APPENDIX K

1 **MONETARY VALUATION OF NONFATAL CANCER RISK FOR**
2 **USE IN COST–BENEFIT ANALYSIS**

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS AND ACRONYMS

3	ADAMS	Agencywide Documents Access and Management System
4	BEIR	Biological Effects of Ionizing Radiation
5	BLS	Bureau of Labor Statistics
6	EPA	U.S. Environmental Protection Agency
7	Gy	gray
8	HRQL	health-related quality of life
9	ICRP	International Commission on Radiological Protection
10	IOM	Institute of Medicine
11	NRC	U.S. Nuclear Regulatory Commission
12	NSCLC	nonsmall cell lung cancer
13	QALY	quality-adjusted life year
14	UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
15	VSI	value of a statistical illness
16	VSL	value of a statistical life
17	WTP	willingness to pay

K.1   PURPOSE

This appendix provides guidance for valuing morbidity risks from radiation exposure for use in cost-benefit analysis at the U.S. Nuclear Regulatory Commission (NRC). Exposure to radiation can increase the chances of developing nonlethal health outcomes resulting in health costs and impacts to quality of life. To account for these impacts in cost-benefit analysis, these changes in morbidity risks are monetized to the extent practicable.

K.2   BACKGROUND

The dollar per person-rem conversion factor in the 1995 version of NUREG-1530, "Reassessment of the NRC's Dollar Per Person-Rem Conversion Factor Policy" (NRC, 1995), is based on the recommendations in the International Commission on Radiological Protection (ICRP) Publication 60, "1990 Recommendations of the International Commission on Radiological Protection," issued 1991 (ICRP, 1991). This ICRP publication provided a recommended nominal risk coefficient, which accounted for the probability of occurrence of a harmful health effect and a judgment of the severity of the effect. The ICRP nominal risk coefficient captures the total detriment, which represents both the probability of a harmful health effect and a judgment of its severity. The components of detriment included in the ICRP nominal risk coefficient are the probability of fatal cancer, the weighted probability of nonfatal cancer, the weighted probability of severe hereditary effects, and the length of life lost. The dollar per person-rem conversion factor is calculated as the product of the ICRP nominal risk coefficient and the value of a statistical life (VSL) in its dollar per person-rem conversion factor to provide a monetary value of the health risks resulting from radiation exposure.

Since the publication of the 1995 dollar per person-rem guidance, both the ICRP and the U.S. Environmental Protection Agency (EPA) have revised their cancer risk coefficient estimates based on updated information. Specifically, in 2006, the National Academies of Sciences published the "Health Risks from Exposure to Low Levels of Ionizing Radiation Biological Effects of Ionizing Radiation (BEIR) VII Phase 2," commonly referred to as the BEIR VII report (National Research Council, 2006). This study was conducted to advise the U.S. Government on the relationship between exposure to ionizing radiation and human health and was supported by several Federal agencies, including the NRC. The models recommended in the BEIR VII report serve as the basis for the estimates of radiogenic cancer risk calculated by the EPA[1] and published in EPA 402-R-11-001, "Radiogenic Cancer Risk Models and Projections for the U.S. Population," issued 2011 (EPA, 2011).

The NRC issued Revision 1 to NUREG-1530 in February 2022 (NRC, 2022). In Revision 1, the NRC adopted the EPA's cancer mortality risk coefficient, which is based on the BEIR VII report and is specific to the U.S. population. Only the cancer mortality risk from radiation exposure is monetized in NUREG-1530. This necessitates the establishment of a method to monetize morbidity (nonfatal) risks for use in cost-benefit analysis.

Valuing morbidity risk reductions presents several unique challenges. Unlike mortality, which has a single endpoint (i.e., death), morbidity effects can vary by the extent of severity, duration, and the perceived dread associated with symptoms and treatment. These differences have resulted in a scarcity of willingness-to-pay (WTP) estimates for morbidity risks. To identify an appropriate method for valuing morbidity risks, the NRC conducted a literature review of Office of Management and Budget guidance and Federal and international agency practices for estimating the economic valuation of nonfatal health risks. SECY-20-0074, "Valuing Nonfatal Cancer Risks in Cost-Benefit Analysis," issued August 2020 (NRC, 2020), documents this review.

