hat{\mu}_i \geq 5$ for all i then *Pearson* χ^2 residuals

$$r_P = (y_i - \hat{\mu}_i)^2 / \hat{\mu}_i \qquad (15)$$

and GOF statistic, $\chi^2 = \sum r^2_P$ are adequate measures of dispersion. If all $\hat{\mu}_i \leq 1$ or $\hat{\mu}_i \to 0$, then *deviance* residuals

$$r_D = 2[y_i \log \frac{y_i}{\hat{\mu}_i}]^{1/2} \qquad (16)$$

[10]Other BEIR-V models for the respiratory, female breast and "other" cancer sites were fitted but are not described in the results or discussion. However, for the reader who is interested, Appendix A includes the coding format for all BEIR-V models.

Table 6: Sex- and city-specific confirmation rates for cancer, θ_c, and non-cancer, θ_{nc}, in the Life Span Study Pathology Report 4.

	Hiroshima, θ_c		Nagasaki, θ_c		Hiroshima, θ_{nc}		Nagasaki, θ_{nc}	
Cancer site	Males	Females	Males	Females	Males	Females	Males	Females
Leukemia	0.846	0.769	0.857	0.999	1.000	0.999	1.000	0.996
Nonleukemia	0.685	0.629	0.695	0.670	0.954	0.959	0.947	0.970
Digestive	0.775	0.779	0.833	0.702	0.964	0.974	0.990	0.994

Table 7: Age ATD-specific confirmation rates for cancer, θ_c, and non-cancer, θ_{nc}, in the Life Span Study Pathology Report 4.

	Age ATD, θ_c				Age ATD, θ_{nc}			
Cancer site	<50	50-59	60-69	70+	<50	50-59	60-69	70+
Leukemia	0.809	0.800	1.000	0.857	0.998	0.998	0.999	1.000
Nonleukemia	0.936	0.944	0.920	0.927	0.927	0.907	0.897	0.893

and (deviance GOF $D = \sum r_D^2$) Freeman-Tukey, r_{FT}, residuals

$$r_{FT} = \sqrt{y_i} + \sqrt{y_i + 1} - \sqrt{4\mu_i + 1} \tag{17}$$

and statistic $G = \sum r_{FT}^2$ are more appropriate for assessing GOF.

A model is said to fit a given set of data if χ^2, D, or G do not exceed tabled values of $\chi^2_{(\alpha,n-s-p)}$ where n is the total number of cells, s is the total number of cells in the stratification and p is the number of parameters in the model. (See Appendix A for a description of numerical methods employed in this study to determine GOF).

3.4 Projection of Lifetime Mortality Risks

3.4.1 Risk Coefficients and Projection Models

Lifetime mortality risks of cancer for non-exposed and exposed populations were calculated using the program SURVRAD (Peterson et al., 1992). Age- and sex-specific AR and ERR coefficients for radiation-induced cancer were obtained from the dose-response analyses described earlier. Risk projections were made with four models in which 100,000 males and females were exposed to 1 Sv at age 25, 45, 65 or to 0.02128 Sv/year continuously from

Table 8: T65DR-specific confirmation rates for cancer, θ_c, and non-cancer, θ_{nc}, in the Life Span Study Pathology Report 4.

	θ_c		θ_{nc}	
Shielded kerma (Gy)	Leukemia	Nonleukemia	Leukemia	Nonleukemia
<0.01	1.000	0.941	1.000	0.895
0.01-0.49	0.769	0.914	0.990	0.916
0.50-0.99	1.000	0.917	0.996	0.881
1.00-1.99	1.000	0.980	1.000	0.875
2.00+	0.714	0.926	0.988	0.867

age 18 to 65, for a total career dose equivalent of 1 Sv[11]. The unconditional probability of radiation-induced cancer mortality, $\pi(\infty; d)$, over a lifetime for the constant AR model was in the form

$$\pi(\infty; d) = \int_0^{\infty} \int_{t-p}^{t-l} H(a)\, \Phi_{AR}(a)\, S(t; d)\, da\, dt \tag{18}$$

where ∞ is by convention 100 years of age, $t - p$ prevents integration below the minimal latency period for the first (or only) age at exposure a, $t - l$ prevents integration beyond the plateau period for the last age at exposure (Checkoway et al., 1989), $H(a)$ is the annual dose equivalent in Sv, $\Phi_{AR}(a)$ is the sex-, age ATB- and age ATD-specific absolute risk coefficient (deaths/10^4PYSv) from §3.3, and $S(t; d)$ is the all-cause survivorship function for each one-year interval of the complete life table. The number of radiation-induced cancer deaths per 100,000 exposed individuals is $\pi(\infty; d) \times 10^5$. The unconditional probability of radiation-induced cancer mortality based on the constant transported RR(AR) model was calculated with the formula

$$\pi(\infty; d) = \int_0^{\infty} \int_{t-p}^{t-l} H(a)\, \Phi_{ERR,US}(a)\, h_c(t; 0)\, S(t; d)\, da\, dt \tag{19}$$

where the integrand $\Phi_{ERR,US}(a)$ is the ERR risk coefficient for the U.S. population determined by applying baseline cancer mortality rates over the relevant 35-year (1950-85) follow-up period[12] in the LSS and $h_c(t; 0)$ is the baseline cancer rate for spontaneously occurring cancer at age t.

Unconditional probabilities for the RR risk projection model were based on applying ERR coefficients obtained in this study directly to baseline (spontaneously occurring) cancer rates and life tables for the U.S. population. This was functionally composed as

$$\pi(\infty; d) = \int_0^{\infty} \int_{t-p}^{t-l} H(a)\, \Phi_{ERR}(a)\, h_c(t; 0)\, S(t; d)\, da\, dt \tag{20}$$

Finally, for the non-constant RERF and BEIR-V models, we used sex-, age ATB- and time-since-exposure (TSE)-specific ERR coefficients obtained in this study in the form

$$\pi(\infty; d) = \int_0^{\infty} \int_{t-p}^{t-l} H(a)\, \Phi_{ERR}(a, t)\, h_c(t; 0)\, S(t; d)\, da\, dt \tag{21}$$

[11]The annual dose for the continuous exposure from age 18 to 65 was based on dividing the total dose of 1 Sv by 47 years, which resulted in 0.02128 Sv/year. In the complete (*complete* life tables have one-year age intervals; *abridged* life tables have, say, 5-year intervals or *quinquennia*) life table calculations, the first annual dose of 0.02128 Sv was applied to the 19th one-year age interval because an individual is 18 years old in the 19th age interval. The last exposure occurred in the 65th age interval, in which an individual spends an entire year. It is assumed that each individual retires when they enter the 66th age interval at their 65th birthday. These one-year differences between a given age and respective life table interval are easily explained by the fact that when an individual is born, the first year of life is spent in the first interval when the infant is zero years old. After the infant's first birthday, the infant enters the second one-year life table interval, but is still only one year old.

[12]Although the total follow-up time from 1 October 1950 to 31 December 1985 was equal to 35 years and 3 months (Table 1), it is assumed to be 35 years in this study.

where $\Phi_{ERR}(a,t)$ is the ERR risk coefficient at age t for exposure at age a.

In the four projection models given above, risk was lagged for 2 years and held constant for 40 years for leukemia and was lagged 10 years and held constant until the end of life (100 years) for solid cancers. Appendix B outlines the underlying construct of lifetime risk projection and provides detailed explanations of each parameter used in the SURVRAD algorithm.

3.4.2 Baseline Rates and Life Tables

Age-specific mortality rates, $h_c(t;0)$, for cancer in the 1985 U.S. population were obtained from data files used by the MONSON program (Monson, 1977). Rates for chronic lymphocytic leukemia (CLL) in whites and non-whites were extracted from the most recent Surveillance, Epidemiology and End Results monograph (NCI, 1986) and divided by the age-specific composite (total) leukemia rates to estimate the per cent contribution of CLL to overall leukemia for each sex and age group in 1988. The resulting proportion of CLL in each quinquennium was then subtracted from the composite leukemia rates. Complete life tables for the 1990 U.S. population were based on data obtained from the Office of the Actuary of the Social Security Administration (Faber and Wade, 1983).

3.4.3 Death Certificate Correction Factors (DCCF)

A common misconception in epidemiology is that baseline cancer mortality rates in vital statistics registries represent precisely the risk for each quinquennium. Percy et al. give clear evidence to support the contention that this assumption does not hold (Percy et al., 1981; Percy et al., 1990). Thus, in an effort to correct for death certificate misclassification in the national cancer rates, we introduce the *Death Certificate Correction Factor* (DCCF), defined by

$$DCCF_c = \frac{\theta_c}{\phi_c} \tag{22}$$

where θ_c is the cancer confirmation rate and ϕ_c is the cancer detection rate (sensitivity) defined in Tables 1 and 2. The confirmation and detection rates are given for each site in the latest Percy et al. (1990) paper and were used to modify the baseline cancer rates used in lifetime risk projection described above. The DCCF has the unique property of increasing rates that are underreported and decreasing rates that are overreported.

For the reader who is interested, see §8 "Notation" and §9 "Abbreviations."

4 RESULTS

4.1 Per Cent Distribution of True Cancer Deaths

For most age ATB and ATD categories, a short minimal latency period was observed for leukemia because a majority of deaths occurred less than 10 years following exposure (data not shown). For older age ATB and ATD categories the shifting of leukemia deaths misclassified as non-cancer deaths increases because 1) the age-specific mortality rate of all deaths less leukemia outweighs the age-specific leukemia rates at all ages and because 2) the number of true cancer deaths is equal to the sum of the product of the observed cancer deaths and the probability that the observed cancer deaths are correctly classified and the product of the observed non-cancer deaths and one minus the the probability that the observed non-cancer deaths were correctly classified. This relationship will hold uniformly with increasing age ATD as long as the confirmation rates are not stratified by age ATD. For solid cancers, most deaths occurred at older age ATB and ATD levels and a visible minimal latency period was apparent (data not shown), because most deaths occurred greater than 10 years post-exposure.

4.2 Poisson Regression

4.2.1 Models with Age ATB, Age ATD and Gender

Regression models containing covariates for age ATB, age ATD and gender were used for leukemia and nonleukemia cancer because of the guaranteed convergence at a global maximum, low scores and low values of the χ^2, D and G goodness-of-fit (GOF) statistics. The modeling results in this section were, in general, in good agreement with with those reported in Table 6 of RERF Report 11, Part 2 (Shimizu et al., 1988). The only difference between the regression results of this study and those reported in Table 6 of RERF Report 11 (Part 2), was that in this study organ dose equivalents were calculated before performing regressions runs, whereas in Report 11, shielded kerma was used for dose.

Leukemia Tables C.1-C.11 of Appendix C list the ERR and AR coefficients for leukemia for various methods of adjustment for diagnostic misclassification without adjustment for DS86 random error. The GOF statistics for all of the models indicated that the model results were consistent with the observed data.

When no adjustment for diagnostic misclassification was made (Table C.1), the regression coefficient for dose (%/Sv) was 42.04 and the χ^2, D, and G statistics (d.f.=3022) were 1262, 632 and 238; however, when DS86-specific confirmation rates were employed (Table C.11) to estimate the number of cell-specific true cancer deaths, the regression coefficient for dose decreased by 18.4% (34.32) and χ^2 and D dropped to 888 and 506, but the G increased slightly to 268. This reduction in GOF statistics indicates that the application DS86-specific confirmation rates for follow-up periods 1950-85 resulted in a model that fitted better than the model in which no adjustments were made.

When marrow dose equivalents were adjusted for DS86 random error (Tables C.12-C.22), ERR and AR coefficients increased in all age ATB and ATD categories. When diagnostic misclassification was not adjusted (Table C.12), the regression coefficient for dose was 6.0% higher (45.64) and χ^2, D, and G statistics were lower (1338, 635 and 252) in comparison with the same model when DS86 random error was not adjusted. When DS86-specific confirmation rates were employed (Table C.22), the regression coefficient decreased by 18.1% and χ^2 and D dropped to 921 and 507, but the G increased slightly

to 278.

Nonleukemia The ERR and AR for nonleukemia results when no adjustment for DS86 random error was made are listed in Tables C.23-C.33 of Appendix C. The GOF statistics for all of the models indicated that the model results were concordant with the observed data. The regression coefficient for dose and χ^2, D, and G statistics (d.f.=3022) when no adjustments for diagnostic misclassification were made (Table C.23) were 5.38, 4636, 2159 and 1909, respectively. However, when DS86-specific confirmation rates were employed (Table C.33) to estimate the number of cell-specific true cancer deaths, the regression coefficient changed to 3.55 (-34% reduction) and the χ^2, D and G dropped to 2608, 1585, and 1816, which indicated that GOF increased when DS86-specific confirmation rates were applied.

When a correction for DS86 random error (Table C.34) was made for the colon (large intestine) dose equivalent, the regression coefficient for dose increased by 2% (5.49) and GOF χ^2, D, and G statistics were were 4619, 2159 and 1905, when no adjustment for diagnostic misclassification was made. When DS86-specific confirmation rates were employed (Table C.44), the dose regression coefficient decreased by 30.4% (3.82) and χ^2, D and G dropped to 2610, 1582 and 1815, which were essentially the same as the GOF statistics for the model in Table C.33, that is where DS86-specific confirmations were used, but no random error adjustments were made.

4.2.2 BEIR-V Models

The non-fully-parametric BEIR-V models included no more than 6 coefficients representing age ATB, time since exposure, and gender and therefore converged at a global maximum rather quickly with reliable goodness-of-fit statistics.

Leukemia Tables C.45 and C.46 list the ERR coefficients for leukemia. Regression coefficients (not in tables) and GOF statistics (d.f.=2404) when no adjustments were made for diagnostic misclassification or DS86 random error were similar to those in the BEIR-V report (α_1=0.28, α_2=0.14, β_1=4.88, β_2=2.40, β_3=2.37, β_4=1.63, χ^2=634, D=397, and G=194). When adjusting for diagnostic misclassification using DS86-specific confirmation rates applied over the years 1950-85, the linear dose coefficient increased substantially, however the remaining coefficients decreased (α_1=0.72, α_2=0.13, β_1=4.03, β_2=1.77, β_3=1.84, β_4=1.27, χ^2=491, D=322, and G=223).

When marrow dose equivalents were corrected for DS86 random error, the linear dose coefficient increased by 64.8% and the linear-quadratic term increased by 97.9% and the GOF statistics did not improve (α_1=0.46, α_2=0.28, β_1=4.42, β_2=1.96, β_3=1.83, β_4=1.20, χ^2=718, D=412, and G=224). The correction for both diagnostic misclassification using DS86-specific confirmation rates and DS86 random error resulted in a 113.4% increase in the linear dose coefficient, but the remaining coefficients were decreased and the GOF statistics decreased slightly (α_1=0.97, α_2=0.21, β_1=3.78, β_2=1.54, β_3=1.56, β_4=1.05, χ^2=543, D=333, and G=218).

Digestive System Tables C.47 and C.48 list the ERR coefficients for digestive system cancers. When no adjustments were made for diagnostic misclassification or DS86 random error the regression coefficients (not in tables) and GOF statistics (d.f.=1910) were identical to those in the BEIR-V report (α_1=0.8068, β_1=0.5558, β_2=-0.1976, χ^2=2159, D=1192,

and G=1039). When adjusting for diagnostic misclassification using sex-city-specific confirmation rates applied over the years 1950-75, the linear dose coefficient decreased 9.9%, however the other log-linear coefficients increased and the GOF statistics decreased moderately (α_1=0.7267, β_1=0.604, β_2=-0.1861, χ^2=1591, D=920, and G=932).

When the stomach dose equivalents (stomach transmission factor were used for the digestive site) were corrected for DS86 random error, the linear dose coefficient decreased by 8.1% and the GOF statistics increased slightly (α_1=0.7356, β_1=0.6698, β_2=-0.1762, χ^2=2272, D=1245, and G=1052). The correction for both diagnostic misclassification using sex-city-specific confirmation rates, and DS86 random error resulted in 15.6% decrease in the linear dose coefficient and a reduction of the GOF statistics (α_1=0.6204, β_1=0.7422, β_2=-0.1631, χ^2=1678, D=962, and G=944).

4.3 Lifetime Risk Projection

4.3.1 Lifetime Risks Without Adjustments

Tables 9-11 list the site- and sex-specific lifetime risks (%/Sv) based on the absolute, transported relative and relative projection models. The trends of excess risks of leukemia as a function age at exposure were similar for the absolute and transported relative models in Tables 9 and 10. Appendix D provides tables of lifetime risks for the 18-65 age at exposure profile for all results in this section.

In Table 11, using a Dose-rate Reduction Effectiveness Factor (DRREF) of two and no correction for DS86 random error or diagnostic misclassification in the non-constant relative projection model, lifetime risks (%/Sv) of nonleukemia among males exposed acutely to 1 Sv at age 25, 45, 65 or continuously from ages 18 to 65 were 2.10%, 2.78%, 1.20% and 1.91%. For females, nonleukemia lifetime risks for the same exposure profiles were 3.49%, 4.32%, 1.97% and 3.23%. Excess leukemia risks for 1 Sv at 25, 45 and 65 and over the years 18 to 65 were 0.35%, 0.46%, 2.46% and 0.87% for males and 0.26%, 0.41%, 1.96% and 0.73% for females. By way of comparison, excess nonleukemia risks based on the constant projection models were 2.84% for males and 4.75% for females; risks of leukemia among males was 0.75% and among females was 0.64%. Thus, lifetime risk estimates based on constant models did not underestimate risks projected by non-constant models.

The results in Tables 9-11 are in very close agreement with lifetime risks used in an ICRP analysis (Land and Sinclair, 1991) and in most cases only differed by several cancers per 100,000. Small differences were noted with the transported relative and constant relative models which were attributable to 1) use of different baseline rates [our baseline rates were for the 1985 epoch, Land and Sinclair's were for the years 1973-77] and 2) a small variation in the estimation of hazard function for the transported relative risk model (Land, 1989). The negligible differences in absolute risks between the present study and those of Land and Sinclair supports the tentative use of projected all-cause vital statistics (Faber and Wade, 1983) in this study, for the study of birth-cohort effects on lifetime risk projection (Peterson et al., 1992) and projection of lifetime risks for the Hanford cohort (Peterson et al., 1993).

Since Sposto et al. (1992) did not project lifetime risks for various exposure profiles, we used their regression coefficients and the SURVRAD program to generate lifetime risks. In Table 11, one notices that excess nonleukemia risks based on the Sposto et al. data for exposure over a career (18 to 65 y) were 156.4% greater for males and 83.3% greater for females when compared with nonleukemia results of our analysis.

Excess risks for ages at exposure 25, 45 65 and 18-65 for the BEIR-V model are listed in Table 12. Results were in good agreement with lifetime risks reported by the BEIR-V

Table 9: Site- and sex-specific excess risks (%/Sv) for the absolute projection model without adjustment for diagnostic misclassification and DS86 random error (DRREF=2).

Site	Age at exposure[a]	Excess risk (%/Sv) Males	Females
Leukemia	25	0.84	0.35
	45	0.42	0.34
	65	0.44	0.45
	18-65	0.67	0.40
Nonleukemia	25	2.24	2.95
	45	2.86	3.78
	65	0.79	1.44
	18-65	1.93	2.77

[a]For exposure at ages 25, 45 and 65, the population of 100,000 was acutely exposed to 1 Sv; the exposure from age 18 to 65 involved chronic exposure to 0.02128 Sv/y for 47 y (total=1 Sv).

Table 10: Site- and sex-specific excess risks (%/Sv) for the transported relative projection model without adjustment for diagnostic misclassification and DS86 random error (DRREF=2).

Site	Age at exposure[a]	Excess risk (%/Sv) Males	Females
Leukemia	25	0.06	0.04
	45	0.34	0.24
	65	0.44	0.48
	18-65	0.35	0.27
Nonleukemia	25	1.89	2.29
	45	2.79	3.66
	65	0.52	0.91
	18-65	1.74	2.38

[a]For exposure at ages 25, 45 and 65, the population of 100,000 was acutely exposed to 1 Sv; the exposure from age 18 to 65 involved chronic exposure to 0.02128 Sv/y for 47 y (total=1 Sv).

Table 11: Site- and sex-specific excess risks (%/Sv) for the relative projection model without adjustment for diagnostic misclassification and DS86 random error (DRREF=2).

Site	Age at exposure[a]	Excess risk (%/Sv) Males	Females
Leukemia	25	0.35	0.26
	45	0.46	0.41
	65	2.46	1.96
	18-65	0.87	0.73
Nonleukemia	25	2.10	3.49
	45	2.78	4.32
	65	1.20	1.97
	18-65	1.91	3.23
Nonleukemia	25	2.61	3.02
(Sposto. et al.)	45	5.72	6.49
	65	2.39	2.46
	18-65	4.90	5.92

[a]For exposure at ages 25, 45 and 65, the population of 100,000 was acutely exposed to 1 Sv; the exposure from age 18 to 65 involved chronic exposure to 0.02128 Sv/y for 47 y (total=1 Sv).

committee (NRC, 1990). The leukemia risks for all ages at exposure were similar to those of the relative projection model in Table 11, in that they increased as age at exposure increased and were the greatest at age 65 (1.46 and 1.14 %/Sv for males and females). Solid cancers, such as the digestive system also had excess risks that closely resembled risks for the relative model listed in Table 11.

4.3.2 Bias in Absolute Projection Models

Lifetime risks for males and females based on the absolute projection model that were negatively biased are listed in Tables 13 and 14. The most negative bias due to diagnostic misclassification was indicated by the liver site (range -68 to -521%). While diagnostic misclassification decreased with increasing age at exposure to negative values less than -50%, bias due to DS86 random error remained above -30% and was relatively stable over varying levels of age at exposure. Another interesting trend that was noted was that exposure over a career (ages 18 to 65) usually led to a total bias that was greater (more positive) than -50%. In addition, when DS86-specific confirmation rates for a particular site were available, their use usually resulted in a bias for diagnostic misclassification that was lower than the other covariates on which confirmation rates were stratified.

4.3.3 Bias in Transported Relative Projection Models

Tables 15 and 16 list bias of excess risk for the transported relative model that were negative. A similar picture emerged with the transported model when comparing results with the purely absolute model in Tables 13 and 14. Overall, there was a tendency for

Table 12: Site- and sex-specific excess risks (%/Sv) for the BEIR-V relative projection model without adjustment for diagnostic misclassification and DS86 random error (DRREF=2).

		Excess risk (%/Sv)	
Site	Age at exposure[a]	Males	Females
Leukemia	25	0.35	0.27
	45	0.99	0.76
	65	1.46	1.14
	18-65	0.53	0.43
Digestive	25	2.06	3.36
	45	0.36	0.59
	65	0.30	0.50
	18-65	0.77	1.30

[a]For exposure at ages 25, 45 and 65, the population of 100,000 was acutely exposed to 1 Sv; the exposure from age 18 to 65 involved chronic exposure to 0.02128 Sv/y for 47 y (total=1 Sv).

Table 13: Negative bias of excess risk (%/Sv) among males for the absolute projection model (DRREF=2).

			Bias			
Site	Age at exposure	Risk (%/Sv)	Diag. misc.	DS86 random error	Total	Strata of θ_c and θ_{nc}^a
Leukemia	25	0.96	0.0	-14.8	-14.8	N/A
	45	0.72	-48.1	-13.6	-61.7	DS86(1950-85)
	65	0.69	-37.1	-12.8	-50.0	DS86(1950-85)
	18-65	0.85	-11.6	-13.6	-25.2	DS86(1950-85)
Nonleukemia	25	3.36	-18.4	-26.6	-45.0	DS86(1950-85)
	45	4.66	-32.1	-23.6	-55.7	DS86(1950-85)
	65	1.97	-99.8	-24.3	-124.1	DS86(1950-85)
	18-65	3.23	-35.5	-23.6	-59.1	DS86(1950-85)

[a]Strata of confirmation rates for which correction of diagnostic misclassification resulted in negative bias. N/A denotes that the use of confirmation rates in Tables 4-8 did not result in negative bias from diagnostic misclassification. (1950-85) denotes that confirmation rates were applied only to deaths which occurred during 1950-85.

Table 14: Negative bias of excess risk (%/Sv) among females for the absolute projection model (DRREF=2).

			Bias			
Site	Age at exposure	Risk (%/Sv)	Diag. misc.	DS86 random error	Total	Strata of θ_c and θ_{nc}^a
Leukemia	25	0.40	-0.8	-12.8	-13.6	DS86(1950-85)
	45	0.61	-59.3	-10.9	-70.2	DS86(1950-85)
	65	0.69	-42.3	-8.8	-51.1	DS86(1950-85)
	18-65	0.59	-34.2	-10.3	-44.5	DS86(1950-85)
Nonleukemia	25	3.66	-5.2	-18.2	-23.4	DS86(1950-85)
	45	5.77	-31.6	-15.7	-47.3	DS86(1950-85)
	65	3.33	-99.3	-16.1	-115.4	DS86(1950-85)
	18-65	4.28	-33.7	-15.6	-49.3	DS86(1950-85)

[a]Strata of confirmation rates for which correction of diagnostic misclassification resulted in negative bias. (1950-85) denotes that confirmation rates were applied only to deaths which occurred during 1950-85.

diagnostic misclassification and DS86 random error to be the same with respect to the absolute projection model.

4.3.4 Bias in Relative Projection Models

There were fewer sites and exposure categories for which bias was negative under the relative projection model (Tables 17 and 18). A particularly interesting finding was that in most cases the bias was more positive and less erratic than bias for the absolute and transported relative models. Among males (Table 17), diagnostic misclassification bias for leukemia and nonleukemia for a career exposure was -23.9% and -11.3% and for DS86 random error was -14.0% and -23.7%. Females (Table 18) had a bias of -42.8% and -6.3% for diagnostic misclassification of leukemia and nonleukemia. Bias due to DS86 random error for female leukemia and nonleukemia was -11.4% and -14.9% for exposure over a career.

In comparison, the bias due to diagnostic misclassification in males and females for lifetime risks based on the Sposto et al. anaylsis for exposure over a career (18 to 65 y) was -10.0% and 2.5%. The adjustment of cancer misclassification in U.S. cancer rates used for risk projection resulted in a bias of 11% for leukemia and -2% for nonleukemia.

The total bias for leukemia and nonleukemia among males exposed over a career was -27.1% and -37.1% and resulted in changes of excess risk (%/Sv) from 0.87 to 1.1 and 1.91 to 2.68. Females had a total bias of -43.4% and -23.3% for leukemia and nonleukemia which led to changes in excess risk (%/Sv) of 0.73 to 1.04 and 3.23 to 4.02.

Figures 8 and 9 illustrate schematically, for males and females, the conditional probabilities, $\pi(t;d)$, (see Eq. 68) of radiation-induced nonleukemia based on non-constant relative projections for this investigation and results based on projections using the Sposto et al. (1992) regression coefficients. Figure 8 shows that, for males exposed to 1 Sv at age 25, the difference between $\pi(t;d)$ when a 22% correction for diagnostic misclassification was made and $\pi(t;d)$ when no correction was made for the Sposto et al. data is smaller than

Table 15: Negative bias of excess risk (%/Sv) among males for the transported relative projection model (DRREF=2).

			Bias			
Site	Age at exposure	Risk (%/Sv)	Diag. misc.	DS86 random error	Total	Strata of θ_c and θ_{nc}^a
Leukemia	25	0.08	-17.5	-15.3	-32.8	DS86(1950-85)
	45	0.60	-54.6	-13.4	-68.0	DS86(1950-85)
	65	0.65	-32.1	-12.3	-44.4	DS86(1950-85)
	18-65	0.54	-36.1	-12.8	-48.9	DS86(1950-85)
Nonleukemia	25	2.80	-17.1	-26.2	-43.3	DS86(1950-85)
	45	4.50	-31.5	-22.3	-53.8	DS86(1950-85)
	65	1.36	-108.9	-26.15	-135.1	DS86(1950-85)
	18-65	2.90	-35.7	-22.8	-58.5	DS86(1950-85)

[a]Strata of confirmation rates for which correction of diagnostic misclassification resulted in negative bias. (1950-85) denotes that confirmation rates were applied only to deaths which occurred during 1950-85.

Table 16: Negative bias of excess risk (%/Sv) among females for the transported relative projection model (DRREF=2).

			Bias			
Site	Age at exposure	Risk (%/Sv)	Diag. misc.	DS86 random error	Total	Strata of θ_c and θ_{nc}^a
Leukemia	25	0.06	-42.7	-13.7	-56.4	DS86(1950-85)
	45	0.46	-73.7	-10.9	-84.6	DS86(1950-85)
	65	0.71	-34.7	-8.7	-43.4	DS86(1950-85)
	18-65	0.43	-48.3	-9.6	-57.9	DS86(1950-85)
Nonleukemia	25	2.91	-7.7	-18.4	-26.1	DS86(1950-85)
	45	5.47	-30.1	-14.8	-44.9	DS86(1950-85)
	65	2.11	-98.8	-17.1	-115.9	DS86(1950-85)
	18-65	3.69	-34.1	15.1	-49.2	DS86(1950-85)

[a]Strata of confirmation rates for which correction of diagnostic misclassification resulted in negative bias. (1950-85) denotes that confirmation rates were applied only to deaths which occurred during 1950-85.

the difference when an adjustment was made with the DS86-specific confirmation rates. The same was true for exposure at ages 45 and 65 and for the continuous exposure (18 to 65). At 65 years of age, an acute exposure to 1 Sv seemed to cause $\pi(t;d)$ to increase rapidly with increasing attained age. This finding may be in accord with a suggestion by Moolgavkar and Knudson (1981) that relative risk is highest at older ages at exposure because the number of premalignant clones in the body increases with attained age. One also notes the striking similarity in the shapes of the curves for the Sposto et al. data and this study. The height of the curves for $\pi(t;d)$ based on the Sposto et al. data was higher than $\pi(t;d)$ for this study because a neutron RBE of unity was used (this study used a neutron RBE of 10). For females (Figure 9), the 22% correction for diagnostic misclassification made in the Sposto et al. analysis always resulted in a corrected $\pi(t;d)$ that was lower than the $\pi(t;d)$ when no correction was made because the regression coefficient for females in the uncorrected model was reduced from 0.356 to 0.315 after correction. In addition, the patterns of $\pi(t;d)$ for all exposure profiles in Figure 9 indicate that neutron RBE had a lower impact on risk of nonleukemia among females.

4.3.5 Bias in BEIR-V Relative Projection Models

Tables 19 and 20 list the sites and exposure profiles for which bias from diagnostic misclassification and DS86 random errors in the BEIR-V models were negative. For males (Table 19), bias due to DS86 random errors were more positive than in the relative models with values typically above -10%. Diagnostic misclassification bias for leukemia for males was more negative when compared to the relative models (Tables 17) and was more positive for females when compared with the relative model (Table 18). While the the bias due to DS86 random error for leukemia (1 Sv 18-65) among males and females were -3.7% and -3.9%, the same bias was -14.0% and -11.4% in the relative models. One also notices in Tables 19 and 20 that, for the digestive site, there were only two exposure profiles (1 Sv acute at ages 45 and 65) for which correction of diagnostic misclassification was negatively biased; however, the magnitude of the bias is negligible.

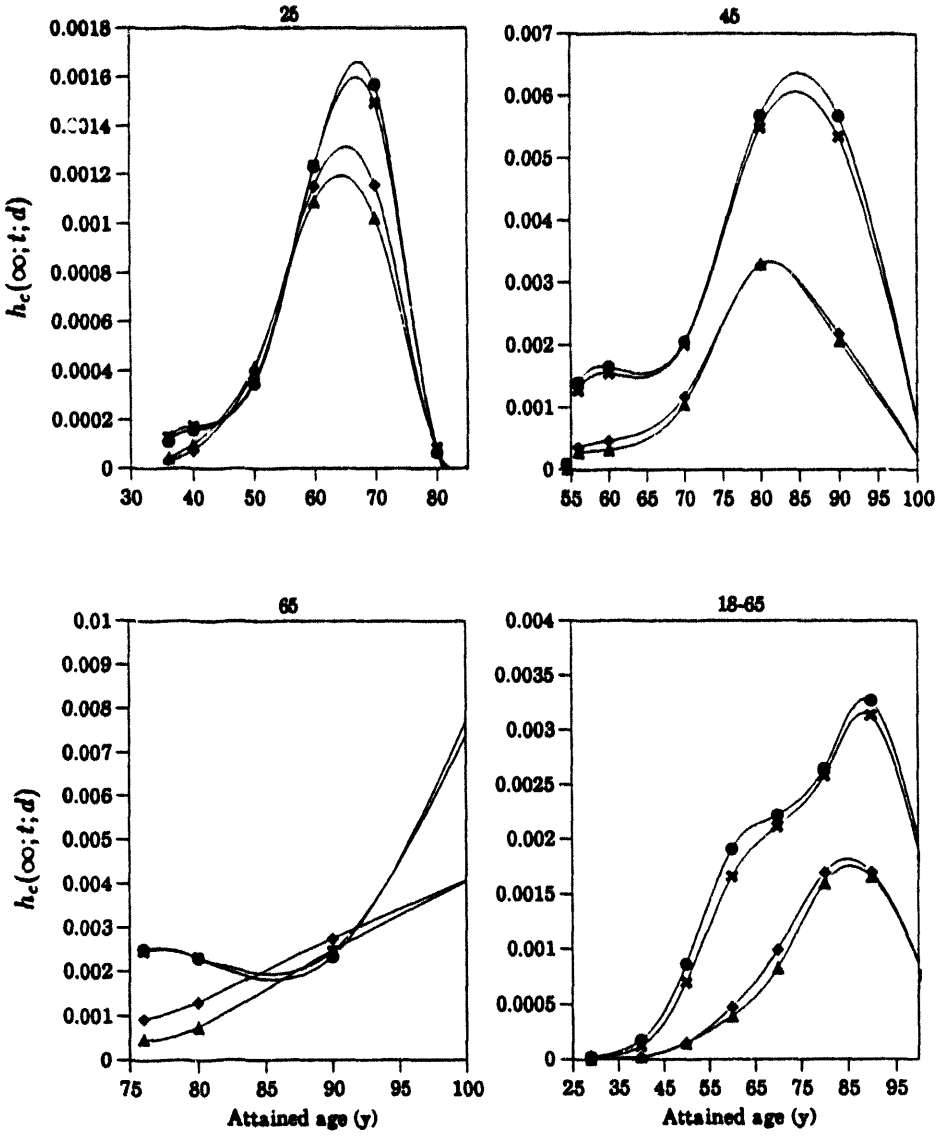


Figure 8: Conditional probabilities of radiation-induced nonleukemia among males for this study and results based on the Sposto et al. regression coefficients. (× —no adjustment in Sposto et al.; • — 22% adjustment in Sposto et al.; ▲ — no adjustment in this study; ◆ — DS86-specific adjustment in this study).

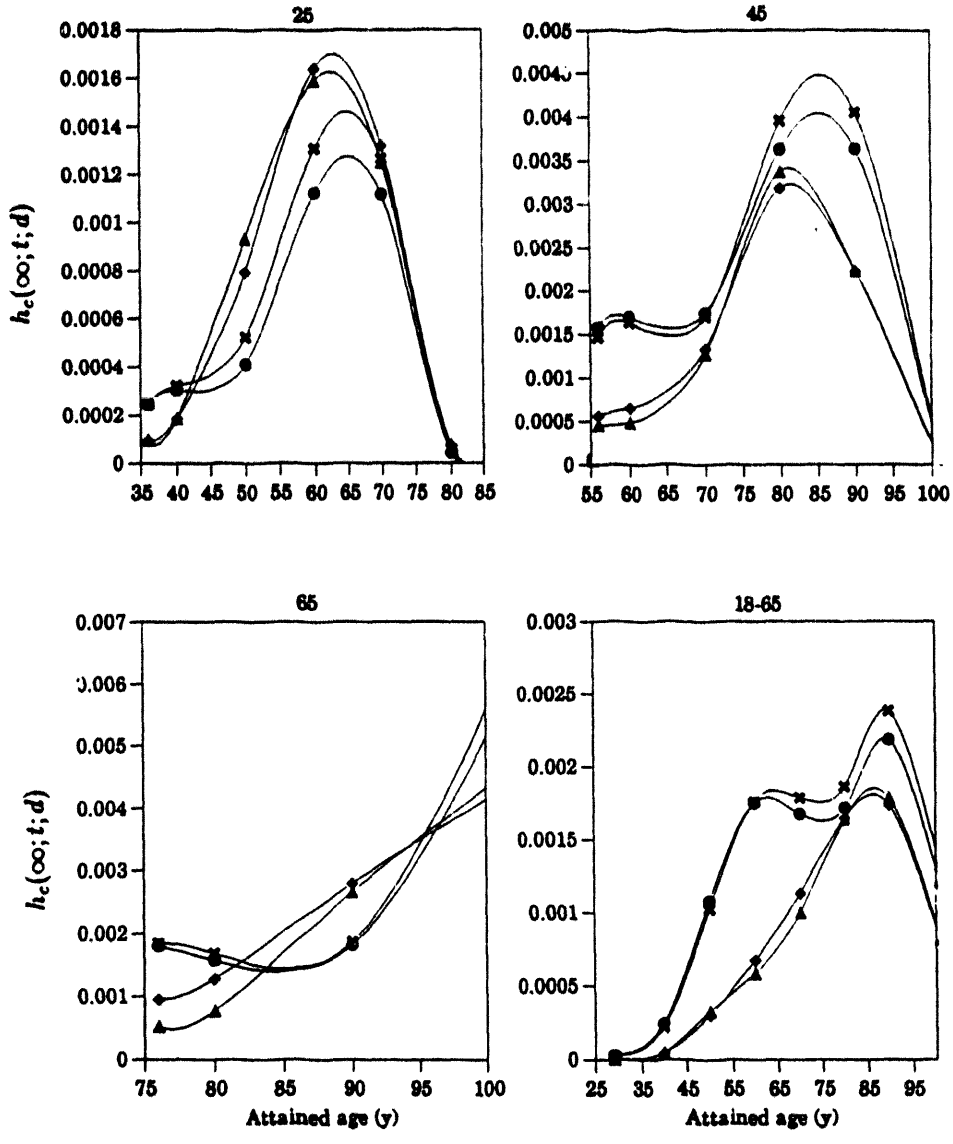


Figure 9: Conditional probabilities of radiation-induced nonleukemia among females for this study and results based on the Sposto et al. regression coefficients. (× —no adjustment in Sposto et al.; • — 22% adjustment in Sposto et al.; ▲ — no adjustment in this study; ◆ — DS86-specific adjustment in this study).

Table 17: Negative bias of excess risk (%/Sv) among males for the relative projection model (DRREF=2).

			Bias				
Site	Age at exposure	Risk (%/Sv)	Diag. misc.	DS86 random error	DCCF	Total	Strata of θ_c and θ_{nc}^a
Leukemia	25	0.39	-6.0	-17.4	10.8	-12.6	Sex(1950-85)
	45	0.79	-69.7	-14.2	10.8	-73.1	DS86(1950-85)
	65	3.08	-23.3	-13.3	10.5	-26.1	DS86(1950-85)
	18-65	1.10	-23.9	-14.0	10.8	-27.1	DS86(1950-85)
Nonleukemia	25	2.90	-5.0	-27.1	-2.1	-34.2	DS86(1950-85)
	45	3.76	-7.3	-23.5	-2.1	-32.9	DS86(1950-85)
	65	2.12	-38.9	-24.6	-2.1	-65.6	DS86(1950-85)
	18-65	2.68	-11.3	-23.7	-2.1	-37.1	DS86(1950-85)
Nonleukemia	25	2.64	-1.0	-	-	-1.0	N/A-EM algorithm
(Sposto et al.)	45	5.95	-4.0	-	-	-4.0	N/A-EM algorithm
	65	2.36	1.3	-	-	1.3	N/A-EM algorithm
	18-65	5.39	-10.0	-	-	-10.0	N/A-EM algorithm

[a]Strata of confirmation rates for which correction of diagnostic misclassification resulted in negative bias. N/A-EM algorithm denotes that the diagnostic misclassification was estimated from the Sposto et al. (1992) Poisson regression coefficients obtained with the EM algorithm. (1950-85) denotes that confirmation rates were applied only to deaths which occurred during 1950-85.

Table 18: Negative bias of excess risk (%/Sv) among females for the relative projection model (DRREF=2).

			Bias				
Site	Age at exposure	Risk (%/Sv)	Diag. misc.	DS86 random error	DCCF	Total	Strata of θ_c and θ_{nc}^a
Leukemia	25	0.31	-12.1	-15.1	10.9	-16.3	DS86(1950-85)
	45	0.75	-83.4	-11.6	10.8	-84.2	DS86(1950-85)
	65	2.75	-40.9	-10.9	10.6	-41.2	DS86(1950-85)
	18-65	1.04	-42.8	-11.4	10.8	-43.4	DS86(1950-85)
Nonleukemia	25	4.33	-1.5	-19.6	-2.1	-23.2	DS86(1950-85)
	45	5.22	-3.9	-13.9	-2.0	-19.8	DS86(1950-85)
	65	2.94	-26.2	-15.9	-2.1	-44.2	DS86(1950-85)
	18-65	4.02	-6.3	-14.9	-2.1	-23.3	DS86(1950-75)
Nonleukemia	25	2.62	13.3	-	-	13.3	N/A-EM algorithm
(Sposto et al.)	45	6.28	3.2	-	-	3.2	N/A-EM algorithm
	65	2.32	5.2	-	-	5.2	N/A-EM algorithm
	18-65	5.77	2.5	-	-	2.5	N/A-EM algorithm

[a]Strata of confirmation rates for which correction of diagnostic misclassification resulted in negative bias. N/A-EM algorithm denotes that the diagnostic misclassification was estimated from the Sposto et al. (1992) Poisson regression coefficients obtained with the EM algorithm. (1950-75) denotes that confirmation rates were applied only to deaths that occurred during 1950-75. Likewise, (1950-85) denotes that confirmation rates were applied only to deaths which occurred during 1950-85.

Table 19: Negative bias of excess risk (%/Sv) among males for the BEIR-V projection model (DRREF=2).

			Bias				
Site	Age at exposure	Risk (%/Sv)	Diag. misc.	DS86 random error	DCCF	Total	Strata of θ_c and θ_{nc}^a
Leukemia	25	0.44	-32.2	-8.4	10.8	-29.8	DS86(1950-85)
	45	1.20	-28.8	-7.3	10.8	-25.3	DS86(1950-85)
	65	1.64	-20.4	-4.3	10.7	-14.0	DS86(1950-85)
	18-65	0.79	-59.4	-3.7	10.8	-52.3	DS86(1950-85)
Digestive	25	1.95	0.0	6.6	-1.5	5.1	N/A
	45	0.44	-1.4	-17.8	-1.6	-22.5	Crude(1950-75)
	65	0.37	-1.0	-19.5	-1.6	-20.4	Sex-city(1950-75)
	18-65	0.77	0.0	1.4	-1.6	-0.2	N/A

[a]Strata of confirmation rates for which correction of diagnostic misclassification resulted in negative bias. N/A denotes that the use of confirmation rates in Tables 4-8 did not result in negative bias from diagnostic misclassification. (1950-75) denotes that confirmation rates were applied only to deaths that occurred during 1950-75. Likewise, (1950-85) denotes that confirmation rates were applied only to deaths which occurred during 1950-85.

Table 20: Negative bias of excess risk (%/Sv) among females for the BEIR-V projection model (DRREF=2).

			Bias				
Site	Age at exposure	Risk (%/Sv)	Diag. misc.	DS86 random error	DCCF	Total	Strata of θ_c and θ_{nc}^a
Leukemia	25	0.34	-31.8	-8.3	10.9	-29.2	DS86(1950-85)
	45	1.0	-29.9	-7.7	10.8	-26.8	DS86(1950-85)
	65	1.3	-21.2	-0.5	10.8	-10.9	DS86(1950-85)
	18-65	0.6	-60.5	-3.9	10.8	-53.6	DS86(1950-85)
Digestive	25	3.55	0.0	-4.18	-1.53	-5.71	N/A
	45	0.80	-6.2	-26.5	-1.6	-28.5	Sex(1950-75)
	65	0.67	-6.2	-26.6	-1.6	-28.6	Sex(1950-75)
	18-65	1.46	0.0	-10.5	-1.57	-12.1	N/A

[a]Strata of confirmation rates for which correction of diagnostic misclassification resulted in negative bias. N/A denotes that the use of confirmation rates in Tables 4-8 did not result in negative bias from diagnostic misclassification. (1950-75) denotes that confirmation rates were applied only to deaths that occurred during 1950-75. Likewise, (1950-85) denotes that confirmation rates were applied only to deaths which occurred during 1950-85.