---

[1] The EPA estimates the risk from low-level ionizing radiation as part of its responsibilities for regulating environmental exposures and as part of its Federal guidance role in radiation protection (EPA, 2011). The EPA is assigned the responsibility for developing guidance for all Federal agencies in the formulation of radiation protection standards (National Research Council, 1999).

1   This appendix provides the technical bases for valuing morbidity from averted radiation-induced
2   illnesses for staff use in the preparation of NRC cost-benefit analyses.
3

K.3 VALUE OF A STATISTICAL ILLNESS

The value of a statistical illness[2] (VSI) is used to monetize the benefit of a reduction in the risk of developing nonfatal cancer and is similar to the more commonly used metric for mortality risk values, the VSL. The VSI uses the marginal rate of substitution between small changes in illness risk and wealth to determine the equivalent monetary value of a statistical illness averted, for the sole purpose of describing the likely benefits of a regulatory action. This method is not applicable for estimating an identifiable individual or very large reductions in individual risks or large dose rate scenarios.

The VSI is estimated using a cost-effectiveness analysis measure known as quality-adjusted life year (QALY). QALYs are used extensively in medical decisionmaking as a measure to compare the nonmonetary benefit provided by various medical interventions and as a general measure of disease burden in health policy (IOM, 2006). The QALY remaining for a hypothetical individual living in a given health state is estimated as the product of two components: a utility[3] weight representing quality of life, and the length of time living in that particular state of health.

Figure K-1 illustrates the QALYs remaining for two health outcomes, one with a disease and one disease free. The health utility weight, often referred to as a health-related quality of life (HRQL) weight, is defined on the y-axis. It is indexed between 0 and 1, where 1 represents full health and 0 represents a state equivalent to death (Jia et al., 2016). The time lived in each state is represented on the x-axis. Thus, the QALYs remaining for each case can be estimated as the area under the health profile represented by the respective curves.

---

[2]   The VSI approximates society's WTP for small changes in nonfatal cancer risks. Conceptually, it represents an average individual's marginal rate of substitution between wealth and small risk reductions. Importantly, this term does not place a value on the pain and suffering of any specific individual who develops an illness. Instead, it reflects the WTP for small risk reductions from an individual's baseline, such as a 1 in 100,000 reduction in the chance of developing nonfatal cancer.

[3]   In health economics, utilities may be defined as cardinal values that represent the strength of an individual's preference for specific health outcomes (Tolley, 2009).
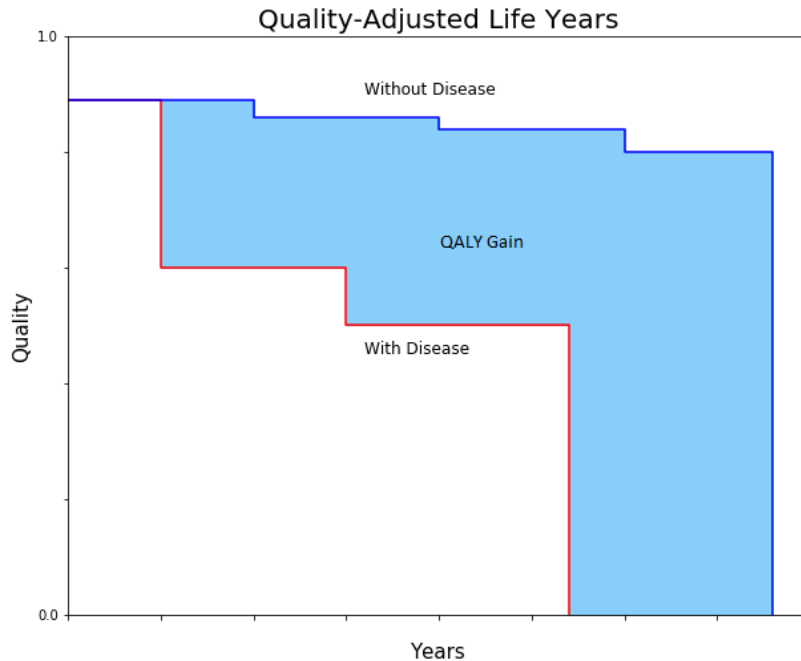
Figure K-1 QALYs Gained from an Averted Illness

Figure K-1 shows that the QALYs gained from an averted case of an illness can be approximated by the difference in areas under the "with disease" curve and the "without disease" curve, as illustrated by the shaded portion. This framework is used to estimate the QALYs gained, which is then used to monetize the benefits associated with an averted case of nonfatal cancer.

K.3.1   Selection of Illnesses

Cancers pose a significant risk from low-level chronic radiation exposure. The selection of cancer types for valuation is based on the lifetime attributable risk projections for cancer incidence reported in Table 3-15 of EPA 402-R-11-001. According to this EPA report, breast cancer and lung cancer are projected to have the highest gender-averaged lifetime attributable risk in cases per 10,000 person-gray (Gy) among solid cancers from low-dose, low-linear energy transfer, uniform whole body irradiation. These two cancer types also are among the most prevalent in the United States (Siegel, Miller, and Jemal, 2020).

While studies have demonstrated that radiation can induce hereditary effects in plants and animals, these effects have not been seen in human studies. Given the absence of genetic effects observed in children of atomic bomb survivors, the largest study population of individuals exposed to moderate acute doses, researchers are unable to reliably estimate the risk coefficient for heritable effects. Nonetheless, both the Committee on the Biological Effects of Ionizing Radiation (BEIR) and the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) have attempted to deduce human hereditary effect estimates indirectly. According to a 2001 UNSCEAR report, the total hereditary risk coefficient is estimated at approximately one-tenth that of fatal cancer (UNSCEAR, 2001). The BEIR VII report estimates that, at low or chronic doses of low-linear energy transfer radiation, the genetic risks "are very small compared to the baseline frequencies of genetic diseases in the population." Further, ICRP Publication 103, "The 2007 Recommendations of the International Commission on

Radiological Protection," issued 2007 (ICRP, 2007), provides a lower weighting factor for heritable effects after exposure to radiation due to a lack of observed effects.

While evidence shows that radiation can induce noncancer health effects (i.e., cataracts and cardiovascular disease), there is no evidence of an increase in the risk of these effects from low-level exposures (EPA, 2011).

This appendix focuses solely on the risks associated with low-level chronic exposures. It does not consider deterministic health effects from acute high doses.

K.3.2   Valuation Methodology and Data Sources

One of the principal challenges of applying the monetized QALY method to cancer illnesses is in developing a representative temporal illness profile that fully captures the potential disease states that an individual might experience. Cancer progression, like cancer initiation, is believed to be largely a stochastic process (Frei et al., 2020) in which metastasis involves some randomness and uncertainty. This means that an individual diagnosed with cancer has some likelihood of progressing through different stages or states that may have very different impacts on quality of life, but it is impossible to know with certainty in which state they will be at any future point in time. This stochastic property of carcinogenesis is well-suited to be modeled as a Markov process (Tan, 2015). In a Markov process, the state of a system in any period of time cannot be determined with certainty, but transition probabilities can describe the manner in which the system may transition from one period to the next (Anderson et al., 2018). A Markov chain is a mathematical model used to describe this process in discrete time steps (Manning et al., 2008). These models are used extensively in cost-effectiveness analysis and medical decisionmaking to simulate large patient cohorts over their lifetimes and therefore estimate long-term health outcomes (Graves et al., 2016).

In the fields of economics and decision theory, expected utility theory provides a way of quantifying an individual's preferences over future states that have uncertain outcomes called "gambles." Under certain expected utility theory axioms[4] for rational behavior, a utility function exists such that the utility associated with a gamble is the statistical expectation of an individual's valuations of the outcomes of that gamble. This is calculated by taking the weighted average of all possible outcomes, with the weights being assigned by the likelihood, or probability, that any particular event will occur. An example from Nechyba (2017) assumes that there are two potential future states, a "bad" state and a "good" state, where the probability of the bad state occurring is represented by δ. Given that the assumptions of expected utility theory are satisfied, there exists a utility function of the form:

$$EU = \delta u_B + (1 - \delta)u_G$$

where: u_B represents the utility associated with the bad state and
u_G represents the utility associated with the good state.