5 DISCUSSION

5.1 Confirmation Rates

The use of cancer and non-cancer confirmation rates or the *predictive value positive* to estimate the true number of cancer deaths in the LSS confirmed the impression that correction of non-differential misclassification does not alway lead to a bias that is toward the null (Green, 1983). Bias due to random error in the DS86, however, was always negative, the correction of which produced increased ERR and AR coefficients.

A major influence on the validity of correction methods for diagnostic misclassification in the LSS is the large number of non-cancer deaths that have occurred (and are occurring) at the higher age ATD groups and middle-aged age ATB groups. If precautions are not taken when *shifting* the small number of misclassified cancer deaths from the large number of non-cancer deaths into the presumed correct cells, then invalid results may be obtained. We did not use the EM algorithm (Dempster et al., 1977) for imputing the true cancer deaths in cells for which no autopsy data existed, rather we employed the *sufficient* statistics that are used before the first iteration of the EM algorithm and applied the results to all cells after a minimal latency period of 2 years for leukemia and 10 years for solid cancers.

Table 21: Weighted per cent distribution of non-cancer deaths among both sexes in both cities in the Life Span Study (1950-85).

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	0.88	0.66	0.76	0.33	0.00	0.00	0.00
10-19	0.24	1.63	1.13	1.45	0.73	0.00	0.00
20-29	0.00	0.45	1.05	1.03	1.56	0.77	0.00
30-39	0.00	0.00	0.42	1.65	2.80	4.86	2.30
40-49	0.00	0.00	0.00	0.95	4.80	7.59	15.00
50+	0.00	0.00	0.00	0.00	1.50	7.63	37.81

Table 22: Weighted per cent distribution of non-cancer deaths among males in both cities in the Life Span Study (1950-85).

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	1.19	0.88	1.15	0.54	0.00	0.00	0.00
10-19	0.28	2.00	1.49	2.04	0.98	0.00	0.00
20-29	0.00	0.35	0.67	0.88	1.30	0.90	0.00
30-39	0.00	0.00	0.34	1.66	3.14	4.35	1.87
40-49	0.00	0.00	0.00	1.04	5.70	8.55	13.63
50+	0.00	0.00	0.00	0.00	1.97	9.64	33.46

5.2 Regression Methods

The maximum likelihood results we obtained indicated that, in some cases, and in some cross-classifications of the data, there were indeed locations on the likelihood surface where

Table 23: Weighted per cent distribution of non-cancer deaths among females in both cities in the Life Span Study (1950-85).

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	0.62	0.47	0.43	0.16	0.00	0.00	0.00
10-19	0.21	1.33	0.83	0.96	0.52	0.00	0.00
20-29	0.00	0.53	1.37	1.17	1.78	0.65	0.00
30-39	0.00	0.00	0.49	1.64	2.51	5.30	2.66
40-49	0.00	0.00	0.00	0.87	4.03	6.78	16.17
50+	0.00	0.00	0.00	0.00	1.09	5.93	41.50

incongruities exist. For example, the stomach model had to be fit for each sex since models that contained a parameter for gender either 1) did not converge after 100 iterations; 2) had highly non-significant Wald statistics; or 3) had log-linear regression coefficients that were <-10,000! In the case of the liver, sometimes AMFIT warned us that the results may not be the maximum likelihood values. Such *perturbations* can be attributable to *local maxima* that are proximal to areas located near starting points on the likelihood surface or a general lack of a signal-to-noise ratio in certain cross-classifications of the data. The choice of regression models must also be taken into consideration because AMFIT uses partial-likelihood models that are stratified, non-fully parametric mixtures of linear and log-linear parameters. Therefore, interpretation of results when using such *quasi-likelihood* models for fitting data with little or no signal-to-noise, e.g., liver, should be treated with caution.

A very interesting finding was that the Freeman-Tukey goodness-of-fit statistic was much more stable than the Pearson χ^2 or D statistics. There were many situations where χ^2 and D decreased after adjusting for diagnostic misclassification and the Freeman-Tukey GOF (G) either remained the same or increased. We can infer from this apparent pattern in GOF statistics that the G may be a more reliable measure of goodness-of-fit and that G may indicate when an appropriate adjustment is made when imputing missing data. It would be interesting to see how χ^2, D and G would behave when the EM algorithm is used for adjusting for diagnostic misclassification.

Table 24: Weighted per cent distribution of non-cancer deaths among Hiroshima males in the Life Span Study (1950-85).

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	0.96	0.74	0.94	0.36	0.00	0.00	0.00
10-19	0.00	1.84	1.25	1.76	1.12	0.00	0.00
20-29	0.00	0.28	0.70	0.90	1.31	1.00	0.00
30-39	0.00	0.00	0.42	1.83	3.04	4.74	1.98
40-49	0.00	0.00	0.00	1.06	5.57	8.62	14.45
50+	0.00	0.00	0.00	0.00	1.90	9.04	34.19

Table 25: Weighted per cent distribution of non-cancer deaths among Nagasaki males in the Life Span Study (1950-85).

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	1.76	1.21	1.63	0.96	0.00	0.00	0.00
10-19	0.96	2.36	2.05	2.68	0.67	0.00	0.00
20-29	0.00	0.51	0.61	0.83	1.28	0.67	0.00
30-39	0.00	0.00	0.16	1.25	3.39	3.42	1.63
40-49	0.00	0.00	0.00	0.99	6.01	8.37	11.67
50+	0.00	0.00	0.00	0.00	2.14	11.06	31.74

Table 26: Weighted per cent distribution of non-cancer deaths among Hiroshima females in the Life Span Study (1950-85).

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	0.41	0.35	0.35	0.12	0.00	0.00	0.00
10-19	0.02	1.28	0.78	0.90	0.58	0.00	0.00
20-29	0.00	0.50	1.24	1.09	1.94	0.60	0.00
30-39	0.00	0.00	0.41	1.53	2.47	5.74	2.81
40-49	0.00	0.00	0.00	0.82	3.99	6.75	16.78
50+	0.00	0.00	0.00	0.00	1.09	5.61	41.86

5.3 DS86 Random Error

With regard to differential misclassification of exposure, where it was assumed that that sensitivities and specificities were unequal across exposure strata, the correction of DS86 random errors was successful and in many situations produced increased excess risks. This is in agreement with analyses performed by Pierce and Vaeth (1991) and Pierce et al. (1991). In most situations, the bias due to DS86 random errors was on average -15% to -30%, and depended on the sex, site, or regression (with or without age ATD) or projection model that was used. The BEIR-V models provided a bias for DS86 random error that was in some cases positive, and was most likely due to truncation of dose equivalent to 4 Sv.

Table 27: Weighted per cent distribution of non-cancer deaths among Nagasaki females in the Life Span Study (1950-85).

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	1.10	0.73	0.63	0.26	0.00	0.00	0.00
10-19	0.63	1.44	0.94	1.07	0.39	0.00	0.00
20-29	0.00	0.60	1.68	1.34	1.44	0.76	0.00
30-39	0.00	0.00	0.68	1.89	2.59	4.30	2.33
40-49	0.00	0.00	0.00	0.97	4.14	6.86	14.80
50+	0.00	0.00	0.00	0.00	1.10	6.65	40.68

5.4 Autopsy Program and Diagnostic Misclassiciation

The use of autopsy data to correct for diagnostic misclassification in RERF models proved useful and typically resulted in negative bias in the excess risks. On the other hand, correction of diagnostic misclassification in the BEIR-V models that excluded records for which mean age at death was greater than 75 may have been moot and not beneficial.

A plausible inference concerning exposure misclassification and the assumption that the true exposure-specific sensitivities are known, is that LSS subjects who have or who are undergoing either radiodiagnoses or radiotherapy would gravitate, if not adjusted for in an analysis, to the false negative exposure category because of underestimation of dose. Future studies should focus on, or at least take into consideration, medical exposures of LSS subjects when fitting dose-response.

It is certain that much of the information obtained from the Autopsy Program will not change. The vital status of autopsied decedents for whom no tissue or biological specimens exist may not change and may remain fixed forever. As the RERF tumor registries in Hiroshima and Nagasaki increase in size, the utility of cancer incidence data for determing the risk of developing radiation-induced neoplasia will begin to overshadow mortality data and lend itself well for verifying the decedents' true cause of death.

5.5 Bias in Lifetime Mortality Risks

There was a wide variation of bias for the various combinations of sites, gender and exposure profiles. Bias in the absolute and transported relative models was erratic and did not seem to follow any particular pattern. Land and Sinclair (1991) found that, when comparing lifetime risks of radiation across countries, international correlations under the absolute and transported relative models were lower than those provided by the relative model. Storer et al. (1988) also found that the relative risk model was more suitable for extrapolating risk from radiobiological studies in various mouse strains to man. In view of our findings in relationship to variability of bias across projection models, it is likely that similar findings could be obtained in future radiobiologic and international epidemiologic studies.

Cases for which bias was negative are shown for all models, sites, and sexes in Tables 13-20. For leukemia and nonleukemia, dose-related (T65DR) confirmation rates for cancer and non-cancer were available and always resulted in the most negative bias when compared with lifetime risks for which other or no adjustments were made. With regard to risk projection and studies of information bias, we recommend the relative model because its use, when compared with other models, results in fewer instances where total bias approaches -50%. The use of autopsy data to correct for diagnostic misclassification in BEIR-V sites that exclude records for which mean age at death is greater than 75 may be moot. in fewer instances where total bias approaches -50%.

Several authors suggest that when misclassification of outcome status is differential, that is, can be corrected with dose-specific sensitivities and specificities, the results of correction will typically result in bias that is negative and toward the null, but can go in either direction (Fleiss, 1981; Kleinbaum et al., 1982; Flegal et al., 1986). This was not unexpected since it was shown in the Autopsy Program that the probability of autopsy increased with increasing radiation dose, therefore, cancer misclassification is greater in the exposed than it is in the zero-dose or not-in-city category (Yamamoto et al., 1978).

Green (1983) published a report of an extensive evaluation of the use of predictive value positive (confirmation rates) to adjust relative risk biased by misclassification of outcome status. While equations and examples were given for the adjustment of RR in

a number of situations, the entire analysis was based on the predictive value positive of the non-exposed group. Under the constraint of using PV^+ for only the nonexposed group, it would have been impossible to employ, with the exception of leukemia and nonleukemia, the confirmation rates from the Autopsy Study used in this study because for most sites confirmation rates were not available for the zero dose groups. There have been other studies on correction of diagnostic misclassification reported but, in the main, they address two-way tables used in log-linear analyses rather than maximum likelihood applications with Poisson regression modeling (Greenland and Robins, 1985; Savitz and Baron, 1989; Hsieh and Walter, 1988; Duffy et al., 1989; Greenland, 1989; Chen, 1989; Elton, 1989). Tables 21-27 give the weighted per cent distribution of non-cancer deaths on a crude, sex- and sex- and city-specific basis. Variation in the number of non-cancer deaths from table to table (Tables 21-27) suggest that, along with the excess radiation-induced cases, these data could strongly influence the bias due to misclassification. A thorough analysis of regression coefficients for most sites revealed that when the adjustment of diagnostic misclassification resulted in a negative bias (lifetime risks increased), it was wholly attributable to an increase of regression coefficients. Nevertheless, models for which the correction of misclassification resulted in negative bias always had goodness-of-fit statistics that were lower (better) than models for which no adjustment was made.

There is only a spattering of information on Poisson regression and diagnostic misclassification in the literature. In one particular study, the investigators developed likelihood equations based on binomial misclassification probabilities and international rates of cervical cancer mortality rates that followed the Poisson assumption (Whittemore and Gong, 1991). They developed four models to account for combinations of the presence of age and country covariates and error rates that were either independent of country (crude) or dependent on country. Their choice of a model was based solely on the log-likelihood ratio statistic, and interestingly, resulted in selection of the model with the most negative bias. The only other study was the one by Sposto et al. (1992) on the effect of diagnostic misclassification on the cancer dose-response curve in the LSS. Logistic regression was used to estimate cancer and non-cancer misclassification probabilities, along with the EM algorithm to impute true cancer deaths in cells for which no autopsy data existed. Poisson regression was used with a continuous model including covariates for age ATB, attained age, sex and stratified on city, sex, age ATB, and follow-up period. In order to compare our results with theirs, we used the Sposto et al. Poisson regression coefficients for nonleukemia to estimate lifetime risks with the non-constant relative projection model for acute exposures to 1 Sv at ages 25, 45 and 65 and exposure to a total of 1 Sv from age 18 to 65 over a 47 year career.

Although a 12% increase (-12% bias) in ERR was reported for 50-year old Hiroshima males exposed at age 25, the bias of lifetime risk (Tables 17 and 18) for exposure to 1 Sv at age 25 was only -1%, 1 Sv at age 45 was -4%, 1 Sv at age 65 was 1.3% and continuous exposure from age 18 to 65 (1 Sv total) was -10%. For females, bias of lifetime risk based on the Sposto et al. regression coefficients for nonleukemia were 13.3% for 1 Sv at 25, 3.2% for 1 Sv at 45, 5.2% for 1 Sv at 65, and 2.5% for exposure over a career. Bias for the female lifetime risks was always positive for the Sposto et al. data because the log-linear regression coefficient for gender (0-males, 1-females) changed from 0.356 when no adjustment for diagnostic misclassification was made to 0.315 (positive bias) when a 22% correction was made. The bias of lifetime risks of nonleukemia among males under the relative model (Tables 17) for exposure over a career (-11.3%) was in accord with lifetime risk based on the Sposto et al. data (-10%). However, for females, bias of lifetime risk of nonleukemia for exposure over a career (Table 18) was dissimilar.

The implication of these findings is that investigators may focus on modeling to the extent that the relevance of modeling to worker protection (via lifetime risk projection) may become obfuscated and not portray the picture that is sought by policy makers. Since information bias was dependent on gender, site, method of correction, projection model and exposure profile, the full effect of diagnostic misclassification and DS86 random errors on risk for Western working populations, that is, the *generalizability*, is best seen when lifetime risk projections are made following adjustments for information bias.

Variation of the misclassification bias in the two studies reflect the different methods which were used for estimating the true number of deaths in the cancer mortality data. Whereas Sposto et al. used logistic regression to estimate cancer misclassification probabilities and then used a full implementation of the EM algorithm to impute data in cells for which autopsy information did and did not exist, we used cancer and non-cancer confirmation rates to impute the true number of cancer deaths in all cells after a minimal latency period of 10 years. Differences existed in the models that were used: while Sposto et al. used a continuous model, the present study employed grouped models. Breslow and Day (1987) compared relative risk estimates from continuous and grouped Poisson regression models and concluded that there was no dramatic difference between results obtained with the two methods. However, a common assumption about using grouped methods is that the results will be less affected by distortion due to measurement error (Gilbert, 1982).

For all cases, lifetime risks based on Sposto et al. regression coefficients were higher than those for nonleukemia in the present study because Sposto et al. used a neutron RBE of unity when applying large intestine body self-shielding transmission factors to shielded kerma to obtain organ dose estimates. In consideration of our findings, and those of Sposto et al., it is likely that the two studies represented limited analyses of a larger problem related to information bias and the validity of generalizing LSS results to working Western working populations that are mostly chronically exposed to low doses of ionizing radiation.

6 SUMMARY

The numerical methods employed in the present study were extensive. Poisson regression results are provided for a variety of corrections made for diagnostic misclassification and DS86 random dosimetry error. Since there were so many combinations of correction methods, the results were listed in tabular notation because the use of a graphic format would result in figures that would have been too difficult to comprehend. Readers who are interested in comparison figures can construct graphics from the tabular data in the text or the appendices.

The major findings of this investigation were:

(1). As age at death increased a greater proportion of true cancer deaths were attributable to non-cancer deaths because the true number of cancer deaths is equal to the sum of the product of the observed cancer deaths and the probability that the observed cancer deaths are correctly classified and the product of the observed non-cancer deaths and one minus the the probability that the observed non-cancer deaths were correctly classified (see Eq. 5 in §3.2.2).

(2). Poisson regression resulted in fitted maximum likelihood models that were in concordance with the observed data. When the goodness-of-fit of regression models containing time-dependent covariates is reasonable, non-constant lifetime risk projection should be used.

(3). Excess relative risk coefficients for the RERF and BEIR-V models were in good agreement with those published in RERF Report 11 (Part 2) and the BEIR-V report. Small differences existed between regression results for RERF models that contained parameters for age at-time-of-bombing (ATB), age at-time-of-death (ATD), and gender because organ dose estimates were used rather than shielded kerma. Thus, the lifetime risks based on these models were slightly higher than those that would obtain from the use of coefficients in RERF Report 11.

(4). Statistical modeling with the BEIR-V models provided regression coefficients that were almost exactly identical to those in the BEIR-V report. For leukemia, the linear-quadratic contribution of dose to excess mortality was slightly lower than that in the BEIR-V report. Lifetime risks based on the BEIR-V models were similar to those published in the BEIR-V Report (NRC, 1990). Bias due to DS86 random error for the digestive site was smaller than bias in the RERF non-constant nonleukemia projection models, which was most likely due to truncation of dose equivalent to 4 Sv. The correction of diagnostic misclassification in excess risks for the BEIR-V digestive cancer site had little effect on bias (-2%) because records with an age at death beyond 75, when cancer misclassification rises markedly, were excluded.

(5). Using a Dose-Rate Reduction Effectiveness Factor (DRREF) of two and no correction for DS86 random error or diagnostic misclassification in the non-constant relative projection model, lifetime risks (%/Sv) of nonleukemia among males exposed acutely to 1 Sv at age 25, 45, 65 or continuously from ages 18 to 65 were 2.10%, 2.78%, 1.20% and 1.91%. For females, nonleukemia lifetime risks for the same exposure profiles were 3.49%, 4.32%, 1.97% and 3.23%. Excess leukemia risks for 1 Sv at 25, 45 and 65 and over the years 18 to 65 were 0.35%, 0.46%, 2.46% and 0.87% for males and 0.26%, 0.41%, 1.96% and 0.73% for females. These data were in good agreement with the results of Land and Sinclair (1991). By way of comparison, for exposure from ages 18 to 65, excess nonleukemia risks based on the constant relative projection model were 2.84% for males and 4.75% for females. The risks of leukemia among males was 0.75% and among females was 0.64%. Therefore, lifetime risk estimates based on constant models did not underestimate risks

projected by non-constant models.

(6). The correction of differential diagnostic misclassification with leukemia and non-leukemia (and non-cancer) confirmation rates that were stratified on T65DR dose (DS86 shielded kerma was converted to T65DR shielded in order to select T65DR-specific confirmation rates) resulted in bias that was negative. Confirmation rates for leukemia and nonleukemia that were stratified on age ATD did not provide bias that was more negative than that obtained with DS86-specific confirmation rates. Correction of diagnostic misclassification using confirmation rates that were crude or stratified on either gender or city and gender resulted in bias that was negative or positive. The bias of excess risk of non-leukemia due to diagnostic misclassification for 1 Sv at age 25, 45, 65 or continuously from ages 18 to 65 under the non-constant relative projection model was -5.0% (2.13%/Sv vs. 2.24%/Sv), -7.3% (2.78%/Sv vs. 2.99%/Sv), -38.9% (1.20%/Sv vs. 1.67%/Sv) and -11.3% (1.91%/Sv vs. 2.13%/Sv) for males and -1.5% (3.49%/Sv vs. 3.54%/Sv), -3.9% (4.32%/Sv vs. 4.49%/Sv), -26.2% (1.97%/Sv vs. 2.48%/Sv) and -6.3% (3.23%/Sv vs. 3.43%/Sv) for females. For leukemia excess risks under the same dose profiles, the bias due to diagnostic misclassification was -6.0% (0.36%/Sv vs. 0.37%/Sv), -69.7% (0.46%/Sv vs. 0.77%/Sv), -23.3% (2.46%/Sv vs. 3.04%/Sv) and -23.9% (0.87%/Sv vs. 1.09%/Sv) for males and -12.1% (0.26%/Sv vs. 0.30%/Sv), -83.4% (0.41%/Sv vs. 0.75%/Sv), -40.9% (1.96%/Sv vs. 2.77%/Sv), and -42.8% (0.73%/Sv vs. 1.05%/Sv) for females. When the nonleukemia Poisson regression coefficients from Sposto et al. (1992) were used to project lifetime risks under the non-constant relative model, the bias due to diagnostic misclassification for 1 Sv acute at 25, 45, or 65 and over a career (18 to 65) was -1.0% (2.61%/Sv vs. 2.64%/Sv), -4.0% (5.72%/Sv vs. 5.95%/Sv), 1.3% (2.39%/Sv vs. 2.36%/Sv), and -10.0% (4.90%/Sv vs. 5.39%/Sv) for males and 13.3% (3.02%/Sv vs. 2.62%/Sv), 3.2% (6.49%/Sv vs. 6.28%/Sv), 5.2% (2.46%/Sv vs. 2.32%/Sv) and 2.5% (5.92%/Sv vs. 5.77%/Sv) for females.

(7). The use of reduction factors to correct for DS86 random error in survivor doses indicated that lifetime risks were negatively biased 15%-30%. Bias of excess risk (non-constant relative projection and correction for diagnostic misclassification) of nonleukemia due to DS86 random errors for 1 Sv at age 25, 45, 65 or continuously from ages 18 to 65 was -27.1% (2.24%/Sv vs. 2.28%/Sv) , -23.5% (2.99%/Sv vs. 3.69%/Sv), -24.6% (1.67%/Sv vs. 2.08%/Sv) and -23.7% (2.13%/Sv vs. 2.63%/Sv) for males and -19.6% (3.54%/Sv vs. 4.24%/Sv), -13.9% (4.49%/Sv vs. 5.12%/Sv), -15.9% (2.48%/Sv vs. 2.88%/Sv) and -14.9% (3.43%/Sv vs. 3.94%/Sv) for females. For leukemia excess risks under the same dose profiles, the bias due to DS86 random error was -17.4% (0.37%/Sv vs. 0.44%/Sv), -14.2% (0.77%/Sv vs. 0.88%/Sv), -13.3% (3.04%/Sv vs. 3.44%/Sv) and -14.0% (1.09%/Sv vs. 1.24%/Sv) for males and -15.1% (0.30%/Sv vs. 0.34%/Sv) , -11.6% (0.75%/Sv vs. 0.84%/Sv), -10.9% (2.77%/Sv vs. 3.07%/Sv), and -11.4% (1.05%/Sv vs. 1.17%/Sv) for females.

(8). The correction of mortality misclassification in SEER baseline rates used in lifetime risk projection (non-constant relative model) increased excess risks by 2.1% for nonleukemia and decreased risk by 10.8% for leukemia.

(9). The total bias of excess risk of nonleukemia for exposure from age 18 to 65 under the non-constant relative projection model was -37.1% for males and -23.3% for females. For leukemia excess risks under the relative projection model, the total bias was -27.1% for males and -43.4% for females. Thus, nonleukemia risks increased 37.1% for males (1.91%/Sv to 2.68%/Sv) and 23.3% for females (3.23%/Sv to 4.02%/Sv) and leukemia risks increased 27.1% (0.87%/Sv to 1.10%/Sv) for males and 43.4% (0.73%/Sv to 1.04%/Sv).

(10). In most cases, bias due to diagnostic misclassification for lifetime risk projections

using the relative model was more positive and less erratic than bias for the absolute and transported relative models. With regard to risk projection and future studies of information bias, we recommend the relative model because its use, when compared with other models, resulted in biases with lower variation across gender, sites and exposure profiles.

It is patently clear that the effects of diagnostic misclassification and DS86 random errors are dependent on gender, site, correction methods, exposure profiles and projection models. The effects of increased internal validity on the *generalizability* of Japanese radiation risk information to U.S. nuclear workers are only revealed when lifetime risks are projected after adjustments are made for random and systematic errors. Future studies in which LSS data are generalized to U.S. nuclear workers may be biased if lifetime risks are not adjusted for random and systematic errors.

Epidemiologic theories of bias were applied and expounded throughout the course of this investigation. Adherents of our results should not let their enthusiasm exceed their knowledge of bias, so that our assumptions become regarded as fixed verities, rather than empirical hypotheses. The major purpose for undertaking this study was to confirm the impression that there are certain advantages of projecting lifetime risk, in addition to performing Poisson regression, when studying information bias in the LSS. Since we did not employ logistic regression to estimate cancer misclassification probabilities and did not fully implement the EM algorithm to impute missing data where there was no autopsy information, this study should be regarded as an investigation into the most fundamental assumptions. As a result, new phenomena in the LSS should not force a reevaluation of this study's findings.

7 REFERENCES

Abramowitz, M. and Stegun, I.A. *Handbook of Mathematical Functions.* New York: Dover; 1965.

Algorithm AS32. *J. Royal Stat. Soc.* 19(3); 1970.

Angevine, D.M., Jablon, S., Matsumoto, Y.S. *ABCC-JNIH Pathology Studies, Hiroshima and Nagasaki. Report 1. October 1950 - September 1962.* Atomic Bomb Casualty Commission (ABCC) Technical Report 14-63. Hiroshima: ABCC; 1963.

Beebe, G.W., Usugawa, 1968. The Major ABCC Samples. Atomic Bomb Casualty Commission (ABCC) Technical Report 12-68. Hiroshima: ABCC; 1968.

Beebe, G.W., Yamamoto, T., Matsumoto, Y.S., Gould, S.E. *ABCC-JNIH Pathology Studies, Hiroshima and Nagasaki. Report 2. October 1950 - December 1965.* Atomic Bomb Casualty Commission (ABCC) Technical Report 8-67. Hiroshima: ABCC; 1967.

Breslow, N.E., Day, N.E. *Fitting Models to Continuous Data, Chap. 5.* In: Statistical Methods in Cancer Research. Volume II: The design and analysis of cohort studies. Chapter 4. IARC Scientific Publication No. 82. Lyon: IARC; 1987.

Brown, C.C., Chu, K.C. Additive and multiplicative models and multistage carcinogenesis theory. *Risk Anal.* 9(1):99-105; 1989.

Bunger, B.B., Cook, J.R., Barrick, M.K. Life table methodology for evaluating radiation risk: An application based on occupational exposures. *Health Physics.* 40:439-455; 1981.

Chen, T.T. A review of methods for misclassified categorical data in epidemiology. *Stat. Med.* 8:1095-1106; 1989.

Checkoway, H., Pearce, N., Crawford-Brown, D.J. *Special Applications of Occupational Epidemiology Data, Chap. 10.* In: Research Methods in Occupational Epidemiology. New York: Oxford; 1989.

Chiang, C.L. *Some Stochastic Models of Growth — Pure Death Process, Chap. 8.* In: An Introduction to Stochastic Processes and Their Applications. Huntington(NY): Krieger; 1968.

Chiang, C.L. *The Life Table and Its Construction — The Complete Life Table, Chap. 6.* In: The Life Table and Its Application. Malabar(FL): Krieger; 1984.

Cochran, W.G. *The Estimation of Sample Size, Chap. 4.* In: Sampling Techniques. New York: Wiley; 1977.

Cressie, N., Read, T.R.C. Multinomial goodness-of-fit tests. *J. Royal Stat. Soc. (B).* 46:440-464; 1984.

Dempster, A.P., Laird, N.M., Rubin, D.B. Maximum likelihood from incomplete data via the EM algorithm. *J. Royal Stat. Soc. B.* 39:1-38; 1977.

Dorn, H.F., Horn, J.L. The reliability of certificates of deaths from cancer. *Am. J. of Hygiene.* 34:12-23; 1941.

Dorn, H.F., Cutler, S.J. Morbidity from cancer in the United States. Comparison of death certificates and case reports. *Pub. Hlth. Mono.* 1958. 56:117-124; 1958.

Duffy, S.W., Rohan, T.E., Day, N.E. Misclassification in more than one factor in a case-control study: A combination of Mantel-Haenszel and maximum likelihood approaches. *Stat. Med.* 8(12):1529-1536; 1989.

Elandt-Johnson, R.C., Johnson, N.L. *Theory of Competing Causes: Probabilistic Approach, Chap 9.* In: Survival Models and Data Analysis. New York: Wiley; 1980.

Elton, R.A., Duffy, S.W. Correcting for the effect of misclassification bias in a case-control study using data from two different questionnaires. *Biometrics.* 39(3):659-663; 1983.

Espeland, M.A., Platt, O.S., Gallagher, D. Joint estimation of incidence and diagnostic error rates from irregular longitudinal data. *J. Am. Stat. Assoc.* 84(408):972-979; 1989.

Faber, J.H., Wade, A.H. Life Tables for the United States: 1900-2050. *Actuarial Study No. 89,* Office of the Actuary, U.S. Social Security Administration. SSA Pub. No. 11-11536 (1983). Bethesda: SSA; 1983.

Flegal K.M., Brownie, C., Haas J.D. The effects of exposure misclassification on estimates of relative risk. *Am. J. Epid.* 41(12):1167-1174; 1988.

Fleiss, J.L. *The Effects of Misclassification Errors, Chap. 11.* In: Statistical Methods for Rates and Proportions. New York: Wiley; 1981.

Freeman, M.R., Tukey, J.W. Transformation related to the angular and square root transform. *Ann. Math. Statist.* 21:607-611; 1950.

Frome, E.L., Kutner, M.H., Beauchamp, J.J. Regression analysis of Poisson-distributed data. *J. Am. Stat. Assoc..* 68; 935-940; 1973.

Frome, E.L. The analysis of rates using Poisson regression methods. *Biometrics.* 39; 665-674; 1983.

Frome, E.L. *PREG: A computer program for Poisson regression analysis.* Oak Ridge Associated Universities Report ORAU-178 (1981). Oak Ridge National Laboratory. Oak Ridge(TN): ORAU; 1981.

Gail, M. Measuring the benefit of reduced exposure to environmental carcinogens. *J. Chron. Dis.* 28:135-147; 1975.

Gilbert, E.S. *Some effects of random dose measurement errors on analysis of atomic bomb survivor data.* Radiation Effects Research Foundation (RERF) Technical Report 12-82. Hiroshima: RERF; 1982.

Gilbert, E.S. Late Somatic Effects. In: *Health Effects Model for Nuclear Power Plant Accident Consequence Analysis.* Part 1, Introduction, Integration, and Summary. U.S. Nuclear Regulatory Commission, Report NUREG/CR-4214, Rev. 1, Part I. Washington, D.C., NRC; 1989a.

Gilbert, E.S. Late Somatic Effects, Chap 3. In: *Health Effects Model for Nuclear Power Plant Accident Consequence Analysis.* Part 2, Scientific Basis for Health Effects Models. U.S. Nuclear Regulatory Commission, Report NUREG/CR-4214, Rev. 1, Part II. Washington, D.C.: NRC; 1989b.

Gilbert, E.S. Late Somatic Effects. In: Modifications of Models Resulting From Recent Reports on Health Effects of Ionizing Radiation. Part II: Scientific Bases for Health Effects Models. *Health Effects Model for Nuclear Power Plant Accident Consequence Analysis*, NUREG/CR-4214, Rev.1, Part II, Addendum 1. Washington, D.C.: NRC; 1991.

Green, M.S. Use of predictive value to adjust relative risk estimates biased by misclassification of outcome status. *Am. J. Epid.* 117(1):98-105; 1983.

Greenland, S. On correcting for misclassification in twin studies and other matched-pair studies. *Stat. Med.* 8(7):825-829; 1989.

Greenland, S., Robins, J.M. Confounding and misclassification. *Am. J. Epid.* 122(3):495-506; 1^85.

Greenwood, M. *The Natural Duration of Cancer*, Reports on Public Health and Medical Subjects, Her Majesty's Stationary Office, London, Vol. 33:1-26; 1926.

Hsieh, C.C., Walter, S.D. The effect of non-differential exposure misclassification on estimates of the attributable and prevented fraction. *Stat. Med.* 7(10):98-105; 1983.

ICRP, International Commission on Radiological Protection, 1977. *Recommendations of the ICRP.* ICRP Publication 26. Annals of the ICRP, Vol. 1(3). Oxford: Pergamon; 1977.

ICRP, International Commission on Radiological Protection, 1991. *1990 Recommendations of the International Commission on Radiological Protection.* ICRP Publication 60. Annals of the ICRP, Vol. 21(1-3). Oxford: Pergamon; 1991.

Ishida, M., Beebe, G.W. *Research plan for joint NIH-ABCC study of life span of A-bomb survivors.* Atomic Bomb Casualty Commission (ABCC) Technical Report 04-59. Hiroshima: ABCC; 1959.

Jablon, S., Angevine, D.M., Matsumoto, Y.S., Ishida, M. *On the significance of cause of death as recorded on death certificates in Hiroshima and Nagasaki, Japan.* Study of Cancer and Other Chronic Diseases. In: National Cancer Institute Monograph 19 (1966). Ed, Haenzel, W. National Cancer Institute, Public Health Service, U.S. Department of Health, Education, and Welfare. Bethesda: HEW; 1966.

Jablon, S. *Atomic bomb radiation dose estimation at ABCC.* Atomic Bomb Casualty Commission (ABCC) Technical Report 23-71. Hiroshima: ABCC; 1971.

James, G., Patton, R.E., Heslin, A.S. Accuracy of cause-of-death statements on death certificates. *Pub. Hlth. Rep. 1955.* 70;39-51; 1955.

Kahn, H., Sempos, C.T. *Follow-up Studies: Person-Years, Chap. 8.* In: Statistical Methods in Epidemiology. New York: Oxford; 1989.

Kennedy, W.J., Gentle, J.E. *Unconstrained Optimization and Non-linear Regression, Chap. 10.* In: Statistical Computing. New York: Marcel Dekker; 1980.

Kleinbaum, D.G., Kupper, L.L., Morgenstern, H. *Information Bias, Chap. 12.* In: Epidemiologic Research: Principles and Quantitative Methods. New York: Van Nostrand Reinhold; 1982.

Kleinbaum, D.G., Kupper, L.L., Muller, K.E. *Maximum Likelihood Methods: Theory and Ap-*

plications, Chap. 21. In: Applied Regression Analysis and Other Multivariable Methods. Boston: PWS-Kent; 1988.

Kodell, R.L., Gaylor, D.W. On the additive and multiplicative models of relative risk. *Biom. J.* 31:359-370; 1989.

Kodell, R.L., Krewski, D., Zielinski, J.M. Additive and multiplicative relative risk in the two-stage clonal expansion model of carcinogenesis. *Risk Anal.* 11:483-490; 1991.

Kramer, M.S. *Diagnostic Tests. Chap. 16.* In: Clinical Epidemiology and Biostatistics. Berlin: Springer-Verlag; 1988.

Land, C.E. *Projection of risk from one population to another.* In: Risk Estimates for Radiation Carcinogenesis, (Renz, G.K., Ed). Proceedings of the International Workshop of the Institut für Strahlenschutz. Koln: Institut für Strahlenschutz: 1989.

Land, C.E., Sinclair, W.K. The relative contributions of different organ sites to the total cancer mortality associated with low-dose radiation exposure. *Annals of the ICRP.* 22, 31-57; 1991.

Lee, E.T. *Functions of Survival Time, Chap. 2.* In: Statistical Methods for Survival Data Analysis. Belmont(CA): Wadsworth; 1980.

Lilienfeld, A.M., Lilienfeld, D.E. *Morbidity Statistics, Chap. 6.* In: Foundations of Epidemiology (2nd Ed.). New York: Oxford; 1980.

McCullagh, P., Nelder, J.A. *Model Checking, Chap. 12.* In: Generalized Linear Models. London: Chapman and Hall; 1989.

Miller, A.B., Howe, G.R., Sherman, G.J., Lindsay, J.P., Yaffe, M.J., Dinner, P.J., Risch, H.A., Preston, D.L. Mortality from breast cancer after irradiation during fluoroscopic examinations in patients being treated for tuberculosis. *N. Eng. Journ. Med.* 321:1285-1289; 1989.

Milton, R.C., Shohoji, T. *Tentative 1965 radiation dose estimation for atomic bomb survivors, Hiroshima and Nagasaki.* Atomic Bomb Casualty Commission (ABCC) Technical Report 1-68. Hiroshima: ABCC; 1968.

Monson, R.R.. Analysis of relative survival and proportionate mortality. *Comp. Biomed. Research.* 7;325-332; 1974.

Moolgavkar, S.H., Knudson, A.G. Mutation and cancer: a model for human carcinogenesis. *JNCI.* 66:1037-1052; 1981.

Moriyama, I.M., Baum, W.S., Haenszel, W.M. et al. Inquiry into diagnostic evidence supporting medical certifications of death. *Am. J. Pub. Hlth.* 48:1376-1387; 1958.

Muirhead, C.R., Darby, S.C. Modelling the relative and absolute risks of radiation-induced cancers. *J. Royal Stat. Soc. A.* 150:83-118; 1987.

NCI, National Cancer Institute, 1989. *Cancer Statistics Review 1973-1986.* May 1989. Bethesda: HHS; 1989.

NRC, National Research Council, 1980. *Committee on the Biological Effects of Ionizing Radiations.* The effects on populations of exposure to low-levels of ionizing radiation. Washington, D.C.: NAS; 1980.

NRC, National Research Council, 1990. *Committee on the Biological Effects of Ionizing Radiations (BEIR-V).* Health Effects of Exposure to Low Levels of Ionizing Radiation. Washington, D.C.: NAS; 1990.

Percy, C.L., Stanek,E.,III, Gloecker, L.A. Accuracy of cancer death certificates and its effect on cancer mortality statistics. *Am. J. Pub. Hlth.* 71:242-250; 1981.

Percy, C.L., Miller, B.A., Gloeckler Ries, L.A. Effects of changes in cancer classification and the accuracy of cancer death certificates on trends in cancer mortality. *Ann. N.Y. Acad. Sci.* 409:87-97; 1990.

Peterson, L.E., Schull, W.J., Buffler, P.A., Davis, B.R. *Birth cohort and period effects in absolute and relative risk projection of radiation-induced leukemia.* Abstracts of papers for the 40th Annual Meeting of the Radiation Research Society, March, 1992.

Peterson, L.E., Schull, W.J., Davis, B.R., Buffler, P.A. *SURVRAD: Computer Program for Estimating Lifetime Mortality Risk of Radiation-Induced Cancer.* Epidemiology Research Unit Technical Report, School of Public Health, University of Texas. University of Texas - Health Science Center, Houston, 1992.

Pierce, D.A., Preston, D.L., Ishimaru, T. *A method of analysis of cancer incidence in Japanese atomic bomb survivors with application to acute leukemia.* Radiation Effects Research Foundation (RERF) Technical Report 15-83. Hiroshima: RERF; 1983.

Pierce, D.A., Preston, D.L. *Hazard function modeling for dose response analysis of cancer incidence in the A-bomb survivors.* In: Atomic Bomb Survivor Data: Utilization and Analysis. pp. 51-66. SIAM Institute for Mathematics and Society. Philadelphia: SIAM; 1984.

Pierce, D.A., Preston, D.L. *Analysis of cancer mortality in the A-bomb survivor cohort.* In: Proc. 45th Session Int. Statist. Inst. (pp. 1-13). Amsterdam: Int. Stat. Inst.; 1985.

Pierce, D.A., Preston. D.L. *Developments in cohort analysis with application to radiation-induced cancer.* In: 46th Session Int. Stat. Inst. (pp. 557-570). Amsterdam: Int. Stat. Inst.; 1988.

Pierce, D.A. and Vaeth, M. The shape of the cancer mortality dose-response curve for the atomic bomb survivors. *Radiat. Res.* 126: 36-42; 1991.

Pierce, D.A., Stram, D.O., Vaeth, M. Allowing for random errors in radiation exposure estimates for the atomic bomb survivor data. *Radiat. Res.* 123:275-284; 1990. [RERF TR 2-89].

Pierce, D.A., Vaeth, M. *Cancer risk estimation from the A-bomb survivors: extrapolation to low doses, use of relative risk models, and other uncertainties.* Radiation Effects Research Foundation, Commentary and Review Series, CR 2-89. Hiroshima: RERF; 1989.

Pierce, D.A., Preston, D.L., Stram, D.O., Vaeth, M. Allowing for dose-estimation errors for the A-bomb survivor data. *J. Radiat. Res. (Japan).* Supp. 108-121; 1991.

Preston, D.L., Kato, H., Kopecky, K.J., Fujita, S. *Life Span Study Report 10. Part 1, Cancer Mortality among A-bomb Survivors in Hiroshima and Nagasaki, 1950-82.* Radiation Effects Research Foundation (RERF) Technical Report 1-86. Hiroshima: RERF; 1986.

Preston, D.L., Pierce, D.A. *AMFIT: A program for parameter estimation in additive and*

multiplicative rate models with grouped survival data. EPICURE User's Guide and Command Language Handbooks. Hirosoft International Corporation. Seattle: Hirosoft; 1993.

Puffer, RR., Griffith, G.W. *Patterns of urban mortality.* Pan American Health Organization, WHO; 1967.

Rall, J.F., Beebe, G.W., Hoel, D.G., Jablon, S., Land, C.E., Nygaard, O.F., Upton, A.C., Yalow, R.S. *Report of the National Institutes of Health Ad Hoc Working Group to Develop Radioepidemiological Tables,* DHHS Publication No.(NIH) 85-2748. Washington, D.C.: NIH; 1985.

Rao, C.R. Large sample tests of statistical hypothesis concerning several parameters with applications to problems of estimation. *Proc. Camb. Phil. Soc.* 44:50-57; 1947.

Rayner, J.C.W., Best, D.J. *Asymptotically Optimal Tests, Chap. 3.* In: Smooth Tests of Goodness of Fit. New York: Oxford; 1989.

Ries, L.A.G., Hankey, B.F., Miller, B.A., Hartman, A.M., Edwards, B.K. *Cancer Statistics Review, 1973-88.* National Cancer Institute. NIH Publication No. 91-2789. Bethesda: NIH(NCI); 1991.

Ron, E., Hoel, D.G., Carter, R.L., Mabuchi, K. The influence of death-certificate errors on cancer mortality trends. Radiation Effects Research Foundation, Commentary and Review Series, CR-2-91. Hiroshima: RERF; 1991.

Samter, T.G., Hrubec, Z., et al. *Epidemiologic Evaluation of ABCC and Nagasaki University School of Medicine Autopsies and ABCC Surgical Specimens, Nagasaki 1950-1959.* Atomic Bomb Casualty Commission (ABCC) Technical Report 15-60. Hiroshima: ABCC; 1960.

Santner, T.J., Duffy, D.E. *Univariate Discrete Responses, Chap. 2.* In: The Statistical Analysis of Discrete Data. New York: Springer-Verlag; 1989.

Savitz, D.A., Baron, A.E. Estimating and correcting for confounder misclassification. *Am. J. Epid.* 129(5):1062-71; 1989.

Shimizu, Y., Kato, H., Schull, W.J., Preston, D.L., Fujita, S., Pierce, D.A. *Life Span Study Report 11. Part 1, Comparisons of Risk Coefficients for Site-specific Cancer Mortality Based on the DS86 and T65D Shielded Kerma and Organ Doses.* Radiation Effects Research Foundation (RERF) Technical Report 12-87. Hiroshima: RERF; 1987.

Shimizu, Y., Kato, H., Schull, W.J. *Life Span Study Report 11. Part 2, Cancer Mortality in the Years 1950-85 Based on the Recently Revised Doses (DS86).* Radiation Effects Research Foundation (RERF) Technical Report 5-88. Hiroshima: RERF; 1988.

Shore, R.E., Hildreth, N., Woodard, E., Dvoretsky, P., Hempelmann, L., Pasternack, B. Breast cancer among women given x-ray therapy for acute postpartum mastitis. *JNCI.* 77:689-696; 1986.

Smith, T.L., Putman, J.E., Gehan, E.A. A computer program for estimating survival functions from the life table. *Comp. Prgms. in Biomed.* 1:58-64; 1970.

Sposto, R., Stram, D.O., Awa, A.A. An estimate of the magnitude of random errors in the DS86 Dosimetry System from data on chromosome aberrations and severe epilation. *Radiat. Res.* 128:157-169 (1991). [RERF TR 7-90].

Sposto, R., Preston, D.L, Shimizu, Y., Mabuchi, K. The effect of diagnostic misclassification on non-cancer and cancer mortality dose-response in A-bomb survivors. *Biometrics.* 48:605-617; 1992. [RERF TR 4-91].