This function, referred to as a von Neumann-Morgenstern expected utility function, expresses an individual's utility of facing a particular gamble. Applying this framework, the expected health-related utility for an individual who is diagnosed with cancer at a future date can be

---

[4]   See Machina and Viscusi (2014) for further discussion of expected utility and the set of axioms that underlie this theory.

defined as the average of the HRQL utility associated with the various potential health states weighted by the probability of being in each state during that time period.

The expected QALYs[5] gained by an averted case of cancer is estimated by using a first-order Markov chain to define the health state probability distributions over time. A weighted average HRQL is used to estimate the expected utility associated with each remaining year of life. Cohort-based Markov state transition models based on existing cost-effectiveness analysis model specifications were used to evaluate the long-term impact that a cancer diagnosis has on patient quality of life. Simulated cohorts of individuals newly diagnosed with either nonsmall cell lung cancer (NSCLC) or breast cancer were constructed to model how the cohort transitioned between states over time. The resulting state probability distributions for each year of life following diagnosis were then combined with health utility information from published cost-effectiveness analysis studies and with current VSL estimates to monetize a statistical case of the illness.

K.3.2.1   Cohort Definition

For both public and occupational exposures, the NRC expects that the median age of the affected population is similar. According to the 2020 Labor Force Statistics from the Current Population Survey (BLS, 2021), the median age of workers in the electric power generation sector was estimated to be 44.6 years and the median age of the total U.S. workforce was 42.5 years. The median age of the U.S. population was estimated to be 38.5 years using the middle assumptions in the U.S. Census Bureau's most recently released demographic analysis (U.S. Census Bureau, 2020). The latency period of 13.6 years was chosen[6] and combined with a median age of the U.S. population of 38.5 years, resulting in an approximate age of 50 years for the model cohort. This is much younger than the median age at diagnosis for breast cancer and NSCLC, which are around 62 and 70 years old, respectively. For this reason, both cancer types are used in calculating the value of morbidity.

K.3.2.2   QALY Gain Models

Baseline Case

In estimating the number of QALYs saved by an avoided case of cancer, two approximations are made: (1) the remaining QALYs for an individual without disease and (2) the remaining QALYs for an individual with disease. The remaining QALYs for the case without disease is not equal to the number of life years remaining because survey data show that HRQL tends to decline with age (Hanmer et al., 2016). The scenario with the absence of the disease is referred to as the baseline case.

---

[5]   As described in Section K.3, QALYs remaining for an individual are the product of the health utility weight by the time spent experiencing that health utility. Given that each period of analysis is 1 year, the QALY associated with that year is equal to the HRQL experienced for that year. Thus, the QALYs remaining for an individual is the sum of the expected HRQL for each year of life remaining.

[6]   The age at diagnosis selected for this cohort is based on a review of the literature on radiation-induced cancer latency. The data from secondary malignancies in radiotherapy patients indicate a minimum latency period for induction of solid tumors of 10 years or more (Hall and Giaccia, 2012; Goske et al., 2014). According to the ICRP, the minimum and mean latent period for most solid cancers is 10 years and greater than 20 years, respectively (ICRP, 2001). One analysis looked specifically at a low-dose subcohort of the Japanese atomic bomb survivors and found a latency period of 13.60 years for lung cancer (Dropkin, 2007).

1   For the baseline case, only two states are defined: alive and dead. Age-dependent conditional
2   probabilities of dying for healthy individuals represent time-dependent transition probabilities
3   and are taken from the Centers for Disease Control and Prevention Life Tables for the most
4   recent year that data are available (Arias, 2019). The age-related health utility weights are
5   taken from Hanmer et al. (2016), which estimated nationally representative age and gender
6   stratified HRQL scores for the U.S. population based on data from the Medical Expenditure
7   Panel Survey (AHRQ, 2018). The expected QALYs remaining for the baseline case were
8   computed as the likelihood of survival for each year of life remaining for a 50-year-old times the
9   gender-averaged HRQL score associated with that year. Summing these values over the
10   remaining life years represents the expected QALYs remaining for a 50-year-old for the baseline
11   case.
12
13   **Breast Cancer Markov Model**
14
15   The QALYs remaining for an individual diagnosed with breast cancer are estimated using a
16   Markov model based on an evaluation of the cost-effectiveness of different predictive assay
17   strategies on the outcomes of breast cancer patients (Blank et al., 2010). The model sorts
18   patients into five distinct health states, as shown in Figure K-2, including a single absorbing
19   state of death.
20
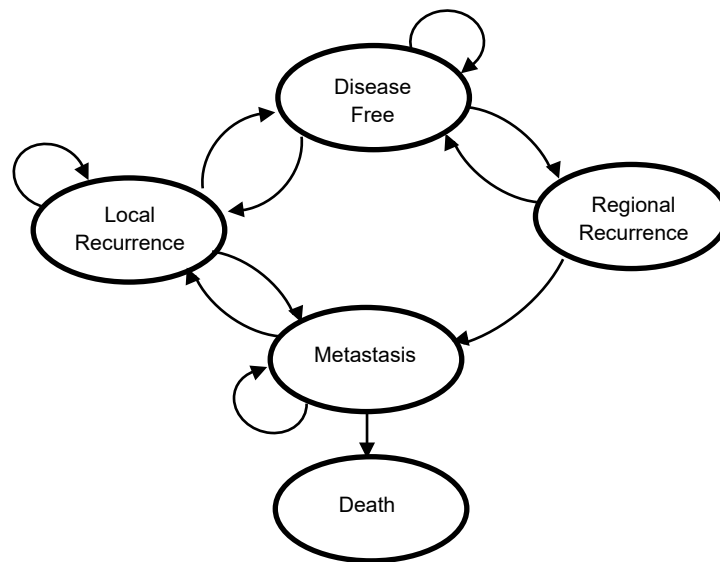
21
22   **Figure K-2 Breast Cancer Model State Transition Diagram**
23   Source: Adapted from Blank et al. (2010)
24
25   The health utility estimates for each state are taken from those reported in Blank et al. (2010).
26
27   **Lung Cancer Markov Model**
28
29   The Lung Cancer Markov model is based in part on the postdiagnosis model described in Hofer
30   et al. (2018), which evaluated the efficacy of lung cancer screening programs in Germany. This
31   model consists of 10 possible health states, including a single absorbing state of death.
32   Figure K-3 shows the model structure and the possible transitions between states. Initially,
33   patients are placed into one of the treatment states (outlined by a dashed line in Figure K-3).
34   Transition probabilities are taken from those reported in Hofer et al. (2018) and converted to
35   1-year transition probabilities from their initial 3-month cycle length using the approach in Ho

1   and Yi (2004). Because data are not available to develop age-specific transition probabilities,
2   the model assumes that age does not affect the speed of progression between stages. The
3   NRC makes the same assumption and uses time-independent transition probabilities for
4   modeling lung cancer using a Markov model.
5
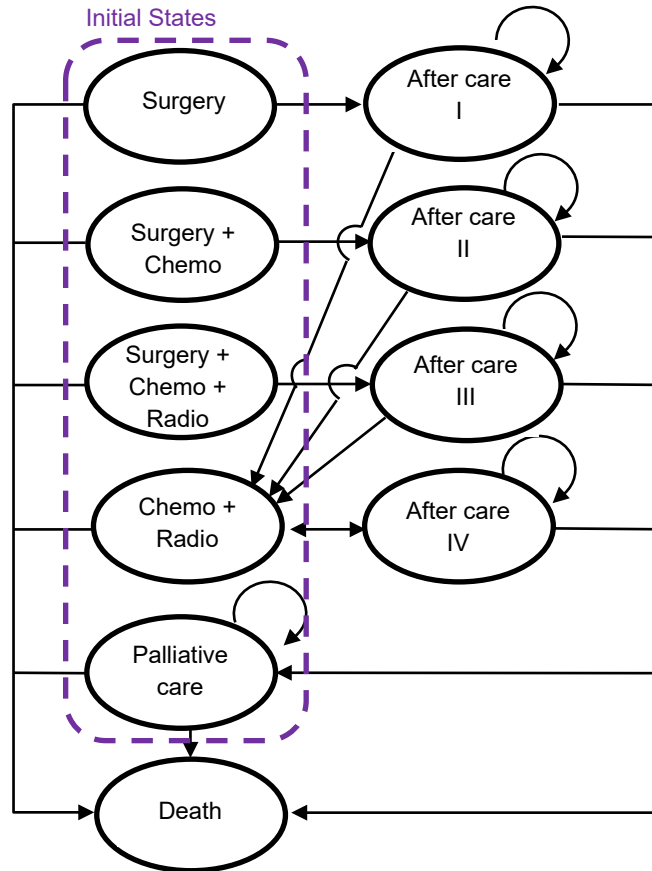
Figure K-3 NSCLC Model State Transition Diagram
Source: Adapted from Hofer et al. (2018)