Stather, J.W., Muirhead, C.R., Edwards, A.A., Harrison, J.D., Lloyd, D.C., Wood, N. *Health Effects Models Developed from the 1988 UNSCEAR Report.* National Radiological Protection Board, Report R226. Oxfordshire: NRPB; 1988.

Steer, A., Moriyama, I.M., Shimizu, K. *ABCC-JNIH Pathology Studies, Hiroshima and Nagasaki. Report 3. January 1951 - December 1970.* Atomic Bomb Casualty Commission (ABCC) Technical Report 16-73. Hiroshima: ABCC; 1973.

Stone, R.S., Anderson, P.S. *Epidemiologic Evaluation of ABCC Autopsies, Hiroshima 1950-59.* Atomic Bomb Casualty Commission (ABCC) Technical Report 22-60. Hiroshima: ABCC; 1960.

Stone, R.S., Anderson, P.S. *A Comparison of Death Certificate and Autopsy Diagnoses, Hiroshima.* Atomic Bomb Casualty Commission (ABCC) Technical Report 19-60. Hiroshima: ABCC; 1960.

Storer, J.B., Mitchell, T.J., Fry, R.J.M. Extrapolation of the relative risk of radiogenic neoplasms across mouse strains and to man. *Radiat. Res.* 114:331-353; 1988.

Thiessen, J.W. and Kaul, D.C. The dosimetry system 1986 (DS86) and the Tentative Dosimetry System 1965 (T65D): How do they compare, what is left to do? *J. Radiat. Res. (Japan).* Supp. 1-10; 1991.

Thomas, D.C., Darby, S., Fagnani, F., Hubert, P., Vaeth, M., Weiss, K. Definition and estimation of lifetime detriment from radiation exposure: Principles and methods. *Health Physics.* 63:259-272; 1992.

UN, United Nations, 1988. *Sources, Effects, and Risks of Ionizing Radiation.* United Nations Scientific Committee on the Effects of Atomic Radiation 1988 Report to the General Assembly, with Annexes. United Nations sales publication No. E.88.IX.7. New York: UN; 1988.

Vaeth, M., Pierce, D.A. *Calculating excess lifetime risk in relative risk models.* Radiation Effects Research Foundation, Commentary and Review Series, CR 3-89. Hiroshima: RERF; 1989.

Wald, A. Tests of statistical hypotheses concerning several parameters when the number of parameters is large. *Trans. of Am. Math. Soc.* 54:426-482; 1943.

White, E. The effect of misclassification of disease status in follow-up studies: implications for selecting disease classification criteria. *Am. J. Epid.* 124(5):816-825; 1986.

Whittemore, A.S., Gong, G. Poisson regression with misclassified counts: application to cervical cancer mortality rates. *Appl. Stat.* 40:81-93; 1991.

World Health Organization, 1959. Manual of the International Statistical Classification of Diseases, Injuries and Causes of Death, 1955 Ed. Geneva: WHO; 1959.

Yamamoto, T., Moriyama, I.M., Asano, M., Guralnick, L. *RERF Pathology Studies, Hiroshima and Nagasaki, Report 4. Autopsy Program and the Life Span Study, January 1961 - December 1975.* Radiation Effects Research Foundation (RERF) Technical Report

18-78. Hiroshima: ABCC; 1978.

Zeldis, L.J., Matsumoto, Y.S. *Research plan for joint ABCC-NIH pathology studies in Hiroshima and Nagasaki.* Atomic Bomb Casualty Commission (ABCC) Technical Report 12-62. Hiroshima: ABCC; 1962.

8 NOTATION

θ	True effect measure of risk for the *target population.*
$\hat{\theta}$	The estimator of θ based on a sample from the target population called the *study population.*
θ°	The parameter estimated by $\hat{\theta}$ for the larger *actual population* that is obtained from the *study population.* When adjustments are only made for random error, risk estimates are equal to $\hat{\theta}$, but when corrections are made for both random and systematic errors, risks are equal to θ.
a	True positive cancer deaths. True cancer deaths certified as cancer deaths.
b	False positive non-cancer deaths. Non-cancer deaths certified as cancer deaths.
c	False negative cancer deaths. Cancer deaths certified as non-cancer deaths.
d	True negative non-cancer deaths. Non-cancer deaths certified as non-cancer deaths.
D_c	True cancer deaths estimated by sufficient statistics (Eq. 5).
D_{nc}	True non-cancer deaths estimated by sufficient statistics (Eq. 6).
d_c	Cancer deaths observed on death certificates.
d_{nc}	Non-cancer deaths observed on death certificates.
d_T	Total observed deaths equal to the sum of cancer and non-cancer deaths.
PV^+	Predictive value positive, equal to the cancer confirmation rate. Defined as the probability that individuals with cancer X as the underlying cause of death on their death certificate truly died of cancer X.
PV^-	Predictive value negative, equal to the non-cancer confirmation rate. Defined as the probability that individuals without cancer X as the underlying cause of death on their death certificate truly did not die of cancer X.
ϕ	Sensitivity, equal to the cancer detection rate. Defined as the probability of correctly assigning an underlying cause of death as cancer X for individuals who truly died of cancer X.
ψ	Specificity, equal to the non-cancer detection rate. Defined as the probability of correctly assigning an underlying cause of death as cause X for individuals who truly died of cause X.

θ_c	Cancer confirmation rate, equal to PV^+.
θ_{nc}	Non-cancer confirmation rate, equal to PV^-.
π_c	True cancer rate.
π_{nc}	True non-cancer rate.
$R(z)_{n+\gamma,city}$	City-specific reduction factor for DS86 random error multiplied by organ dose.
$z_{n+\gamma,city}$	City-specific estimated person-year weighted subpopulation dose from neutrons and γ-rays.
$\mathrm{Avg}(x\|z)$	Average survivor true dose.
$\mathrm{Avg}(z\|x)$	Average survivor estimated dose.
$D^*_{ij,n,65,city}$	Survivor neutron organ dose equivalent based on the T65DR dosimetry system.
$D^*_{ij,n,86,city}$	Survivor neutron organ dose equivalent based on the DS86 dosimetry system.
$\Omega_{n,65,city}$	Average city-specific house transmission factor for neutrons in the T65DR dosimetry system.
$\Omega_{n,86,city}$	Average city-specific house transmission factor for neutrons in the DS86 dosimetry system.
$D^*_{ij,\gamma,65,city}$	Survivor γ organ dose equivalent based on the T65DR dosimetry system.
$D^*_{ij,\gamma,86,city}$	Survivor γ organ dose equivalent based on the DS86 dosimetry system.
$\Omega_{\gamma,65,city}$	Average city-specific house transmission factor for γ-rays the T65DR dosimetry system.
$\Omega_{\gamma,86,city}$	Average city-specific house transmission factor for γ-rays the DS86 dosimetry system.
D_{ij}	Radiation dose in ijth subpopulation.
D^*_{ij}	Radiation dose in ijth subpopulation adjusted for DS86 random error.
k_n	Neutron shielded kerma.

RBE_n	Relative biological effectiveness factor for neutrons. Set equal to 10 for RERF models and 20 for BEIR-V models.
$\Omega_{n,city,ATB}$	City- and age ATB-specific body self-shielding transmission factor for neutrons. Multiplied by k_n and RBE_n to obtain organ dose equivalent from neutrons.
k_γ	γ-ray shielded kerma.
RBE_γ	Relative biological effectiveness factor for γ-rays. Set equal to unity.
$\Omega_{\gamma,city,ATB}$	City- and age ATB-specific body self-shielding transmission factor for γ-rays. Multiplied by k_γ and RBE_γ to obtain organ dose equivalent from γ-rays.
PY_{ij}	Person-years of follow-up in subpopulation ij.
λ_{i0}	Cancer mortality rate in subpopulation i for the zero-dose group.
λ_{ij}	Cancer mortality rate in subpopulation i for the jth dose group.
α_s	Unknown nuisance parameter for background cancer rate in stratum s.
β_0	Multiplicative constant term in regression model.
β_1	Linear parameter for the contribution of dose to excess relative risk.
z_j	Covariate for age ATB, age ATB, or gender in regression model.
β_j	Regression coefficient for covariate z_j.
$\boldsymbol{\beta}^T$	Transpose of row vector of regression coefficients $\beta_1, \ldots, \beta_j$.
$\boldsymbol{z}$	Row vector of covariates $z_1, \ldots, z_j$.
$(\boldsymbol{\beta}^T; \boldsymbol{z})$	Linear predictor of effects for covariates $z_1, \ldots, z_j$.
$e^{\boldsymbol{\beta}^T;\boldsymbol{z}}$	Log-linear link function for linear predictor $(\boldsymbol{\beta}^T; \boldsymbol{z})$
$f(d)$	Dose function in BEIR-V model.
$g(\beta)$	Link function for BEIR-V model.
$\hat{\mu}_i$	Estimated number of deaths, equal to $\lambda_{ij} \times PY_{ij}$.
y_i	Observed deaths in each subpopulation.

r_P	Pearson χ^2 residual.
χ^2	Chi-square goodness-of-fit statistic. Measure of model dispersion.
r_D	Deviance residual.
D	Deviance goodness-of-fit statistic.
r_{FT}	Freeman-Tukey residual.
G	Freeman-Tukey goodness-of-fit statistic.
$f(d)$	Dose function for BEIR-V model.
$g(\beta)$	Link function for BEIR-V model.
Z_α	Standard normal deviate to adjust test statistics for a Type I error.
$H(a)$	Annual dose equivalent in sieverts (Sv).
$\Phi_{RR}(a)$	Fitted relative risk for exposure at age a in the constant RERF models.
$\Phi_{RR}(a,t)$	Fitted relative risk at age at t for exposure at age a in the non-constant RERF and BEIR-V models.
$\Phi_{RR,US}(a)$	Fitted relative risk for exposure at age a in the non-constant transported RERF model.
$\Phi_{RR,US}(a,t)$	Fitted relative risk at age at t for exposure at age a in the non-constant transported RERF model.
$\Phi_{ERR}(a)$	Excess relative risk (%/Sv) for exposure at age a in the constant RERF models. Equal to $\Phi_{RR}(a)$ minus unity.
$\Phi_{ERR}(a,t)$	Excess relative risk (%/Sv) at age t for exposure at age a for the RERF non-constant and BEIR-V models. Equal to $\Phi_{RR}(a,t)$ minus unity.
$\Phi_{ERR,US}(a)$	Excess relative risk (%/Sv) for exposure at age a in the constant transported RERF model. Equal to $\Phi_{RR,US}(a)$ minus unity.
$\Phi_{ERR,US}(a,t)$	Excess relative risk (%/Sv) at age t for exposure at age a for the non-constant transported RERF model. Equal to $\Phi_{RR,US}(a,t)$ minus unity.
$\Phi_{AR}(a)$	Absolute risk (deaths per person-year per sievert (PYSv)) for age at exposure a in the constant absolute RERF models.

$\Phi_{AR}(a,t)$	Absolute risk at age t for exposure at age a for the non-constant absolute RERF models.
$h(t;0)$	Hazard function for all causes of death at age t in the nonexposed population.
$h_c(t;0)$	Hazard function for cancer at age t in the nonexposed population.
$h_c(a;t;d)$	Hazard function for radiation-induced cancer at age t for exposure at age a in the exposed population.
$h_c(\infty;t;d)$	Cumulative hazard function for radiation-induced cancer at age t for multiple radiation exposures at ages a_1, a_2, a_3,..., a_n in the exposed population (Elandt-Johnson and Johnson method).
$q_c(\infty;t;d)$	Attributable probability of radiation-induced cancer death at age t for multiple radiation exposures at ages a_1, a_2, a_3,..., a_n in the exposed population (Bunger et al. method).
$q(t;d)$	Probability of death from all causes and radiation-induced cancer at age t in the exposed population.
$p(t;d)$	Probability of surviving death from all causes and radiation-induced cancer at age t in the exposed population.
$d(t;d)$	Number of deaths from all causes and radiation-induced cancer at age t in the exposed population.
$N(t;d)$	Number alive at age t in the exposed population.
$l(t;d)$	Person-years of life at age t in the exposed population.
$S(t;d)$	Probability of surviving beyond age t in the exposed population.
$q(t;0)$	Probability of dying from all causes at age t in the nonexposed population.
$p(t;0)$	Probability of surviving death from all causes at age t in the nonexposed population.
$d(t;0)$	Number of deaths from all causes at age t in the nonexposed population.
$N(t;0)$	Number alive at age t in the nonexposed population.
$l(t;0)$	Person-years at age t in the nonexposed population.

$S(t;0)$	Probability of surviving beyond age t in the nonexposed population.
$\pi(t;d)$	Conditional probability of death due to radiation-induced cancer at age t in the exposed population.
$\pi(t;0)$	Conditional probability of death due to cancer at age t in the nonexposed population.
$\pi(\infty;d)$	Unconditional probability of radiation-induced death over a lifetime. The number of radiation-induced cancer deaths over the lifetime of the exposed population is $\pi(\infty;d) \times 10^5$, since the double-decrement life table starts with $N(a+L;d)$=100,000.
$\pi(\infty;0)$	Unconditional probability of death over a lifetime in the nonexposed population. The number of deaths over the lifetime of the nonexposed population is $\pi(\infty;0) \times 10^5$, since the single-decrement life table starts with $N(a+L;0)$=100,000.
$Q(t;d)$	Unconditional probability of death due to radiation-induced cancer at age t in the exposed population.
$Q(t;0)$	Unconditional probability of death due to cancer at age t in the nonexposed population.
$YLPD$	Years of life lost per premature radiation-induced cancer death at age t in the exposed population.
PC	Probability of causation of radiation-induced cancer for death at age t. The radiation-induced cancer at age t is $Q(t;d)$ and the PC for spontaneous cancer at age t among nonexposed individuals is $Q(t;0)$
$DCCF$	Death certificate correction factor for correcting mortality rates biased by misclassification of underlying cause of death on death certificates. Use will only affect relative risk projection models because absolute projection models are independent of baseline cancer rates, and the transported absolute model that estimates relative risk coefficients for the U.S. population cancels out the effect.

9 ABBREVIATIONS

%/Sv	Per cent increase of risk at the 1 Sv level. This is the unit of risk for excess relative risk coefficients and lifetime risk coefficients. The risk coefficients, $\Phi_{ERR}(a)$, $\Phi_{ERR}(a,t)$, $\Phi_{ERR,US}(a)$ and $\Phi_{ERR,US}(a,t)$ are in units of %/Sv. If a regression coefficient is 0.5, then the mortality rate is 50% higher in the exposed population, or, $1 + 0.5 = 1.5$ times greater than the baseline mortality rate in the nonexposed population. The value 0.5 is the excess relative risk (ERR) and the value 1.5 is the relative risk (RR). For lifetime risks, if the number of radiation-induced cancer deaths is 2,500 per 100,000 individuals, each given 1 Sv, then the excess risk is 2.5%/Sv ($2{,}500/10^5 \times 100$).
10^4PYSv	Person-year-dose denominator of absolute risk coefficients. The coefficients $\Phi_{AR}(a)$ and $\Phi_{AR}(a,t)$ are in units of deaths/10^4PYSv.
ABCC	Atomic Bomb Casualty Commission.
AHS	Adult Health Study of Hiroshima and Nagasaki A-bomb survivors.
AMFIT	Computer program designed to fit Poisson regression models in the LSS.
AR	Absolute risk in deaths per 10^4 person-years per Sv (10^4PYSv).
ATB	Age at-time-of-bombing.
ATD	Age at-time-of-death.
BEIR-V	NRC Committee on Biological Effects of Low Levels of Ionizing Radiation.
CA	Chromosome Aberrations.
CV	Coefficient of variation.
DRREF	Dose rate reduction effectiveness factor.
EM	Expectation-maximization algorithm used for imputing missing data.
ERR	Excess relative risk in %/Sv. Equal to relative risk less unity.
GOF	Goodness-of-fit.
GSD	Geometric standard deviation. If σ is given on the arithmetic scale, then GSD is $\exp(\sigma)$. However, if GSD is given, σ can be determined as the natural logarithm of GSD.
Gy	Gray. Systems Internationale (SI) unit for radiation absorbed dose in units

	of joules per kilogram of absorbed energy.
ICRP	International Commission on Radiological Protection.
JNIH	Japanese National Institutes of Health.
LSS	Life Span Study of Hiroshima and Nagasaki A-bomb survivors.
NIH	National Institutes of Health.
NRC	National Research Council of the National Academy of Sciences.
RBE	Relative Biological Effectiveness factor. The ratio of biologic effect of a given radiation to the same biologic effect induced by an equal dose of 250 keV X-rays.
RR	Relative risk. Equal to ERR plus unity.
RERF	Radiation Effects Research Foundation, Hiroshima, Japan. Formerly the ABCC.
SEER	Surveillance, Epidemiology and End Results Study of the National Cancer Institute of the National Institutes of Health.
SURVRAD	Computer program used to project lifetime risks of radiation-induced cancer mortality.
Sv	Sievert. Systems Internationale (SI) unit of dose equivalent. Equal to 1 Gy times a Quality Factor.
TSE	Time since exposure.
T65D	Tentative Dosimetry System-1965.
T65DR	Tentative Dosimetry System-1965-Revised.
UN	United Nations.
UNSCEAR	United Nations Committee on the Effects of Atomic Radiation.

10 APPENDIX A. Dose-Response Modeling

10.1 General Approach

The two modeling approaches used in this study were the BEIR-V method (NRC,1990) and the one reported in RERF Report 11 (Shimizu et al., 1988). While the RERF method employed models that included hazards that were either constant or non-constant following exposure, the BEIR-V models were based exclusively on non-constant hazards that changed following exposure. In all of the models, the *relative risk* (RR), *excess relative risk* (ERR), and *absolute risk* (AR) of radiation-induced cancer are estimated at the 1 Gy level. The endpoint is a regression equation relating ERR to radiation dose equivalent and several covariates.

Maximum likelihood (ML) estimates of the regression coefficients (and standard errors) with the subgroup-specific, Poisson distributed, mortality rates (number of deaths/PY) as the dependent variable were based on commonly known procedures (Pierce et al., 1983; Pierce and Preston, 1984; Pierce and Preston, 1985; Pierce and Preston, 1988; Kleinbaum et al., 1988; Frome and Kutner, 1973; Frome, 1981; Frome, 1983). The following sections explain succinctly the methods of estimating organ dose equivalents, adjusting doses for random errors, and the coding methods used in each regression model.

10.2 Correction of Shielded Kerma for Random Uncertainty

The person-year weighted organ dose equivalents for each subpopulation were adjusted for Dosimetry System-86 (DS86) random errors by use of reduction factors (Peirce and Vaeth, 1991) written

$$R(z)_{n+\gamma,city} = [z_{n+\gamma,city} - \mathrm{Avg}(x|z)_{n+\gamma,city}]/z_{n+\gamma,city} \qquad (23)$$

where $z_{n+\gamma,city}$ is the city-specific estimated person-year weighted subpopulation dose (neutron and gamma shielded kerma in Gy), and $\mathrm{Avg}(x|z)_{n+\gamma,city}$ is the city-specific average true subpopulation dose at estimated dose level $z_{n+\gamma,city}$. The relationship to estimate $R(z)_{n+\gamma,city}$ for a random error of 45% (σ=0.45) in Hiroshima was

$$R(z)_{n+\gamma,city} = 0.07765 + 0.11770\, ln(z_{n+\gamma,city}) + 0.01026\, ln^2(z_{n+\gamma,city}) \qquad (24)$$

and for Nagasaki was

$$R(z)_{n+\gamma,city} = 0.03604 + 0.09612\, ln(z_{n+\gamma,city}) + 0.01725\, ln^2(z_{n+\gamma,city}) \qquad (25)$$

The city-specific reduction factors were applied to gamma and neutron portions of shielded kerma described in the next section.

10.3 Neutron Relative Biological Effectiveness and Estimation of Organ Dose Equivalents from Corrected Shielded Kerma

Estimation of the organ dose equivalents, D^*_{ij}, in sieverts (Sv) used in this analysis began by first applying the city-specific reduction factors, $R(z)_{n+\gamma,city}$, to the neutron and gamma components of shielded kerma and adjusting for the Relative Biological Effectiveness factors (*RBEs*). This was in the form

$$D^*_{ij} = (1 - R(z)_{n+\gamma,city})\{(k_n\, \Omega_{n,city,ATB}\, RBE_n + k_\gamma \Omega_{\gamma,city,ATB}\, RBE_\gamma)\, 10^3\} \qquad (26)$$

where $R(z)_{n+\gamma,city}$ is the reduction factor to adjust for DS86 random error (σ=0.45), k_n and k_γ are the neutron and gamma components of shielded kerma in mGy, $\Omega_{n,city,ATB}$ and $\Omega_{\gamma,city,ATB}$ are the sex-specific body self-shielding transmission factors based on phantoms representing infants (0-2 y age ATB), children (3-11 y age ATB) and adults (>12 y age ATB), RBE_n is 10 for neutrons in the RERF models and 20 for neutrons in the BEIR-V models, and RBE_γ is unity for gamma rays.

10.4 RERF Models

10.4.1 Relative and Excess Relative Risks

The first modeling approach to be used in this investigation followed that employed in RERF Report 11 (Shimizu et al., 1988). Write the mortality rate, λ_{ij}, in the ith stratum of city, sex and age ATB categories and jth exposure category as

$$\lambda_{ij} = \lambda_{i0}\Phi_{RR}(a) \tag{27}$$

where λ_{i0} is the mortality rate (D_c/person-years $\times$ 10,000) in the 0 dose category of the ith stratum of city, sex and ATB cross-classification and $\Phi_{RR}(a)$ is the relative risk coefficient for exposure at age ATB a. Since the relative risk is related to the excess relative risk as

$$\Phi_{RR}(a) = [1 + \Phi_{ERR}(a)] \tag{28}$$

we can obtain maximum likelihood (ML) estimates of $\Phi_{ERR}(a)$ by first fitting a model of the form

$$\lambda_{ij} = \alpha_{s_i} e^{\beta_0} [1 + \{\beta_1 D^*_{ij} e^{(\boldsymbol{\beta}^T \cdot \boldsymbol{z})}\}] \tag{29}$$

where α_s is an unknown nuisance parameter for the stratification of background rates (λ_{i0}) on sex (2 levels), city (2 levels), age ATB (13 levels) and follow-up period (7 levels) resulting in i=364 strata, $\exp(\beta_0)$ is a constant term, β_1 is the contribution of dose equivalent to excess relative risk, D^*_{ij} is the organ dose equivalent and $\boldsymbol{z}$ is a row vector of covariates representing age ATB, age ATD or gender.

If the algorithm to fit the α_s parameters in Eq. 29 were to use a 364 x 364 $(\boldsymbol{Z}^T\boldsymbol{W}\boldsymbol{Z})^{-1}$ weighted dispersion matrix with 132,496 (364^2) elements the memory requirement would be 529,984 bytes (4-bytes $\times$ 132,496) - and this approaches the MS-DOS[13] RAM limit of 640,000 bytes. A computer program, called AMFIT, can fit Eq. 29 and avoid the large memory requirement by use of a Gauss-Seidel algorithm to estimate the 364 α_s terms recursively (Preston and Pierce, 1993). AMFIT uses a Newton-Raphson iteration (Kennedy and Gentle, 1980) to maximize the log-likelihood equations, and also adjusts the standard errors of the β terms by the standard errors of the α terms.

10.4.2 Non-constant Excess Relative Risk Models for Leukemia, Non-leukemia, Stomach and Breast Sites

The ML estimates to determine $\Phi_{ERR}(a,t)$ for leukemia, nonleukemia, stomach and breast sites were obtained by regressing the mortality rate in the exposed subgroup λ_{ij} with the relationship

$$\lambda_{ij} = \alpha_{s_i} e^{\beta_0}[1 + \{\beta_1 D^*_{ij} e^{\beta_2 z_2+\beta_3 z_3+\beta_4 z_4+\beta_5 z_5+\beta_6 z_6+\beta_7 z_7+\beta_8 z_8+\beta_9 z_9+\beta_{10} z_{10}+\beta_{11} z_{11}+\beta_{12} z_{12}+\beta_{13} z_{13}}\}] \tag{30}$$

[13] MS-DOS is a registered trademark of the Microsoft Corporation.

where α_s is for stratification of background rates (λ_{i0}) on sex (2 levels), city (2 levels), age ATB (13 levels) and follow-up period (7 levels), $\exp(\beta_0)$ is a constant term, β_1 is the linear coefficient for dose equivalent in Sv, D^*_{ij} is the organ dose equivalent, z_2 is coded with a 1 when the age ATB is 10-19 and 0 otherwise, z_3 is coded 1 when the age ATB is 20-29 and 0 otherwise, z_4 is coded 1 when the age ATB is 30-39 and 0 otherwise, z_5 is coded 1 when the age ATB is 40-49, and 0 otherwise, z_6 is coded with a 1 when the age ATB is 50+ and 0 otherwise, z_7 is coded 1 when the age ATD is 20-29 and 0 otherwise, z_8 is coded 1 when the age ATD is 30-39 and 0 otherwise, z_9 is coded 1 when the age ATD is 40-49, and z_{10} is coded 1 when the age ATD is 50-59, z_{11} is coded with a 1 when the age ATD is 60-69 and 0 otherwise, z_{12} is coded 1 when the age ATD is 70+ and 0 otherwise and z_{13} is coded 1 for males and 0 for females. The 0-9 age ATB and 0-19 age ATD stratum for females is the corner-point where z_2-z_{13} are all dummy coded with zeros. Organ dose equivalents for leukemia, nonleukemia, stomach and breast sites were based on bone marrow, large intestine, stomach and breast body self-shielding transmission factors, respectively, with a neutron RBE of 10. The stomach site did not contain a parameter for gender and was fitted separately for each sex.

10.4.3 Constant Excess Relative Risk Models for Lung, Bladder, Liver, Colon, and Ovary Sites

Since there are fewer deaths for the lung, bladder, liver, colon and ovary sites, it was necessary to use a model with fewer covariates so that the scores (Rao, 1947), Wald tests (Wald, 1943), and Pearson, deviance, and Freeman-Tukey goodness-of-fit tests would remain acceptable (Nelder and McCullagh, 1989; Freeman and Tukey, 1950; Santner and Duffy, 1989). The ML estimates to determine $\Phi_{ERR}(a)$ for these sites were obtained by regressing the mortality rate in the exposed subgroup λ_{ij} with the relationship

$$\lambda_{ij} = \alpha_s e^{\beta_0}[1 + \{\beta_1 D^*_{ij} e^{\beta_2 z_2 + \beta_3 z_3 + \beta_4 z_4 + \beta_5 z_5}\}] \tag{31}$$

where α_s is for stratification of background rates (λ_{i0}) on sex (2 levels), city (2 levels), age ATB (13 levels) and follow-up period (7 levels), $\exp(\beta_0)$ is a constant term, β_1 is the linear coefficient for dose equivalent in Sv, D^*_{ij} is the organ dose equivalent, z_2 is coded with a 1 when the age ATB is 20-29 and 0 otherwise, z_3 is coded 1 when the age ATB is 30-39 and 0 otherwise, z_4 is coded 1 when the age ATB is 40+ and 0 otherwise, z_5 is coded 1 for males and 0 for females if the model contains a gender parameter. The 0-19 age ATB exposure category for females is the corner-point where z_2-z_5 are all dummy coded with zeros. Organ dose equivalents for the lung, bladder, liver, colon and ovary sites were based on lung, urinary bladder, liver, large intestine and ovary body self-shielding transmission factors, respectively, with a neutron RBE of 10.

10.4.4 Determining Excess Relative Risk from Regression Coefficients

Once the ML estimates of parameters were obtained, the non-constant, $\Phi_{ERR}(a,t)$, or constant, $\Phi_{ERR}(a)$, excess relative risk at the 1 Sv level for a given age ATB group and gender were calculated by multiplying the exponent of the sum of the respective age ATB and sex coefficents by the linear coefficent for the dose equivalent β_1. As an example, the linear predictor $(\beta^T; z)$ for a given age ATB group and gender in a constant excess relative risk model was obtained by cross-multiplying the transposed column vector of coefficients

of covariates and row vector of predictor values of the form

$$(\beta^T; z) = \begin{pmatrix} \hat{\beta}_2 \\ \hat{\beta}_3 \\ \hat{\beta}_4 \\ \hat{\beta}_5 \end{pmatrix} (z_2 \quad z_3 \quad z_4 \quad z_5) \tag{32}$$

For example, the linear predictor $(\beta^T; z)$ for the male age ATB group 30-39 is defined in the form

$$(\beta^T; z) = \begin{pmatrix} \hat{\beta}_2 \\ \hat{\beta}_3 \\ \hat{\beta}_4 \\ \hat{\beta}_5 \end{pmatrix} (0 \quad 1 \quad 0 \quad 1) \tag{33}$$

which when substituted into Eq. 30 yields gives

$$\Phi_{ERR}(a) = \hat{\beta}_1 e^{(\beta^T; z)} \tag{34}$$

We notice that D^*_{ij} is not included in Eq. 34 because the unit of dose during regression was Sv. As an example, if the relationship between blood pressure and age is such that each year of life increases blood pressure by one mm of Hg, then when regressing blood pressure on age, the regression coefficient for age, β_{age}, would be equal to one because of the one-to-one relationship. Therefore, in Eq. 34, the linear regression coefficient for dose, β_1, represents the per cent change in risk per one Sv in units of %/Sv and D^*_{ij} is no longer needed when estimating $\Phi_{ERR}(a)$.

For constant hazard models this was done for the three age ATB groups (20-29, 30-39, and 40+) and two genders (females and males) for the lung, bladder, liver, colon and ovary sites. Similar matrix operations were done for the non-constant excess relative risk models for leukemia, nonleukemia, stomach and breast cancer mortality.

10.4.5 Determining Absolute Risks from Regression Coefficients

The number of excess deaths per 10^4 person-years at the 1 Sv level for the constant AR model were estimated by use of the formula

$$\Phi_{AR}(a) = (\sum_i \sum_k (PY_{ij} \lambda_{i0} \Phi_{ERR}(a) D^*_{ij}) / \sum_i \sum_j (PY_{ij} D^*_{ij})) \times 10^4 \tag{35}$$

where PY is the person-years of follow-up and $\Phi_{ERR}(a)$ is the constant ERR from a regression model containing Age ATB and sex parameters. When non-constant regression models contained age ATB, age ATD and sex parameters to estimate $\Phi_{ERR}(a;t)$, the AR coefficients were determined as

$$\Phi_{AR}(a,t) = (\sum_i \sum_k (PY_{ij} \lambda_{i0} \Phi_{ERR}(a,t) D^*_{ij}) / \sum_i \sum_j (PY_{ij} D^*_{ij})) \times 10^4 \tag{36}$$

Coefficients (excess deaths/10^4PYSv) for $\Phi_{AR}(a,t)$ were estimated for the leukemia, non-leukemia, stomach and breast sites with neutron RBEs of 10. For the lung, bladder, liver, colon and ovary sites, only $\Phi_{AR}(a)$ were estimated because the regression models did not include an age ATD term. Absolute risks were not estimated from regression coefficients of the BEIR-V models.

10.5 BEIR-V Models

The linear additive relative risk for each exposed subpopulation of LSS survivors using the BEIR-V linear model is

$$\lambda_{ij} = \alpha_s e^{\beta_0}[1 + \{\beta_1 D^*_{ij} e^{(\beta^T z)}\}] \tag{37}$$

where α_s is for stratification of background rates (λ_{i0}) on sex (2 levels), city (2 levels), age ATB (13 levels) and follow-up period (7 levels), $\exp(\beta_0)$ is a constant term, β_1 is the contribution of the dose term to the excess relative risk and z is a row vector of covariates for sex, mean age at exposure (E) and time since exposure (TSE). The linear-quadratic model is

$$\lambda_{ij} = \alpha_s e^{\beta_0}[1 + \{(\beta_1 D^*_{ij} + \beta_2 D^{*2}_{ij}) e^{(\beta^T z)}\}] \tag{38}$$

where β_1 and β_2 represent the dose and dose-squared contribution to excess relative risk. The $\Phi_{RR}(a,t)$ for the same exposed subpopulation in Eqs. 37 and 38 can be rewritten

$$\Phi_{RR}(a,t) = 1 + \Phi_{ERR}(a,t) \tag{39}$$

The BEIR-V committee defined $\Phi_{ERR}(a,t)$ in the above equation as

$$\Phi_{ERR}(a,t) = f(d)\, g(\beta) \tag{40}$$

where $f(d)$ is a function of either the linear ($\beta_1 D^*_{ij}$) or linear-quadratic ($\beta_1 D^*_{ij} + \beta_2 D^{*2}_{ij}$) contribution of radiation dose and $g(\beta)$ is a link function for sex, age ATB, and time-since-exposure (TSE). The above models were used for fitting excess relative risk leukemia, respiratory cancers, breast cancer, digestive cancers and "other" cancers not included in the ICD rubric of *malignant neoplasms*.

10.5.1 BEIR-V Leukemia model

For modeling leukemia we choose to evaluate only the RR for the L and LQ models as a function of age ATB < 20 years and age ATB > 20 since there are so many structural zeros (empty cells in the cross-classified data). There is no need to adjust for a latency period for leukemia because the first follow-up in the LSS occurred five years afters the bombings. Cases for which the bone marrow dose equivalent (neutron RBE=20) exceeded 4 Sv and TSE>75y were excluded. The Poisson regression model used for modeling the BEIR-V leukemia $\Phi_{RR}(a,t)$ was

$$\lambda_{ij} = \alpha_s e^{\beta_0}[1 + \{(\beta_1 D^*_{ij} + \beta_2 D^*_{ij}) e^{\beta_3 z_1 + \beta_4 z_2 + \beta_5 z_3 + \beta_6 z_4}\}] \tag{41}$$

where α_s is for stratification of background rates (λ_{i0}) on sex (2 levels), city (2 levels), age ATB (13 levels) and follow-up period (7 levels), $\exp(\beta_0)$ is a constant term, β_1 is the linear term for dose equivalent, β_2 is the quadratic term for dose equivalent, D^*_{ij} is the marrow dose equivalent, z_1 is an indicator variable coded as a one when TSE$\leq$15 and age ATB$\leq$20, z_2 is an indicator variable coded as one when 15<TSE$\leq$25 and age ATB$\leq$20, z_3 is an indicator variable coded as one when TSE$\leq$25 and age ATB>20, and z_4 is an indicator variable when 25<TSE$\leq$30 and age ATB>20.

10.5.2 BEIR-V Breast Model

For the breast the RR was modeled only for the L model at the 1 Sv level. Cases for which the breast dose equivalent (neutron RBE=20) exceeded 4 Sv and TSE>75 were excluded.

The TSE was normalized to a TSE of 20, and cases with TSE<10 were excluded from the analysis. The Poisson regression model used for modeling the BEIR-V breast $\Phi_{RR}(a,t)$ was

$$\lambda_{ij} = \alpha_{s_i} e^{\beta_0}[1 + \{\beta_1 D^*_{ij} e^{\beta_2 z_1 + \beta_3 z_2 + \beta_4 z_3 + \beta_5 z_4}\}] \tag{42}$$

where α_s is for stratification of background rates (λ_{i0}) on sex (2 levels), city (2 levels), age ATB (13 levels) and follow-up period (7 levels), $\exp(\beta_0)$ is a constant term, β_1 is the linear coefficient for dose equivalent, D^*_{ij} is the breast dose equivalent, z_1 is a column vector of ones, z_2 is a covariate set to $ln(TSE/20)$ when age ATB<15, z_3 is a covariate set to $ln^2(TSE/20)$ when age ATB<15, and z_4 is a covariate set to age ATB-15 when age ATB15.

10.5.3 BEIR-V Respiratory Model

The lung model took into account a sex effect and an age ATD effect. Sex was dummy coded into male and female groups. TSE was normalized to a TSE of 20. RR was estimated for the L model at the 1 Sv level. Cases for which the lung dose equivalent (neutron RBE=20) exceeded 4 Sv and TSE>75 were excluded. Cases for which TSE<10 years were excluded. The Poisson regression model used for modeling the BEIR-V respiratory $\Phi_{RR}(a,t)$ was

$$\lambda_{ij} = \alpha_{s_i} e^{\beta_0}[1 + \{\beta_1 D^*_{ij} e^{\beta_2 z_1 + \beta_3 z_2}\}] \tag{43}$$

where α_s is for stratification of background rates (λ_{i0}) on sex (2 levels), city (2 levels), age ATB (13 levels) and follow-up period (7 levels), $\exp(\beta_0)$ is a constant term, β_1 is the linear coefficient for dose equivalent, D^*_{ij} is the lung dose equivalent, z_1 is a covariate set to $ln(TSE/20)$ and z_2 is a covariate for gender set to one for females and zero for males, independent of age ATB.

10.5.4 BEIR-V Digestive Model

Modeling mortality from digestive cancer included a sex effect and age ATB effect. Sex was coded into male and female groups. Age ATB was coded into 3 separate groups representing age ATB <25, 25<age ATB<35, and age ATB>35 since the BEIR-V committee reported age ATB to be quite significant. Cases for which the stomach dose equivalent (neutron RBE=20) exceeded 4 Sv and TSE>75 were excluded. Cases for which TSE<10 years were excluded.

The Poisson regression model used for modeling the BEIR-V digestive $\Phi_{RR}(a,t)$ was

$$\lambda_{ij} = \alpha_{s_i} e^{\beta_0}[1 + \{\beta_1 D^*_{ij} e^{\beta_2 z_1 + \beta_3 \sigma_E}\}] \tag{44}$$

where α_s is for stratification of background rates (λ_{i0}) on sex (2 levels), city (2 levels), age ATB (13 levels) and follow-up period (7 levels), $\exp(\beta_0)$ is a constant term, β_1 is the linear coefficient for dose equivalent, D^*_{ij} is the stomach dose equivalent, z_1 is a covariate for gender set to 1 for females and zero for males, and σ_E is a covariate for age ATB set to zero if age ATB$\leq$25, (E-25) when age ATB is >25 and $\leq$35, and 10 when age ATB>35.

10.5.5 BEIR-V Other Cancers Model

Radiation-induced mortality in the remaining sites will only account for age ATB effects. Cases for which the stomach dose equivalent (neutron RBE=20) exceeded 4 Sv and TSE>75 were excluded. Cases for which TSE<10 years were excluded to account for an

assumed minimum latency period. The Poisson regression model used for modeling the BEIR-V breast $\Phi_{RR}(a,t)$ was

$$\lambda_{ij} = \alpha_s e^{\beta_0}[1 + \{\beta_1 D^*_{ij} e^{\beta_2 z_1}\}] \tag{45}$$

where α_s is for stratification of background rates (λ_{i0}) on sex (2 levels), city (2 levels), age ATB (13 levels) and follow-up period (7 levels), $\exp(\beta_0)$ is a constant term, β_1 is the linear coefficient for dose equivalent, D^*_{ij} is the stomach dose equivalent and z_1 is a covariate for age ATB set to one if age ATB$\leq$10 and E-10 if age ATB>10.

10.6 Regression Diagnostics and Goodness-of-Fit (GOF)

The goodness-of-fit (GOF) of each model was estimated to determine the degree of concordance of the model under consideration with the data (Rayner and Best, 1989). Aggregate statistics to determine concordance were based on the squared difference between the observed, y_i, and fitted values, $\hat{\mu}_i$, of the number of deaths in each subpopulation. Cressie and Read (1984) introduced the power divergence family of GOF test statistics employed in this study. When $\hat{\mu}_i \geq 5$ for all i then *Pearson* χ^2 residuals

$$r_P = (y_i - \hat{\mu}_i)^2/\hat{\mu}_i \tag{46}$$

and χ^2 GOF statistic $\sum r_P^2$ are adequate measures of dispersion. If all $\hat{\mu}_i \leq 1$ or $\hat{\mu}_i \rightarrow 0$, then *deviance* residuals

$$r_D = 2[y_i \log \frac{y_i}{\hat{\mu}_i}]^{1/2} \tag{47}$$

and (deviance GOF $D = \sum r_D$) Freeman-Tukey, r_{FT}, residuals

$$r_{FT} = \sqrt{y_i} + \sqrt{y_i + 1} - \sqrt{4\hat{\mu}_i + 1} \tag{48}$$

and statistic $G = \sum r_{FT}^2$ are more appropriate for assessing GOF.

Numerically, the residuals are

$$r_P = ((max(y_i, 10^{-12}) - max(\hat{\mu}_1, 10^{-12})/\sqrt{max(\hat{\mu}_i, 10^{-12})}) \tag{49}$$

where $\max(y_i, 10^{-12})$ is the larger of the two values y_i and 10^{-12} and $\max(\hat{\mu}_i, 10^{-12})$ is the larger of the two values $\hat{\mu}_i$ and 10^{-12}. The deviance is in the form

$$r_D = max(y_i, 10^{-12})\,[ln(max(y_i, 10^{-12}) - ln(max(\hat{\mu}_i, 10^{-12}))] \tag{50}$$

where $\max(y_i, 10^{-12})$ and $\max(\hat{\mu}_i, 10^{-12})$ are defined above. Lastly, the Freeman-Tukey residuals were determined as

$$r_{FT} = (\sqrt{max(y_i, 10^{-12})} + \sqrt{(max(y_i, 10^{-12}) + 1} - \sqrt{4\,max(\hat{\mu}_i, 10^{-12}) - 1} \tag{51}$$

Under the null hypothesis, $\chi^2 = \sum r_P^2 = D = \sum r_D^2 = G = \sum r_{FT}^2 \sim \chi^2_{n-s-p}$. Values of χ^2, D, and G that are less than $n - s - p$ represent models that "fit" the data and will typically result in tail probabilities ≥ 0.25; a perfect fit will yield a tail probability of unity (see Algorithm AS32 in the references).

11 APPENDIX B. Lifetime Risk Projection

11.1 Introduction

The lifetime mortality risk of multiple exposures to radiation is quantified by applying the risks from each age at exposure to the total force of mortality experienced over a lifetime. In one sense, we are applying radiation risk coefficients obtained from the follow-up of a bona fide exposed cohort to the survival of a theoretically exposed population whose mortality increases proportionally with baseline cancer rates (relative projection model) or independently of baseline cancer rates (absolute projection model). The following sections will explain succinctly the complexities involved in calculating the lifetime risks of radiation-induced cancer mortality.

11.2 Hazard Functions for Radiation-Induced Cancer

First define a as the age at exposure for an exposed population. The hazard of radiation-induced cancer at age t from exposure at age a for the constant relative model is

$$h_c(a;t;d) = H(a)\,\Phi_{ERR}(a)\,h_c(t;0) \tag{52}$$

where $H(a)$ is the annual dose (Sv) at age a, $\Phi_{ERR}(a)$ is the excess relative risk at age a and $h_c(t;0)$ is the hazard rate for spontaneously occurring cancer at age t. The hazard function for radiation-induced cancer at age t from multiple exposures at various ages is written

$$h_c(\infty;t;d) = \int_{t-p}^{t-l} H(a)\,\Phi_{ERR}(a)\,h_c(t;0)\,da \tag{53}$$

where the integrands are defined in Eq. 52. The upper limit of integration $t-l$ prevents integration at ages beyond the plateau period and the lower limit prevents integration below the minimal latency period (Checkoway et al., 1989). When using risk coefficients that are only age at-time-of-bombing (ATB) specific, $\Phi_{ERR}(a)$ for exposure at age a remains constant for all subsequent age intervals. However, when using risk coefficients that are age ATB and time-since-exposure (TSE) specific, then $\Phi_{ERR}(a)$ changes and is termed $\Phi_{ERR}(a,t)$ to indicate the hazard at age t from exposure at age a. The terms l and p in the limits of integration of Eq. 53 represent the beginning (minimum latency) and end of the plateau period for exposure at age a.