10   To construct an initial cohort vector representative of U.S.-based NSCLC patients, the stage at
11   diagnosis distribution for newly diagnosed NSCLC patients was obtained from the National
12   Cancer Database[7] using 2016 data, the most recent year of diagnosis available. Patients are
13   binned into initial treatment states by mapping the stage at diagnosis from the National Cancer
14   Database to the stages delineated in the postdiagnosis model. The unknown stages are
15   excluded, and the percentages are normalized to provide the initial distribution, as shown in
16   Figure K-4.
17

---

[7]   The National Cancer Database is a nationwide oncology outcomes database sponsored by the American
         College of Surgeons and the American Cancer Society. This database contains hospital registry data from
         over 1,500 facilities representing approximately 70 percent of newly diagnosed cancer cases in the United
         States (NCDB, 2021).

National Cancer Database		Lung Cancer Model	
Stage	%	Stage	%
0	0.42%	I	32%
I	30.36%	II	9.5%
II	9.26%	IIIa	9.3%
III	18.22%	IIIb	9.3%
IV	39.25%	IV	40.3%
Total[a]	97.51%	Total	100%

[a] Unknown diagnosis stages are excluded and the adjusted total is used to normalize the Lung Cancer Model stage percentages.

Figure K-4 Stage at Diagnosis Mapping – Lung Cancer

The stage distributions mapped in Figure K-4 are used in combination with the distribution of treatments by lung cancer stage reported in Hofer et al. (2018) to sort the cohort into the treatment states to form the initial states vector. This model simulates yearly transitions of patients between states for up to 60 years. Each year, the proportion of patients in each state is used to weight the HRQL index for those health states to develop an annual weighted HRQL.

QALY Gained from Averted Cancers

The QALYs gained from an averted case of cancer are computed by subtracting the annual weighted HRQL estimates of the "with cancer" case from that of the baseline model. Table K-1 presents the QALYs gained from an averted case of nonfatal breast cancer and lung cancer.

Table K-1 QALYs Gained from Averted Case of Nonfatal Cancers

Nonfatal Cancer	QALYs Gained Per Case
Breast cancer	0.89
Lung cancer	1.62

The expected QALYs gained are because of averted morbidity only and do not reflect any potential life years gained or lost from averted cancer mortality.

K.3.2.3   Valuing of Morbidity Risk Reductions

Willingness to pay (WTP) refers to the maximum amount of money an individual would be willing to pay to obtain a benefit or avoid a detriment. As described in SECY-20-0074, WTP is widely accepted as the preferred method for valuing the benefits of government regulation and for valuing changes in health risk. High-quality WTP estimates are not available for many morbidity risks, which require the use of proxy measures. Analysts should first review the literature to determine whether WTP estimates of reasonable quality are available for morbidity risks similar to those that would be addressed in the cost-benefit analysis.[8] If such estimates are available, the WTP values should be adjusted for inflation to reflect the time that has

---

[8]   Possible sources to search for potential WTP studies include bibliographic databases (e.g., American Economic Association EconLit Web site (http://www.aeaweb.org/econlit/index.php) and Environmental Valuation Reference Inventory Web site (https://www.evri.ca/en)).