Risk projection for each age interval under the constant absolute model is similar to that of the constant relative model, however the absolute risk (deaths/person-year-Sv), $\Phi_{AR}(a)$, for exposure at age a is applied to the dose equivalent, $H(a)$, received at age a in the absence of baseline cancer mortality rates. Thus, Eq. 52 becomes

$$h_c(a;t;d) = H(a)\,\Phi_{AR}(a) \tag{54}$$

and Eq. 53 becomes

$$h_c(\infty;t;d) = \int_{t-p}^{t-l} H(a)\,\Phi_{AR}(a)\,da \tag{55}$$

11.3 Double-Decrement Life Table (Radiation-Induced Cancers)

We recall that for a double-decrement life table (Elandt-Johnson and Johnson, 1980) the conditional death probability, $q(t;d)$ in age interval $(t, t+1)$ due to the combination of death from all causes in the absence of exposure and deaths due to radiation-induced cancer is

$$q(t;d) = \frac{2\,(h(t;0) + h_c(\infty;t;d))}{2 + (h(t;0) + h_c(\infty;t;d))} \tag{56}$$

where $h(t;0)$ is the age-specific central death rate due to all causes in the absence of exposure and $h_c(\infty;t;d)$ is the total age-specific central death rate for cancer due to radiation exposure (Eqs. 53 and 55). The conditional probability that an individual will not die in the interval $(t, t+1)$ is

$$p(t;d) = 1 - q(t;d)\,. \tag{57}$$

and the number of expected deaths from radiation-induced cancer and all causes in the absence of exposure is

$$d(t;d) = q(t;d)\,N(t;d)\,. \tag{58}$$

The expected number of survivors, $N(t;d)$ in interval $(t, t+1)$ out of a population of $N(a+L;d)$ is found recursively as

$$N(t;d) = N(t-1;d) - d(t-1;d) \tag{59}$$

and the number of person-years in each interval $(t, t+1)$ is approximated by

$$l(t;d) = N(t;d) - \frac{1}{2}d(t;d)\,. \tag{60}$$

The survivorship function (Chiang, 1968; Chiang, 1984; Smith et al., 1970; Lee, 1980) or cumulative probability of surviving beyond each interval is estimated with the equation

$$S(t;d) = \prod_{y=0}^{t-1}(1 - q(t;d)) = \prod_{y=0}^{t-1} p(t;d) \tag{61}$$

which is used later for estimating the lifetime risks of radiation-induced cancer in an exposed working population.

11.4 Single-Decrement Life Table (Baseline cancers)

Whereas the double-decrement life table provides estimates of radiation-induced cancer mortality, the single-decrement life table is applied to obtain estimates of baseline (spontaneous) cancer mortality risks over a career or lifetime. The probability and number of baseline cancers for the relevant projection periods are calculated the same way as the number of radiation-induced cancers was determined. In this instance, Eq. 53 is rearranged to

$$q(t;0) = \frac{2\,h(t;0)}{2 + (h(t;0)} \tag{62}$$

In the absence of radiation exposure, the conditional probability that an individual will not die in the interval $(t, t+1)$ is

$$p(t;0) = 1 - q(t;0)\,. \tag{63}$$

and the number of expected deaths from all causes in the absence of exposure is

$$d(t;0) = q(t;0)\,N(t;0)\ . \tag{64}$$

The expected number of survivors, $N(t;0)$, in interval $(t, t+1)$ out of a population of $N(a+L;0)$ nonexposed workers is found recursively as

$$N(t;0) = N(t-1;0) - d(t-1;0) \tag{65}$$

and the number of person-years in each interval $(t, t+1)$ is approximated by

$$l(t;0) = N(t;0) - \frac{1}{2}d(t;0)\ . \tag{66}$$

The cumulative probability of surviving beyond each interval (survivorship function) is estimated with the equation

$$S(t;0) = \prod_{y=0}^{t-1}(1 - q(t;0)) = \prod_{y=0}^{t-1} p(t;0) \tag{67}$$

The above parameters are endpoints that are used for determining the lifetime risks of baseline cancers in a nonexposed population. The next two sections describe the method for obtaining lifetime risks.

11.5 Lifetime Risks Based on Method of Elandt-Johnson and Johnson

The conditional probability of death due to radiation-induced cancer is estimated using the formula

$$\pi(t;d) = h_c(\infty;t;d)\,S(t;d) \tag{68}$$

where $h_c(\infty;t;d)$ is the hazard function defined in Eqs. 53 and 55 and $S(t;d)$ is the survivorship function from the double-decrement life table (Eq. 61) for the exposed population. The unconditional probability of death due to radiation-induced cancer at age t is

$$Q(t;d) = \int_0^t \pi(x;d)\,dx = \int_0^t h_c(\infty;x;d)\,S(x;d)\,dx \tag{69}$$

Over a lifetime, the unconditional probability of radiation-induced cancer mortality for an exposed population over a lifetime is

$$\pi(\infty;d) = \int_0^\infty \pi(x;d)\,dx = \int_0^\infty h_c(\infty;x;d)\,S(x;d)\,dx \tag{70}$$

where ∞ is by convention 100 years of age. The number of radiation-induced cancer deaths (per 10^5 exposed individuals) is $\pi(\infty;d) \times 10^5$.

The unconditional death probability for the constant RR risk projection model was based on applying ERR coefficients obtained in this study directly to baseline (spontaneously occurring) cancer rates and life tables for the U.S. population. This was functionally composed by substituting the integrands of Eq. 53 into Eq. 70 as

$$\pi(\infty;d) = \int_0^\infty \int_{t-p}^{t-l} H(a)\,\Phi_{ERR}(a)\,h_c(t;0)\,S(t;d)\,da\,dt \tag{71}$$

where ∞ is by convention 100 years of age, $t-p$ prevents integration below the minimal latency period for the first (or only) age at exposure a, $t-l$ prevents integration beyond the plateau period for the last age at exposure (Checkoway et al., 1989), $H(a)$ is the annual dose equivalent in Sv, $\Phi_{ERR}(a)$ is the sex- and age ATB-specific excess risk coefficient (%/Sv) from §3.3, $h_c(t;0)$ is the hazard rate of spontaneously occuring cancer in the interval $(t, t+1)$ and $S(t;d)$ is the all-cause survivorship function for each one-year interval of the complete life table. The number of radiation-induced cancer deaths per 100,000 exposed individuals is $\pi(\infty;d) \times 10^5$.

The unconditional death probability for the non-constant RERF and BEIR-V relative models were based on sex-, age ATB- and either age ATD- or TSE-specific ERR coefficients obtained in this study in the form

$$\pi(\infty;d) = \int_0^{\infty} \int_{t-p}^{t-l} H(a)\,\Phi_{ERR}(a,t)\,h_c(t;0)\,S(t;d)\,da\,dt \tag{72}$$

where $\Phi_{ERR}(a,t)$ is the ERR risk coefficient at age t for exposure at age a.

The unconditional probability, $\pi(\infty;d)$, of radiation-induced cancer mortality over a lifetime for the constant AR model is obtained by substitution of integrands of Eq. 55 into Eq. 70 in the form

$$\pi(\infty;d) = \int_0^{\infty} \int_{t-p}^{t-l} H(a)\,\Phi_{AR}(a)\,S(t;d)\,da\,dt \tag{73}$$

where $\Phi_{AR}(a)$ is the sex-, age ATB- and/or age ATD-specific absolute risk coefficient (deaths/10^4PYSv) from §3.3, and $S(t;d)$ is the all-cause survivorship function for each one-year interval of the complete life table. Non-constant absolute unconditional probabilities were estimated with $\Phi_{AR}(a,t)$ using the equation

$$\pi(\infty;d) = \int_0^{\infty} \int_{t-p}^{t-l} H(a)\,\Phi_{AR}(a,t)\,S(t;d)\,da\,dt \tag{74}$$

Unconditional probabilities based on the constant transported RR(AR) model were calculated with the formula

$$\pi(\infty;d) = \int_0^{\infty} \int_{t-p}^{t-l} H(a)\,\Phi_{ERR,US}(a)\,h_c(t;0)\,S(t;d)\,da\,dt \tag{75}$$

where the integrand $\Phi_{ERR,US}(a)$ is based on the relationship

$$\Phi_{ERR,US}(a) = \frac{\int_{a+5}^{a+40} \Phi_{AR}(a)\,h_c(t;0)\,S(t;d)\,dt}{\int_{a+5}^{a+40} h_c(t;0)\,S(t;0)\,dt} \tag{76}$$

over the relevant 35-year (1950-85) follow-up period in the LSS from $a+5$ to $a+40$ where $h_c(t;0)$ is the baseline cancer rate for spontaneously occurring cancer at age t and $S(t;d)$ and $S(t;0)$ are the survivorship functions for the radiation exposed (Eq. 62) and the non-exposed populations (Eq. 67), respectively. For unconditional probabilities based on the

non-constant transported relative model of $\Phi_{ERR,US}(a,t)$, lifetime risks were calculated with the formula

$$\pi(\infty;d) = \int_0^{\infty} \int_{t-p}^{t-l} H(a)\,\Phi_{ERR,US}(a,t)\,h_c(t;0)\,S(t;d)\,da\,dt \tag{77}$$

where the integrand $\Phi_{ERR,US}(a,t)$ is based on the relationship

$$\Phi_{ERR,US}(a,t) = \frac{\int_{a+5}^{a+40} \Phi_{AR}(a,t)\,h_c(x;0)\,S(x;d)\,dx}{\int_{a+5}^{a+40} h_c(t;0)\,S(t;0)\,dt} \tag{78}$$

It is noteworthy to point out that the Risk of Exposure-Induced Death (REID) introduced by Thomas et al. (1992) as

$$REID_c(e,D) = \int_e^{\infty} [\mu_c(a|e,D) - \mu_c(a)]S(a|e,D)\,da \tag{79}$$

is equivalent to $\pi(\infty;d)$ because the hazard function $h_c(\infty;x;d)$ in Eqs. 53 and 55 does not include the baseline hazard function $h_c(t;0)$ for spontaneously occurring cancer. Thus, the hazard functions in Eqs. 6 and 7 of Thomas et al. would be stated in this report as

$$\mu_c(a,e,t,s,y,D) = \beta(a,e,t,s)\,g(D) \tag{80}$$

for the additive projection model and

$$\mu_c(a,e,t,s,y,D) = \mu(a,y)\,\beta(a,e,t,s)\,g(D) \tag{81}$$

for the multiplicative model. Results of the Elandt-Johnson and Johnson (1980) method of estimating lifetime risks have been found to be similar to those estimated by the Bunger et al. (1981) and Gail (1975) methods because the SURVRAD algorithm implements all three methods of estimation (Peterson et al., 1992). The only difference between the Elandt-Johnson and Johnson method and Bunger method is that the former is based on the integral product of a hazard function, $h_c(\infty;t;d)$, and $S(t;d)$ and the latter is based on the integral product of the conditional probability, $q(t;d)$, and $S(t;d)$. Kahn and Sempos (1989) suggest that the use of hazard rates will not underestimate risks based on probabilities because the denominator of a rate is comprised of fewer individuals (person-years) since it is based on the midpoint of the interval – probabilities, on the other hand, are based on denominator data at the beginning of the interval where the average person-years of follow-up is greater. Thus, the use of hazard rates in lifetime risk projection will result in estimates that are essentially slightly greater than risks based on probabilities.

The conditional probability of death due to spontaneously occurring cancer at age t is estimated using the formula

$$\pi(t;0) = h_c(t;0)\,S(t;0) \tag{82}$$

where $h_c(t;0)$ is the hazard function for spontaneous cancer and $S(t;0)$ is the survivorship function from the single-decrement life table (Eq. 67) for the nonexposed population. To determine the unconditional probability of death and lifetime risk of spontaneously (baseline) occurring cancer at age t Eq. 69 is rewritten

$$Q(t;0) = \int_0^t \pi(x;0)\,dx = \int_0^t h_c(x;0)\,S(x;0)\,dx \tag{83}$$

The unconditional probability of spontaneously occurring cancer in the nonexposed population over a lifetime is

$$\pi(\infty;0) = \int_0^\infty \pi(x;0)\,dx = \int_0^\infty h_c(x;0)\,S(x;0)\,dx \tag{84}$$

and once again ∞ is by convention 100 years of age. The number of baseline cancer deaths in the nonexposed population (per 10^5 individuals) is $\pi(\infty;0) \times 10^5$.

11.6 Years of Life Lost Per Premature Radiation-Induced Cancer Death

One of the most useful, if not most important, indices of radiation risk in an exposed population is the number of years of life lost per premature radiation-induced cancer death. The years of life lost by the exposed cohort per premature radiation-induced cancer death at age t is

$$YLPD = \frac{\int_0^t l(x;0) - l(x;d)\,dx}{Q(t;d) \times 10^5} \tag{85}$$

where $l(x;d)$ and $l(x;0)$ are the number of person-years in each age interval $(x, x+1)$ and $Q(t;d)$ is the unconditional probability of radiation-induced cancer in the exposed population at age t.

11.7 Probability of Causation

Sometimes it is useful to determine the attributable risk caused by one or more radiation exposures. In principle, the attributable risk or probability of causation (PC) is defined as the fraction of radiation-induced cancer deaths out of the total cancer deaths in an exposed population. Using the lifetime risks of radiation-induced cancer explained earlier, the PC at age t is calculated with the equation

$$PC = \frac{Q(t;d)\,/\,Q(t;0)}{1 + (Q(t;d)\,/\,Q(t;0))} \tag{86}$$

11.8 Error Propagation

A thorough evaluation of statistical uncertainty in numerical analysis will always involve the propagation of error. Estimates of the total uncertainty are determined several ways depending on the numerical methods used.

11.8.1 Constant and Non-constant Absolute and Relative Projection Models

The cause-specific hazard rates for radiation-induced cancer in the double-decrement life table have standard error

$$\sigma_{h_c(a;t;d)} = h_c(a;t;d)\sqrt{\left(\frac{\sigma_{H(a)}}{H(a)}\right)^2 + \left(\frac{\sigma_{\Phi_{ERR}(a)}}{\Phi_{ERR}(a)}\right)^2 + \left(\frac{\sigma_{h_c(t;0)}}{h_c(t;0)}\right)^2} \tag{87}$$

where $\sigma_{H(a)}$ is the standard error of the annual dose equivalent (assumed to be 0.1), $\sigma_{\Phi_{ERR}(a)}$ is the standard error of the excess relative risk, and $\sigma_{h(t;0)}$ is written

$$\sigma_{h_c(t;0)} = \sqrt{\frac{h_c(t;0)\,(1-h_c(t;0))}{N(t;0)}} \tag{88}$$

The standard error of the central mortality rate for the absolute model is

$$\sigma_{h_c(a;t;d)} = h_c(a;t;d)\sqrt{\left(\frac{\sigma_{H(a)}}{H(a)}\right)^2 + \left(\frac{\sigma_{\Phi_{AR}(a)}}{\Phi_{AR}(a)}\right)^2} \tag{89}$$

where $\sigma_{H(a)}$ is the standard error of the annual dose equivalent (assumed to be 0.1) and $\sigma_{AR(a)}$, the standard error of the absolute risk is defined by the equation

$$\sigma_{\Phi_{AR}(a)} = \sqrt{\frac{(\Phi_{AR}(a))\,(1-\Phi_{AR}(a))}{10^4 PYSv}} \tag{90}$$

Next, using the standard error of $h_c(a;t;d)$, estimate the standard error of $h_c(\infty;t;d)$ with the relationship

$$\sigma_{h_c(\infty;t;d)} = \sqrt{\sum_{a+L}^{100}(\sigma^2_{h_c(a;t;d)})} \tag{91}$$

The survivorship function's standard error is obtained with Greenwood's (1926) formula

$$Var[S(t;d)] = S(t;d)^2 \sum_{a+L}^{t-1} \frac{q(t;d)}{N(t;d)\,p(t;d)} \tag{92}$$

where $a+L$ is the first age at exposure plus the minimal latency period and t and $t-1$ are somewhere in the plateau period. The standard error of the survivorship function is the square root of $Var[S(t;d)]$. The standard error of the conditional death probability is written

$$\sigma_{\pi(t;d)} = \pi(t;d)\sqrt{\left(\frac{\sigma_{S(t;d)}}{S(t;d)}\right)^2 + \left(\frac{\sigma_{h_c(\infty;t;d)}}{h_c(\infty;t;d)}\right)^2} \tag{93}$$

and the standard error for the unconditional probability of radiation-induced cancer risk is defined as

$$\sigma_{\pi(\infty;d)} = \sqrt{\sum_{a+L}^{100}\sigma^2_{\pi(t;d)}} \tag{94}$$

For baseline cancers in the non-exposed population, we do the same as that for propagating error in the double-decrement life table but with different and far fewer steps. The standard error of $h_c(t;0)$ is given in Eq. 88 and the survivorship function has, according to Greenwood (1926), variance

$$Var[S(t;0)] = S(t;0)^2 \sum_{a+L}^{t-1} \frac{q(t;0)}{N(t;0)\,p(t;0)} \tag{95}$$

where $a+L$ is based on the same first age at exposure of the exposed population plus the minimal latency period and t and $t-1$ are somewhere in the plateau period. The standard

error of the survivorship function is the square root of $Var[S(t;0)]$. The conditional death probability of baseline cancer at each interval is

$$\sigma_{\pi(t;0)} = \pi(t;0)\sqrt{\left(\frac{\sigma_{S(t;0)}}{S(t;0)}\right)^2 + \left(\frac{\sigma_{h_c(t;0)}}{h_c(t;0)}\right)^2} \tag{96}$$

and the standard error for the unconditional probability of spontaneously occurring cancer is

$$\sigma_{\pi(\infty;0)} = \sqrt{\sum_{a+L}^{100} \sigma^2_{\pi(t;0)}} \tag{97}$$

11.8.2 BEIR-V Relative Projection Model

Although the numerical methods for estimating central death rates of the BEIR-V relative risk projection model are similar to those used for the constant models, there are several additional steps that must be taken to determine the uncertainty. We pointed out earlier that the excess relative risk of the BEIR-V model, $\Phi_{ERR}(a,t)$, is the product of a dose function $f(d)$ and a link function $g(\beta)$. The standard error of the link function $g(\beta)$ is the natural logarithm of its geometric standard deviation (GSD)

$$\sigma_{g(\beta)} = \sqrt{\sigma^2_{\beta_1} + \sigma^2_{\beta_2} + \sigma^2_{\beta_3} + \sigma^2_{\beta_4}} \tag{98}$$

where σ^2 is the variance of the coefficients of the BEIR-V regression models. The standard error of the dose function $f(d)$ is functionally composed as

$$\sigma_{f(d)} = \sqrt{\sigma^2_{\alpha_1} + \sigma^2_{\alpha_2}} \tag{99}$$

Since the excess relative risk $\Phi_{ERR}(a,t)$ is the product of the dose $f(d)$ and link function $g(\beta)$, its standard error is of the form

$$\sigma_{\Phi_{ERR}(a,t)} = \Phi_{ERR}(a,t)\sqrt{\left(\frac{\sigma_{g(\beta)}}{g(\beta)}\right)^2 + \left(\frac{\sigma_{f(d)}}{f(d)}\right)^2} \tag{100}$$

The hazard function for radiation-induced cancer at age t in the double-decrement life table is the product of $\Phi_{ERR}(a,t)$ and the age-specific cancer mortality rate $h_c(t;0)$

$$h_c(a;t;d) = \Phi_{ERR}(a,t)\, h_c(t;0) \tag{101}$$

and its standard error is

$$\sigma_{h_c(a;t;d)} = h_c(a;t;d)\sqrt{\left(\frac{\sigma_{\Phi_{ERR}(a,t)}}{\Phi_{ERR}(a,t)}\right)^2 + \left(\frac{\sigma_{h_c(t;0)}}{h_c(t;0)}\right)^2} \tag{102}$$

Once the standard errors of the age-specific central death rates are known, we next estimate the standard error for the total central death rate as the square root of the sum of their variances given in the form

$$\sigma_{h_c(\infty;t;d)} = \sqrt{\sum_{a+L}^{100}(\sigma^2_{h_c(a;t;d)})} \tag{103}$$

This standard error is then used in the right-hand side of Eq. 93.

Table 28: Error components of lifetime risk.

Sex	Race	$\sigma_{\pi(\infty;d)}$	σ_{DS86}	σ_{SEER}	σ_{Pop}
Males	White	Eq. 94	0.45	0.2	ln(1.2)
	Nonwhite	"	"	0.1	"
Females	White	"	"	0.8	"
	Nonwhite	"	"	0.5	"

11.8.3 Probability of Causation

Calculating the standard error of the PC is a rather simple task. We recall that the PC is the ratio of $(Q(t;d)/Q(t;0))$ to $(1+((Q(t;d)/Q(t;0))$ and therefore, the standard error of the PC is determined according to the formula

$$\sigma_{PC} = PC \sqrt{\left(\frac{Q(t;d)/Q(t;0)\sqrt{\left(\frac{\sigma_{Q(t;d)}}{Q(t;d)}\right)^2 + \left(\frac{\sigma_{Q(t;0)}}{Q(t;d)}\right)^2}}{Q(t;d)/Q(t;0)}\right)^2 + \left(\frac{Q(t;d)/Q(t;0)\sqrt{\left(\frac{\sigma_{Q(t;d)}}{Q(t;d)}\right)^2 + \left(\frac{\sigma_{Q(t;0)}}{Q(t;0)}\right)^2}}{Q(t;d)/Q(t;0)}\right)^2} \tag{104}$$

which reduces to

$$\sigma_{PC} = PC \sqrt{2\left(\left(\frac{\sigma_{Q(t;d)}}{Q(t;d)}\right)^2 + \left(\frac{\sigma_{Q(t;0)}}{Q(t;0)}\right)^2\right)} \tag{105}$$

11.9 Credibility Intervals of Lifetime Risk

Credibility intervals $(1-\alpha)$ for lifetime risks and PCs are based on the geometric standard deviation (GSD). Therefore, the arithmetic parameter, i.e., σ, will need to be exponentiated after it is adjusted for a Type I error, that is, multiplied by the standard normal deviate, Z_α (Abramowitz and Stegun, 1965). The $(1-\alpha)$ credibility interval for radiation-induced lifetime risk is defined as

$$\pi(\infty;d) / \exp(Z_\alpha\, \sigma_T) < \pi(\infty;d) < \pi(\infty;d)\, \exp(Z_\alpha\, \sigma_T) \tag{106}$$

where $\pi(\infty;d)$ is the unconditional death probability and σ_T is the quadrature sum of errors for lifetime risks, DS86 standard error, sampling variation of the SEER mortality rates and differences between the U.S. and Japanese populations. The total error is of the form

$$\sigma_T = \sqrt{\sigma^2_{\pi(\infty;d)} + \sigma^2_{DS86} + \sigma^2_{SEER} + \sigma^2_{Pop}} \tag{107}$$

where the component standard errors are given in Table 28. Similarly, the $(1-\alpha)$ credibility interval for the PC is

$$PC / \exp(Z_\alpha\, \sigma_T) < PC < PC\, \exp(Z_\alpha\, \sigma_T) \tag{108}$$

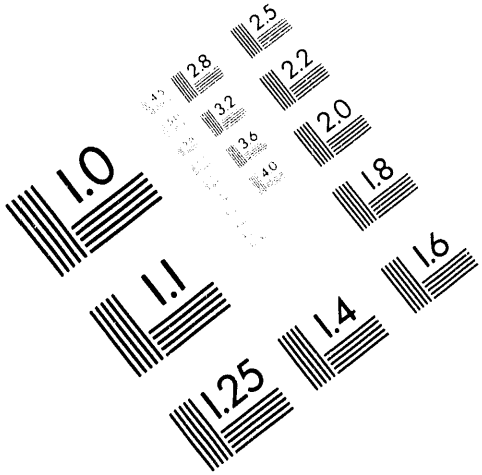
with total error of the form

$$\sigma_T = \sqrt{\sigma^2_{PC} + \sigma^2_{DS86} + \sigma^2_{SEER} + \sigma^2_{Pop}} \tag{109}$$

where the standard error of the PC, σ_{PC}, is from Eq. 105 and the standard error σ_{DS86} is from Sposto et al. (1991), the standard error σ_{SEER} is from the "Total U.S." row of Tables I-22 and I-23 of the *Cancer Statistics Review* (Ries et al., 1989) and σ_{Pop} is from the standard error of "Population differences" row in the table of GSDs on page 214 of the BEIR-V report (NRC, 1990).

12 APPENDIX C. Relative and Absolute Risk Coefficients.

Tables C.1 - C.48.



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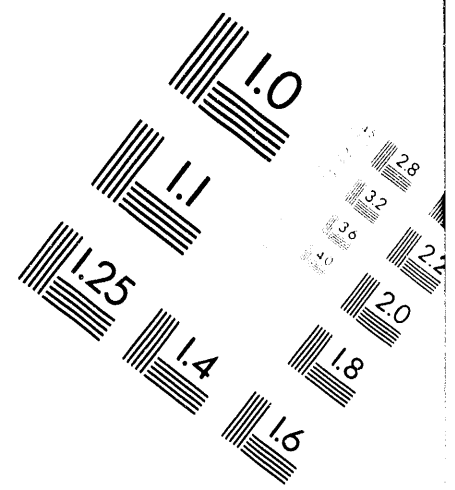

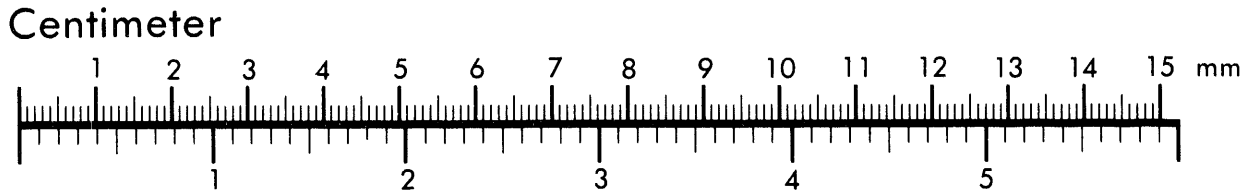

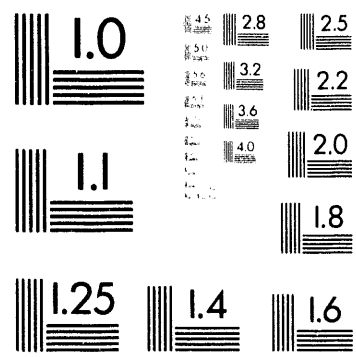

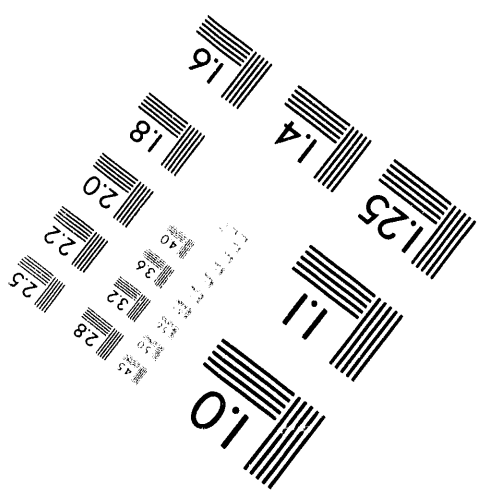

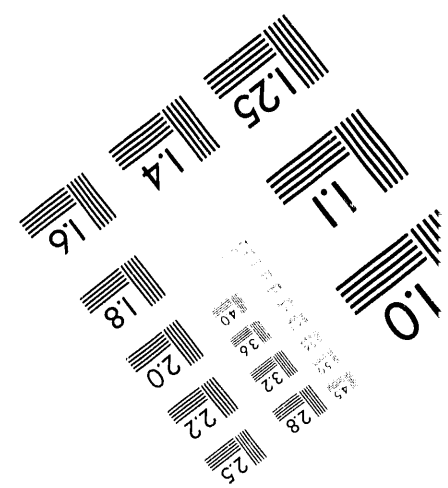

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Table C.1. Excess relative and absolute risk coefficients for leukemia.

Male Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	37.770	6.294	2.865	.000	.000	.000	.000
10-19	.000	12.227	5.566	2.313	.585	.000	.000
20-29	.000	19.856	9.039	3.757	.951	.435	.000
30-39	.000	.000	43.664	18.147	4.593	2.103	1.527
40-49	.000	.000	.000	7.297	1.847	.846	.614
50+	.000	.000	.000	.000	16.095	7.371	5.352

Male Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	7.514	2.853	.136	.000	.000	.000	.000
10-19	.000	4.503	1.360	1.656	.155	.000	.000
20-29	.000	13.323	8.046	3.168	.470	.520	.000
30-39	.000	.000	8.859	4.831	4.076	7.629	6.977
40-49	.000	.000	.000	5.718	3.302	.606	2.894
50+	.000	.000	.000	.000	4.626	6.975	6.124

Female Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	42.040	7.005	3.189	1.325	.000	.000	.000
10-19	.000	13.609	6.195	2.575	.652	.000	.000
20-29	.000	22.101	10.061	4.181	1.058	.485	.000
30-39	.000	.000	.000	20.199	5.112	2.341	1.700
40-49	.000	.000	.000	8.122	2.056	.941	.684
50+	.000	.000	.000	.000	17.915	8.204	5.957

Female Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	6.429	.474	.742	.555	.000	.000	.000
10-19	.000	1.688	.503	1.109	.175	.000	.000
20-29	.000	6.560	1.629	2.802	.278	.959	.000
30-39	.000	.000	.000	2.274	1.212	2.570	1.603
40-49	.000	.000	.000	7.283	2.094	1.001	.918
50+	.000	.000	.000	.000	5.186	5.213	4.703

Goodness of fit	Value	d.f.	Prob
Chi-square	1262.2200	3022	1.0000
Deviance	632.3860	3022	1.0000
Freeman-Tukey	238.5760	3022	1.0000

Table C.2. Excess relative and absolute risk coefficients for leukemia adjusted for confirmation rates not stratified, i.e., crude(1950-75).

Male Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	36.162	6.567	3.111	.000	.000	.000	.000
10-19	56.120	10.191	4.828	2.037	.529	.000	.000
20-29	.000	17.097	8.100	3.417	.887	.465	.000
30-39	.000	.000	34.570	14.585	3.785	1.986	1.551
40-49	.000	.000	.000	6.760	1.754	.920	.719
50+	.000	.000	.000	.000	7.885	4.137	3.232

Male Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	6.446	2.545	.135	.000	.000	.000	.000
10-19	.545	3.730	1.158	1.367	.141	.000	.000
20-29	.000	11.325	6.736	2.672	.476	.553	.000
30-39	.000	.000	7.623	4.137	3.341	7.092	7.073
40-49	.000	.000	.000	5.021	2.902	.771	3.348
50+	.000	.000	.000	.000	3.812	5.297	5.697

Female Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	40.960	7.438	3.524	1.487	.000	.000	.000
10-19	63.567	11.543	5.469	2.307	.599	.000	.000
20-29	.000	19.366	9.175	3.871	1.005	.527	.000
30-39	.000	.000	39.158	16.520	4.287	2.249	1.757
40-49	.000	.000	.000	7.657	1.987	1.042	.814
50+	.000	.000	.000	.000	8.932	4.686	3.660

Female Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	5.525	.446	.768	.607	.000	.000	.000
10-19	.261	1.440	.451	.943	.162	.000	.000
20-29	.000	5.568	1.429	2.352	.268	1.038	.000
30-39	.000	.000	.223	2.032	1.075	2.497	1.649
40-49	.000	.000	.000	6.295	1.876	1.077	1.109
50+	.000	.000	.000	.000	3.957	3.905	4.601

Goodness of fit	Value	d.f.	Prob
Chi-square	1077.8200	3022	1.0000
Deviance	534.8830	3022	1.0000
Freeman-Tukey	226.3790	3022	1.0000

Table C.3. Excess relative and absolute risk coefficients for leukemia adjusted for confirmation rates not stratified, i.e., crude (1950-85).

Male Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	36.671	6.221	2.751	1.257	.000	.000	.000
10-19	63.067	10.700	4.731	2.162	.575	.000	.000
20-29	.000	18.047	7.980	3.647	.969	.465	.000
30-39	.000	.000	33.248	15.196	4.039	1.939	1.235
40-49	.000	.000	.000	6.360	1.690	.811	.517
50+	.000	.000	.000	.000	10.034	4.816	3.068

Male Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	6.472	2.469	.141	.024	.000	.000	.000
10-19	.573	3.805	1.138	1.417	.163	.000	.000
20-29	.000	11.577	6.657	2.801	.485	.535	.000
30-39	.000	.000	7.494	4.200	3.496	6.492	5.390
40-49	.000	.000	.000	4.842	2.826	.690	2.434
50+	.000	.000	.000	.000	4.186	5.852	5.407

Female Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	40.000	6.786	3.001	1.371	.000	.000	.000
10-19	68.791	11.671	5.161	2.359	.627	.000	.000
20-29	.000	19.685	8.705	3.978	1.057	.508	.000
30-39	.000	.000	36.266	16.575	4.406	2.115	1.347
40-49	.000	.000	.000	6.937	1.844	.885	.564
50+	.000	.000	.000	.000	10.945	5.253	3.346

Female Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	5.507	.422	.626	.505	.000	.000	.000
10-19	.268	1.447	.437	.924	.161	.000	.000
20-29	.000	5.591	1.397	2.394	.280	.891	.000
30-39	.000	.000	.220	2.033	1.097	2.225	1.385
40-49	.000	.000	.000	5.973	1.776	.934	.872
50+	.000	.000	.000	.000	4.308	4.189	4.515

Goodness of fit	Value	d.f.	Prob
Chi-square	1042.8300	3022	1.0000
Deviance	501.8550	3022	1.0000
Freeman-Tukey	227.3180	3022	1.0000

Table C.4. Excess relative and absolute risk coefficients for leukemia adjusted for confirmation rates stratified on gender (1950-75).

Male Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	39.293	7.008	3.330	.000	.000	.000	.000
10-19	.000	11.476	5.453	2.264	.574	.000	.000
20-29	.000	19.318	9.180	3.812	.967	.493	.000
30-39	.000	.000	39.847	16.544	4.196	2.141	1.602
40-49	.000	.000	.000	7.886	2.000	1.020	.763
50+	.000	.000	.000	.000	11.101	5.664	4.238

Male Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	6.429	2.569	.127	.000	.000	.000	.000
10-19	.000	3.743	1.152	1.426	.152	.000	.000
20-29	.000	11.196	6.892	2.716	.477	.584	.000
30-39	.000	.000	7.425	4.001	3.263	7.353	7.248
40-49	.000	.000	.000	5.069	2.971	.607	3.425
50+	.000	.000	.000	.000	3.530	5.186	4.854

Female Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	38.730	6.908	3.283	1.363	.000	.000	.000
10-19	63.422	11.311	5.375	2.232	.566	.000	.000
20-29	.000	19.041	9.049	3.757	.953	.486	.000
30-39	.000	.000	39.276	16.307	4.136	2.110	1.579
40-49	.000	.000	.000	7.773	1.971	1.006	.752
50+	.000	.000	.000	.000	10.942	5.582	4.177

Female Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	5.493	.429	.731	.567	.000	.000	.000
10-19	.261	1.434	.448	.922	.154	.000	.000
20-29	.000	5.562	1.426	2.317	.256	.963	.000
30-39	.000	.000	.223	2.030	1.054	2.379	1.509
40-49	.000	.000	.000	6.369	1.868	1.047	1.033
50+	.000	.000	.000	.000	4.318	4.351	5.047

Goodness of fit	Value	d.f.	Prob
Chi-square	1093.6500	3022	1.0000
Deviance	547.2830	3022	1.0000
Freeman-Tukey	222.2210	3022	1.0000

Table C.5. Excess relative and absolute risk coefficients for leukemia adjusted for confirmation rates stratified on gender (1950-85).

Male Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	41.068	7.080	3.099	.000	.000	.000	.000
10-19	.000	12.362	5.412	2.603	.695	.000	.000
20-29	.000	21.269	9.311	4.478	1.196	.578	.000
30-39	.000	.000	35.101	16.882	4.510	2.178	1.266
40-49	.000	.000	.000	7.685	2.053	.991	.577
50+	.000	.000	.000	.000	13.082	6.317	3.674

Male Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	6.488	2.581	.119	.000	.000	.000	.000
10-19	.000	3.846	1.136	1.521	.154	.000	.000
20-29	.000	11.561	6.866	3.027	.486	.573	.000
30-39	.000	.000	7.130	4.043	3.427	6.673	5.063
40-49	.000	.000	.000	4.989	3.037	.590	2.323
50+	.000	.000	.000	.000	3.716	5.560	4.029

Female Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	32.640	5.627	2.463	1.185	.000	.000	.000
10-19	56.994	9.825	4.301	2.069	.553	.000	.000
20-29	.000	16.904	7.400	3.559	.951	.459	.000
30-39	.000	.000	27.898	13.417	3.584	1.731	1.007
40-49	.000	.000	.000	6.108	1.632	.788	.458
50+	.000	.000	.000	.000	10.397	5.021	2.920

Female Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	5.388	.403	.560	.466	.000	.000	.000
10-19	.531	1.438	.439	.876	.160	.000	.000
20-29	.000	5.532	1.389	2.314	.298	.849	.000
30-39	.000	.000	.427	2.099	1.104	2.081	1.296
40-49	.000	.000	.000	5.838	1.741	.963	.909
50+	.000	.000	.000	.000	4.800	4.793	5.795

Goodness of fit	Value	d.f.	Prob
Chi-square	1049.3300	3022	1.0000
Deviance	509.2610	3022	1.0000
Freeman-Tukey	243.6890	3022	1.0000

Table C.6. Excess relative and absolute risk coefficients for leukemia adjusted for confirmation rates stratified on gender and city (1950-75).

Male Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	41.459	7.140	3.472	.000	.000	.000	.000
10-19	.000	11.434	5.560	2.341	.646	.000	.000
20-29	.000	18.091	8.797	3.704	1.022	.553	.000
30-39	.000	.000	34.977	14.727	4.062	2.198	1.565
40-49	.000	.000	.000	8.026	2.214	1.198	.853
50+	.000	.000	.000	.000	9.735	5.268	3.750

Male Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	6.515	2.583	.131	.000	.000	.000	.000
10-19	.000	3.725	1.160	1.453	.170	.000	.000
20-29	.000	10.933	6.743	2.670	.500	.648	.000
30-39	.000	.000	7.217	3.838	3.196	7.513	7.110
40-49	.000	.000	.000	5.100	3.191	.693	3.778
50+	.000	.000	.000	.000	3.360	4.984	4.461

Female Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	31.690	5.458	2.654	1.117	.000	.000	.000
10-19	50.749	8.740	4.250	1.789	.494	.000	.000
20-29	.000	13.828	6.724	2.831	.781	.423	.000
30-39	.000	.000	26.736	11.257	3.105	1.680	1.196
40-49	.000	.000	.000	6.135	1.692	.916	.652
50+	.000	.000	.000	.000	7.441	4.027	2.866

Female Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	5.251	.471	.664	.485	.000	.000	.000
10-19	.944	1.269	.416	.744	.137	.000	.000
20-29	.000	5.128	1.235	1.838	.223	.846	.000
30-39	.000	.000	.583	1.928	.965	2.017	1.193
40-49	.000	.000	.000	5.311	1.677	1.034	.955
50+	.000	.000	.000	.000	3.825	3.878	5.164

Goodness of fit	Value	d.f.	Prob
Chi-square	1083.3700	3022	1.0000
Deviance	533.4790	3022	1.0000
Freeman-Tukey	238.3740	3022	1.0000

Table C.7. Excess relative and absolute risk coefficients for leukemia adjusted for confirmation rates stratified on gender and city (1950-85).

Male Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	42.681	6.644	2.871	.000	.000	.000	.000
10-19	.000	12.493	5.399	2.558	.731	.000	.000
20-29	.000	20.181	8.721	4.132	1.181	.588	.000
30-39	.000	.000	33.041	15.655	4.476	2.227	1.260
40-49	.000	.000	.000	7.635	2.183	1.086	.614
50+	.000	.000	.000	.000	12.985	6.461	3.654

Male Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	6.563	2.483	.113	.000	.000	.000	.000
10-19	.000	3.852	1.128	1.498	.161	.000	.000
20-29	.000	11.386	6.663	2.883	.479	.580	.000
30-39	.000	.000	7.040	3.927	3.410	6.773	5.011
40-49	.000	.000	.000	4.958	3.168	.636	2.449
50+	.000	.000	.000	.000	3.693	5.618	4.010

Female Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	29.930	4.659	2.013	.954	.000	.000	.000
10-19	56.276	8.761	3.786	1.794	.513	.000	.000
20-29	.000	14.152	6.116	2.898	.828	.412	.000
30-39	.000	.000	23.170	10.978	3.139	1.562	.883
40-49	.000	.000	.000	5.354	1.531	.762	.431
50+	.000	.000	.000	.000	9.105	4.531	2.562

Female Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	5.192	.424	.476	.358	.000	.000	.000
10-19	.975	1.272	.388	.749	.137	.000	.000
20-29	.000	5.166	1.177	1.870	.252	.693	.000
30-39	.000	.000	.558	1.906	.975	1.777	1.156
40-49	.000	.000	.000	4.898	1.552	.877	.786
50+	.000	.000	.000	.000	4.218	4.199	5.125

Goodness of fit	Value	d.f.	Prob
Chi-square	1042.8900	3022	1.0000
Deviance	499.8330	3022	1.0000
Freeman-Tukey	230.1240	3022	1.0000

Table C.8. Excess relative and absolute risk coefficients for leukemia adjusted for confirmation rates stratified on age ATD (1950-75).

Male Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	33.289	6.549	3.106	.000	.000	.000	.000
10-19	40.978	8.061	3.823	1.817	.494	.000	.000
20-29	.000	13.984	6.632	3.152	.856	.587	.000
30-39	.000	.000	22.404	10.647	2.893	1.982	1.618
40-49	.000	.000	.000	5.597	1.521	1.042	.851
50+	.000	.000	.000	.000	6.919	4.741	3.870

Male Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	6.104	2.476	.149	.000	.000	.000	.000
10-19	1.369	3.402	1.072	1.257	.133	.000	.000
20-29	.000	10.763	6.031	2.612	.514	.684	.000
30-39	.000	.000	7.024	3.928	2.913	7.373	7.323
40-49	.000	.000	.000	4.798	2.680	.941	3.828
50+	.000	.000	.000	.000	4.417	6.433	5.534

Female Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	37.190	7.316	3.470	1.649	.000	.000	.000
10-19	45.780	9.006	4.271	2.030	.551	.000	.000
20-29	.000	15.623	7.409	3.521	.957	.656	.000
30-39	.000	.000	25.029	11.894	3.232	2.215	1.808
40-49	.000	.000	.000	6.253	1.699	1.164	.950
50+	.000	.000	.000	.000	7.729	5.296	4.323

Female Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	5.206	.463	.758	.665	.000	.000	.000
10-19	.685	1.359	.445	.854	.151	.000	.000
20-29	.000	5.173	1.373	2.206	.269	1.270	.000
30-39	.000	.000	.576	2.035	1.089	2.531	1.690
40-49	.000	.000	.000	5.734	1.739	1.355	1.244
50+	.000	.000	.000	.000	4.200	4.785	4.217

Goodness of fit	Value	d.f.	Prob
Chi-square	1046.1700	3022	1.0000
Deviance	520.0840	3022	1.0000
Freeman-Tukey	254.2180	3022	1.0000

Table C.9. Excess relative and absolute risk coefficients for leukemia adjusted for confirmation rates stratified on age ATD (1950-85).

Male Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	33.223	5.908	2.530	1.306	.000	.000	.000
10-19	47.458	8.439	3.614	1.866	.519	.000	.000
20-29	.000	14.771	6.326	3.266	.909	.573	.000
30-39	.000	.000	20.848	10.764	2.996	1.889	1.380
40-49	.000	.000	.000	5.276	1.469	.926	.677
50+	.000	.000	.000	.000	8.267	5.213	3.809

Male Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	6.112	2.336	.175	.071	.000	.000	.000
10-19	1.477	3.478	1.028	1.312	.189	.000	.000
20-29	.000	11.057	5.854	2.690	.529	.756	.000
30-39	.000	.000	6.821	3.956	2.995	7.288	5.850
40-49	.000	.000	.000	4.624	2.612	.848	2.888
50+	.000	.000	.000	.000	4.772	6.824	5.243

Female Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	36.990	6.577	2.817	1.454	.000	.000	.000
10-19	52.839	9.396	4.024	2.078	.578	.000	.000
20-29	.000	16.445	7.043	3.637	1.012	.638	.000
30-39	.000	.000	23.211	11.985	3.336	2.104	1.537
40-49	.000	.000	.000	5.875	1.635	1.031	.753
50+	.000	.000	.000	.000	9.204	5.805	4.240

Female Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	5.205	.433	.597	.530	.000	.000	.000
10-19	.720	1.383	.428	.852	.166	.000	.000
20-29	.000	5.249	1.339	2.254	.318	1.258	.000
30-39	.000	.000	.562	2.041	1.116	2.553	1.448
40-49	.000	.000	.000	5.531	1.690	1.221	.992
50+	.000	.000	.000	.000	4.554	5.048	4.169

Goodness of fit	Value	d.f.	Prob
Chi-square	1020.8000	3022	1.0000
Deviance	493.6020	3022	1.0000
Freeman-Tukey	244.6780	3022	1.0000

Table C.10. Excess relative and absolute risk coefficients for leukemia adjusted for confirmation rates stratified on DS86 shielded kerma (1950-75).

Male Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	28.757	5.338	2.713	.000	.000	.000	.000
10-19	60.045	11.146	5.664	2.235	.611	.000	.000
20-29	.000	14.540	7.388	2.915	.797	.550	.000
30-39	.000	.000	32.717	12.909	3.529	2.435	1.931
40-49	.000	.000	.000	8.052	2.201	1.519	1.204
50+	.000	.000	.000	.000	13.789	9.515	7.545

Male Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	5.662	2.275	.149	.000	.000	.000	.000
10-19	.080	3.976	1.483	1.537	.161	.000	.000
20-29	.000	8.993	6.213	2.413	.450	.645	.000
30-39	.000	.000	6.492	3.976	3.462	8.586	8.402
40-49	.000	.000	.000	5.738	3.459	1.291	5.312
50+	.000	.000	.000	.000	5.509	8.902	10.731

Female Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	34.360	6.378	3.241	1.279	.000	.000	.000
10-19	71.743	13.318	6.767	2.670	.730	.000	.000
20-29	.000	17.373	8.828	3.483	.952	.657	.000
30-39	.000	.000	39.091	15.424	4.216	2.909	2.307
40-49	.000	.000	.000	9.620	2.630	1.815	1.439
50+	.000	.000	.000	.000	16.476	11.369	9.015

Female Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	5.397	.463	.764	.537	.000	.000	.000
10-19	.320	1.274	.515	1.036	.194	.000	.000
20-29	.000	5.752	1.310	2.149	.271	1.273	.000
30-39	.000	.000	.313	2.222	1.014	3.074	2.045
40-49	.000	.000	.000	7.524	2.437	1.976	1.900
50+	.000	.000	.000	.000	5.996	6.056	8.473

Goodness of fit	Value	d.f.	Prob
Chi-square	952.8740	3022	1.0000
Deviance	536.0480	3022	1.0000
Freeman-Tukey	255.8280	3022	1.0000

Table C.11. Excess relative and absolute risk coefficients for leukemia adjusted for confirmation rates stratified on DS86 shielded kerma (1950-85).

Male Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	28.350	5.021	2.405	1.241	.000	.000	.000
10-19	64.886	11.492	5.505	2.840	.980	.000	.000
20-29	.000	14.949	7.161	3.694	1.275	.890	.000
30-39	.000	.000	21.023	10.844	3.742	2.613	2.577
40-49	.000	.000	.000	6.832	2.358	1.646	1.624
50+	.000	.000	.000	.000	13.061	9.121	8.995

Male Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	5.648	2.193	.157	.028	.000	.000	.000
10-19	.082	4.028	1.453	1.840	.332	.000	.000
20-29	.000	9.126	6.057	2.863	.643	.944	.000
30-39	.000	.000	5.688	3.746	3.619	9.281	9.743
40-49	.000	.000	.000	5.172	3.644	1.375	6.915
50+	.000	.000	.000	.000	5.422	8.587	11.753

Female Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	34.320	6.078	2.912	1.502	.000	.000	.000
10-19	78.549	13.912	6.664	3.437	1.186	.000	.000
20-29	.000	18.097	8.669	4.472	1.543	1.078	.000
30-39	.000	.000	25.450	13.128	4.530	3.164	3.120
40-49	.000	.000	.000	8.271	2.854	1.993	1.965
50+	.000	.000	.000	.000	15.811	11.042	10.889

Female Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	5.398	.448	.613	.574	.000	.000	.000
10-19	.329	1.292	.510	1.179	.283	.000	.000
20-29	.000	5.816	1.294	2.511	.423	1.886	.000
30-39	.000	.000	.283	2.087	1.069	3.243	3.338
40-49	.000	.000	.000	6.904	2.602	2.123	3.030
50+	.000	.000	.000	.000	5.922	5.980	9.847

Goodness of fit	Value	d.f.	Prob
Chi-square	888.3530	3022	1.0000
Deviance	506.2570	3022	1.0000
Freeman-Tukey	267.5660	3022	1.0000

Table C.12. Excess relative and absolute risk coefficients for leukemia. Organ dose equivalent adjusted for DS86 random error.

Male Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	41.963	7.069	3.465	.000	.000	.000	.000
10-19	.000	14.993	7.349	2.871	.727	.000	.000
20-29	.000	22.664	11.109	4.340	1.099	.499	.000
30-39	.000	.000	52.867	20.651	5.232	2.374	1.637
40-49	.000	.000	.000	8.222	2.083	.945	.652
50+	.000	.000	.000	.000	18.950	8.600	5.929

Male Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	8.231	3.142	.161	.000	.000	.000	.000
10-19	.000	5.229	1.653	1.978	.193	.000	.000
20-29	.000	14.873	9.430	3.633	.534	.603	.000
30-39	.000	.000	9.997	5.455	4.505	8.705	7.516
40-49	.000	.000	.000	6.403	3.715	.678	3.096
50+	.000	.000	.000	.000	5.226	7.975	6.875

Female Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	45.640	7.689	3.769	1.472	.000	.000	.000
10-19	.000	16.307	7.993	3.122	.791	.000	.000
20-29	.000	24.650	12.083	4.720	1.196	.543	.000
30-39	.000	.000	.000	22.461	5.690	2.583	1.780
40-49	.000	.000	.000	8.942	2.265	1.028	.709
50+	.000	.000	.000	.000	20.610	9.354	6.448

Female Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	7.027	.520	.849	.619	.000	.000	.000
10-19	.000	1.914	.578	1.320	.207	.000	.000
20-29	.000	7.315	1.859	3.131	.314	1.072	.000
30-39	.000	.000	.000	2.516	1.331	2.828	1.683
40-49	.000	.000	.000	7.926	2.308	1.096	.949
50+	.000	.000	.000	.000	5.691	5.761	5.074

Goodness of fit	Value	d.f.	Prob
Chi-square	1337.7300	3022	1.0000
Deviance	635.1690	3022	1.0000
Freeman-Tukey	251.6360	3022	1.0000

Table C.13. Excess relative and absolute risk coefficients for leukemia adjusted for confirmation rates not stratified, i.e., crude(1950-75). Organ dose equivalent adjusted for DS86 random error.

Male Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	40.233	7.416	3.769	.000	.000	.000	.000
10-19	67.672	12.474	6.339	2.526	.656	.000	.000
20-29	.000	19.568	9.943	3.963	1.029	.538	.000
30-39	.000	.000	41.624	16.588	4.309	2.252	1.670
40-49	.000	.000	.000	7.673	1.993	1.042	.772
50+	.000	.000	.000	.000	9.343	4.883	3.621

Male Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	7.063	2.810	.160	.000	.000	.000	.000
10-19	.600	4.341	1.410	1.636	.175	.000	.000
20-29	.000	12.662	7.901	3.074	.543	.646	.000
30-39	.000	.000	8.609	4.677	3.700	8.122	7.651
40-49	.000	.000	.000	5.645	3.284	.872	3.621
50+	.000	.000	.000	.000	4.355	6.133	6.441

Female Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	44.400	8.184	4.159	1.657	.000	.000	.000
10-19	74.682	13.767	6.995	2.788	.724	.000	.000
20-29	.000	21.595	10.973	4.373	1.136	.594	.000
30-39	.000	.000	45.936	18.306	4.755	2.485	1.843
40-49	.000	.000	.000	8.468	2.200	1.149	.852
50+	.000	.000	.000	.000	10.311	5.388	3.996

Female Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	6.038	.489	.875	.679	.000	.000	.000
10-19	.282	1.633	.519	1.124	.192	.000	.000
20-29	.000	6.208	1.632	2.631	.303	1.166	.000
30-39	.000	.000	.246	2.247	1.181	2.754	1.734
40-49	.000	.000	.000	6.868	2.075	1.189	1.157
50+	.000	.000	.000	.000	4.393	4.375	5.003

Goodness of fit	Value	d.f.	Prob
Chi-square	1139.4000	3022	1.0000
Deviance	537.3280	3022	1.0000
Freeman-Tukey	238.6100	3022	1.0000

Table C.14. Excess relative and absolute risk coefficients for leukemia adjusted for confirmation rates not stratified, i.e., crude (1950-85). Organ dose equivalent adjusted for DS86 random error.

Male Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	40.802	7.013	3.319	1.434	.000	.000	.000
10-19	76.404	13.132	6.215	2.686	.715	.000	.000
20-29	.000	20.692	9.794	4.232	1.126	.536	.000
30-39	.000	.000	40.074	17.318	4.608	2.192	1.310
40-49	.000	.000	.000	7.190	1.913	.910	.544
50+	.000	.000	.000	.000	12.022	5.719	3.417

Male Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	7.092	2.723	.166	.027	.000	.000	.000
10-19	.631	4.429	1.386	1.697	.202	.000	.000
20-29	.000	12.951	7.808	3.223	.554	.622	.000
30-39	.000	.000	8.465	4.752	3.877	7.415	5.759
40-49	.000	.000	.000	5.435	3.189	.774	2.580
50+	.000	.000	.000	.000	4.785	6.779	6.089

Female Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	43.320	7.446	3.524	1.523	.000	.000	.000
10-19	81.119	13.942	6.599	2.852	.759	.000	.000
20-29	.000	21.969	10.398	4.493	1.196	.569	.000
30-39	.000	.000	42.547	18.386	4.892	2.327	1.390
40-49	.000	.000	.000	7.634	2.031	.966	.577
50+	.000	.000	.000	.000	12.764	6.072	3.628

Female Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	6.016	.462	.714	.563	.000	.000	.000
10-19	.290	1.642	.504	1.100	.191	.000	.000
20-29	.000	6.234	1.596	2.677	.316	.995	.000
30-39	.000	.000	.243	2.248	1.205	2.447	1.440
40-49	.000	.000	.000	6.504	1.957	1.022	.891
50+	.000	.000	.000	.000	4.786	4.698	4.888

Goodness of fit	Value	d.f.	Prob
Chi-square	1105.0700	3022	1.0000
Deviance	504.1510	3022	1.0000
Freeman-Tukey	231.9940	3022	1.0000

Table C.15. Excess relative and absolute risk coefficients for leukemia adjusted for confirmation rates stratified on gender (1950-75). Organ dose equivalent adjusted for DS86 random error.

Male Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	43.722	7.900	4.030	.000	.000	.000	.000
10-19	.000	14.004	7.145	2.802	.711	.000	.000
20-29	.000	22.084	11.267	4.419	1.121	.568	.000
30-39	.000	.000	47.983	18.819	4.772	2.420	1.726
40-49	.000	.000	.000	8.934	2.266	1.149	.819
50+	.000	.000	.000	.000	13.038	6.612	4.715

Male Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	7.043	2.833	.151	.000	.000	.000	.000
10-19	.000	4.345	1.396	1.702	.189	.000	.000
20-29	.000	12.503	8.067	3.121	.543	.680	.000
30-39	.000	.000	8.374	4.521	3.605	8.399	7.848
40-49	.000	.000	.000	5.691	3.356	.684	3.705
50+	.000	.000	.000	.000	4.001	5.952	5.483

Female Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	42.050	7.598	3.876	1.520	.000	.000	.000
10-19	74.542	13.469	6.871	2.695	.683	.000	.000
20-29	.000	21.239	10.836	4.250	1.078	.547	.000
30-39	.000	.000	46.148	18.099	4.590	2.328	1.660
40-49	.000	.000	.000	8.592	2.179	1.105	.788
50+	.000	.000	.000	.000	12.539	6.359	4.535

Female Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	6.004	.471	.835	.635	.000	.000	.000
10-19	.283	1.627	.516	1.098	.182	.000	.000
20-29	.000	6.202	1.629	2.593	.290	1.080	.000
30-39	.000	.000	.246	2.246	1.159	2.621	1.590
40-49	.000	.000	.000	6.949	2.065	1.152	1.079
50+	.000	.000	.000	.000	4.768	4.837	5.470

Goodness of fit	Value	d.f.	Prob
Chi-square	1157.7300	3022	1.0000
Deviance	549.7620	3022	1.0000
Freeman-Tukey	222.2430	3022	1.0000

Table C.16. Excess relative and absolute risk coefficients for leukemia adjusted for confirmation rates stratified on gender (1950-85). Organ dose equivalent adjusted for DS86 random error.

Male Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	45.773	7.970	3.735	.000	.000	.000	.000
10-19	.000	15.067	7.060	3.227	.860	.000	.000
20-29	.000	24.329	11.401	5.211	1.389	.661	.000
30-39	.000	.000	42.169	19.273	5.138	2.444	1.341
40-49	.000	.000	.000	8.712	2.323	1.105	.606
50+	.000	.000	.000	.000	15.606	7.424	4.074

Male Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	7.109	2.842	.141	.000	.000	.000	.000
10-19	.000	4.459	1.374	1.812	.191	.000	.000
20-29	.000	12.917	8.024	3.481	.554	.663	.000
30-39	.000	.000	8.039	4.575	3.791	7.586	5.404
40-49	.000	.000	.000	5.600	3.424	.659	2.463
50+	.000	.000	.000	.000	4.223	6.391	4.539

Female Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	35.470	6.176	2.894	1.323	.000	.000	.000
10-19	67.053	11.675	5.471	2.500	.667	.000	.000
20-29	.000	18.853	8.835	4.038	1.076	.512	.000
30-39	.000	.000	32.678	14.935	3.982	1.894	1.039
40-49	.000	.000	.000	6.751	1.800	.856	.470
50+	.000	.000	.000	.000	12.094	5.753	3.157

Female Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	5.889	.442	.641	.522	.000	.000	.000
10-19	.577	1.633	.509	1.044	.189	.000	.000
20-29	.000	6.169	1.592	2.594	.336	.945	.000
30-39	.000	.000	.473	2.324	1.216	2.281	1.348
40-49	.000	.000	.000	6.370	1.921	1.049	.930
50+	.000	.000	.000	.000	5.339	5.358	6.267

Goodness of fit	Value	d.f.	Prob
Chi-square	1113.3900	3022	1.0000
Deviance	511.5560	3022	1.0000
Freeman-Tukey	261.6730	3022	1.0000

Table C.17. Excess relative and absolute risk coefficients for leukemia adjusted for confirmation rates stratified on gender and city (1950-75). Organ dose equivalent adjusted for DS86 random error.

Male Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	46.374	8.075	4.173	.000	.000	.000	.000
10-19	.000	13.968	7.219	2.909	.802	.000	.000
20-29	.000	20.704	10.701	4.312	1.189	.637	.000
30-39	.000	.000	41.710	16.806	4.635	2.481	1.673
40-49	.000	.000	.000	9.141	2.521	1.350	.910
50+	.000	.000	.000	.000	11.551	6.183	4.169

Male Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	7.142	2.851	.154	.000	.000	.000	.000
10-19	.000	4.326	1.398	1.737	.211	.000	.000
20-29	.000	12.225	7.865	3.080	.571	.754	.000
30-39	.000	.000	8.122	4.346	3.536	8.570	7.650
40-49	.000	.000	.000	5.741	3.617	.781	4.068
50+	.000	.000	.000	.000	3.824	5.739	5.035

Female Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	34.310	5.974	3.088	1.244	.000	.000	.000
10-19	59.349	10.334	5.341	2.152	.594	.000	.000
20-29	.000	15.318	7.917	3.190	.880	.471	.000
30-39	.000	.000	30.859	12.434	3.430	1.836	1.238
40-49	.000	.000	.000	6.763	1.865	.998	.673
50+	.000	.000	.000	.000	8.546	4.574	3.085

Female Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	5.738	.516	.753	.543	.000	.000	.000
10-19	1.014	1.443	.483	.888	.160	.000	.000
20-29	.000	5.716	1.411	2.057	.253	.941	.000
30-39	.000	.000	.644	2.135	1.058	2.205	1.239
40-49	.000	.000	.000	5.800	1.854	1.136	.985
50+	.000	.000	.000	.000	4.264	4.325	5.592

Goodness of fit	Value	d.f.	Prob
Chi-square	1148.6400	3022	1.0000
Deviance	535.9970	3022	1.0000
Freeman-Tukey	242.9840	3022	1.0000

Table C.18. Excess relative and absolute risk coefficients for leukemia adjusted for confirmation rates stratified on gender and city (1950-85). Organ dose equivalent adjusted for DS86 random error.

Male Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	47.718	7.481	3.429	.000	.000	.000	.000
10-19	.000	15.319	7.022	3.181	.908	.000	.000
20-29	.000	23.181	10.626	4.813	1.373	.669	.000
30-39	.000	.000	39.619	17.945	5.121	2.495	1.320
40-49	.000	.000	.000	8.674	2.475	1.206	.638
50+	.000	.000	.000	.000	15.679	7.639	4.040

Male Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	7.194	2.735	.133	.000	.000	.000	.000
10-19	.000	4.474	1.361	1.788	.199	.000	.000
20-29	.000	12.747	7.774	3.321	.546	.667	.000
30-39	.000	.000	7.930	4.451	3.781	7.680	5.299
40-49	.000	.000	.000	5.572	3.578	.708	2.568
50+	.000	.000	.000	.000	4.210	6.472	4.505

Female Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	32.350	5.071	2.325	1.053	.000	.000	.000
10-19	66.249	10.386	4.761	2.156	.615	.000	.000
20-29	.000	15.715	7.204	3.263	.931	.454	.000
30-39	.000	.000	26.859	12.166	3.472	1.691	.895
40-49	.000	.000	.000	5.880	1.678	.818	.432
50+	.000	.000	.000	.000	10.629	5.179	2.739

Female Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	5.671	.463	.539	.397	.000	.000	.000
10-19	1.047	1.447	.452	.893	.162	.000	.000
20-29	.000	5.761	1.345	2.090	.284	.763	.000
30-39	.000	.000	.618	2.113	1.070	1.930	1.183
40-49	.000	.000	.000	5.335	1.707	.948	.792
50+	.000	.000	.000	.000	4.725	4.695	5.515

Goodness of fit	Value	d.f.	Prob
Chi-square	1108.8200	3022	1.0000
Deviance	502.1960	3022	1.0000
Freeman-Tukey	245.1860	3022	1.0000

Table C.19. Excess relative and absolute risk coefficients for leukemia adjusted for confirmation rates stratified on age ATD (1950-75). Organ dose equivalent adjusted for DS86 random error.

Male Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	37.054	7.421	3.752	.000	.000	.000	.000
10-19	49.125	9.839	4.975	2.253	.612	.000	.000
20-29	.000	16.011	8.095	3.667	.996	.684	.000
30-39	.000	.000	26.692	12.090	3.285	2.255	1.769
40-49	.000	.000	.000	6.381	1.734	1.190	.934
50+	.000	.000	.000	.000	8.064	5.537	4.342

Male Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	6.691	2.741	.176	.000	.000	.000	.000
10-19	1.519	3.971	1.308	1.508	.165	.000	.000
20-29	.000	12.061	7.074	3.016	.587	.804	.000
30-39	.000	.000	7.937	4.446	3.226	8.457	8.021
40-49	.000	.000	.000	5.418	3.044	1.073	4.225
50+	.000	.000	.000	.000	5.025	7.401	6.259

Female Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	40.330	8.078	4.084	1.850	.000	.000	.000
10-19	53.469	10.709	5.415	2.452	.666	.000	.000
20-29	.000	17.427	8.811	3.991	1.084	.745	.000
30-39	.000	.000	29.052	13.159	3.575	2.455	1.925
40-49	.000	.000	.000	6.946	1.887	1.296	1.016
50+	.000	.000	.000	.000	8.777	6.026	4.726

Female Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	5.689	.509	.863	.748	.000	.000	.000
10-19	.745	1.547	.516	1.019	.178	.000	.000
20-29	.000	5.770	1.569	2.474	.306	1.437	.000
30-39	.000	.000	.637	2.249	1.198	2.795	1.800
40-49	.000	.000	.000	6.282	1.930	1.508	1.324
50+	.000	.000	.000	.000	4.642	5.315	4.583

Goodness of fit	Value	d.f.	Prob
Chi-square	1104.7200	3022	1.0000
Deviance	522.4780	3022	1.0000
Freeman-Tukey	252.4250	3022	1.0000

Table C.20. Excess relative and absolute risk coefficients for leukemia adjusted for confirmation rates stratified on age ATD (1950-85). Organ dose equivalent adjusted for DS86 random error.

Male Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	36.962	6.672	3.034	1.496	.000	.000	.000
10-19	57.282	10.340	4.702	2.319	.646	.000	.000
20-29	.000	16.971	7.717	3.806	1.060	.669	.000
30-39	.000	.000	24.801	12.230	3.407	2.149	1.499
40-49	.000	.000	.000	6.013	1.675	1.056	.737
50+	.000	.000	.000	.000	9.688	6.110	4.263

Male Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	6.700	2.583	.206	.081	.000	.000	.000
10-19	1.636	4.063	1.257	1.576	.234	.000	.000
20-29	.000	12.408	6.872	3.108	.609	.888	.000
30-39	.000	.000	7.709	4.477	3.320	8.351	6.358
40-49	.000	.000	.000	5.217	2.967	.965	3.163
50+	.000	.000	.000	.000	5.431	7.853	5.918

Female Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	40.040	7.227	3.287	1.621	.000	.000	.000
10-19	62.052	11.201	5.094	2.512	.700	.000	.000
20-29	.000	18.384	8.360	4.123	1.149	.724	.000
30-39	.000	.000	26.866	13.248	3.691	2.328	1.624
40-49	.000	.000	.000	6.514	1.815	1.144	.798
50+	.000	.000	.000	.000	10.495	6.619	4.618

Female Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	5.686	.476	.678	.592	.000	.000	.000
10-19	.782	1.574	.498	1.015	.196	.000	.000
20-29	.000	5.858	1.532	2.527	.361	1.424	.000
30-39	.000	.000	.623	2.254	1.227	2.817	1.525
40-49	.000	.000	.000	6.049	1.873	1.354	1.047
50+	.000	.000	.000	.000	5.032	5.606	4.523

Goodness of fit	Value	d.f.	Prob
Chi-square	1080.0500	3022	1.0000
Deviance	495.9100	3022	1.0000
Freeman-Tukey	243.6370	3022	1.0000

Table C.21. Excess relative and absolute risk coefficients for leukemia adjusted for confirmation rates stratified on DS86 shielded kerma (1950-75). Organ dose equivalent adjusted for DS86 random error.

Male Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	32.038	6.031	3.270	.000	.000	.000	.000
10-19	73.152	13.771	7.467	2.786	.764	.000	.000
20-29	.000	16.793	9.106	3.397	.931	.645	.000
30-39	.000	.000	39.249	14.643	4.015	2.779	2.147
40-49	.000	.000	.000	9.253	2.537	1.756	1.357
50+	.000	.000	.000	.000	15.974	11.056	8.541

Male Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	6.211	2.517	.177	.000	.000	.000	.000
10-19	.088	4.632	1.799	1.841	.201	.000	.000
20-29	.000	10.081	7.300	2.788	.517	.762	.000
30-39	.000	.000	7.333	4.489	3.831	9.869	9.322
40-49	.000	.000	.000	6.488	3.947	1.486	5.987
50+	.000	.000	.000	.000	6.210	10.105	12.109

Female Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	37.350	7.031	3.813	1.422	.000	.000	.000
10-19	85.279	16.054	8.705	3.248	.890	.000	.000
20-29	.000	19.577	10.616	3.960	1.086	.752	.000
30-39	.000	.000	45.756	17.070	4.680	3.239	2.503
40-49	.000	.000	.000	10.787	2.957	2.047	1.581
50+	.000	.000	.000	.000	18.622	12.888	9.958

Female Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	5.899	.509	.871	.599	.000	.000	.000
10-19	.349	1.447	.593	1.237	.230	.000	.000
20-29	.000	6.435	1.499	2.417	.307	1.449	.000
30-39	.000	.000	.345	2.452	1.114	3.405	2.212
40-49	.000	.000	.000	8.254	2.723	2.219	2.069
50+	.000	.000	.000	.000	6.556	6.647	9.205

Goodness of fit	Value	d.f.	Prob
Chi-square	991.1560	3022	1.0000
Deviance	537.1580	3022	1.0000
Freeman-Tukey	269.2380	3022	1.0000

Table C.22. Excess relative and absolute risk coefficients for leukemia adjusted for confirmation rates stratified on DS86 shielded kerma (1950-85). Organ dose equivalent adjusted for DS86 random error.

Male Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	31.560	5.674	2.903	1.419	.000	.000	.000
10-19	78.799	14.167	7.249	3.543	1.227	.000	.000
20-29	.000	17.252	8.828	4.314	1.495	1.055	.000
30-39	.000	.000	25.051	12.242	4.241	2.995	2.903
40-49	.000	.000	.000	7.845	2.718	1.919	1.861
50+	.000	.000	.000	.000	14.849	10.485	10.164

Male Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	6.194	2.428	.187	.031	.000	.000	.000
10-19	.091	4.686	1.764	2.198	.412	.000	.000
20-29	.000	10.228	7.123	3.307	.741	1.126	.000
30-39	.000	.000	6.437	4.227	3.998	10.703	10.866
40-49	.000	.000	.000	5.853	4.162	1.594	7.898
50+	.000	.000	.000	.000	6.080	9.715	13.194

Female Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	37.360	6.717	3.437	1.680	.000	.000	.000
10-19	93.280	16.770	8.581	4.194	1.453	.000	.000
20-29	.000	20.422	10.450	5.107	1.769	1.249	.000
30-39	.000	.000	29.654	14.492	5.021	3.545	3.437
40-49	.000	.000	.000	9.287	3.217	2.272	2.203
50+	.000	.000	.000	.000	17.577	12.411	12.032

Female Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	5.901	.494	.702	.643	.000	.000	.000
10-19	.358	1.467	.588	1.400	.336	.000	.000
20-29	.000	6.508	1.485	2.827	.480	2.174	.000
30-39	.000	.000	.313	2.301	1.174	3.612	3.668
40-49	.000	.000	.000	7.586	2.915	2.403	3.354
50+	.000	.000	.000	.000	6.446	6.543	10.657

Goodness of fit	Value	d.f.	Prob
Chi-square	920.6160	3022	1.0000
Deviance	507.0910	3022	1.0000
Freeman-Tukey	277.7080	3022	1.0000

Table C.23. Excess relative and absolute risk coefficients for nonleukemia.

Male Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	2.660	1.930	.627	.959	.000	.000	.000
10-19	.000	1.292	.420	.642	.513	.000	.000
20-29	.000	.000	.419	.640	.512	.370	.000
30-39	.000	.000	.151	.230	.184	.133	.310
40-49	.000	.000	.000	.227	.182	.131	.306
50+	.000	.000	.000	.000	.087	.063	.147

Male Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	.108	1.441	1.341	5.335	.000	.000	.000
10-19	.000	.517	.912	7.701	15.690	.000	.000
20-29	.000	.000	1.426	7.394	15.981	26.584	.000
30-39	.000	.000	.738	1.923	6.320	12.224	47.012
40-49	.000	.000	.000	4.636	7.144	11.508	54.139
50+	.000	.000	.000	.000	3.298	6.000	20.997

Female Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	5.380	3.902	1.268	1.940	.000	.000	.000
10-19	3.602	2.612	.849	1.299	1.038	.000	.000
20-29	.000	2.605	.847	1.295	1.035	.749	.000
30-39	.000	.000	.305	.466	.373	.269	.627
40-49	.000	.000	.000	.460	.367	.266	.619
50+	.000	.000	.000	.000	.177	.128	.297

Female Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	.591	2.681	4.985	10.782	.000	.000	.000
10-19	1.791	2.432	3.082	10.686	14.953	.000	.000
20-29	.000	3.290	3.595	14.294	21.768	24.194	.000
30-39	.000	.000	2.376	6.947	9.548	11.015	43.589
40-49	.000	.000	.000	7.283	9.457	12.345	52.494
50+	.000	.000	.000	.000	4.351	6.837	25.983

Goodness of fit	Value	d.f.	Prob
Chi-square	4636.2000	3022	.0000
Deviance	2159.1900	3022	1.0000
Freeman-Tukey	1909.5400	3022	1.0000

Table C.24. Excess relative and absolute risk coefficients for nonleukemia adjusted for confirmation rates not stratified, i.e., crude(1950-75).

Male Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	1.026	.319	.331	.716	.000	.000	.000
10-19	.663	.206	.214	.463	.453	.000	.000
20-29	.000	.170	.176	.381	.373	.396	.000
30-39	.000	.000	.073	.158	.154	.164	.317
40-49	.000	.000	.000	.114	.111	.118	.228
50+	.000	.000	.000	.000	.033	.035	.067

Male Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	2.615	.980	1.003	4.085	.000	.000	.000
10-19	4.934	1.468	1.394	6.874	13.991	.000	.000
20-29	.000	3.100	2.078	6.602	12.937	28.428	.000
30-39	.000	.000	1.082	2.657	6.580	15.406	47.950
40-49	.000	.000	.000	3.676	5.739	12.264	43.009
50+	.000	.000	.000	.000	2.135	4.662	17.512

Female Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	2.350	.732	.759	1.640	.000	.000	.000
10-19	1.518	.473	.491	1.060	1.036	.000	.000
20-29	.000	.389	.404	.873	.853	.907	.000
30-39	.000	.000	.167	.361	.353	.376	.726
40-49	.000	.000	.000	.260	.254	.271	.523
50+	.000	.000	.000	.000	.075	.080	.154

Female Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	3.220	1.333	3.296	9.393	.000	.000	.000
10-19	8.230	2.204	2.477	9.065	14.959	.000	.000
20-29	.000	2.648	2.876	9.757	17.998	28.879	.000
30-39	.000	.000	1.904	5.660	8.734	15.610	49.858
40-49	.000	.000	.000	5.658	8.123	15.682	49.755
50+	.000	.000	.000	.000	2.989	6.006	28.837

Goodness of fit	Value	d.f.	Prob
Chi-square	1998.6200	3022	1.0000
Deviance	1480.4500	3022	1.0000
Freeman-Tukey	1746.1600	3022	1.0000

Table C.25. Excess relative and absolute risk coefficients for nonleukemia adjusted for confirmation rates not stratified, i.e., crude (1950-85).

Male Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	1.135	.385	.372	.713	.000	.000	.000
10-19	.628	.213	.206	.394	.374	.000	.000
20-29	.000	.193	.187	.358	.340	.318	.000
30-39	.000	.000	.093	.179	.170	.159	.211
40-49	.000	.000	.000	.126	.119	.111	.148
50+	.000	.000	.000	.000	.052	.048	.064

Male Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	2.861	1.171	1.597	5.601	.000	.000	.000
10-19	4.671	1.511	1.342	5.897	10.848	.000	.000
20-29	.000	3.517	2.200	6.225	12.175	21.297	.000
30-39	.000	.000	1.380	3.004	7.233	15.373	33.535
40-49	.000	.000	.000	4.055	6.154	11.577	36.009
50+	.000	.000	.000	.000	3.371	6.475	17.803

Female Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	2.336	.792	.766	1.467	.000	.000	.000
10-19	1.292	.438	.424	.811	.771	.000	.000
20-29	.000	.398	.385	.737	.700	.654	.000
30-39	.000	.000	.192	.368	.350	.327	.434
40-49	.000	.000	.000	.258	.245	.229	.304
50+	.000	.000	.000	.000	.107	.100	.132

Female Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	3.204	1.436	3.074	7.404	.000	.000	.000
10-19	7.090	2.054	2.158	6.845	10.181	.000	.000
20-29	.000	2.703	2.749	8.376	14.173	20.270	.000
30-39	.000	.000	2.183	5.763	8.650	14.813	37.436
40-49	.000	.000	.000	5.621	7.844	13.377	41.644
50+	.000	.000	.000	.000	4.236	7.493	28.656

Goodness of fit	Value	d.f.	Prob
Chi-square	1625.7000	3022	1.0000
Deviance	1141.8700	3022	1.0000
Freeman-Tukey	1604.5900	3022	1.0000

Table C.26. Excess relative and absolute risk coefficients for nonleukemia adjusted for confirmation rates stratified on gender (1950-75).

Male Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	1.054	.331	.330	.725	.000	.000	.000
10-19	.680	.214	.213	.468	.453	.000	.000
20-29	.000	.176	.176	.386	.374	.394	.000
30-39	.000	.000	.074	.162	.157	.165	.317
40-49	.000	.000	.000	.117	.113	.119	.229
50+	.000	.000	.000	.000	.033	.035	.067

Male Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	2.750	1.044	1.017	4.133	.000	.000	.000
10-19	5.192	1.559	1.430	7.069	14.011	.000	.000
20-29	.000	3.298	2.133	6.925	13.212	28.283	.000
30-39	.000	.000	1.124	2.812	6.926	15.738	47.978
40-49	.000	.000	.000	3.913	6.061	12.856	43.685
50+	.000	.000	.000	.000	2.222	4.818	17.920

Female Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	2.414	.758	.756	1.661	.000	.000	.000
10-19	1.558	.489	.488	1.072	1.039	.000	.000
20-29	.000	.404	.402	.884	.856	.903	.000
30-39	.000	.000	.169	.370	.359	.378	.727
40-49	.000	.000	.000	.268	.259	.273	.525
50+	.000	.000	.000	.000	.076	.080	.153

Female Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	3.096	1.308	3.238	9.495	.000	.000	.000
10-19	7.926	2.150	2.352	8.992	14.984	.000	.000
20-29	.000	2.587	2.728	9.485	17.894	28.749	.000
30-39	.000	.000	1.829	5.558	8.512	15.466	49.901
40-49	.000	.000	.000	5.552	7.908	15.135	49.234
50+	.000	.000	.000	.000	2.863	5.715	27.234

Goodness of fit	Value	d.f.	Prob
Chi-square	2013.9200	3022	1.0000
Deviance	1482.2600	3022	1.0000
Freeman-Tukey	1750.8700	3022	1.0000

Table C.27. Excess relative and absolute risk coefficients for nonleukemia adjusted for confirmation rates stratified on gender (1950-85).

Male Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	1.162	.398	.370	.715	.000	.000	.000
10-19	.639	.219	.204	.393	.374	.000	.000
20-29	.000	.200	.186	.360	.343	.318	.000
30-39	.000	.000	.094	.182	.173	.160	.212
40-49	.000	.000	.000	.127	.121	.112	.148
50+	.000	.000	.000	.000	.052	.048	.064

Male Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	2.999	1.246	1.641	5.820	.000	.000	.000
10-19	4.882	1.596	1.370	6.108	11.295	.000	.000
20-29	.000	3.741	2.262	6.485	12.744	22.162	.000
30-39	.000	.000	1.433	3.151	7.634	16.119	35.115
40-49	.000	.000	.000	4.244	6.465	12.072	37.439
50+	.000	.000	.000	.000	3.518	6.712	18.382

Female Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	2.396	.820	.763	1.475	.000	.000	.000
10-19	1.318	.451	.420	.811	.772	.000	.000
20-29	.000	.413	.385	.743	.707	.655	.000
30-39	.000	.000	.194	.374	.356	.330	.438
40-49	.000	.000	.000	.262	.249	.231	.306
50+	.000	.000	.000	.000	.108	.100	.133

Female Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	3.076	1.407	2.943	7.160	.000	.000	.000
10-19	6.798	1.995	2.044	6.575	9.818	.000	.000
20-29	.000	2.645	2.616	8.105	13.756	19.508	.000
30-39	.000	.000	2.099	5.620	8.467	14.339	36.116
40-49	.000	.000	.000	5.434	7.611	12.868	39.856
50+	.000	.000	.000	.000	4.078	7.165	27.178

Goodness of fit	Value	d.f.	Prob
Chi-square	1645.2500	3022	1.0000
Deviance	1145.5800	3022	1.0000
Freeman-Tukey	1594.7300	3022	1.0000

Table C.28. Excess relative and absolute risk coefficients for nonleukemia adjusted for confirmation rates stratified on gender and city (1950-75).

Male Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	1.065	.336	.323	.726	.000	.000	.000
10-19	.691	.218	.210	.471	.452	.000	.000
20-29	.000	.179	.173	.387	.372	.397	.000
30-39	.000	.000	.072	.161	.155	.165	.318
40-49	.000	.000	.000	.116	.112	.119	.229
50+	.000	.000	.000	.000	.032	.034	.066

Male Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	2.784	1.063	.999	4.135	.000	.000	.000
10-19	5.394	1.594	1.410	7.104	13.972	.000	.000
20-29	.000	3.367	2.093	6.942	13.147	28.448	.000
30-39	.000	.000	1.094	2.800	6.836	15.725	48.059
40-49	.000	.000	.000	3.884	5.973	12.808	43.697
50+	.000	.000	.000	.000	2.178	4.774	17.776

Female Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	2.448	.773	.743	1.669	.000	.000	.000
10-19	1.588	.501	.482	1.082	1.039	.000	.000
20-29	.000	.412	.397	.890	.855	.912	.000
30-39	.000	.000	.165	.370	.356	.379	.731
40-49	.000	.000	.000	.267	.257	.274	.527
50+	.000	.000	.000	.000	.074	.079	.153

Female Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	3.021	1.305	3.179	9.530	.000	.000	.000
10-19	7.519	2.173	2.329	9.064	14.991	.000	.000
20-29	.000	2.620	2.672	9.514	17.867	29.003	.000
30-39	.000	.000	1.769	5.533	8.407	15.508	50.152
40-49	.000	.000	.000	5.529	7.830	15.122	49.401
50+	.000	.000	.000	.000	2.823	5.672	27.152

Goodness of fit	Value	d.f.	Prob
Chi-square	2024.1000	3022	1.0000
Deviance	1483.0000	3022	1.0000
Freeman-Tukey	1748.2500	3022	1.0000

Table C.29. Excess relative and absolute risk coefficients for nonleukemia adjusted for confirmation rates stratified on gender and city (1950-85).

Male Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	1.173	.408	.372	.723	.000	.000	.000
10-19	.639	.222	.203	.394	.372	.000	.000
20-29	.000	.202	.184	.357	.338	.319	.000
30-39	.000	.000	.093	.181	.171	.161	.212
40-49	.000	.000	.000	.125	.119	.112	.147
50+	.000	.000	.000	.000	.051	.049	.064

Male Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	3.034	1.280	1.656	5.907	.000	.000	.000
10-19	5.000	1.625	1.368	6.125	11.228	.000	.000
20-29	.000	3.776	2.231	6.429	12.553	22.267	.000
30-39	.000	.000	1.415	3.134	7.531	16.213	35.141
40-49	.000	.000	.000	4.186	6.337	12.070	37.149
50+	.000	.000	.000	.000	3.455	6.724	18.244

Female Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	2.431	.846	.771	1.498	.000	.000	.000
10-19	1.325	.461	.420	.817	.772	.000	.000
20-29	.000	.418	.381	.741	.700	.662	.000
30-39	.000	.000	.193	.375	.354	.335	.440
40-49	.000	.000	.000	.260	.246	.232	.306
50+	.000	.000	.000	.000	.107	.101	.133

Female Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	3.003	1.419	2.956	7.280	.000	.000	.000
10-19	6.370	2.012	2.050	6.613	9.806	.000	.000
20-29	.000	2.654	2.576	8.056	13.663	19.599	.000
30-39	.000	.000	2.063	5.594	8.369	14.510	36.187
40-49	.000	.000	.000	5.384	7.505	12.919	39.814
50+	.000	.000	.000	.000	4.033	7.198	27.148

Goodness of fit	Value	d.f.	Prob
Chi-square	1658.0000	3022	1.0000
Deviance	1148.4900	3022	1.0000
Freeman-Tukey	1594.3500	3022	1.0000

Table C.30. Excess relative and absolute risk coefficients for nonleukemia adjusted for confirmation rates stratified on age ATD (1950-75).

Male Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	1.294	.863	.521	.914	.000	.000	.000
10-19	.793	.529	.319	.560	.486	.000	.000
20-29	.000	.490	.296	.519	.450	.389	.000
30-39	.000	.000	.113	.198	.171	.148	.313
40-49	.000	.000	.000	.167	.145	.125	.265
50+	.000	.000	.000	.000	.054	.047	.099

Male Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	1.200	1.403	1.307	5.110	.000	.000	.000
10-19	2.085	1.461	1.230	7.460	14.929	.000	.000
20-29	.000	3.123	1.953	7.491	15.356	27.871	.000
30-39	.000	.000	.988	2.370	7.103	14.217	47.387
40-49	.000	.000	.000	4.355	7.081	13.031	49.802
50+	.000	.000	.000	.000	2.954	5.820	21.703

Female Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	2.767	1.844	1.114	1.954	.000	.000	.000
10-19	1.696	1.130	.682	1.198	1.039	.000	.000
20-29	.000	1.047	.632	1.110	.963	.831	.000
30-39	.000	.000	.241	.422	.366	.316	.669
40-49	.000	.000	.000	.357	.310	.268	.566
50+	.000	.000	.000	.000	.116	.101	.213

Female Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	1.577	2.130	4.606	10.859	.000	.000	.000
10-19	3.876	2.623	2.984	10.268	14.976	.000	.000
20-29	.000	3.460	3.508	13.098	20.734	26.632	.000
30-39	.000	.000	2.303	6.815	10.147	13.476	46.261
40-49	.000	.000	.000	6.790	9.654	15.179	52.357
50+	.000	.000	.000	.000	3.978	6.999	31.444

Goodness of fit	Value	d.f.	Prob
Chi-square	3098.7800	3022	.1616
Deviance	1756.9900	3022	1.0000
Freeman-Tukey	1864.1500	3022	1.0000

Table C.31. Excess relative and absolute risk coefficients for nonleukemia adjusted for confirmation rates stratified on age ATD (1950-85).