1 elapsed since the WTP studies were conducted and for changes in real income using the
2 methods discussed in NUREG-1530, Revision 1. After the WTP estimate is inflated to the
3 common dollar year used in the analysis, the value of the averted nonfatal cancer is equal to:

5 $$Value\ of\ averted\ nonfatal\ cancer = WTP\ estimate_{adjusted}\ x\ QALY\ gain$$

7 If high-quality WTP estimates are not available, the analyst should apply values that combine
8 estimates of the results with estimates of the monetary value per QALY. The monetary value
9 per QALY gained is computed by dividing the current estimate of the VSL by the remaining
10 expected QALYs of an individual of the average age (40 years old) from the underlying VSL
11 studies.

13 The resulting expected QALYs remaining for an average individual aged 40 years is
14 33.217 QALYs. The low, best, and high VSL values are divided by the future expected QALYs,
15 33.217 QALYs, to provide a range of dollar per QALY values for monetizing health detriment as
16 shown in Table K-2.

18 **Table K-2 Value per QALY**

Estimate	VSL [a] (2014 dollars)	Value per QALY (2014 dollars) [b]
Low	$4,500,000	$140,000
Best	$9,000,000	$270,000
High	$13,000,000	$390,000

19 [a] The VSL estimates are from NUREG-1530, Revision 1, Table 3. For analyses that use a different dollar year, the
20 VSL estimates need to be adjusted to reflect inflation and real income growth, as discussed in NUREG-1530,
21 Revision 1.
22 [b] The value per QALY is calculated by dividing the respective VSL estimates by the expected QALYs gained and
23 rounded to two significant figures.

K.3.3 Results

27 Based on this modeling, the NRC uses the values provided in Table K-3 as the bases to value a
28 nonspecific radiation-induced cancer and uses the low estimate based on the breast cancer
29 model, the average of the estimates for the best estimate, and the high lung cancer model
30 estimate for the high estimate.

32 **Table K-3 Value per Nonfatal Cancer Case**

Estimate	Value per QALY (2014 dollars)	QALYs Gained	Value per Nonfatal Cancer (2014 dollars)
Low	$140,000	0.89	$130,000
Best	$270,000	1.26	$340,000
High	$390,000	1.62	$630,000

34 The NRC acknowledges that there may be unique circumstances for which other dollar
35 conversion factors may warrant consideration, such as for environmental justice. For example,

1 doses to a population whose age distribution is not representative of the general population
2 could be subject to a different risk coefficient because health risks are directly related to the age
3 distribution of the affected population. The analyst could include alternative valuations in the
4 regulatory analysis to reflect these impacts. To convert the value per nonfatal cancer case to
5 value changes in routine or accident-related exposures requires the use of a nonfatal cancer
6 risk coefficient. As discussed in Section K.2 of this appendix and consistent with the risk
7 coefficient in NUREG-1530, Revision 1, the NRC adopted the nonfatal component of the EPA's
8 cancer mortality risk coefficient in EPA 402-R-11-001 to quantify the change in probability of
9 developing a nonfatal cancer from a change in dose. This value of 5.8×10^{-4} per person-rem is
10 calculated by subtracting the EPA's mortality cancer risk coefficient of 5.8×10^{-2} Gy^{-1} from the
11 cancer incidence risk coefficient of 1.16×10^{-1} Gy^{-1} and converting to rem^{-1} for low-linear energy
12 transfer radiation.
13
14 The morbidity risk conversion factor is the product of the value per nonfatal cancer and the
15 cancer morbidity risk coefficient, which yields the values in Table K-4.
16
17 **Table K-4 Morbidity Risk Conversion Factors**

Estimate	Morbidity Risk Conversion Factor (Dollar per Person-Rem) [a,b]
Low	75
Best	200
High	370

18 [a] The morbidity risk conversion factor is calculated by multiplying the value per nonfatal cancer estimate by the
19 cancer morbidity risk conversion factor and rounding to two significant figures.
20 [b] The low and high values represent the range of reasonable estimates and not a confidence interval.
21
22 The dollar per person-rem conversion factors presented in Table K-4 can be added directly to
23 the "low," "best," and "high" dollar per person-rem for mortality values presented in Table 3 of
24 NUREG-1530, Revision 1. Summing both the mortality and morbidity dollar per person-rem
25 values provides a total health detriment dollar per person-rem conversion factor as shown in
26 Table K-5 that the analyst can apply directly to the integrated dose averted over the lifetime of
27 the affected facilities, as outlined in Section 5.3.2 of the main body of this NUREG.
28
29 **Table K-5   Valuation of Radiation Exposure**