Male Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	1.325	.887	.523	.891	.000	.000	.000
10-19	.799	.535	.315	.537	.455	.000	.000
20-29	.000	.508	.300	.510	.433	.349	.000
30-39	.000	.000	.123	.210	.178	.143	.256
40-49	.000	.000	.000	.175	.149	.120	.214
50+	.000	.000	.000	.000	.063	.051	.091

Male Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	1.224	1.439	1.591	5.972	.000	.000	.000
10-19	2.099	1.477	1.217	7.411	14.903	.000	.000
20-29	.000	3.235	1.980	7.377	15.761	26.575	.000
30-39	.000	.000	1.079	2.511	7.359	14.759	43.917
40-49	.000	.000	.000	4.567	7.260	12.482	49.575
50+	.000	.000	.000	.000	3.431	6.314	20.883

Female Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	2.753	1.843	1.088	1.851	.000	.000	.000
10-19	1.660	1.111	.656	1.116	.946	.000	.000
20-29	.000	1.056	.623	1.061	.899	.724	.000
30-39	.000	.000	.256	.436	.369	.297	.532
40-49	.000	.000	.000	.365	.309	.249	.445
50+	.000	.000	.000	.000	.132	.106	.190

Female Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	1.570	2.130	4.575	10.506	.000	.000	.000
10-19	3.805	2.585	2.877	9.835	14.424	.000	.000
20-29	.000	3.486	3.462	12.593	20.477	25.095	.000
30-39	.000	.000	2.444	7.019	10.221	13.988	45.530
40-49	.000	.000	.000	6.924	9.625	14.164	53.982
50+	.000	.000	.000	.000	4.488	7.379	31.255

Goodness of fit	Value	d.f.	Prob
Chi-square	2929.7400	3022	.8831
Deviance	1582.8300	3022	1.0000
Freeman-Tukey	1806.5000	3022	1.0000

Table C.32. Excess relative and absolute risk coefficients for nonleukemia adjusted for confirmation rates stratified on DS86 shielded kerma (1950-75)

Male Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	1.793	.885	.591	.929	.000	.000	.000
10-19	1.130	.558	.373	.585	.523	.000	.000
20-29	.000	.538	.360	.565	.505	.400	.000
30-39	.000	.000	.166	.261	.233	.185	.316
40-49	.000	.000	.000	.247	.221	.175	.300
50+	.000	.000	.000	.000	.145	.115	.197

Male Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	2.209	1.695	1.558	5.178	.000	.000	.000
10-19	4.071	2.087	1.670	8.096	15.973	.000	.000
20-29	.000	4.811	2.790	8.720	17.209	28.642	.000
30-39	.000	.000	1.703	3.477	9.692	17.718	47.819
40-49	.000	.000	.000	6.917	10.844	18.229	55.958
50+	.000	.000	.000	.000	7.955	14.135	41.638

Female Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	3.559	1.757	1.174	1.843	.000	.000	.000
10-19	2.243	1.107	.740	1.162	1.038	.000	.000
20-29	.000	1.068	.714	1.121	1.002	.795	.000
30-39	.000	.000	.329	.517	.462	.367	.628
40-49	.000	.000	.000	.491	.439	.348	.596
50+	.000	.000	.000	.000	.288	.228	.391

Female Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	2.501	2.298	4.898	10.334	.000	.000	.000
10-19	6.310	3.133	3.470	10.195	14.967	.000	.000
20-29	.000	4.174	4.305	13.656	21.476	25.555	.000
30-39	.000	.000	3.368	8.537	12.632	15.551	43.516
40-49	.000	.000	.000	9.810	13.540	19.563	54.643
50+	.000	.000	.000	.000	9.879	15.676	55.178

Goodness of fit	Value	d.f.	Prob
Chi-square	2787.9100	3022	.9990
Deviance	1758.5000	3022	1.0000
Freeman-Tukey	1861.5000	3022	1.0000

Table C.33. Excess relative and absolute risk coefficients for nonleukemia adjusted for confirmation rates stratified on DS86 shielded kerma (1950-85)

Male Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	1.851	.935	.628	.956	.000	.000	.000
10-19	1.110	.561	.377	.573	.514	.000	.000
20-29	.000	.554	.372	.566	.507	.407	.000
30-39	.000	.000	.181	.275	.247	.198	.322
40-49	.000	.000	.000	.254	.228	.183	.298
50+	.000	.000	.000	.000	.151	.122	.198

Male Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	2.268	1.783	2.104	6.855	.000	.000	.000
10-19	4.001	2.099	1.687	8.354	16.804	.000	.000
20-29	.000	4.941	2.881	8.738	18.473	31.026	.000
30-39	.000	.000	1.852	3.664	10.253	20.363	54.793
40-49	.000	.000	.000	7.113	11.192	19.039	67.384
50+	.000	.000	.000	.000	8.291	14.911	43.730

Female Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	3.549	1.793	1.204	1.833	.000	.000	.000
10-19	2.128	1.075	.722	1.099	.986	.000	.000
20-29	.000	1.061	.713	1.085	.973	.781	.000
30-39	.000	.000	.346	.527	.473	.380	.618
40-49	.000	.000	.000	.488	.437	.351	.572
50+	.000	.000	.000	.000	.290	.233	.379

Female Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	2.495	2.339	5.154	10.682	.000	.000	.000
10-19	6.030	3.056	3.396	10.063	14.901	.000	.000
20-29	.000	4.151	4.302	13.273	21.892	27.061	.000
30-39	.000	.000	3.537	8.695	12.912	17.702	51.996
40-49	.000	.000	.000	9.755	13.511	19.752	67.100
50+	.000	.000	.000	.000	9.950	15.975	59.348

Goodness of fit	Value	d.f.	Prob
Chi-square	2608.3700	3022	1.0000
Deviance	1584.5700	3022	1.0000
Freeman-Tukey	1815.6600	3022	1.0000

Table C.34. Excess relative and absolute risk coefficients for nonleukemia. Organ dose equivalent adjusted for DS86 random error.

Male Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	2.956	2.244	.787	1.167	.000	.000	.000
10-19	.000	1.516	.532	.788	.667	.000	.000
20-29	.000	.000	.544	.807	.683	.489	.000
30-39	.000	.000	.190	.282	.239	.171	.364
40-49	.000	.000	.000	.295	.250	.179	.381
50+	.000	.000	.000	.000	.118	.085	.181

Male Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	.115	1.641	1.658	6.390	.000	.000	.000
10-19	.000	.620	1.164	9.416	20.161	.000	.000
20-29	.000	.000	1.828	9.212	21.220	35.146	.000
30-39	.000	.000	.927	2.350	8.205	15.675	55.273
40-49	.000	.000	.000	5.986	9.788	15.582	67.153
50+	.000	.000	.000	.000	4.466	8.038	25.741

Female Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	5.491	4.169	1.462	2.167	.000	.000	.000
10-19	3.708	2.815	.988	1.463	1.239	.000	.000
20-29	.000	2.883	1.011	1.498	1.269	.908	.000
30-39	.000	.000	.353	.523	.443	.317	.676
40-49	.000	.000	.000	.548	.464	.332	.709
50+	.000	.000	.000	.000	.220	.157	.335

Female Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	.629	2.891	5.713	12.021	.000	.000	.000
10-19	1.903	2.656	3.609	12.101	17.748	.000	.000
20-29	.000	3.670	4.261	16.438	26.443	29.222	.000
30-39	.000	.000	2.746	7.794	11.332	12.967	47.324
40-49	.000	.000	.000	8.655	11.884	15.341	59.873
50+	.000	.000	.000	.000	5.409	8.387	29.201

Goodness of fit	Value	d.f.	Prob
Chi-square	4619.1500	3022	.0000
Deviance	2158.8800	3022	1.0000
Freeman-Tukey	1905.4100	3022	1.0000

Table C.35. Excess relative and absolute risk coefficients for nonleukemia adjusted for confirmation rates not stratified, i.e., crude(1950-75). Organ dose equivalent adjusted for DS86 random error.

Male Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	1.217	.379	.446	.881	.000	.000	.000
10-19	.786	.245	.288	.569	.586	.000	.000
20-29	.000	.207	.243	.481	.495	.525	.000
30-39	.000	.000	.096	.189	.195	.207	.384
40-49	.000	.000	.000	.141	.145	.154	.287
50+	.000	.000	.000	.000	.041	.044	.082

Male Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	3.070	1.154	1.335	4.961	.000	.000	.000
10-19	5.831	1.739	1.871	8.422	17.923	.000	.000
20-29	.000	3.798	2.843	8.275	17.103	37.739	.000
30-39	.000	.000	1.408	3.193	8.335	19.434	58.202
40-49	.000	.000	.000	4.561	7.498	15.966	53.810
50+	.000	.000	.000	.000	2.700	5.865	21.255

Female Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	2.562	.798	.939	1.855	.000	.000	.000
10-19	1.655	.515	.606	1.198	1.233	.000	.000
20-29	.000	.435	.512	1.012	1.041	1.105	.000
30-39	.000	.000	.202	.399	.410	.435	.809
40-49	.000	.000	.000	.297	.306	.325	.603
50+	.000	.000	.000	.000	.087	.093	.172

Female Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	3.534	1.455	4.035	10.593	.000	.000	.000
10-19	8.957	2.406	3.043	10.301	17.697	.000	.000
20-29	.000	2.966	3.628	11.277	21.816	34.987	.000
30-39	.000	.000	2.294	6.252	10.134	18.102	55.873
40-49	.000	.000	.000	6.473	9.749	18.770	57.244
50+	.000	.000	.000	.000	3.473	6.954	32.251

Goodness of fit	Value	d.f.	Prob
Chi-square	2004.1000	3022	1.0000
Deviance	1480.2700	3022	1.0000
Freeman-Tukey	1765.6700	3022	1.0000

Table C.36. Excess relative and absolute risk coefficients for nonleukemia adjusted for confirmation rates not stratified, i.e., crude (1950-85). Organ dose equivalent adjusted for DS86 random error.

Male Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	1.310	.437	.473	.845	.000	.000	.000
10-19	.738	.246	.267	.476	.469	.000	.000
20-29	.000	.230	.248	.444	.437	.400	.000
30-39	.000	.000	.117	.208	.205	.188	.246
40-49	.000	.000	.000	.156	.154	.141	.184
50+	.000	.000	.000	.000	.065	.059	.077

Male Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	3.277	1.323	2.014	6.572	.000	.000	.000
10-19	5.484	1.750	1.738	7.114	13.513	.000	.000
20-29	.000	4.209	2.904	7.670	15.624	26.870	.000
30-39	.000	.000	1.713	3.511	8.789	18.257	39.354
40-49	.000	.000	.000	5.030	7.928	14.580	44.704
50+	.000	.000	.000	.000	4.193	7.858	21.451

Female Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	2.567	.856	.927	1.655	.000	.000	.000
10-19	1.447	.483	.522	.933	.919	.000	.000
20-29	.000	.450	.487	.869	.857	.783	.000
30-39	.000	.000	.229	.408	.403	.368	.483
40-49	.000	.000	.000	.306	.301	.276	.361
50+	.000	.000	.000	.000	.126	.116	.152

Female Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	3.538	1.555	3.692	8.324	.000	.000	.000
10-19	7.918	2.265	2.648	7.892	12.086	.000	.000
20-29	.000	3.060	3.460	9.833	17.229	24.248	.000
30-39	.000	.000	2.597	6.406	9.964	16.757	41.997
40-49	.000	.000	.000	6.651	9.605	16.034	49.226
50+	.000	.000	.000	.000	5.013	8.665	32.788

Goodness of fit	Value	d.f.	Prob
Chi-square	1635.7500	3022	1.0000
Deviance	1142.3300	3022	1.0000
Freeman-Tukey	1589.2800	3022	1.0000

Table C.37. Excess relative and absolute risk coefficients for nonleukemia adjusted for confirmation rates stratified on gender (1950-75). Organ dose equivalent adjusted for DS86 random error.

Male Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	1.245	.392	.443	.890	.000	.000	.000
10-19	.804	.253	.286	.575	.586	.000	.000
20-29	.000	.214	.242	.486	.496	.522	.000
30-39	.000	.000	.096	.194	.197	.208	.384
40-49	.000	.000	.000	.145	.148	.156	.288
50+	.000	.000	.000	.000	.042	.044	.081

Male Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	3.219	1.228	1.355	5.009	.000	.000	.000
10-19	6.122	1.846	1.920	8.650	17.934	.000	.000
20-29	.000	4.037	2.921	8.670	17.451	37.530	.000
30-39	.000	.000	1.462	3.374	8.763	19.826	58.175
40-49	.000	.000	.000	4.851	7.915	16.729	54.641
50+	.000	.000	.000	.000	2.803	6.047	21.696

Female Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	2.625	.825	.934	1.876	.000	.000	.000
10-19	1.695	.533	.603	1.212	1.235	.000	.000
20-29	.000	.451	.511	1.025	1.045	1.100	.000
30-39	.000	.000	.203	.408	.416	.438	.809
40-49	.000	.000	.000	.306	.312	.328	.606
50+	.000	.000	.000	.000	.088	.092	.170

Female Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	3.390	1.426	3.966	10.696	.000	.000	.000
10-19	8.615	2.346	2.893	10.218	17.725	.000	.000
20-29	.000	2.898	3.446	10.959	21.694	34.840	.000
30-39	.000	.000	2.205	6.134	9.871	17.935	55.906
40-49	.000	.000	.000	6.350	9.493	18.122	56.665
50+	.000	.000	.000	.000	3.321	6.607	30.407

Goodness of fit	Value	d.f.	Prob
Chi-square	2019.6500	3022	1.0000
Deviance	1482.0900	3022	1.0000
Freeman-Tukey	1751.7700	3022	1.0000

Table C.38. Excess relative and absolute risk coefficients for nonleukemia adjusted for confirmation rates stratified on gender (1950-85). Organ dose equivalent adjusted for DS86 random error.

Male Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	1.339	.452	.470	.846	.000	.000	.000
10-19	.752	.254	.264	.475	.470	.000	.000
20-29	.000	.239	.248	.447	.442	.401	.000
30-39	.000	.000	.118	.212	.209	.190	.248
40-49	.000	.000	.000	.158	.156	.142	.185
50+	.000	.000	.000	.000	.065	.059	.077

Male Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	3.431	1.407	2.070	6.819	.000	.000	.000
10-19	5.732	1.850	1.777	7.369	14.091	.000	.000
20-29	.000	4.486	2.993	7.997	16.393	28.022	.000
30-39	.000	.000	1.781	3.682	9.288	19.160	41.209
40-49	.000	.000	.000	5.266	8.345	15.229	46.519
50+	.000	.000	.000	.000	4.375	8.141	22.115

Female Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	2.627	.886	.922	1.659	.000	.000	.000
10-19	1.476	.498	.518	.932	.922	.000	.000
20-29	.000	.468	.487	.876	.867	.786	.000
30-39	.000	.000	.231	.415	.411	.372	.487
40-49	.000	.000	.000	.310	.306	.278	.363
50+	.000	.000	.000	.000	.128	.116	.151

Female Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	3.391	1.522	3.531	8.033	.000	.000	.000
10-19	7.588	2.201	2.510	7.575	11.664	.000	.000
20-29	.000	2.998	3.298	9.516	16.745	23.364	.000
30-39	.000	.000	2.498	6.240	9.756	16.219	40.484
40-49	.000	.000	.000	6.426	9.330	15.436	47.112
50+	.000	.000	.000	.000	4.819	8.274	31.024

Goodness of fit	Value	d.f.	Prob
Chi-square	1655.3200	3022	1.0000
Deviance	1146.0100	3022	1.0000
Freeman-Tukey	1590.0000	3022	1.0000

Table C.39. Excess relative and absolute risk coefficients for nonleukemia adjusted for confirmation rates stratified on gender and city (1950-75). Organ dose equivalent adjusted for DS86 random error.

Male Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	1.258	.398	.435	.890	.000	.000	.000
10-19	.817	.259	.282	.578	.584	.000	.000
20-29	.000	.218	.238	.488	.493	.525	.000
30-39	.000	.000	.094	.193	.195	.207	.384
40-49	.000	.000	.000	.144	.146	.155	.288
50+	.000	.000	.000	.000	.041	.043	.081

Male Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	3.258	1.251	1.332	5.011	.000	.000	.000
10-19	6.363	1.891	1.896	8.697	17.879	.000	.000
20-29	.000	4.130	2.870	8.692	17.354	37.738	.000
30-39	.000	.000	1.424	3.358	8.639	19.795	58.249
40-49	.000	.000	.000	4.813	7.792	16.657	54.635
50+	.000	.000	.000	.000	2.751	6.002	21.568

Female Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	2.663	.843	.921	1.885	.000	.000	.000
10-19	1.729	.547	.598	1.224	1.236	.000	.000
20-29	.000	.462	.504	1.033	1.043	1.111	.000
30-39	.000	.000	.199	.408	.412	.439	.814
40-49	.000	.000	.000	.305	.309	.329	.609
50+	.000	.000	.000	.000	.086	.092	.170

Female Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	3.308	1.425	3.900	10.738	.000	.000	.000
10-19	8.187	2.374	2.869	10.308	17.737	.000	.000
20-29	.000	2.938	3.378	10.997	21.658	35.154	.000
30-39	.000	.000	2.135	6.106	9.743	17.981	56.191
40-49	.000	.000	.000	6.321	9.393	18.099	56.861
50+	.000	.000	.000	.000	3.279	6.570	30.376

Goodness of fit	Value	d.f.	Prob
Chi-square	2029.3400	3022	1.0000
Deviance	1482.8200	3022	1.0000
Freeman-Tukey	1755.7700	3022	1.0000

Table C.40. Excess relative and absolute risk coefficients for nonleukemia adjusted for confirmation rates stratified on gender and city (1950-85). Organ dose equivalent adjusted for DS86 random error.

Male Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	1.352	.463	.473	.854	.000	.000	.000
10-19	.754	.258	.263	.476	.467	.000	.000
20-29	.000	.240	.245	.443	.434	.403	.000
30-39	.000	.000	.116	.210	.206	.191	.248
40-49	.000	.000	.000	.156	.153	.142	.184
50+	.000	.000	.000	.000	.064	.059	.077

Male Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	3.473	1.447	2.087	6.917	.000	.000	.000
10-19	5.880	1.889	1.775	7.396	14.002	.000	.000
20-29	.000	4.536	2.950	7.929	16.126	28.176	.000
30-39	.000	.000	1.757	3.659	9.145	19.272	41.249
40-49	.000	.000	.000	5.190	8.163	15.225	46.157
50+	.000	.000	.000	.000	4.291	8.162	21.972

Female Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	2.669	.915	.933	1.686	.000	.000	.000
10-19	1.487	.510	.520	.940	.921	.000	.000
20-29	.000	.474	.484	.874	.857	.795	.000
30-39	.000	.000	.230	.415	.407	.378	.490
40-49	.000	.000	.000	.308	.302	.280	.363
50+	.000	.000	.000	.000	.126	.117	.152

Female Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	3.312	1.537	3.547	8.171	.000	.000	.000
10-19	7.133	2.223	2.519	7.629	11.654	.000	.000
20-29	.000	3.011	3.248	9.463	16.627	23.501	.000
30-39	.000	.000	2.454	6.211	9.634	16.428	40.607
40-49	.000	.000	.000	6.365	9.188	15.504	47.089
50+	.000	.000	.000	.000	4.763	8.323	31.032

Goodness of fit	Value	d.f.	Prob
Chi-square	1667.4400	3022	1.0000
Deviance	1148.8800	3022	1.0000
Freeman-Tukey	1592.1900	3022	1.0000

Table C.41. Excess relative and absolute risk coefficients for nonleukemia adjusted for confirmation rates stratified on age ATD (1950-75). Organ dose equivalent adjusted for DS86 random error.

Male Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	1.504	1.010	.663	1.109	.000	.000	.000
10-19	.934	.627	.412	.689	.631	.000	.000
20-29	.000	.597	.392	.656	.600	.513	.000
30-39	.000	.000	.143	.240	.219	.188	.372
40-49	.000	.000	.000	.213	.195	.167	.331
50+	.000	.000	.000	.000	.072	.061	.121

Male Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	1.380	1.622	1.642	6.116	.000	.000	.000
10-19	2.447	1.735	1.588	9.145	19.168	.000	.000
20-29	.000	3.823	2.560	9.385	20.366	36.864	.000
30-39	.000	.000	1.248	2.880	9.126	18.045	56.434
40-49	.000	.000	.000	5.534	9.502	17.288	61.912
50+	.000	.000	.000	.000	3.887	7.569	26.484

Female Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	2.958	1.985	1.303	2.181	.000	.000	.000
10-19	1.837	1.233	.809	1.355	1.240	.000	.000
20-29	.000	1.174	.770	1.290	1.181	1.009	.000
30-39	.000	.000	.282	.471	.432	.369	.731
40-49	.000	.000	.000	.419	.384	.328	.650
50+	.000	.000	.000	.000	.141	.120	.239

Female Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	1.708	2.303	5.349	12.103	.000	.000	.000
10-19	4.215	2.874	3.544	11.668	17.769	.000	.000
20-29	.000	3.890	4.245	15.144	25.209	32.189	.000
30-39	.000	.000	2.690	7.612	11.936	15.722	50.911
40-49	.000	.000	.000	7.953	11.899	18.513	59.894
50+	.000	.000	.000	.000	4.812	8.365	35.332

Goodness of fit	Value	d.f.	Prob
Chi-square	3104.6500	3022	.1441
Deviance	1756.6600	3022	1.0000
Freeman-Tukey	1851.0100	3022	1.0000

Table C.42. Excess relative and absolute risk coefficients for nonleukemia adjusted for confirmation rates stratified on age ATD (1950-85). Organ dose equivalent adjusted for DS86 random error.

Male Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	1.527	1.027	.657	1.070	.000	.000	.000
10-19	.936	.630	.403	.656	.585	.000	.000
20-29	.000	.615	.393	.640	.571	.451	.000
30-39	.000	.000	.154	.251	.224	.177	.300
40-49	.000	.000	.000	.224	.200	.158	.268
50+	.000	.000	.000	.000	.083	.066	.111

Male Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	1.397	1.648	1.974	7.083	.000	.000	.000
10-19	2.451	1.742	1.556	9.034	18.960	.000	.000
20-29	.000	3.932	2.568	9.182	20.712	34.483	.000
30-39	.000	.000	1.341	3.013	9.301	18.288	51.634
40-49	.000	.000	.000	5.814	9.725	16.396	61.683
50+	.000	.000	.000	.000	4.506	8.127	25.560

Female Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	2.949	1.984	1.268	2.067	.000	.000	.000
10-19	1.808	1.217	.778	1.267	1.129	.000	.000
20-29	.000	1.188	.759	1.237	1.102	.872	.000
30-39	.000	.000	.298	.485	.432	.342	.579
40-49	.000	.000	.000	.433	.386	.305	.517
50+	.000	.000	.000	.000	.161	.127	.215

Female Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	1.704	2.304	5.301	11.711	.000	.000	.000
10-19	4.157	2.841	3.418	11.214	17.122	.000	.000
20-29	.000	3.931	4.190	14.607	24.899	30.123	.000
30-39	.000	.000	2.840	7.823	11.954	16.112	50.008
40-49	.000	.000	.000	8.209	11.965	17.288	62.466
50+	.000	.000	.000	.000	5.476	8.822	35.481

Goodness of fit	Value	d.f.	Prob
Chi-square	2936.8300	3022	.8638
Deviance	1582.6900	3022	1.0000
Freeman-Tukey	1803.1600	3022	1.0000

Table C.43. Excess relative and absolute risk coefficients for nonleukemia adjusted for confirmation rates stratified on DS86 shielded kerma (1950-75) Organ dose equivalent adjusted for DS86 random error.

Male Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	2.071	1.035	.750	1.119	.000	.000	.000
10-19	1.330	.664	.481	.718	.674	.000	.000
20-29	.000	.656	.475	.709	.665	.522	.000
30-39	.000	.000	.211	.314	.295	.232	.373
40-49	.000	.000	.000	.314	.295	.231	.372
50+	.000	.000	.000	.000	.194	.152	.245

Male Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	2.523	1.959	1.951	6.155	.000	.000	.000
10-19	4.767	2.485	2.156	9.896	20.352	.000	.000
20-29	.000	5.888	3.646	10.851	22.547	37.419	.000
30-39	.000	.000	2.148	4.201	12.313	22.229	56.533
40-49	.000	.000	.000	8.742	14.396	23.924	69.122
50+	.000	.000	.000	.000	10.597	18.615	51.620

Female Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	3.815	1.906	1.381	2.060	.000	.000	.000
10-19	2.449	1.224	.887	1.322	1.240	.000	.000
20-29	.000	1.208	.875	1.305	1.224	.961	.000
30-39	.000	.000	.388	.579	.543	.426	.686
40-49	.000	.000	.000	.579	.543	.426	.686
50+	.000	.000	.000	.000	.357	.280	.451

Female Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	2.714	2.502	5.715	11.534	.000	.000	.000
10-19	6.894	3.470	4.153	11.646	17.775	.000	.000
20-29	.000	4.726	5.236	15.816	26.025	30.790	.000
30-39	.000	.000	3.962	9.566	14.824	18.092	47.948
40-49	.000	.000	.000	11.529	16.653	23.810	62.652
50+	.000	.000	.000	.000	12.195	19.125	63.540

Goodness of fit	Value	d.f.	Prob
Chi-square	2787.7400	3022	.9990
Deviance	1756.8400	3022	1.0000
Freeman-Tukey	1866.0900	3022	1.0000

Table C.44. Excess relative and absolute risk coefficients for nonleukemia adjusted for confirmation rates stratified on DS86 shielded kerma (1950-85) Organ dose equivalent adjusted for DS86 random error.

Male Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	2.124	1.083	.785	1.139	.000	.000	.000
10-19	1.303	.664	.481	.699	.655	.000	.000
20-29	.000	.670	.485	.704	.661	.523	.000
30-39	.000	.000	.227	.329	.309	.245	.382
40-49	.000	.000	.000	.321	.301	.239	.373
50+	.000	.000	.000	.000	.199	.158	.246

Male Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	2.575	2.041	2.599	8.067	.000	.000	.000
10-19	4.673	2.484	2.158	10.159	21.216	.000	.000
20-29	.000	6.003	3.722	10.790	23.950	39.927	.000
30-39	.000	.000	2.308	4.393	12.872	25.199	65.136
40-49	.000	.000	.000	8.938	14.716	24.687	83.759
50+	.000	.000	.000	.000	10.867	19.270	54.352

Female Excess relative risk (%/Sv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	3.816	1.945	1.411	2.047	.000	.000	.000
10-19	2.341	1.193	.865	1.255	1.177	.000	.000
20-29	.000	1.203	.872	1.266	1.187	.941	.000
30-39	.000	.000	.408	.592	.555	.440	.687
40-49	.000	.000	.000	.578	.542	.429	.670
50+	.000	.000	.000	.000	.357	.283	.442

Female Absolute risk (deaths/10^4PYSv)

	Age ATD						
Age ATB	<20	20-29	30-39	40-49	50-59	60-69	70+
<10	2.714	2.546	5.991	11.911	.000	.000	.000
10-19	6.631	3.397	4.064	11.537	17.692	.000	.000
20-29	.000	4.711	5.224	15.403	26.489	32.489	.000
30-39	.000	.000	4.155	9.763	15.126	20.532	58.177
40-49	.000	.000	.000	11.514	16.626	23.991	78.208
50+	.000	.000	.000	.000	12.210	19.325	68.991

Goodness of fit	Value	d.f.	Prob
Chi-square	2610.1000	3022	1.0000
Deviance	1582.5200	3022	1.0000
Freeman-Tukey	1815.2400	3022	1.0000

Table C.45. BEIR-V excess relative risk (%/Sv) of leukemia for various stratifications of confirmation rates.

		E<=20	E>20	
Adjustment	T<15	15<T<=25	T<=25	25<T<=30
No adjustment	5.14	0.43	0.42	0.20
Crude(1950-75)	4.56	0.41	0.13	0.18
Crude(1950-85)	4.25	0.39	0.33	0.17
Sex(1950-75)	4.84	0.43	0.39	0.19
Sex(1950-85)	4.46	0.40	0.34	0.17
Sex and city(1950-075)	4.43	0.39	0.33	0.17
Sex and city(1950-075)	3.82	0.34	0.29	0.15
Age ATD(1950-75)	3.37	0.37	0.31	0.16
Age ATD(1950-85)	3.06	0.34	0.29	0.15
DS86(1950-75)	2.91	0.30	0.33	0.18
DS86(1950-85)	5.19	0.54	0.58	0.33

E denotes age at exposure (age ATB)
T denotes time since exposure

Table C.46. BEIR-V excess relative risk (%/Sv) of leukemia for various stratifications of confirmation rates. DS86 dose equivalents adjusted for random error.

		E<=20	E>20	
Adjustment	T<15	15<T<=25	T<=25	25<T<=30
No adjustment	10.56	0.90	0.80	0.42
Crude(1950-75)	9.36	0.85	0.67	0.38
Crude(1950-85)	8.62	0.80	0.62	0.35
Sex(1950-75)	9.94	0.89	0.75	0.40
Sex(1950-85)	8.99	0.81	0.64	0.36
Sex and city(1950-075)	9.12	0.80	0.63	0.35
Sex and city(1950-075)	8.66	0.77	0.60	0.33
Age ATD(1950-75)	6.88	0.75	0.60	0.33
Age ATD(1950-85)	6.50	0.72	0.57	0.32
DS86(1950-75)	6.36	0.67	0.69	0.42
DS86(1950-85)	8.85	0.95	0.96	0.58

E denotes age at exposure (age ATB)
T denotes time since exposure

Table C.47. BEIR-V excess relative risk (%/Sv) of digestive cancer for various stratifications of confirmation rates.

	MALES			FEMALES		
Adjustment	E<=25	25<E<=35	E>35	E<=25	25<E<=35	E>35
No adjustment	0.81	0.30	0.11	1.41	0.52	0.19
Crude(1950-75)	0.62	0.26	0.11	1.11	0.48	0.20
Crude(1950-85)	0.48	0.22	0.10	0.96	0.44	0.20
Sex(1950-75)	0.60	0.26	0.11	1.13	0.48	0.21
Sex(1950-85)	0.46	0.21	0.10	0.99	0.45	0.20
Sex and city(1950-075)	0.73	0.29	0.11	1.33	0.52	0.21
Sex and city(1950-075)	0.66	0.26	0.11	1.27	0.51	0.20

E denotes age at exposure (age ATB)
T denotes time since exposure

Table C.48. BEIR-V excess relative risk (%/Sv) of digestive cancer for various stratifications of confirmation rates. DS86 dose equivalents adjusted for random error.

	MALES			FEMALES		
Adjustment	E<=25	25<E<=35	E>35	E<=25	25<E<=35	E>35
No adjustment	0.74	0.30	0.13	1.44	0.60	0.25
Crude(1950-75)	0.59	0.28	0.14	1.13	0.54	0.26
Crude(1950-85)	0.47	0.24	0.12	0.98	0.49	0.25
Sex(1950-75)	0.58	0.28	0.13	1.15	0.55	0.26
Sex(1950-85)	0.46	0.23	0.11	1.01	0.51	0.25
Sex and city(1950-075)	0.69	0.30	0.13	1.36	0.60	0.26
Sex and city(1950-075)	0.62	0.27	0.12	1.30	0.58	0.26

E denotes age at exposure (age ATB)
T denotes time since exposure

13 APPENDIX D. Lifetime Mortality Risks (%/Sv).

Tables D.1 - D.56.

Table D.1. Excess mortality risk (%/Sv) of leukemia among males exposed to 0.02 Sv/y from ages 18 to 65 for the absolute projection model.

```
          Run date:  10/ 3/1993
             Title:  Lifetime risks
               Sex:  MALE
              Race:  WHITE
    Life table used:  1990
  Risk coefficients:  BASED ON AGE ATB- AND ATD-SPECIFIC (RBE=10) COEFFICIENTS
           Leukemia:  Minimal latency(yrs):   2      Plateau(yrs):  40
      Solid cancers:  Minimal latency(yrs):  10      Plateau(yrs): 101
              DRREF:  2.0
Age at first expos.:   18
 Age at last expos.:   65
Total dose eq. (Sv):     1.000000
```

Strata for confirmation rates used in adjustment	Radiation-induced cancer deaths per 10**5	90.0% CI	Baseline cancer deaths per 10**5	Years of life lost	PC(90.0% CI)
None	673	(273, 1654)	750	49	.47(.17,1.00)
Crude(1950-75)	613	(249, 1507)	750	47	.45(.16,1.00)
Crude(1950-85)	603	(245, 1483)	750	49	.45(.16,1.00)
Sex(1950-75)	585	(238, 1439)	750	48	.44(.16,1.00)
Sex(1950-85)	559	(227, 1375)	750	50	.43(.16,1.00)
Sex-city(1950-85)	580	(236, 1426)	750	48	.44(.16,1.00)
Sex-city(1950-85)	557	(226, 1369)	750	50	.43(.16,1.00)
Age ATD(1950-75)	595	(242, 1464)	750	46	.44(.16,1.00)
Age ATD(1950-85)	580	(236, 1425)	750	47	.44(.16,1.00)
DS86(1950-75)	714	(290, 1756)	750	42	.49(.17,1.00)
DS86(1950-85)	751	(305, 1846)	750	41	.50(.18,1.00)

Table D.2. Excess mortality risk (%/Sv) of leukemia among males exposed to 0.02 Sv/y from ages 18 to 65 for the transported relative projection model.

```
          Run date:  10/ 3/1993
             Title:  Lifetime risks
               Sex:  MALE
              Race:  WHITE
    Life table used:  1990
  Risk coefficients:  BASED ON AGE ATB- AND ATD-SPECIFIC (RBE=10) COEFFICIENTS
           Leukemia:  Minimal latency(yrs):   2      Plateau(yrs):  40
      Solid cancers:  Minimal latency(yrs):  10      Plateau(yrs): 101
              DRREF:  2.0
Age at first expos.:   18
 Age at last expos.:   65
Total dose eq. (Sv):     1.000000
```

Strata for confirmation rates used in adjustment	Radiation-induced cancer deaths per 10**5	90.0% CI	Baseline cancer deaths per 10**5	Years of life lost	PC(90.0% CI)
None	354	(144, 871)	750	24	.32(.12, .84)
Crude(1950-75)	327	(133, 806)	750	24	.30(.12, .79)
Crude(1950-85)	319	(130, 785)	750	24	.30(.12, .77)
Sex(1950-75)	309	(125, 760)	750	25	.29(.11, .75)
Sex(1950-85)	284	(115, 700)	750	24	.28(.11, .71)
Sex-city(1950-85)	307	(124, 754)	750	25	.29(.11, .75)
Sex-city(1950-85)	287	(116, 706)	750	24	.28(.11, .71)
Age ATD(1950-75)	339	(138, 834)	750	24	.31(.12, .81)
Age ATD(1950-85)	328	(133, 806)	750	24	.30(.12, .79)
DS86(1950-75)	451	(183, 1109)	750	23	.38(.14,1.00)
DS86(1950-85)	482	(196, 1186)	750	23	.39(.15,1.00)

Table D.3. Excess mortality risk (%/Sv) of leukemia among males exposed to 0.02 Sv/y from ages 18 to 65 for the relative projection model.

```
           Run date:  10/ 3/1993
              Title:  Lifetime risks
                Sex:  MALE
               Race:  WHITE
    Life table used:  1990
  Risk coefficients:  BASED ON AGE ATB- AND ATD-SPECIFIC (RBE=10) COEFFICIENTS
            Leukemia:  Minimal latency(yrs):   2      Plateau(yrs):  40
       Solid cancers:  Minimal latency(yrs):  10      Plateau(yrs): 101
              DRREF:  2.0
Age at first expos.:   18
 Age at last expos.:   65
Total dose eq. (Sv):     1.000000
```

Strata for confirmation rates used in adjustment	Radiation-induced cancer deaths per 10**5	90.0% CI	Baseline cancer deaths per 10**5	Years of life lost	PC(90.0% CI)
None	875	(356, 2152)	750	34	.54(.19,1.00)
Crude(1950-75)	291	(118, 716)	750	34	.28(.11, .72)
Crude(1950-85)	640	(260, 1574)	750	36	.46(.17,1.00)
Sex(1950-75)	758	(308, 1863)	750	35	.50(.18,1.00)
Sex(1950-85)	755	(307, 1856)	750	36	.50(.18,1.00)
Sex-city(1950-85)	715	(291, 1758)	750	35	.49(.17,1.00)
Sex-city(1950-85)	752	(306, 1848)	750	35	.50(.18,1.00)
Age ATD(1950-75)	624	(254, 1535)	750	32	.45(.16,1.00)
Age ATD(1950-85)	623	(253, 1532)	750	32	.45(.16,1.00)
DS86(1950-75)	1010	(410, 2482)	750	30	.57(.19,1.00)
DS86(1950-85)	1085	(441, 2668)	750	28	.59(.20,1.00)

Table D.4. Excess mortality risk (%/Sv) of leukemia among males exposed to 0.02 Sv/y from ages 18 to 65 for the transported relative projection model. Baseline rates adjusted with death certificate correction factors (DCCFs).

```
           Run date:  10/ 3/1993
              Title:  Lifetime risks
                Sex:  MALE
               Race:  WHITE
    Life table used:  1990
  Risk coefficients:  BASED ON AGE ATB- AND ATD-SPECIFIC (RBE=10) COEFFICIENTS
            Leukemia:  Minimal latency(yrs):   2      Plateau(yrs):  40
       Solid cancers:  Minimal latency(yrs):  10      Plateau(yrs): 101
              DRREF:  2.0
Age at first expos.:   18
 Age at last expos.:   65
Total dose eq. (Sv):     1.000000
```

Strata for confirmation rates used in adjustment	Radiation-induced cancer deaths per 10**5	90.0% CI	Baseline cancer deaths per 10**5	Years of life lost	PC(90.0% CI)
None	354	(144, 871)	668	24	.35(.13, .92)
Crude(1950-75)	327	(133, 806)	668	24	.33(.12, .87)
Crude(1950-85)	319	(130, 785)	668	24	.32(.12, .85)
Sex(1950-75)	309	(125, 760)	668	25	.32(.12, .83)
Sex(1950-85)	284	(115, 700)	668	24	.30(.11, .78)
Sex-city(1950-85)	307	(124, 754)	668	25	.31(.12, .83)
Sex-city(1950-85)	287	(116, 706)	668	24	.30(.12, .78)
Age ATD(1950-75)	339	(138, 834)	668	24	.34(.13, .89)
Age ATD(1950-85)	328	(133, 806)	668	24	.33(.12, .87)
DS86(1950-75)	451	(183, 1109)	668	23	.40(.15,1.00)
DS86(1950-85)	482	(196, 1186)	668	23	.42(.15,1.00)

Table D.5. Excess mortality risk (%/Sv) of leukemia among males exposed to 0.02 Sv/y from ages 18 to 65 for the relative projection model. Baseline rates adjusted with death certificate correction factors (DCCFs).

```
          Run date:  10/ 3/1993
             Title:  Lifetime risks
               Sex:  MALE
              Race:  WHITE
    Life table used:  1990
  Risk coefficients:  BASED ON AGE ATB- AND ATD-SPECIFIC (RBE=10) COEFFICIENTS
           Leukemia:  Minimal latency(yrs):   2      Plateau(yrs):  40
      Solid cancers:  Minimal latency(yrs):  10      Plateau(yrs): 101
              DRREF:  2.0
Age at first expos.:   18
 Age at last expos.:   65
Total dose eq. (Sv):     1.000000
```

Strata for confirmation rates used in adjustment	Radiation-induced cancer deaths per 10**5	90.0% CI	Baseline cancer deaths per 10**5	Years of life lost	PC(90.0% CI)
None	780	(317, 1919)	668	34	.54(.18,1.00)
Crude(1950-75)	259	(105, 638)	668	34	.28(.11, .72)
Crude(1950-85)	571	(232, 1403)	668	36	.46(.16,1.00)
Sex(1950-75)	676	(275, 1661)	668	35	.50(.17,1.00)
Sex(1950-85)	673	(273, 1654)	668	36	.50(.17,1.00)
Sex-city(1950-85)	637	(259, 1568)	668	35	.49(.17,1.00)
Sex-city(1950-85)	670	(272, 1648)	668	35	.50(.17,1.00)
Age ATD(1950-75)	556	(226, 1368)	668	32	.45(.16,1.00)
Age ATD(1950-85)	555	(226, 1366)	668	32	.45(.16,1.00)
DS86(1950-75)	900	(366, 2214)	668	30	.57(.19,1.00)
DS86(1950-85)	968	(394, 2380)	668	28	.59(.19,1.00)

Table D.6. Excess mortality risk (%/Sv) of leukemia among females exposed to 0.02 Sv/y from ages 18 to 65 for the absolute projection model.

```
          Run date:  10/ 3/1993
             Title:  Lifetime risks
               Sex:  FEMALE
              Race:  WHITE
    Life table used:  1990
  Risk coefficients:  BASED ON AGE ATB- AND ATD-SPECIFIC (RBE=10) COEFFICIENTS
           Leukemia:  Minimal latency(yrs):   2      Plateau(yrs):  40
      Solid cancers:  Minimal latency(yrs):  10      Plateau(yrs): 101
              DRREF:  2.0
Age at first expos.:   18
 Age at last expos.:   65
Total dose eq. (Sv):     1.000000
```

Strata for confirmation rates used in adjustment	Radiation-induced cancer deaths per 10**5	90.0% CI	Baseline cancer deaths per 10**5	Years of life lost	PC(90.0% CI)
None	396	(169, 931)	653	52	.38(.14,1.00)
Crude(1950-75)	375	(160, 881)	653	51	.37(.14, .95)
Crude(1950-85)	361	(154, 848)	653	52	.36(.14, .93)
Sex(1950-75)	360	(153, 846)	653	51	.36(.14, .93)
Sex(1950-85)	367	(156, 863)	653	50	.36(.14, .94)
Sex-city(1950-85)	326	(139, 766)	653	50	.33(.13, .86)
Sex-city(1950-85)	322	(137, 757)	653	50	.33(.13, .85)
Age ATD(1950-75)	362	(154, 851)	653	50	.36(.14, .93)
Age ATD(1950-85)	360	(153, 846)	653	51	.36(.14, .93)
DS86(1950-75)	477	(203, 1121)	653	46	.42(.16,1.00)
DS86(1950-85)	532	(227, 1249)	653	44	.45(.16,1.00)

Table D.7. Excess mortality risk (%/Sv) of leukemia among females exposed to 0.02 Sv/y from ages 18 to 65 for the transported relative projection model.

```
          Run date:  10/ 3/1993
             Title:  Lifetime risks
               Sex:  FEMALE
              Race:  WHITE
   Life table used:  1990
  Risk coefficients: BASED ON AGE ATB- AND ATD-SPECIFIC (RBE=10) COEFFICIENTS
           Leukemia: Minimal latency(yrs):  2      Plateau(yrs):  40
      Solid cancers: Minimal latency(yrs):  10     Plateau(yrs): 101
              DRREF: 2.0
Age at first expos.:  18
 Age at last expos.:  65
Total dose eq. (Sv):    1.000000
```

Strata for confirmation rates used in adjustment	Radiation-induced cancer deaths per 10**5	90.0% CI	Baseline cancer deaths per 10**5	Years of life lost	PC(90.0% CI)
None	267	(113, 627)	653	26	.29(.12, .73)
Crude(1950-75)	228	(97, 535)	653	28	.26(.10, .64)
Crude(1950-85)	242	(103, 568)	653	26	.27(.11, .68)
Sex(1950-75)	243	(103, 572)	653	26	.27(.11, .68)
Sex(1950-85)	256	(109, 600)	653	26	.28(.11, .71)
Sex-city(1950-85)	222	(94, 522)	653	26	.25(.10, .63)
Sex-city(1950-85)	225	(95, 528)	653	26	.26(.10, .64)
Age ATD(1950-75)	246	(105, 578)	653	27	.27(.11, .68)
Age ATD(1950-85)	247	(105, 580)	653	26	.27(.11, .69)
DS86(1950-75)	352	(150, 827)	653	26	.35(.14, .91)
DS86(1950-85)	396	(168, 929)	653	26	.38(.14, .99)

Table D.8. Excess mortality risk (%/Sv) of leukemia among females exposed to 0.02 Sv/y from ages 18 to 65 for the relative projection model.

```
          Run date:  10/ 3/1993
             Title:  Lifetime risks
               Sex:  FEMALE
              Race:  WHITE
   Life table used:  1990
  Risk coefficients: BASED ON AGE ATB- AND ATD-SPECIFIC (RBE=10) COEFFICIENTS
           Leukemia: Minimal latency(yrs):  2      Plateau(yrs):  40
      Solid cancers: Minimal latency(yrs):  10     Plateau(yrs): 101
              DRREF: 2.0
Age at first expos.:  18
 Age at last expos.:  65
Total dose eq. (Sv):    1.000000
```

Strata for confirmation rates used in adjustment	Radiation-induced cancer deaths per 10**5	90.0% CI	Baseline cancer deaths per 10**5	Years of life lost	PC(90.0% CI)
None	733	(312, 1722)	653	40	.53(.18,1.00)
Crude(1950-75)	260	(111, 612)	653	40	.29(.11, .72)
Crude(1950-85)	546	(232, 1281)	653	44	.46(.16,1.00)
Sex(1950-75)	588	(250, 1380)	653	43	.47(.17,1.00)
Sex(1950-85)	469	(199, 1100)	653	44	.42(.15,1.00)
Sex-city(1950-85)	432	(184, 1013)	653	42	.40(.15,1.00)
Sex-city(1950-85)	412	(175, 967)	653	43	.39(.15,1.00)
Age ATD(1950-75)	554	(236, 1300)	653	39	.46(.17,1.00)
Age ATD(1950-85)	547	(233, 1284)	653	40	.46(.16,1.00)
DS86(1950-75)	949	(404, 2228)	653	37	.59(.19,1.00)
DS86(1950-85)	1047	(446, 2458)	653	35	.62(.20,1.00)

Table D.9. Excess mortality risk (%/Sv) of leukemia among females exposed to 0.02 Sv/y from ages 18 to 65 for the transported relative projection model. Baseline rates adjusted with death certificate correction factors (DCCFs).

Run date:	10/ 3/1993
Title:	Lifetime risks
Sex:	FEMALE
Race:	WHITE
Life table used:	1990
Risk coefficients:	BASED ON AGE ATB- AND ATD-SPECIFIC (RBE=10) COEFFICIENTS
Leukemia:	Minimal latency(yrs): 2 Plateau(yrs): 40
Solid cancers:	Minimal latency(yrs): 10 Plateau(yrs): 101
DRREF:	2.0
Age at first expos.:	18
Age at last expos.:	65
Total dose eq. (Sv):	1.000000

Strata for confirmation rates used in adjustment	Radiation-induced cancer deaths per 10**5	90.0% CI	Baseline cancer deaths per 10**5	Years of life lost	PC(90.0% CI)
None	267	(113, 627)	581	26	.31(.12, .81)
Crude(1950-75)	228	(97, 535)	581	28	.28(.11, .71)
Crude(1950-85)	242	(103, 568)	581	26	.29(.12, .75)
Sex(1950-75)	243	(103, 572)	581	26	.30(.12, .75)
Sex(1950-85)	256	(109, 600)	581	26	.31(.12, .78)
Sex-city(1950-85)	222	(94, 522)	581	26	.28(.11, .70)
Sex-city(1950-85)	225	(95, 528)	581	26	.28(.11, .70)
Age ATD(1950-75)	246	(105, 578)	581	27	.30(.12, .76)
Age ATD(1950-85)	247	(105, 580)	581	26	.30(.12, .76)
DS86(1950-75)	352	(150, 827)	581	26	.38(.14,1.00)
DS86(1950-85)	396	(168, 929)	581	26	.41(.15,1.00)

Table D.10. Excess mortality risk (%/Sv) of leukemia among females exposed to 0.02 Sv/y from ages 18 to 65 for the relative projection model. Baseline rates adjusted with death certificate correction factors (DCCFs).

Run date:	10/ 3/1993
Title:	Lifetime risks
Sex:	FEMALE
Race:	WHITE
Life table used:	1990
Risk coefficients:	BASED ON AGE ATB- AND ATD-SPECIFIC (RBE=10) COEFFICIENTS
Leukemia:	Minimal latency(yrs): 2 Plateau(yrs): 40
Solid cancers:	Minimal latency(yrs): 10 Plateau(yrs): 101
DRREF:	2.0
Age at first expos.:	18
Age at last expos.:	65
Total dose eq. (Sv):	1.000000

Strata for confirmation rates used in adjustment	Radiation-induced cancer deaths per 10**5	90.0% CI	Baseline cancer deaths per 10**5	Years of life lost	PC(90.0% CI)
None	654	(278, 1535)	581	40	.53(.18,1.00)
Crude(1950-75)	232	(99, 545)	581	40	.29(.11, .72)
Crude(1950-85)	486	(207, 1142)	581	44	.46(.16,1.00)
Sex(1950-75)	524	(223, 1230)	581	42	.47(.17,1.00)
Sex(1950-85)	417	(178, 980)	581	44	.42(.15,1.00)
Sex-city(1950-85)	385	(164, 903)	581	42	.40(.15,1.00)
Sex-city(1950-85)	367	(156, 861)	581	43	.39(.14,1.00)
Age ATD(1950-75)	493	(210, 1158)	581	39	.46(.16,1.00)
Age ATD(1950-85)	487	(207, 1144)	581	40	.46(.16,1.00)
DS86(1950-75)	847	(361, 1987)	581	37	.59(.19,1.00)
DS86(1950-85)	934	(398, 2192)	581	34	.62(.19,1.00)

Table D.11. Excess mortality risk (%/Sv) of leukemia among males exposed to 0.02 Sv/y from ages 18 to 65 for the absolute projection model. DS86 Dose equivalents adjusted for random error.

```
           Run date:  9/30/1993
              Title:  Lifetime risks
                Sex:  MALE
               Race:  WHITE
     Life table used:  1990
   Risk coefficients:  BASED ON AGE ATB- AND ATD-SPECIFIC (RBE=10) COEFFICIENTS
            Leukemia:  Minimal latency(yrs):   2      Plateau(yrs):  40
       Solid cancers:  Minimal latency(yrs):  10      Plateau(yrs): 101
              DRREF:  2.0
Age at first expos.:  18
 Age at last expos.:  65
Total dose eq. (Sv):     1.000000
```

Strata for confirmation rates used in adjustment	Radiation-induced cancer deaths per 10**5	90.0% CI	Baseline cancer deaths per 10**5	Years of life lost	PC(90.0% CI)
None	759	(309, 1867)	750	50	.50(.18,1.00)
Crude(1950-75)	670	(272, 1648)	750	48	.47(.17,1.00)
Crude(1950-85)	651	(264, 1600)	750	50	.46(.17,1.00)
Sex(1950-75)	661	(269, 1626)	750	49	.47(.17,1.00)
Sex(1950-85)	632	(257, 1554)	750	51	.46(.17,1.00)
Sex-city(1950-85)	655	(266, 1610)	750	48	.47(.17,1.00)
Sex-city(1950-85)	629	(256, 1546)	750	50	.46(.16,1.00)
Age ATD(1950-75)	676	(275, 1662)	750	47	.47(.17,1.00)
Age ATD(1950-85)	658	(268, 1619)	750	47	.47(.17,1.00)
DS86(1950-75)	810	(329, 1993)	750	43	.52(.18,1.00)
DS86(1950-85)	853	(347, 2097)	750	41	.53(.18,1.00)

Table D.12. Excess mortality risk (%/Sv) of leukemia among males exposed to 0.02 Sv/y from ages 18 to 65 for the transported relative projection model. DS86 Dose equivalents adjusted for random error.

```
           Run date:  9/30/1993
              Title:  Lifetime risks
                Sex:  MALE
               Race:  WHITE
     Life table used:  1990
   Risk coefficients:  BASED ON AGE ATB- AND ATD-SPECIFIC (RBE=10) COEFFICIENTS
            Leukemia:  Minimal latency(yrs):   2      Plateau(yrs):  40
       Solid cancers:  Minimal latency(yrs):  10      Plateau(yrs): 101
              DRREF:  2.0
Age at first expos.:  18
 Age at last expos.:  65
Total dose eq. (Sv):     1.000000
```

Strata for confirmation rates used in adjustment	Radiation-induced cancer deaths per 10**5	90.0% CI	Baseline cancer deaths per 10**5	Years of life lost	PC(90.0% CI)
None	397	(161, 975)	750	24	.35(.13, .91)
Crude(1950-75)	357	(145, 878)	750	24	.32(.12, .84)
Crude(1950-85)	342	(139, 841)	750	24	.31(.12, .82)
Sex(1950-75)	346	(141, 852)	750	25	.32(.12, .82)
Sex(1950-85)	319	(129, 785)	750	24	.30(.12, .77)
Sex-city(1950-85)	344	(140, 845)	750	25	.31(.12, .82)
Sex-city(1950-85)	321	(130, 790)	750	24	.30(.12, .78)
Age ATD(1950-75)	383	(155, 942)	750	24	.34(.13, .89)
Age ATD(1950-85)	370	(150, 910)	750	24	.33(.13, .87)
DS86(1950-75)	509	(207, 1251)	750	23	.40(.15,1.00)
DS86(1950-85)	544	(221, 1338)	750	23	.42(.15,1.00)

Table D.13. Excess mortality risk (%/Sv) of leukemia among males exposed to 0.02 Sv/y from ages 18 to 65 for the relative projection model. DS86 Dose equivalents adjusted for random error.

```
           Run date:  9/30/1993
              Title:  Lifetime risks
                Sex:  MALE
               Race:  WHITE
    Life table used:  1990
  Risk coefficients:  BASED ON AGE ATB- AND ATD-SPECIFIC (RBE=10) COEFFICIENTS
           Leukemia:  Minimal latency(yrs):   2      Plateau(yrs):  40
      Solid cancers:  Minimal latency(yrs):  10      Plateau(yrs): 101
              DRREF:  2.0
Age at first expos.:  18
 Age at last expos.:  65
Total dose eq. (Sv):     1.000000
```

Strata for confirmation rates used in adjustment	Radiation-induced cancer deaths per 10**5	90.0% CI	Baseline cancer deaths per 10**5	Years of life lost	PC(90.0% CI)
None	999	(406, 2455)	750	35	.57(.19,1.00)
Crude(1950-75)	714	(290, 1754)	750	36	.49(.17,1.00)
Crude(1950-85)	725	(295, 1783)	750	37	.49(.17,1.00)
Sex(1950-75)	864	(351, 2124)	750	36	.54(.19,1.00)
Sex(1950-85)	864	(351, 2124)	750	36	.54(.19,1.00)
Sex-city(1950-85)	815	(331, 2005)	750	35	.52(.18,1.00)
Sex-city(1950-85)	862	(350, 2118)	750	36	.53(.19,1.00)
Age ATD(1950-75)	712	(289, 1751)	750	32	.49(.17,1.00)
Age ATD(1950-85)	712	(290, 1751)	750	33	.49(.17,1.00)
DS86(1950-75)	1157	(470, 2844)	750	30	.61(.20,1.00)
DS86(1950-85)	1238	(503, 3043)	750	28	.62(.21,1.00)

Table D.14. Excess mortality risk (%/Sv) of leukemia among males exposed to 0.02 Sv/y from ages 18 to 65 for the transported relative projection model. Baseline rates adjusted with death certificate correction factors (DCCFs). DS86 Dose equivalents adjusted for random error.

```
           Run date:  9/30/1993
              Title:  Lifetime risks
                Sex:  MALE
               Race:  WHITE
    Life table used:  1990
  Risk coefficients:  BASED ON AGE ATB- AND ATD-SPECIFIC (RBE=10) COEFFICIENTS
           Leukemia:  Minimal latency(yrs):   2      Plateau(yrs):  40
      Solid cancers:  Minimal latency(yrs):  10      Plateau(yrs): 101
              DRREF:  2.0
Age at first expos.:  18
 Age at last expos.:  65
Total dose eq. (Sv):     1.000000
```

Strata for confirmation rates used in adjustment	Radiation-induced cancer deaths per 10**5	90.0% CI	Baseline cancer deaths per 10**5	Years of life lost	PC(90.0% CI)
None	397	(161, 975)	668	24	.37(.14,1.00)
Crude(1950-75)	357	(145, 878)	668	24	.35(.13, .93)
Crude(1950-85)	342	(139, 841)	668	24	.34(.13, .90)
Sex(1950-75)	346	(141, 852)	668	25	.34(.13, .91)
Sex(1950-85)	319	(129, 785)	668	24	.32(.12, .85)
Sex-city(1950-85)	344	(140, 845)	668	25	.34(.13, .90)
Sex-city(1950-85)	321	(130, 790)	668	24	.32(.12, .86)
Age ATD(1950-75)	383	(155, 942)	668	24	.36(.14, .98)
Age ATD(1950-85)	370	(150, 910)	668	24	.36(.13, .95)
DS86(1950-75)	509	(207, 1251)	668	23	.43(.16,1.00)
DS86(1950-85)	544	(221, 1338)	668	23	.45(.16,1.00)

Table D.15. Excess mortality risk (%/Sv) of leukemia among males exposed to 0.02 Sv/y from ages 18 to 65 for the relative projection model. Baseline rates adjusted with death certificate correction factors (DCCFs). DS86 Dose equivalents adjusted for random error.

```
          Run date:  9/30/1993
             Title:  Lifetime risks
               Sex:  MALE
              Race:  WHITE
   Life table used:  1990
 Risk coefficients:  BASED ON AGE ATB- AND ATD-SPECIFIC (RBE=10) COEFFICIENTS
           Leukemia:  Minimal latency(yrs):   2      Plateau(yrs):  40
      Solid cancers:  Minimal latency(yrs):  10      Plateau(yrs): 101
              DRREF:  2.0
Age at first expos.:  18
 Age at last expos.:  65
Total dose eq. (Sv):     1.000000
```

Strata for confirmation rates used in adjustment	Radiation-induced cancer deaths per 10**5	90.0% CI	Baseline cancer deaths per 10**5	Years of life lost	PC(90.0% CI)
None	891	(362, 2190)	668	35	.57(.19,1.00)
Crude(1950-75)	636	(259, 1564)	668	36	.49(.17,1.00)
Crude(1950-85)	646	(263, 1590)	668	37	.49(.17,1.00)
Sex(1950-75)	770	(313, 1894)	668	35	.54(.18,1.00)
Sex(1950-85)	770	(313, 1894)	668	36	.54(.18,1.00)
Sex-city(1950-85)	727	(295, 1787)	668	35	.52(.18,1.00)
Sex-city(1950-85)	768	(312, 1889)	668	36	.53(.18,1.00)
Age ATD(1950-75)	635	(258, 1561)	668	32	.49(.17,1.00)
Age ATD(1950-85)	635	(258, 1561)	668	33	.49(.17,1.00)
DS86(1950-75)	1032	(420, 2537)	668	30	.61(.20,1.00)
DS86(1950-85)	1104	(449, 2715)	668	28	.62(.20,1.00)

Table D.16. Excess mortality risk (%/Sv) of leukemia among females exposed to 0.02 Sv/y from ages 18 to 65 for the absolute projection model. DS86 Dose equivalents adjusted for random error.

```
          Run date:  9/30/1993
             Title:  Lifetime risks
               Sex:  FEMALE
              Race:  WHITE
   Life table used:  1990
 Risk coefficients:  BASED ON AGE ATB- AND ATD-SPECIFIC (RBE=10) COEFFICIENTS
           Leukemia:  Minimal latency(yrs):   2      Plateau(yrs):  40
      Solid cancers:  Minimal latency(yrs):  10      Plateau(yrs): 101
              DRREF:  2.0
Age at first expos.:  18
 Age at last expos.:  65
Total dose eq. (Sv):     1.000000
```

Strata for confirmation rates used in adjustment	Radiation-induced cancer deaths per 10**5	90.0% CI	Baseline cancer deaths per 10**5	Years of life lost	PC(90.0% CI)
None	435	(185, 1022)	653	52	.40(.15,1.00)
Crude(1950-75)	388	(165, 911)	653	51	.37(.14, .98)
Crude(1950-85)	379	(161, 890)	653	52	.37(.14, .96)
Sex(1950-75)	396	(169, 931)	653	51	.38(.14,1.00)
Sex(1950-85)	404	(172, 949)	653	51	.38(.14,1.00)
Sex-city(1950-85)	359	(153, 843)	653	51	.35(.14, .92)
Sex-city(1950-85)	354	(150, 831)	653	51	.35(.14, .91)
Age ATD(1950-75)	400	(170, 939)	653	50	.38(.14,1.00)
Age ATD(1950-85)	398	(169, 934)	653	51	.38(.14,1.00)
DS86(1950-75)	526	(224, 1235)	653	47	.45(.16,1.00)
DS86(1950-85)	587	(250, 1378)	653	44	.47(.17,1.00)

Table D.17. Excess mortality risk (%/Sv) of leukemia among females exposed to 0.02 Sv/y from ages 18 to 65 for the transported projection model. DS86 Dose equivalents adjusted for random error.

```
          Run date:  9/30/1993
             Title:  Lifetime risks
               Sex:  FEMALE
              Race:  WHITE
   Life table used:  1990
 Risk coefficients:  BASED ON AGE ATB- AND ATD-SPECIFIC (RBE=10) COEFFICIENTS
           Leukemia:  Minimal latency(yrs):   2      Plateau(yrs):  40
      Solid cancers:  Minimal latency(yrs):  10      Plateau(yrs): 101
              DRREF:  2.0
Age at first expos.:  18
 Age at last expos.:  65
Total dose eq. (Sv):     1.000000
```

Strata for confirmation rates used in adjustment	Radiation-induced cancer deaths per 10**5	90.0% CI	Baseline cancer deaths per 10**5	Years of life lost	PC(90.0% CI)
None	291	(124, 684)	653	26	.31(.12, .78)
Crude(1950-75)	255	(108, 599)	653	27	.28(.11, .70)
Crude(1950-85)	253	(107, 594)	653	26	.28(.11, .70)
Sex(1950-75)	267	(113, 626)	653	26	.29(.12, .73)
Sex(1950-85)	280	(119, 658)	653	26	.30(.12, .76)
Sex-city(1950-85)	243	(103, 572)	653	26	.27(.11, .68)
Sex-city(1950-85)	246	(104, 577)	653	26	.27(.11, .68)
Age ATD(1950-75)	270	(115, 635)	653	27	.29(.12, .74)
Age ATD(1950-85)	271	(115, 637)	653	26	.29(.12, .74)
DS86(1950-75)	386	(164, 906)	653	26	.37(.14, .98)
DS86(1950-85)	433	(184, 1018)	653	26	.40(.15,1.00)

Table D.18. Excess mortality risk (%/Sv) of leukemia among females exposed to 0.02 Sv/y from ages 18 to 65 for the relative projection model. DS86 Dose equivalents adjusted for random error.

```
          Run date:  9/30/1993
             Title:  Lifetime risks
               Sex:  FEMALE
              Race:  WHITE
   Life table used:  1990
 Risk coefficients:  BASED ON AGE ATB- AND ATD-SPECIFIC (RBE=10) COEFFICIENTS
           Leukemia:  Minimal latency(yrs):   2      Plateau(yrs):  40
      Solid cancers:  Minimal latency(yrs):  10      Plateau(yrs): 101
              DRREF:  2.0
Age at first expos.:  18
 Age at last expos.:  65
Total dose eq. (Sv):     1.000000
```

Strata for confirmation rates used in adjustment	Radiation-induced cancer deaths per 10**5	90.0% CI	Baseline cancer deaths per 10**5	Years of life lost	PC(90.0% CI)
None	814	(346, 1910)	653	40	.55(.19,1.00)
Crude(1950-75)	621	(264, 1457)	653	44	.49(.17,1.00)
Crude(1950-85)	601	(256, 1410)	653	45	.48(.17,1.00)
Sex(1950-75)	652	(278, 1532)	653	43	.50(.18,1.00)
Sex(1950-85)	521	(222, 1224)	653	45	.44(.16,1.00)
Sex-city(1950-85)	475	(202, 1115)	653	43	.42(.16,1.00)
Sex-city(1950-85)	455	(194, 1068)	653	44	.41(.15,1.00)
Age ATD(1950-75)	614	(261, 1441)	653	39	.48(.17,1.00)
Age ATD(1950-85)	607	(258, 1425)	653	40	.48(.17,1.00)
DS86(1950-75)	1060	(452, 2489)	653	37	.62(.20,1.00)
DS86(1950-85)	1168	(497, 2741)	653	35	.64(.20,1.00)

Table D.19. Excess mortality risk (%/Sv) of leukemia among females exposed to 0.02 Sv/y from ages 18 to 65 for the transported relative projection model. Baseline rates adjusted with death certificate correction factors (DCCFs). DS86 Dose equivalents adjusted for random error.

```
          Run date:  9/30/1993
             Title:  Lifetime risks
               Sex:  FEMALE
              Race:  WHITE
   Life table used:  1990
  Risk coefficients:  BASED ON AGE ATB- AND ATD-SPECIFIC (RBE=10) COEFFICIENTS
           Leukemia:  Minimal latency(yrs):   2      Plateau(yrs):  40
      Solid cancers:  Minimal latency(yrs):  10      Plateau(yrs): 101
              DRREF:  2.0
Age at first expos.:  18
 Age at last expos.:  65
Total dose eq. (Sv):     1.000000
```

Strata for confirmation rates used in adjustment	Radiation-induced cancer deaths per 10**5	90.0% CI	Baseline cancer deaths per 10**5	Years of life lost	PC(90.0% CI)
None	291	(124, 684)	581	26	.33(.13, .87)
Crude(1950- 5)	255	(108, 599)	581	27	.31(.12, .78)
Crude(1950-85)	253	(107, 594)	581	26	.30(.12, .77)
Sex(1950-75)	267	(113, 626)	581	26	.31(.12, .81)
Sex(1950-85)	280	(119, 658)	581	26	.33(.13, .84)
Sex-city(1950-85)	243	(103, 572)	581	26	.30(.12, .75)
Sex-city(1950-85)	246	(104, 577)	581	26	.30(.12, .76)
Age ATD(1950-75)	270	(115, 635)	581	27	.32(.12, .82)
Age ATD(1950-85)	271	(115, 637)	581	26	.32(.12, .82)
DS86(1950-75)	386	(164, 906)	581	26	.40(.15,1.00)
DS86(1950-85)	433	(184, 1018)	581	26	.43(.15,1.00)

Table D.20. Excess mortality risk (%/Sv) of leukemia among females exposed to 0.02 Sv/y from ages 18 to 65 for the relative projection model. Baseline rates adjusted with death certificate correction factors (DCCFs). DS86 Dose equivalents adjusted for random error.

```
          Run date:  9/30/1993
             Title:  Lifetime risks
               Sex:  FEMALE
              Race:  WHITE
   Life table used:  1990
  Risk coefficients:  BASED ON AGE ATB- AND ATD-SPECIFIC (RBE=10) COEFFICIENTS
           Leukemia:  Minimal latency(yrs):   2      Plateau(yrs):  40
      Solid cancers:  Minimal latency(yrs):  10      Plateau(yrs): 101
              DRREF:  2.0
Age at first expos.:  18
 Age at last expos.:  65
Total dose eq. (Sv):     1.000000
```

Strata for confirmation rates used in adjustment	Radiation-induced cancer deaths per 10**5	90.0% CI	Baseline cancer deaths per 10**5	Years of life lost	PC(90.0% CI)
None	725	(309, 1703)	581	40	.56(.18,1.00)
Crude(1950-75)	553	(235, 1299)	581	44	.49(.17,1.00)
Crude(1950-85)	535	(228, 1257)	581	45	.48(.17,1.00)
Sex(1950-75)	582	(248, 1365)	581	43	.50(.17,1.00)
Sex(1950-85)	465	(198, 1091)	581	45	.44(.16,1.00)
Sex-city(1950-85)	423	(180, 994)	581	43	.42(.15,1.00)
Sex-city(1950-85)	405	(172, 952)	581	44	.41(.15,1.00)
Age ATD(1950-75)	547	(233, 1284)	581	39	.48(.17,1.00)
Age ATD(1950-85)	541	(230, 1270)	581	40	.48(.17,1.00)
DS86(1950-75)	946	(403, 2220)	581	37	.62(.19,1.00)
DS86(1950-85)	1042	(444, 2445)	581	35	.64(.20,1.00)

Table D.21. Excess mortality risk (%/Sv) of nonleukemia among males exposed to 0.02 Sv/y from ages 18 to 65 for the absolute projection model.

```
          Run date: 10/ 1/1993
             TITLE: Lifetime risks
               Sex: MALE
              Race: WHITE
   Life table used: 1990
  Risk coefficients: BASED ON AGE ATB- AND ATD-SPECIFIC (RBE=10) COEFFICIENTS
           Leukemia: Minimal latency(yrs):  2      Plateau(yrs): 40
      Solid cancers: Minimal latency(yrs): 10      Plateau(yrs): 101
              DRREF: 2.0
Age at first expos.: 18
 Age at last expos.: 65
Total dose eq. (Sv):    1.000000
```

Strata for confirmation rates used in adjustment	Radiation-induced cancer deaths per 10**5	90.0% CI	Baseline cancer deaths per 10**5	Years of life lost	PC(90.0% CI)
None	1934	(786, 4753)	24536	26	.07(.03, .18)
Crude(1950-75)	1826	(743, 4488)	24536	26	.07(.03, .17)
Crude(1950-85)	1571	(639, 3862)	24536	27	.06(.02, .15)
Sex(1950-75)	1855	(754, 4559)	24536	27	.07(.03, .17)
Sex(1950-85)	1637	(666, 4025)	24536	27	.06(.03, .15)
Sex-city(1950-85)	1853	(754, 4555)	24536	27	.07(.03, .17)
Sex-city(1950-85)	1631	(663, 4010)	24536	27	.06(.03, .15)
Age ATD(1950-75)	1952	(794, 4799)	24536	26	.07(.03, .18)
Age ATD(1950-85)	1909	(777, 4694)	24536	27	.07(.03, .18)
DS86(1950-75)	2375	(966, 5837)	24536	27	.09(.04, .22)
DS86(1950-85)	2621	(1066, 6441)	24536	26	.10(.04, .24)

Table D.22. Excess mortality risk (%/Sv) of nonleukemia among males exposed to 0.02 Sv/y from ages 18 to 65 for the transported relative projection model.

```
          Run date: 10/ 1/1993
             TITLE: Lifetime risks
               Sex: MALE
              Race: WHITE
   Life table used: 1990
  Risk coefficients: BASED ON AGE ATB- AND ATD-SPECIFIC (RBE=10) COEFFICIENTS
           Leukemia: Minimal latency(yrs):  2      Plateau(yrs): 40
      Solid cancers: Minimal latency(yrs): 10      Plateau(yrs): 101
              DRREF: 2.0
Age at first expos.: 18
 Age at last expos.: 65
Total dose eq. (Sv):    1.000000
```

Strata for confirmation rates used in adjustment	Radiation-induced cancer deaths per 10**5	90.0% CI	Baseline cancer deaths per 10**5	Years of life lost	PC(90.0% CI)
None	1744	(709, 4286)	24536	21	.07(.03, .16)
Crude(1950-75)	1640	(667, 4031)	24536	21	.06(.03, .15)
Crude(1950-85)	1429	(581, 3512)	24536	21	.06(.02, .14)
Sex(1950-75)	1664	(677, 4089)	24536	21	.06(.03, .16)
Sex(1950-85)	1488	(605, 3658)	24536	21	.06(.02, .14)
Sex-city(1950-85)	1662	(676, 4084)	24536	21	.06(.03, .16)
Sex-city(1950-85)	1483	(603, 3645)	24536	21	.06(.02, .14)
Age ATD(1950-75)	1753	(713, 4308)	24536	21	.07(.03, .16)
Age ATD(1950-85)	1723	(701, 4236)	24536	21	.07(.03, .16)
DS86(1950-75)	2152	(875, 5289)	24536	21	.08(.03, .20)
DS86(1950-85)	2367	(963, 5819)	24536	21	.09(.04, .22)

Table D.23. Excess mortality risk (%/Sv) of nonleukemia among males exposed to 0.02 Sv/y from ages 18 to 65 for the relative projection model.

```
          Run date: 10/ 1/1993
             TITLE: Lifetime risks
               Sex: MALE
              Race: WHITE
   Life table used: 1990
 Risk coefficients: BASED ON AGE ATB- AND ATD-SPECIFIC (RBE=10) COEFFICIENTS
          Leukemia: Minimal latency(yrs):  2      Plateau(yrs):  40
     Solid cancers: Minimal latency(yrs): 10      Plateau(yrs): 101
             DRREF: 2.0
Age at first expos.: 18
 Age at last expos.: 65
Total dose eq. (Sv):    1.000000
```

Strata for confirmation rates used in adjustment	Radiation-induced cancer deaths per 10**5	90.0% CI	Baseline cancer deaths per 10**5	Years of life lost	PC(90.0% CI)
None	1913	(778, 4702)	24536	24	.07(.03, .18)
Crude(1950-75)	1643	(668, 4038)	24536	24	.06(.03, .15)
Crude(1950-85)	1290	(524, 3170)	24536	25	.05(.02, .12)
Sex(1950-75)	1646	(669, 4046)	24536	24	.06(.03, .15)
Sex(1950-85)	1295	(526, 3183)	24536	25	.05(.02, .12)
Sex-city(1950-85)	1647	(670, 4048)	24536	24	.06(.03, .15)
Sex-city(1950-85)	1293	(526, 3178)	24536	25	.05(.02, .12)
Age ATD(1950-75)	1771	(720, 4354)	24536	24	.07(.03, .17)
Age ATD(1950-85)	1561	(635, 3838)	24536	25	.06(.02, .15)
DS86(1950-75)	2094	(852, 5147)	24536	24	.08(.03, .19)
DS86(1950-85)	2129	(866, 5233)	24536	24	.08(.03, .20)

Table D.24. Excess mortality risk (%/Sv) of nonleukemia among males exposed to 0.02 Sv/y from ages 18 to 65 for the transported relative projection model. Baseline rates adjusted with death certificate correction factors (DCCFs).

```
          Run date: 10/ 1/1993
             TITLE: Lifetime risks
               Sex: MALE
              Race: WHITE
   Life table used: 1990
 Risk coefficients: BASED ON AGE ATB- AND ATD-SPECIFIC (RBE=10) COEFFICIENTS
          Leukemia: Minimal latency(yrs):  2      Plateau(yrs):  40
     Solid cancers: Minimal latency(yrs): 10      Plateau(yrs): 101
             DRREF: 2.0
Age at first expos.: 18
 Age at last expos.: 65
Total dose eq. (Sv):    1.000000
```

Strata for confirmation rates used in adjustment	Radiation-induced cancer deaths per 10**5	90.0% CI	Baseline cancer deaths per 10**5	Years of life lost	PC(90.0% CI)
None	1744	(709, 4286)	25066	21	.07(.03, .16)
Crude(1950-75)	1640	(667, 4031)	25066	21	.06(.02, .15)
Crude(1950-85)	1429	(581, 3512)	25066	21	.05(.02, .13)
Sex(1950-75)	1663	(677, 4089)	25066	21	.06(.03, .15)
Sex(1950-85)	1488	(605, 3658)	25066	21	.06(.02, .14)
Sex-city(1950-85)	1662	(676, 4085)	25066	21	.06(.03, .15)
Sex-city(1950-85)	1483	(603, 3645)	25066	21	.06(.02, .14)
Age ATD(1950-75)	1753	(713, 4308)	25066	21	.07(.03, .16)
Age ATD(1950-85)	1723	(701, 4236)	25066	21	.06(.03, .16)
DS86(1950-75)	2152	(875, 5289)	25066	21	.08(.03, .19)
DS86(1950-85)	2367	(963, 5819)	25066	21	.09(.04, .21)

Table D.25. Excess mortality risk (%/Sv) of nonleukemia among males exposed to 0.02 Sv/y from ages 18 to 65 for the relative projection model. Baseline rates adjusted with death certificate correction factors (DCCFs).

```
          Run date: 10/ 1/1993
             TITLE: Lifetime risks
               Sex: MALE
              Race: WHITE
   Life table used: 1990
 Risk coefficients: BASED ON AGE ATB- AND ATD-SPECIFIC (RBE=10) COEFFICIENTS
          Leukemia: Minimal latency(yrs):  2      Plateau(yrs): 40
     Solid cancers: Minimal latency(yrs): 10      Plateau(yrs): 101
             DRREF: 2.0
Age at first expos.: 18
 Age at last expos.: 65
Total dose eq. (Sv):    1.000000
```

Strata for confirmation rates used in adjustment	Radiation-induced cancer deaths per 10**5	90.0% CI	Baseline cancer deaths per 10**5	Years of life lost	PC(90.0% CI)
None	1953	(794, 4801)	25066	24	.07(.03, .18)
Crude(1950-75)	1677	(682, 4123)	25066	24	.06(.03, .15)
Crude(1950-85)	1317	(536, 3237)	25066	25	.05(.02, .12)
Sex(1950-75)	1681	(684, 4132)	25066	24	.06(.03, .15)
Sex(1950-85)	1322	(538, 3250)	25066	25	.05(.02, .12)
Sex-city(1950-85)	1681	(684, 4133)	25066	24	.06(.03, .15)
Sex-city(1950-85)	1320	(537, 3245)	25066	25	.05(.02, .12)
Age ATD(1950-75)	1808	(736, 4445)	25066	24	.07(.03, .17)
Age ATD(1950-85)	1594	(648, 3919)	25066	25	.06(.02, .15)
DS86(1950-75)	2138	(869, 5255)	25066	24	.08(.03, .19)
DS86(1950-85)	2173	(884, 5342)	25066	24	.08(.03, .20)

Table D.26. Excess mortality risk (%/Sv) of nonleukemia among females exposed to 0.02 Sv/y from ages 18 to 65 for the absolute projection model.

```
          Run date: 10/ 1/1993
             TITLE: Lifetime risks
               Sex: FEMALE
              Race: WHITE
   Life table used: 1990
 Risk coefficients: BASED ON AGE ATB- AND ATD-SPECIFIC (RBE=10) COEFFICIENTS
          Leukemia: Minimal latency(yrs):  2      Plateau(yrs): 40
     Solid cancers: Minimal latency(yrs): 10      Plateau(yrs): 101
             DRREF: 2.0
Age at first expos.: 18
 Age at last expos.: 65
Total dose eq. (Sv):    1.000000
```

Strata for confirmation rates used in adjustment	Radiation-induced cancer deaths per 10**5	90.0% CI	Baseline cancer deaths per 10**5	Years of life lost	PC(90.0% CI)
None	2766	(1179, 6492)	21029	33	.12(.05, .27)
Crude(1950-75)	2852	(1215, 6692)	21029	32	.12(.05, .28)
Crude(1950-85)	2398	(1022, 5628)	21029	32	.10(.04, .24)
Sex(1950-75)	2810	(1197, 6594)	21029	32	.12(.05, .28)
Sex(1950-85)	2309	(984, 5418)	21029	32	.10(.04, .23)
Sex-city(1950-85)	2815	(1200, 6607)	21029	32	.12(.05, .28)
Sex-city(1950-85)	2309	(984, 5418)	21029	32	.10(.04, .23)
Age ATD(1950-75)	2918	(1243, 6847)	21029	33	.12(.05, .29)
Age ATD(1950-85)	2900	(1236, 6806)	21029	33	.12(.05, .28)
DS86(1950-75)	3338	(1422, 7832)	21029	33	.14(.06, .32)
DS86(1950-85)	3698	(1576, 8678)	21029	32	.15(.06, .35)

Table D.27. Excess mortality risk (%/Sv) of nonleukemia among females exposed to 0.02 Sv/y from ages 18 to 65 for the transported relative projection model.

```
          Run date: 10/ 1/1993
             TITLE: Lifetime risks
               Sex: FEMALE
              Race: WHITE
   Life table used: 1990
 Risk coefficients: BASED ON AGE ATB- AND ATD-SPECIFIC (RBE=10) COEFFICIENTS
           Leukemia: Minimal latency(yrs):  2      Plateau(yrs):  40
      Solid cancers: Minimal latency(yrs): 10      Plateau(yrs): 101
             DRREF: 2.0
Age at first expos.: 18
 Age at last expos.: 65
Total dose eq. (Sv):    1.000000
```

Strata for confirmation rates used in adjustment	Radiation-induced cancer deaths per 10**5	90.0% CI	Baseline cancer deaths per 10**5	Years of life lost	PC(90.0% CI)
None	2387	(1017, 5601)	21029	26	.10(.04, .24)
Crude(1950-75)	2486	(1059, 5835)	21029	26	.11(.05, .25)
Crude(1950-85)	2111	(899, 4954)	21029	26	.09(.04, .21)
Sex(1950-75)	2455	(1046, 5760)	21029	26	.10(.04, .25)
Sex(1950-85)	2035	(867, 4777)	21029	26	.09(.04, .21)
Sex-city(1950-85)	2459	(1048, 5771)	21029	26	.10(.04, .25)
Sex-city(1950-85)	2036	(867, 4777)	21029	26	.09(.04, .21)
Age ATD(1950-75)	2517	(1073, 5907)	21029	26	.11(.05, .25)
Age ATD(1950-85)	2510	(1070, 5891)	21029	26	.11(.05, .25)
DS86(1950-75)	2905	(1238, 6818)	21029	25	.12(.05, .28)
DS86(1950-85)	3202	(1364, 7513)	21029	25	.13(.06, .31)

Table D.28. Excess mortality risk (%/Sv) of nonleukemia among females exposed to 0.02 Sv/y from ages 18 to 65 for the relative projection model.

```
          Run date: 10/ 1/1993
             TITLE: Lifetime risks
               Sex: FEMALE
              Race: WHITE
   Life table used: 1990
 Risk coefficients: BASED ON AGE ATB- AND ATD-SPECIFIC (RBE=10) COEFFICIENTS
           Leukemia: Minimal latency(yrs):  2      Plateau(yrs):  40
      Solid cancers: Minimal latency(yrs): 10      Plateau(yrs): 101
             DRREF: 2.0
Age at first expos.: 18
 Age at last expos.: 65
Total dose eq. (Sv):    1.000000
```

Strata for confirmation rates used in adjustment	Radiation-induced cancer deaths per 10**5	90.0% CI	Baseline cancer deaths per 10**5	Years of life lost	PC(90.0% CI)
None	3228	(1375, 7575)	21029	31	.13(.06, .31)
Crude(1950-75)	3116	(1328, 7312)	21029	30	.13(.05, .30)
Crude(1950-85)	2198	(937, 5158)	21029	32	.09(.04, .22)
Sex(1950-75)	3123	(1331, 7328)	21029	30	.13(.06, .30)
Sex(1950-85)	2214	(943, 5196)	21029	32	.10(.04, .22)
Sex-city(1950-85)	3135	(1336, 7357)	21029	30	.13(.06, .30)
Sex-city(1950-85)	2221	(946, 5212)	21029	32	.10(.04, .22)
Age ATD(1950-75)	3150	(1342, 7392)	21029	31	.13(.06, .31)
Age ATD(1950-85)	2701	(1151, 6339)	21029	32	.11(.05, .27)
DS86(1950-75)	3433	(1463, 8056)	21029	31	.14(.06, .33)
DS86(1950-85)	3372	(1437, 7913)	21029	31	.14(.06, .32)

Table D.29. Excess mortality risk (%/Sv) of nonleukemia among females exposed to 0.02 Sv/y from ages 18 to 65 for the transported relative projection model. Baseline rates adjusted with death certificate correction factors (DCCFs).

```
           Run date: 10/ 1/1993
              TITLE: Lifetime risks
                Sex: FEMALE
               Race: WHITE
     Life table used: 1990
   Risk coefficients: BASED ON AGE ATB- AND ATD-SPECIFIC (RBE=10) COEFFICIENTS
            Leukemia: Minimal latency(yrs):  2      Plateau(yrs): 40
       Solid cancers: Minimal latency(yrs): 10      Plateau(yrs): 101
               DRREF: 2.0
Age at first expos.: 18
 Age at last expos.: 65
Total dose eq. (Sv):    1.000000
```

Strata for confirmation rates used in adjustment	Radiation-induced cancer deaths per 10**5	90.0% CI	Baseline cancer deaths per 10**5	Years of life lost	PC(90.0% CI)
None	2387	(1017, 5601)	21483	26	.10(.04, .23)
Crude(1950-75)	2486	(1059, 5835)	21483	26	.10(.04, .24)
Crude(1950-85)	2111	(899, 4954)	21483	26	.09(.04, .21)
Sex(1950-75)	2455	(1046, 5760)	21483	26	.10(.04, .24)
Sex(1950-85)	2035	(867, 4777)	21483	26	.09(.04, .20)
Sex-city(1950-85)	2459	(1048, 5770)	21483	26	.10(.04, .24)
Sex-city(1950-85)	2036	(867, 4777)	21483	26	.09(.04, .20)
Age ATD(1950-75)	2517	(1072, 5907)	21483	26	.10(.04, .25)
Age ATD(1950-85)	2510	(1070, 5891)	21483	26	.10(.04, .25)
DS86(1950-75)	2905	(1238, 6818)	21483	25	.12(.05, .28)
DS86(1950-85)	3202	(1364, 7513)	21483	25	.13(.06, .30)

Table D.30. Excess mortality risk (%/Sv) of nonleukemia among females exposed to 0.02 Sv/y from ages 18 to 65 for the relative projection model. Baseline rates adjusted with death certificate correction factors (DCCFs).

```
           Run date: 10/ 1/1993
              TITLE: Lifetime risks
                Sex: FEMALE
               Race: WHITE
     Life table used: 1990
   Risk coefficients: BASED ON AGE ATB- AND ATD-SPECIFIC (RBE=10) COEFFICIENTS
            Leukemia: Minimal latency(yrs):  2      Plateau(yrs): 40
       Solid cancers: Minimal latency(yrs): 10      Plateau(yrs): 101
               DRREF: 2.0
Age at first expos.: 18
 Age at last expos.: 65
Total dose eq. (Sv):    1.000000
```

Strata for confirmation rates used in adjustment	Radiation-induced cancer deaths per 10**5	90.0% CI	Baseline cancer deaths per 10**5	Years of life lost	PC(90.0% CI)
None	3295	(1404, 7732)	21483	31	.13(.06, .31)
Crude(1950-75)	3180	(1355, 7463)	21483	30	.13(.05, .30)
Crude(1950-85)	2244	(956, 5267)	21483	32	.09(.04, .22)
Sex(1950-75)	3188	(1358, 7480)	21483	30	.13(.06, .30)
Sex(1950-85)	2261	(963, 5306)	21483	32	.10(.04, .22)
Sex-city(1950-85)	3200	(1364, 7509)	21483	30	.13(.06, .30)
Sex-city(1950-85)	2268	(966, 5322)	21483	32	.10(.04, .22)
Age ATD(1950-75)	3215	(1370, 7545)	21483	31	.13(.06, .31)
Age ATD(1950-85)	2758	(1175, 6472)	21483	32	.11(.05, .27)
DS86(1950-75)	3504	(1493, 8223)	21483	31	.14(.06, .33)
DS86(1950-85)	3442	(1466, 8076)	21483	31	.14(.06, .32)

Table D.31. Excess mortality risk (%/Sv) of nonleukemia among males exposed to 0.02 Sv/y from ages 18 to 65 for the absolute projection model.

Run date: 10/ 1/1993
TITLE: Lifetime risks
Sex: MALE
Race: WHITE
Life table used: 1990
Risk coefficients: BASED ON AGE ATB- AND ATD-SPECIFIC (RBE=10) COEFFICIENTS
Leukemia: Minimal latency(yrs): 2 Plateau(yrs): 40
Solid cancers: Minimal latency(yrs): 10 Plateau(yrs): 101
DRREF: 2.0
Age at first expos.: 18
Age at last expos.: 65
Total dose eq. (Sv): 1.000000

Strata for confirmation rates used in adjustment	Radiation-induced cancer deaths per 10**5	90.0% CI	Baseline cancer deaths per 10**5	Years of life lost	PC(90.0% CI)
None	2412	(981, 5930)	24536	26	.09(.04, .22)
Crude(1950-75)	2286	(930, 5620)	24536	27	.09(.03, .21)
Crude(1950-85)	1916	(779, 4709)	24536	28	.07(.03, .18)
Sex(1950-75)	2321	(944, 5704)	24536	27	.09(.04, .21)
Sex(1950-85)	1998	(813, 4910)	24536	28	.08(.03, .19)
Sex-city(1950-85)	2318	(943, 5698)	24536	27	.09(.04, .21)
Sex-city(1950-85)	1990	(810, 4892)	24536	28	.08(.03, .18)
Age ATD(1950-75)	2438	(992, 5992)	24536	27	.09(.04, .22)
Age ATD(1950-85)	2366	(962, 5816)	24536	27	.09(.04, .22)
DS86(1950-75)	2950	(1200, 7251)	24536	27	.11(.04, .26)
DS86(1950-85)	3239	(1318, 7962)	24536	26	.12(.05, .29)

Table D.32. Excess mortality risk (%/Sv) of nonleukemia among males exposed to 0.02 Sv/y from ages 18 to 65 for the transported relative projection model.

Run date: 10/ 1/1993
TITLE: Lifetime risks
Sex: MALE
Race: WHITE
Life table used: 1990
Risk coefficients: BASED ON AGE ATB- AND ATD-SPECIFIC (RBE=10) COEFFICIENTS
Leukemia: Minimal latency(yrs): 2 Plateau(yrs): 40
Solid cancers: Minimal latency(yrs): 10 Plateau(yrs): 101
DRREF: 2.0
Age at first expos.: 18
Age at last expos.: 65
Total dose eq. (Sv): 1.000000

Strata for confirmation rates used in adjustment	Radiation-induced cancer deaths per 10**5	90.0% CI	Baseline cancer deaths per 10**5	Years of life lost	PC(90.0% CI)
None	2170	(883, 5334)	24536	21	.08(.03, .20)
Crude(1950-75)	2043	(831, 5021)	24536	21	.08(.03, .19)
Crude(1950-85)	1735	(705, 4264)	24536	21	.07(.03, .16)
Sex(1950-75)	2070	(842, 5089)	24536	21	.08(.03, .19)
Sex(1950-85)	1807	(735, 4442)	24536	21	.07(.03, .17)
Sex-city(1950-85)	2067	(841, 5082)	24536	21	.08(.03, .19)
Sex-city(1950-85)	1801	(732, 4426)	24536	21	.07(.03, .17)
Age ATD(1950-75)	2180	(887, 5358)	24536	21	.08(.03, .20)
Age ATD(1950-85)	2127	(865, 5229)	24536	21	.08(.03, .20)
DS86(1950-75)	2662	(1083, 6543)	24536	21	.10(.04, .24)
DS86(1950-85)	2908	(1183, 7147)	24536	21	.11(.04, .26)

Table D.33. Excess mortality risk (%/Sv) of nonleukemia among males exposed to 0.02 Sv/y from ages 18 to 65 for the relative projection model.

```
          Run date: 10/ 1/1993
             TITLE: Lifetime risks
               Sex: MALE
              Race: WHITE
   Life table used: 1990
  Risk coefficients: BASED ON AGE ATB- AND ATD-SPECIFIC (RBE=10) COEFFICIENTS
           Leukemia: Minimal latency(yrs):  2      Plateau(yrs): 40
      Solid cancers: Minimal latency(yrs): 10      Plateau(yrs): 101
             DRREF: 2.0
Age at first expos.: 18
 Age at last expos.: 65
Total dose eq. (Sv):    1.000000
```

Strata for confirmation rates used in adjustment	Radiation-induced cancer deaths per 10**5	90.0% CI	Baseline cancer deaths per 10**5	Years of life lost	PC(90.0% CI)
None	2384	(970, 5861)	24536	24	.09(.04, .22)
Crude(1950-75)	2059	(837, 5060)	24536	24	.08(.03, .19)
Crude(1950-85)	1569	(638, 3856)	24536	25	.06(.02, .15)
Sex(1950-75)	2061	(838, 5065)	24536	24	.08(.03, .19)
Sex(1950-85)	1579	(642, 3881)	24536	25	.06(.02, .15)
Sex-city(1950-85)	2059	(837, 5061)	24536	24	.08(.03, .19)
Sex-city(1950-85)	1575	(641, 3873)	24536	25	.06(.02, .15)
Age ATD(1950-75)	2208	(898, 5428)	24536	24	.08(.03, .20)
Age ATD(1950-85)	1933	(786, 4751)	24536	25	.07(.03, .18)
DS86(1950-75)	2598	(1057, 6387)	24536	24	.10(.04, .24)
DS86(1950-85)	2634	(1072, 6475)	24536	24	.10(.04, .24)

Table D.34. Excess mortality risk (%/Sv) of nonleukemia among males exposed to 0.02 Sv/y from ages 18 to 65 for the transported relative projection model. Baseline rates adjusted with death certificate correction factors (DCCFs).

```
          Run date: 10/ 1/1993
             TITLE: Lifetime risks
               Sex: MALE
              Race: WHITE
   Life table used: 1990
  Risk coefficients: BASED ON AGE ATB- AND ATD-SPECIFIC (RBE=10) COEFFICIENTS
           Leukemia: Minimal latency(yrs):  2      Plateau(yrs): 40
      Solid cancers: Minimal latency(yrs): 10      Plateau(yrs): 101
             DRREF: 2.0
Age at first expos.: 18
 Age at last expos.: 65
Total dose eq. (Sv):    1.000000
```

Strata for confirmation rates used in adjustment	Radiation-induced cancer deaths per 10**5	90.0% CI	Baseline cancer deaths per 10**5	Years of life lost	PC(90.0% CI)
None	2170	(883, 5334)	25066	21	.08(.03, .20)
Crude(1950-75)	2043	(831, 5021)	25066	21	.08(.03, .19)
Crude(1950-85)	1735	(705, 4264)	25066	21	.06(.03, .16)
Sex(1950-75)	2070	(842, 5089)	25066	21	.08(.03, .19)
Sex(1950-85)	1807	(735, 4442)	25066	21	.07(.03, .17)
Sex-city(1950-85)	2067	(841, 5082)	25066	21	.08(.03, .19)
Sex-city(1950-85)	1801	(732, 4426)	25066	21	.07(.03, .16)
Age ATD(1950-75)	2180	(887, 5358)	25066	21	.08(.03, .20)
Age ATD(1950-85)	2127	(865, 5229)	25066	21	.08(.03, .19)
DS86(1950-75)	2662	(1083, 6543)	25066	21	.10(.04, .24)
DS86(1950-85)	2908	(1183, 7147)	25066	21	.10(.04, .26)

Table D.35. Excess mortality risk (%/Sv) of nonleukemia among males exposed to 0.02 Sv/y from ages 18 to 65 for the relative projection model. Baseline rates adjusted with death certificate correction factors (DCCFs).

```
           Run date: 10/ 1/1993
              TITLE: Lifetime risks
                Sex: MALE
               Race: WHITE
     Life table used: 1990
   Risk coefficients: BASED ON AGE ATB- AND ATD-SPECIFIC (RBE=10) COEFFICIENTS
            Leukemia: Minimal latency(yrs):  2      Plateau(yrs):  40
       Solid cancers: Minimal latency(yrs): 10      Plateau(yrs): 101
              DRREF: 2.0
Age at first expos.: 18
 Age at last expos.: 65
Total dose eq. (Sv):    1.000000
```

Strata for confirmation rates used in adjustment	Radiation-induced cancer deaths per 10**5	90.0% CI	Baseline cancer deaths per 10**5	Years of life lost	PC(90.0% CI)
None	2434	(990, 5983)	25066	24	.09(.04, .22)
Crude(1950-75)	2102	(855, 5166)	25066	24	.08(.03, .19)
Crude(1950-85)	1602	(651, 3937)	25066	25	.06(.02, .15)
Sex(1950-75)	2104	(856, 5171)	25066	24	.08(.03, .19)
Sex(1950-85)	1612	(656, 3963)	25066	25	.06(.02, .15)
Sex-city(1950-85)	2102	(855, 5167)	25066	24	.08(.03, .19)
Sex-city(1950-85)	1609	(654, 3955)	25066	25	.06(.02, .15)
Age ATD(1950-75)	2254	(917, 5542)	25066	24	.08(.03, .20)
Age ATD(1950-85)	1973	(803, 4850)	25066	25	.07(.03, .18)
DS86(1950-75)	2652	(1079, 6519)	25066	24	.10(.04, .24)
DS86(1950-85)	2689	(1094, 6610)	25066	24	.10(.04, .24)

Table D.36. Excess mortality risk (%/Sv) of nonleukemia among females exposed to 0.02 Sv/y from ages 18 to 65 for the absolute projection model.

```
           Run date: 10/ 1/1993
              TITLE: Lifetime risks
                Sex: FEMALE
               Race: WHITE
     Life table used: 1990
   Risk coefficients: BASED ON AGE ATB- AND ATD-SPECIFIC (RBE=10) COEFFICIENTS
            Leukemia: Minimal latency(yrs):  2      Plateau(yrs):  40
       Solid cancers: Minimal latency(yrs): 10      Plateau(yrs): 101
              DRREF: 2.0
Age at first expos.: 18
 Age at last expos.: 65
Total dose eq. (Sv):    1.000000
```

Strata for confirmation rates used in adjustment	Radiation-induced cancer deaths per 10**5	90.0% CI	Baseline cancer deaths per 10**5	Years of life lost	PC(90.0% CI)
None	3164	(1348, 7424)	21029	34	.13(.06, .31)
Crude(1950-75)	3272	(1394, 7679)	21029	32	.13(.06, .32)
Crude(1950-85)	2774	(1182, 6511)	21029	32	.12(.05, .27)
Sex(1950-75)	3224	(1374, 7566)	21029	32	.13(.06, .31)
Sex(1950-85)	2670	(1138, 6266)	21029	32	.11(.05, .26)
Sex-city(1950-85)	3231	(1377, 7583)	21029	32	.13(.06, .31)
Sex-city(1950-85)	2672	(1138, 6270)	21029	32	.11(.05, .26)
Age ATD(1950-75)	3342	(1424, 7841)	21029	33	.14(.06, .32)
Age ATD(1950-85)	3329	(1418, 7811)	21029	33	.14(.06, .32)
DS86(1950-75)	3841	(1637, 9014)	21029	33	.15(.07, .36)
DS86(1950-85)	4277	(1822, 10036)	21029	32	.17(.07, .40)

Table D.37. Excess mortality risk (%/Sv) of nonleukemia among females exposed to 0.02 Sv/y from ages 18 to 65 for the transported relative projection model.

```
          Run date: 10/ 1/1993
             TITLE: Lifetime risks
               Sex: FEMALE
              Race: WHITE
    Life table used: 1990
  Risk coefficients: BASED ON AGE ATB- AND ATD-SPECIFIC (RBE=10) COEFFICIENTS
           Leukemia: Minimal latency(yrs):  2      Plateau(yrs): 40
      Solid cancers: Minimal latency(yrs): 10      Plateau(yrs): 101
              DRREF: 2.0
Age at first expos.: 18
 Age at last expos.: 65
Total dose eq. (Sv):    1.000000
```

Strata for confirmation rates used in adjustment	Radiation-induced cancer deaths per 10**5	90.0% CI	Baseline cancer deaths per 10**5	Years of life lost	PC(90.0% CI)
None	2731	(1163, 6408)	21029	26	.11(.05, .27)
Crude(1950-75)	2844	(1212, 6675)	21029	26	.12(.05, .28)
Crude(1950-85)	2433	(1037, 5710)	21029	26	.10(.04, .24)
Sex(1950-75)	2808	(1196, 6590)	21029	26	.12(.05, .28)
Sex(1950-85)	2347	(1000, 5507)	21029	26	.10(.04, .24)
Sex-city(1950-85)	2814	(1199, 6603)	21029	26	.12(.05, .28)
Sex-city(1950-85)	2348	(1000, 5510)	21029	26	.10(.04, .24)
Age ATD(1950-75)	2879	(1226, 6755)	21029	26	.12(.05, .28)
Age ATD(1950-85)	2876	(1225, 6749)	21029	26	.12(.05, .28)
DS86(1950-75)	3338	(1422, 7834)	21029	25	.14(.06, .32)
DS86(1950-85)	3688	(1571, 8654)	21029	25	.15(.06, .35)

Table D.38. Excess mortality risk (%/Sv) of nonleukemia among females exposed to 0.02 Sv/y from ages 18 to 65 for the relative projection model.

```
          Run date: 10/ 1/1993
             TITLE: Lifetime risks
               Sex: FEMALE
              Race: WHITE
    Life table used: 1990
  Risk coefficients: BASED ON AGE ATB- AND ATD-SPECIFIC (RBE=10) COEFFICIENTS
           Leukemia: Minimal latency(yrs):  2      Plateau(yrs): 40
      Solid cancers: Minimal latency(yrs): 10      Plateau(yrs): 101
              DRREF: 2.0
Age at first expos.: 18
 Age at last expos.: 65
Total dose eq. (Sv):    1.000000
```

Strata for confirmation rates used in adjustment	Radiation-induced cancer deaths per 10**5	90.0% CI	Baseline cancer deaths per 10**5	Years of life lost	PC(90.0% CI)
None	3689	(1572, 8656)	21029	31	.15(.06, .35)
Crude(1950-75)	3580	(1525, 8400)	21029	30	.15(.06, .34)
Crude(1950-85)	2545	(1084, 5973)	21029	33	.11(.05, .25)
Sex(1950-75)	3586	(1528, 8415)	21029	30	.15(.06, .34)
Sex(1950-85)	2562	(1092, 6013)	21029	33	.11(.05, .25)
Sex-city(1950-85)	3602	(1535, 8452)	21029	30	.15(.06, .34)
Sex-city(1950-85)	2572	(1096, 6035)	21029	33	.11(.05, .26)
Age ATD(1950-75)	3606	(1537, 8463)	21029	31	.15(.06, .34)
Age ATD(1950-85)	3103	(1322, 7282)	21029	32	.13(.05, .30)
DS86(1950-75)	3945	(1681, 9257)	21029	31	.16(.07, .37)
DS86(1950-85)	3906	(1664, 9166)	21029	31	.16(.07, .37)

Table D.39. Excess mortality risk (%/Sv) of nonleukemia among females exposed to 0.02 Sv/y from ages 18 to 65 for the transported relative projection model. Baseline rates adjusted with death certificate correction factors (DCCFs).

```
          Run date: 10/ 1/1993
             TITLE: Lifetime risks
               Sex: FEMALE
              Race: WHITE
   Life table used: 1990
  Risk coefficients: BASED ON AGE ATB- AND ATD-SPECIFIC (RBE=10) COEFFICIENTS
           Leukemia: Minimal latency(yrs):  2     Plateau(yrs):  40
      Solid cancers: Minimal latency(yrs): 10     Plateau(yrs): 101
              DRREF: 2.0
Age at first expos.: 18
 Age at last expos.: 65
Total dose eq. (Sv):    1.000000
```

Strata for confirmation rates used in adjustment	Radiation-induced cancer deaths per 10**5	90.0% CI	Baseline cancer deaths per 10**5	Years of life lost	PC(90.0% CI)
None	2731	(1163, 6408)	21483	26	.11(.05, .26)
Crude(1950-75)	2844	(1212, 6675)	21483	26	.12(.05, .27)
Crude(1950-85)	2433	(1037, 5710)	21483	26	.10(.04, .24)
Sex(1950-75)	2808	(1196, 6590)	21483	26	.12(.05, .27)
Sex(1950-85)	2347	(1000, 5507)	21483	26	.10(.04, .23)
Sex-city(1950-85)	2814	(1199, 6603)	21483	26	.12(.05, .27)
Sex-city(1950-85)	2348	(1000, 5510)	21483	26	.10(.04, .23)
Age ATD(1950-75)	2879	(1227, 6755)	21483	26	.12(.05, .28)
Age ATD(1950-85)	2876	(1225, 6749)	21483	26	.12(.05, .28)
DS86(1950-75)	3338	(1423, 7834)	21483	25	.13(.06, .32)
DS86(1950-85)	3688	(1571, 8654)	21483	25	.15(.06, .34)

Table D.40. Excess mortality risk (%/Sv) of nonleukemia among females exposed to 0.02 Sv/y from ages 18 to 65 for the relative projection model. Baseline rates adjusted with death certificate correction factors (DCCFs).

```
          Run date: 10/ 1/1993
             TITLE: Lifetime risks
               Sex: FEMALE
              Race: WHITE
   Life table used: 1990
  Risk coefficients: BASED ON AGE ATB- AND ATD-SPECIFIC (RBE=10) COEFFICIENTS
           Leukemia: Minimal latency(yrs):  2     Plateau(yrs):  40
      Solid cancers: Minimal latency(yrs): 10     Plateau(yrs): 101
              DRREF: 2.0
Age at first expos.: 18
 Age at last expos.: 65
Total dose eq. (Sv):    1.000000
```

Strata for confirmation rates used in adjustment	Radiation-induced cancer deaths per 10**5	90.0% CI	Baseline cancer deaths per 10**5	Years of life lost	PC(90.0% CI)
None	3765	(1604, 8834)	21483	31	.15(.06, .35)
Crude(1950-75)	3654	(1557, 8573)	21483	30	.15(.06, .34)
Crude(1950-85)	2598	(1107, 6098)	21483	33	.11(.05, .25)
Sex(1950-75)	3660	(1560, 8589)	21483	30	.15(.06, .34)
Sex(1950-85)	2616	(1115, 6139)	21483	33	.11(.05, .25)
Sex-city(1950-85)	3676	(1566, 8626)	21483	30	.15(.06, .34)
Sex-city(1950-85)	2626	(1119, 6162)	21483	33	.11(.05, .26)
Age ATD(1950-75)	3681	(1568, 8637)	21483	31	.15(.06, .34)
Age ATD(1950-85)	3167	(1350, 7433)	21483	32	.13(.05, .30)
DS86(1950-75)	4026	(1715, 9447)	21483	31	.16(.07, .37)
DS86(1950-85)	3986	(1699, 9354)	21483	31	.16(.07, .37)

Table D.41. Excess mortality risk (%/Sv) of digestive cancer among males exposed to 0.02 Sv/y from ages 18 to 65 for the BEIR-V relative projection model.

```
           Run date:  10/ 3/1993
              Title:  Lifetime risks
                Sex:  MALE
               Race:  WHITE
    Life table used:  1990
  Risk coefficients:  BASED ON BEIR-V MODELS
            Leukemia:  Minimal latency(yrs):   2      Plateau(yrs):  40
       Solid cancers:  Minimal latency(yrs):  10      Plateau(yrs): 101
               DRREF:  2.0
Age at first expos.:    18
 Age at last expos.:    65
Total dose eq. (Sv):      1.000000
```

Strata for confirmation rates used in adjustment	Radiation-induced cancer deaths per 10**5	90.0% CI	Baseline cancer deaths per 10**5	Years of life lost	PC(90.0% CI)
None	772	(314, 1899)	6371	22	.11(.04, .27)
Crude(1950-75)	656	(267, 1613)	6371	21	.09(.04, .23)
Crude(1950-85)	540	(219, 1327)	6371	21	.08(.03, .19)
Sex(1950-75)	639	(260, 1572)	6371	21	.09(.04, .23)
Sex(1950-85)	518	(210, 1274)	6371	21	.08(.03, .19)
Sex-city(1950-85)	725	(295, 1783)	6371	21	.10(.04, .25)
Sex-city(1950-85)	668	(272, 1644)	6371	21	.10(.04, .24)

Table D.42. Excess mortality risk (%/Sv) of leukemia among males exposed to 0.02 Sv/y from ages 18 to 65 for the BEIR-V relative projection model.

```
           Run date:  10/ 3/1993
              Title:  Lifetime risks
                Sex:  MALE
               Race:  WHITE
    Life table used:  1990
  Risk coefficients:  BASED ON BEIR-V MODELS
            Leukemia:  Minimal latency(yrs):   2      Plateau(yrs):  40
       Solid cancers:  Minimal latency(yrs):  10      Plateau(yrs): 101
               DRREF:  2.0
Age at first expos.:    18
 Age at last expos.:    65
Total dose eq. (Sv):      1.000000
```

Strata for confirmation rates used in adjustment	Radiation-induced cancer deaths per 10**5	90.0% CI	Baseline cancer deaths per 10**5	Years of life lost	PC(90.0% CI)
None	536	(218, 1318)	750	29	.42(.15,1.00)
Crude(1950-75)	276	(112, 679)	750	29	.27(.10, .69)
Crude(1950-85)	459	(186, 1129)	750	29	.38(.14,1.00)
Sex(1950-75)	492	(200, 1210)	750	29	.40(.15,1.00)
Sex(1950-85)	461	(187, 1134)	750	29	.38(.14,1.00)
Sex-city(1950-85)	414	(168, 1018)	750	29	.36(.13, .94)
Sex-city(1950-85)	418	(170, 1029)	750	29	.36(.13, .95)
Age ATD(1950-75)	424	(172, 1042)	750	29	.36(.14, .96)
Age ATD(1950-85)	427	(174, 1051)	750	29	.36(.14, .97)
DS86(1950-75)	846	(344, 2080)	750	28	.53(.18,1.00)
DS86(1950-85)	855	(348, 2102)	750	28	.53(.18,1.00)

Table D.43. Excess mortality risk (%/Sv) of digestive cancer among males exposed to 0.02 Sv/y from ages 18 to 65 for the BEIR-V relative projection model. Baseline rates adjusted with death certificate correction factors (DCCFs).

```
           Run date:  10/ 3/1993
              Title:  Lifetime risks
                Sex:  MALE
               Race:  WHITE
     Life table used:  1990
   Risk coefficients:  BASED ON BEIR-V MODELS
            Leukemia:  Minimal latency(yrs):   2      Plateau(yrs):  40
       Solid cancers:  Minimal latency(yrs):  10      Plateau(yrs): 101
               DRREF:  2.0
Age at first expos.:    18
 Age at last expos.:    65
Total dose eq. (Sv):      1.000000
```

Strata for confirmation rates used in adjustment	Radiation-induced cancer deaths per 10**5	90.0% CI	Baseline cancer deaths per 10**5	Years of life lost	PC(90.0% CI)
None	785	(319, 1929)	6474	22	.11(.04, .27)
Crude(1950-75)	667	(271, 1639)	6474	21	.09(.04, .23)
Crude(1950-85)	548	(223, 1349)	6474	21	.08(.03, .19)
Sex(1950-75)	650	(264, 1597)	6474	21	.09(.04, .23)
Sex(1950-85)	526	(214, 1294)	6474	21	.08(.03, .19)
Sex-city(1950-85)	737	(299, 1811)	6474	21	.10(.04, .25)
Sex-city(1950-85)	679	(276, 1670)	6474	21	.10(.04, .24)

Table D.44. Excess mortality risk (%/Sv) of leukemia among males exposed to 0.02 Sv/y from ages 18 to 65 for the BEIR-V relative projection model. Baseline rates adjusted with death certificate correction factors (DCCFs).

```
           Run date:  10/ 3/1993
              Title:  Lifetime risks
                Sex:  MALE
               Race:  WHITE
     Life table used:  1990
   Risk coefficients:  BASED ON BEIR-V MODELS
            Leukemia:  Minimal latency(yrs):   2      Plateau(yrs):  40
       Solid cancers:  Minimal latency(yrs):  10      Plateau(yrs): 101
               DRREF:  2.0
Age at first expos.:    18
 Age at last expos.:    65
Total dose eq. (Sv):      1.000000
```

Strata for confirmation rates used in adjustment	Radiation-induced cancer deaths per 10**5	90.0% CI	Baseline cancer deaths per 10**5	Years of life lost	PC(90.0% CI)
None	478	(194, 1175)	668	29	.42(.15,1.00)
Crude(1950-75)	246	(100, 605)	668	29	.27(.10, .70)
Crude(1950-85)	409	(166, 1006)	668	29	.38(.14,1.00)
Sex(1950-75)	439	(178, 1079)	668	29	.40(.15,1.00)
Sex(1950-85)	411	(167, 1011)	668	29	.38(.14,1.00)
Sex-city(1950-85)	369	(150, 907)	668	29	.36(.13, .95)
Sex-city(1950-85)	373	(151, 917)	668	29	.36(.13, .96)
Age ATD(1950-75)	378	(153, 929)	668	29	.36(.13, .97)
Age ATD(1950-85)	381	(155, 937)	668	29	.36(.14, .98)
DS86(1950-75)	754	(307, 1855)	668	28	.53(.18,1.00)
DS86(1950-85)	762	(310, 1874)	668	28	.53(.18,1.00)

Table D.45. Excess mortality risk (%/Sv) of digestive cancer among females exposed to 0.02 Sv/y from ages 18 to 65 for the BEIR-V relative projection model.

```
          Run date:  10/ 3/1993
             Title:  Lifetime risks
               Sex:  FEMALE
              Race:  WHITE
    Life table used:  1990
  Risk coefficients:  BASED ON BEIR-V MODELS
           Leukemia:  Minimal latency(yrs):   2      Plateau(yrs):  40
      Solid cancers:  Minimal latency(yrs):  10      Plateau(yrs): 101
              DRREF:  2.0
Age at first expos.:   18
 Age at last expos.:   65
Total dose eq. (Sv):     1.000000
```

Strata for confirmation rates used in adjustment	Radiation-induced cancer deaths per 10**5	90.0% CI	Baseline cancer deaths per 10**5	Years of life lost	PC(90.0% CI)
None	1303	(555, 3057)	6096	23	.18(.07, .43)
Crude(1950-75)	1147	(489, 2692)	6096	23	.16(.07, .39)
Crude(1950-85)	1044	(445, 2450)	6096	23	.15(.06, .36)
Sex(1950-75)	1170	(498, 2746)	6096	23	.16(.07, .39)
Sex(1950-85)	1071	(456, 2515)	6096	23	.15(.06, .37)
Sex-city(1950-85)	1285	(547, 3015)	6096	23	.17(.07, .42)
Sex-city(1950-85)	1239	(528, 2909)	6096	23	.17(.07, .41)

Table D.46. Excess mortality risk (%/Sv) of leukemia among females exposed to 0.02 Sv/y from ages 18 to 65 for the BEIR-V relative projection model.

```
          Run date:  10/ 3/1993
             Title:  Lifetime risks
               Sex:  FEMALE
              Race:  WHITE
    Life table used:  1990
  Risk coefficients:  BASED ON BEIR-V MODELS
           Leukemia:  Minimal latency(yrs):   2      Plateau(yrs):  40
      Solid cancers:  Minimal latency(yrs):  10      Plateau(yrs): 101
              DRREF:  2.0
Age at first expos.:   18
 Age at last expos.:   65
Total dose eq. (Sv):     1.000000
```

Strata for confirmation rates used in adjustment	Radiation-induced cancer deaths per 10**5	90.0% CI	Baseline cancer deaths per 10**5	Years of life lost	PC(90.0% CI)
None	433	(184, 1016)	653	36	.40(.15,1.00)
Crude(1950-75)	229	(97, 537)	653	34	.26(.10, .65)
Crude(1950-85)	371	(158, 871)	653	36	.36(.14, .95)
Sex(1950-75)	397	(169, 933)	653	36	.38(.14,1.00)
Sex(1950-85)	373	(159, 875)	653	36	.36(.14, .95)
Sex-city(1950-85)	334	(142, 785)	653	36	.34(.13, .88)
Sex-city(1950-85)	338	(144, 794)	653	36	.34(.13, .88)
Age ATD(1950-75)	343	(146, 805)	653	35	.34(.13, .89)
Age ATD(1950-85)	345	(147, 811)	653	35	.35(.13, .90)
DS86(1950-75)	687	(293, 1613)	653	34	.51(.18,1.00)
DS86(1950-85)	694	(296, 1630)	653	34	.52(.18,1.00)

Table D.47. Excess mortality risk (%/Sv) of digestive cancer among females exposed to 0.02 Sv/y from ages 18 to 65 for the BEIR-V relative projection model. Baseline rates adjusted with death certificate correction factors (DCCFs).

```
           Run date:  10/ 3/1993
              Title:  Lifetime risks
                Sex:  FEMALE
               Race:  WHITE
     Life table used:  1990
   Risk coefficients:  BASED ON BEIR-V MODELS
            Leukemia:  Minimal latency(yrs):   2      Plateau(yrs):  40
       Solid cancers:  Minimal latency(yrs):  10      Plateau(yrs): 101
               DRREF:  2.0
Age at first expos.:    18
 Age at last expos.:    65
Total dose eq. (Sv):      1.000000
```

Strata for confirmation rates used in adjustment	Radiation-induced cancer deaths per 10**5	90.0% CI	Baseline cancer deaths per 10**5	Years of life lost	PC(90.0% CI)
None	1323	(564, 3106)	6194	23	.18(.07, .43)
Crude(1950-75)	1165	(496, 2735)	6194	23	.16(.07, .39)
Crude(1950-85)	1060	(452, 2489)	6194	23	.15(.06, .36)
Sex(1950-75)	1188	(506, 2789)	6194	23	.16(.07, .39)
Sex(1950-85)	1088	(463, 2554)	6194	23	.15(.06, .37)
Sex-city(1950-85)	1305	(556, 3063)	6194	23	.17(.07, .42)
Sex-city(1950-85)	1259	(536, 2955)	6194	23	.17(.07, .41)

Table D.48. Excess mortality risk (%/Sv) of leukemia among females exposed to 0.02 Sv/y from ages 18 to 65 for the BEIR-V relative projection model. Baseline rates adjusted with death certificate correction factors (DCCFs).

```
           Run date:  10/ 3/1993
              Title:  Lifetime risks
                Sex:  FEMALE
               Race:  WHITE
     Life table used:  1990
   Risk coefficients:  BASED ON BEIR-V MODELS
            Leukemia:  Minimal latency(yrs):   2      Plateau(yrs):  40
       Solid cancers:  Minimal latency(yrs):  10      Plateau(yrs): 101
               DRREF:  2.0
Age at first expos.:    18
 Age at last expos.:    65
Total dose eq. (Sv):      1.000000
```

Strata for confirmation rates used in adjustment	Radiation-induced cancer deaths per 10**5	90.0% CI	Baseline cancer deaths per 10**5	Years of life lost	PC(90.0% CI)
None	385	(164, 905)	581	36	.40(.15,1.00)
Crude(1950-75)	204	(86, 478)	581	34	.26(.10, .65)
Crude(1950-85)	331	(141, 777)	581	36	.36(.14, .96)
Sex(1950-75)	354	(151, 832)	581	36	.38(.14,1.00)
Sex(1950-85)	332	(141, 780)	581	36	.36(.14, .97)
Sex-city(1950-85)	298	(127, 699)	581	36	.34(.13, .89)
Sex-city(1950-85)	301	(128, 707)	581	36	.34(.13, .89)
Age ATD(1950-75)	305	(130, 717)	581	35	.34(.13, .90)
Age ATD(1950-85)	308	(131, 723)	581	35	.35(.13, .91)
DS86(1950-75)	613	(261, 1438)	581	34	.51(.17,1.00)
DS86(1950-85)	619	(264, 1453)	581	34	.52(.17,1.00)

Table D.49. Excess mortality risk (%/Sv) of digestive cancer among males exposed to 0.02 Sv/y from ages 18 to 65 for the relative projection model.
DS86 Dose equivalents adjusted for random error.

```
           Run date:  10/ 3/1993
              Title:  Lifetime risks
                Sex:  MALE
               Race:  WHITE
    Life table used:  1990
  Risk coefficients:  BASED ON BEIR-V MODELS
            Leukemia:  Minimal latency(yrs):   2      Plateau(yrs):  40
       Solid cancers:  Minimal latency(yrs):  10      Plateau(yrs): 101
              DRREF:  2.0
Age at first expos.:   18
 Age at last expos.:   65
Total dose eq. (Sv):     1.000000
```

Strata for confirmation rates used in adjustment	Radiation-induced cancer deaths per 10**5	90.0% CI	Baseline cancer deaths per 10**5	Years of life lost	PC(90.0% CI)
None	831	(338, 2042)	6371	21	.12(.05, .29)
Crude(1950-75)	751	(305, 1846)	6371	21	.11(.04, .26)
Crude(1950-85)	624	(254, 1535)	6371	21	.09(.04, .22)
Sex(1950-75)	734	(299, 1806)	6371	21	.10(.04, .26)
Sex(1950-85)	606	(246, 1489)	6371	21	.09(.03, .22)
Sex-city(1950-85)	816	(332, 2006)	6371	21	.11(.05, .28)
Sex-city(1950-85)	738	(300, 1814)	6371	21	.10(.04, .26)

Table D.50. Excess mortality risk (%/Sv) of leukemia among males exposed to 0.02 Sv/y from ages 18 to 65 for the relative projection model.
DS86 Dose equivalents adjusted for random error.

```
           Run date:  10/ 3/1993
              Title:  Lifetime risks
                Sex:  MALE
               Race:  WHITE
    Life table used:  1990
  Risk coefficients:  BASED ON BEIR-V MODELS
            Leukemia:  Minimal latency(yrs):   2      Plateau(yrs):  40
       Solid cancers:  Minimal latency(yrs):  10      Plateau(yrs): 101
              DRREF:  2.0
Age at first expos.:   18
 Age at last expos.:   65
Total dose eq. (Sv):     1.000000
```

Strata for confirmation rates used in adjustment	Radiation-induced cancer deaths per 10**5	90.0% CI	Baseline cancer deaths per 10**5	Years of life lost	PC(90.0% CI)
None	537	(218, 1321)	750	29	.42(.15,1.00)
Crude(1950-75)	455	(185, 1119)	750	29	.38(.14,1.00)
Crude(1950-85)	463	(188, 1139)	750	29	.38(.14,1.00)
Sex(1950-75)	489	(199, 1204)	750	29	.39(.15,1.00)
Sex(1950-85)	464	(189, 1142)	750	29	.38(.14,1.00)
Sex-city(1950-85)	412	(167, 1014)	750	29	.35(.13, .94)
Sex-city(1950-85)	417	(169, 1025)	750	29	.36(.13, .95)
Age ATD(1950-75)	429	(174, 1054)	750	29	.36(.14, .97)
Age ATD(1950-85)	433	(176, 1066)	750	29	.37(.14, .98)
DS86(1950-75)	865	(352, 2127)	750	28	.54(.18,1.00)
DS86(1950-85)	886	(360, 2179)	750	28	.54(.19,1.00)

Table D.51. Excess mortality risk (%/Sv) of digestive cancer among males exposed to 0.02 Sv/y from ages 18 to 65 for the relative projection model.
Baseline rates adjusted with death certificate correction factors (DCCFs).
DS86 Dose equivalents adjusted for random error.

```
           Run date:  10/ 3/1993
              Title:  Lifetime risks
                Sex:  MALE
               Race:  WHITE
    Life table used:  1990
  Risk coefficients:  BASED ON BEIR-V MODELS
            Leukemia:  Minimal latency(yrs):   2      Plateau(yrs):  40
       Solid cancers:  Minimal latency(yrs):  10      Plateau(yrs): 101
              DRREF:  2.0
Age at first expos.:   18
 Age at last expos.:   65
Total dose eq. (Sv):     1.000000
```

Strata for confirmation rates used in adjustment	Radiation-induced cancer deaths per 10**5	90.0% CI	Baseline cancer deaths per 10**5	Years of life lost	PC(90.0% CI)
None	844	(343, 2075)	6474	21	.12(.05, .29)
Crude(1950-75)	763	(310, 1875)	6474	21	.11(.04, .26)
Crude(1950-85)	634	(258, 1560)	6474	21	.09(.04, .22)
Sex(1950-75)	746	(303, 1835)	6474	21	.10(.04, .26)
Sex(1950-85)	615	(250, 1513)	6474	21	.09(.03, .22)
Sex-city(1950-85)	829	(337, 2037)	6474	21	.11(.05, .28)
Sex-city(1950-85)	750	(305, 1843)	6474	21	.10(.04, .26)

Table D.52. Excess mortality risk (%/Sv) of leukemia among males exposed to 0.02 Sv/y from ages 18 to 65 for the relative projection model.
Baseline rates adjusted with death certificate correction factors (DCCFs).
DS86 Dose equivalents adjusted for random error.

```
           Run date:  10/ 3/1993
              Title:  Lifetime risks
                Sex:  MALE
               Race:  WHITE
    Life table used:  1990
  Risk coefficients:  BASED ON BEIR-V MODELS
            Leukemia:  Minimal latency(yrs):   2      Plateau(yrs):  40
       Solid cancers:  Minimal latency(yrs):  10      Plateau(yrs): 101
              DRREF:  2.0
Age at first expos.:   18
 Age at last expos.:   65
Total dose eq. (Sv):     1.000000
```

Strata for confirmation rates used in adjustment	Radiation-induced cancer deaths per 10**5	90.0% CI	Baseline cancer deaths per 10**5	Years of life lost	PC(90.0% CI)
None	479	(194, 1177)	668	29	.42(.15,1.00)
Crude(1950-75)	405	(165, 997)	668	29	.38(.14,1.00)
Crude(1950-85)	413	(168, 1015)	668	29	.38(.14,1.00)
Sex(1950-75)	436	(177, 1073)	668	29	.40(.14,1.00)
Sex(1950-85)	414	(168, 1018)	668	29	.38(.14,1.00)
Sex-city(1950-85)	367	(149, 904)	668	29	.36(.13, .95)
Sex-city(1950-85)	371	(151, 914)	668	29	.36(.13, .96)
Age ATD(1950-75)	382	(155, 940)	668	29	.36(.14, .98)
Age ATD(1950-85)	386	(157, 950)	668	29	.37(.14, .99)
DS86(1950-75)	772	(314, 1897)	668	28	.54(.18,1.00)
DS86(1950-85)	790	(321, 1943)	668	28	.54(.18,1.00)

Table D.53. Excess mortality risk (%/Sv) of digestive cancer among females exposed to 0.02 Sv/y from ages 18 to 65 for the relative projection model.
DS86 Dose equivalents adjusted for random error.

```
           Run date:  10/ 3/1993
              Title:  Lifetime risks
                Sex:  FEMALE
               Race:  WHITE
     Life table used:  1990
   Risk coefficients:  BASED ON BEIR-V MODELS
            Leukemia:  Minimal latency(yrs):   2      Plateau(yrs):  40
       Solid cancers:  Minimal latency(yrs):  10      Plateau(yrs): 101
               DRREF:  2.0
Age at first expos.:    18
 Age at last expos.:    65
Total dose eq. (Sv):      1.000000
```

Strata for confirmation rates used in adjustment	Radiation-induced cancer deaths per 10**5	90.0% CI	Baseline cancer deaths per 10**5	Years of life lost	PC(90.0% CI)
None	1505	(641, 3531)	6096	23	.20(.08, .48)
Crude(1950-75)	1332	(567, 3126)	6096	23	.18(.07, .44)
Crude(1950-85)	1213	(517, 2848)	6096	23	.17(.07, .41)
Sex(1950-75)	1358	(579, 3188)	6096	23	.18(.07, .45)
Sex(1950-85)	1244	(530, 2919)	6096	23	.17(.07, .42)
Sex-city(1950-85)	1490	(635, 3497)	6096	23	.20(.08, .48)
Sex-city(1950-85)	1438	(613, 3376)	6096	23	.19(.08, .47)

Table D.54. Excess mortality risk (%/Sv) of leukemia among females exposed to 0.02 Sv/y from ages 18 to 65 for the relative projection model.
DS86 Dose equivalents adjusted for random error.

```
           Run date:  10/ 3/1993
              Title:  Lifetime risks
                Sex:  FEMALE
               Race:  WHITE
     Life table used:  1990
   Risk coefficients:  BASED ON BEIR-V MODELS
            Leukemia:  Minimal latency(yrs):   2      Plateau(yrs):  40
       Solid cancers:  Minimal latency(yrs):  10      Plateau(yrs): 101
               DRREF:  2.0
Age at first expos.:    18
 Age at last expos.:    65
Total dose eq. (Sv):      1.000000
```

Strata for confirmation rates used in adjustment	Radiation-induced cancer deaths per 10**5	90.0% CI	Baseline cancer deaths per 10**5	Years of life lost	PC(90.0% CI)
None	435	(185, 1020)	653	36	.40(.15,1.00)
Crude(1950-75)	369	(157, 866)	653	35	.36(.14, .94)
Crude(1950-85)	375	(160, 881)	653	35	.37(.14, .96)
Sex(1950-75)	396	(169, 930)	653	36	.38(.14,1.00)
Sex(1950-85)	376	(160, 883)	653	36	.37(.14, .96)
Sex-city(1950-85)	334	(142, 784)	653	36	.34(.13, .87)
Sex-city(1950-85)	337	(144, 793)	653	36	.34(.13, .88)
Age ATD(1950-75)	347	(148, 816)	653	35	.35(.13, .90)
Age ATD(1950-85)	351	(149, 824)	653	35	.35(.13, .91)
DS86(1950-75)	704	(300, 1653)	653	34	.52(.18,1.00)
DS86(1950-85)	721	(307, 1694)	653	34	.52(.18,1.00)

Table D.55. Excess mortality risk (%/Sv) of digestive cancer among females exposed to 0.02 Sv/y from ages 18 to 65 for the relative projection model.
Baseline rates adjusted with death certificate correction factors (DCCFs).
DS86 Dose equivalents adjusted for random error.

```
          Run date:  10/ 3/1993
             Title:  Lifetime risks
               Sex:  FEMALE
              Race:  WHITE
   Life table used:  1990
 Risk coefficients:  BASED ON BEIR-V MODELS
           Leukemia:  Minimal latency(yrs):   2      Plateau(yrs):  40
      Solid cancers:  Minimal latency(yrs):  10      Plateau(yrs): 101
              DRREF:  2.0
Age at first expos.:   18
 Age at last expos.:   65
Total dose eq. (Sv):     1.000000
```

Strata for confirmation rates used in adjustment	Radiation-induced cancer deaths per 10**5	90.0% CI	Baseline cancer deaths per 10**5	Years of life lost	PC(90.0% CI)
None	1528	(651, 3587)	6194	23	.20(.08, .48)
Crude(1950-75)	1353	(576, 3175)	6194	23	.18(.07, .44)
Crude(1950-85)	1232	(525, 2893)	6194	23	.17(.07, .41)
Sex(1950-75)	1380	(588, 3238)	6194	23	.18(.07, .45)
Sex(1950-85)	1263	(538, 2965)	6194	23	.17(.07, .42)
Sex-city(1950-85)	1513	(645, 3552)	6194	23	.20(.08, .48)
Sex-city(1950-85)	1461	(622, 3429)	6194	23	.19(.08, .47)

Table D.56. Excess mortality risk (%/Sv) of leukemia among females exposed to 0.02 Sv/y from ages 18 to 65 for the relative projection model.
Baseline rates adjusted with death certificate correction factors (DCCFs).
DS86 Dose equivalents adjusted for random error.

```
          Run date:  10/ 3/1993
             Title:  Lifetime risks
               Sex:  FEMALE
              Race:  WHITE
   Life table used:  1990
 Risk coefficients:  BASED ON BEIR-V MODELS
           Leukemia:  Minimal latency(yrs):   2      Plateau(yrs):  40
      Solid cancers:  Minimal latency(yrs):  10      Plateau(yrs): 101
              DRREF:  2.0
Age at first expos.:   18
 Age at last expos.:   65
Total dose eq. (Sv):     1.000000
```

Strata for confirmation rates used in adjustment	Radiation-induced cancer deaths per 10**5	90.0% CI	Baseline cancer deaths per 10**5	Years of life lost	PC(90.0% CI)
None	387	(165, 909)	581	36	.40(.15,1.00)
Crude(1950-75)	328	(140, 771)	581	35	.36(.14, .96)
Crude(1950-85)	334	(142, 785)	581	35	.37(.14, .97)
Sex(1950-75)	353	(150, 829)	581	35	.38(.14,1.00)
Sex(1950-85)	335	(143, 787)	581	36	.37(.14, .97)
Sex-city(1950-85)	297	(126, 698)	581	36	.34(.13, .88)
Sex-city(1950-85)	301	(128, 706)	581	36	.34(.13, .89)
Age ATD(1950-75)	309	(132, 727)	581	35	.35(.13, .91)
Age ATD(1950-85)	313	(133, 735)	581	35	.35(.13, .92)
DS86(1950-75)	628	(267, 1474)	581	34	.52(.17,1.00)
DS86(1950-85)	643	(274, 1510)	581	34	.53(.18,1.00)

NRC FORM 335 (2-89) NRCM 1102, 3201, 3202

U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

(See instructions on the reverse)

1. REPORT NUMBER (Assigned by NRC. Add Vol., Supp., Rev., and Addendum Numbers, if any.)

NUREG/GR-0011

2. TITLE AND SUBTITLE

Information Bias and Lifetime Mortality Risks of Radiation-Induced Cancer

Low LET Radiation

3. DATE REPORT PUBLISHED

MONTH	YEAR
April	1994

4. FIN OR GRANT NUMBER

G1992

5. AUTHOR(S)

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6. TYPE OF REPORT

7. PERIOD COVERED *(Inclusive Dates)*

8. PERFORMING ORGANIZATION – NAME AND ADDRESS *(If NRC, provide Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address; if contractor, provide name and mailing address.)*

School of Public Health
University of Texas
Health Science Center
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Berkeley, CA 94720

9. SPONSORING ORGANIZATION – NAME AND ADDRESS *(If NRC, type "Same as above"; if contractor, provide NRC Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address.)*

Division of Regulatory Applications
Office of Nuclear Regulatory Research
U. S. Nuclear Regulatory Commission
Washington, D. C. 20555-0001

10. SUPPLEMENTARY NOTES

11. ABSTRACT *(200 words or less)*

Additive and multiplicative models of relative risk were used to measure the effect of cancer misclassification and DS86 random errors on lifetime risk projections in the Life Span Study (LSS) of Hiroshima and Nagasaki atomic bomb survivors. The true number of cancer deaths in each stratum of the cancer mortality cross-classification was estimated using sufficient statistics from the EM algorithm. Average survivor doses in the strata were corrected for DS86 random error (σ=0.45) by use of reduction factors. Poisson regression was used to model the corrected and uncorrected mortality rates with covariates for age at-time-of-bombing, age at-time-of-death and gender. Excess risks were in good agreement with risks in RERF Report 11 (Part 2) and the BEIR-V Report. Bias due to DS86 random error typically ranged from -15% to -30% for both sexes, and all sites and models. The total bias, including diagnostic misclassification, of excess risk of nonleukemia for exposure to 1 Sv from age 18 to 65 under the non-constant relative projection model was -37.1% for males and -23.3% for females. Total excess risks of leukemia under the relative projection model were biased -27.1% for males and -43.4% for females. Thus, nonleukemia risks for 1 Sv from ages 18 to 65 (DRREF=2) increased from 1.91%/Sv to 2.68%/Sv among males and from 3.23%/Sv to 4.02%/Sv among females. Leukemia excess risks increased from 0.87%/Sv to 1.10%/Sv among males and from 0.73%/Sv to 1.04%/Sv among females. Bias was dependent on the gender, site, correction method, exposure profile and projection model considered. Future studies that use LSS data for U.S. nuclear workers may be downwardly biased if lifetime risk projections are not adjusted for random and systematic errors.

12. KEY WORDS/DESCRIPTORS *(List words or phrases that will assist researchers in locating the report.)*

Hiroshima and Nagasaki
Radiation-induced cancer
Information bias
Dose-response modeling
Lifetime risk projection

13. AVAILABILITY STATEMENT

Unlimited

14. SECURITY CLASSIFICATION

(This Page) Unclassified

(This Report) Unclassified

15. NUMBER OF PAGES

16. PRICE

NRC FORM 335 (2-89)

DATE

FILMED

6/24/94

END