Estimate	Valuation of Radiation Exposure (Dollar per Person-Rem) (2014 Dollars)		
	Morbidity Valuation [a] (A)	Mortality Valuation [b] (B)	Total Valuation c (A + B)
Low	$75	$2,600	$2,700
Best	$200	$5,200	$5,400
High	$370	$7,800	$8,200

30 [a] Values from Table K-4 in this appendix.
31 [b] Values from Table 3 of NUREG-1530, Revision 1.

K.4   REFERENCES

Agency for Healthcare Research and Quality (AHRQ), Medical Expenditure Panel Survey, 2018. Agency for Healthcare Research and Quality, Rockville, MD. Content last reviewed August 2018. Available at https://www.ahrq.gov/data/meps.html.

American Economic Association EconLit Web site http://www.aeaweb.org/econlit/index.php, 2022.

Anderson, D., et al., "An Introduction to Management Science: Qualitative Approaches to Decision Making," 15th Ed, Cengage Learning, Inc., Boston, MA, 2018.

Arias E., J.Q. Xu, "United States Life Tables," 2017. National Vital Statistics Reports; Vol. 68 No. 7, National Center for Health Statistics, Hyattsville, MD, 2019. Available at https://www.cdc.gov/nchs/data/nvsr/nvsr68/nvsr68_07-508.pdf.

Blank, P.R., et al., "Human epidermal growth factor receptor 2 expression in early breast cancer patients: a Swiss cost–effectiveness analysis of different predictive assay strategies," *Breast Cancer Res. Treat.* 124, pages 497–507, 2010. Available at https://doi.org/10.1007/s10549-010-0862-7.

Dropkin, G., "Low dose radiation and cancer in A-bomb survivors: latency and non-linear dose-response in the 1950–90 mortality cohort," *Environmental Health* 6, 1, 2007. Available at https://doi.org/10.1186/1476-069X-6-1.

Environmental Valuation Reference Inventory Web site https://www.evri.ca/en, 2022.

Frei, C., T. Hillen, and A. Rhodes, "A stochastic model for cancer metastasis: branching stochastic process with settlement," *Mathematical Medicine and Biology: A Journal of the IMA*, Volume 37, Issue 2, pages 153–182, June 2020. Available at https://doi.org/10.1093/imammb/dqz009.

Goske, M.J., et al., "Curbing Potential Radiation-Induced Cancer Risks in Oncologic Imaging: Perspectives From the 'Image Gently' and 'Image Wisely' Campaigns," *Oncology Journal*, 28(3), 2014. Available at https://www.cancernetwork.com/view/curbing-potential-radiation-induced-cancer-risks-oncologic-imaging-perspectives-image-gently-and-.

Graves, N., et al., "A cost-effectiveness modelling study of strategies to reduce risk of infection following primary hip replacement based on a systematic review," *Health Technology Assessment*, No. 20.54, Chapter 4, "Cost-effectiveness methods," National Institute for Health and Care Research, Southampton, UK, July 2016. Available at https://www.ncbi.nlm.nih.gov/books/NBK374339/.

Hall, E., and A. Giaccia, *Radiobiology for the Radiologist*, Wolters Kluwer: Lippincott Williams & Wilkins, Philadelphia, PA, 2012.

Hanmer, J., et al., "Health Condition Impacts in a Nationally Representative Cross-Sectional Survey Vary Substantially by Preference-Based Health Index," *Medical decision making: an international journal of the Society for Medical Decision Making*, *36*(2), 264–274, 2016. Available at https://doi.org/10.1177/0272989X15599546.

Ho, T., and S. Lee, *The Oxford Guide to Financial Modeling*, Oxford University Press, Oxford, England, 2004.

Hofer, F., H.-U. Kauczor, and T. Stargardt, "Cost-Utility Analysis of a Potential Lung Cancer Screening Program for a High-Risk Population in Germany: A Modelling Approach," *Lung Cancer* 124: 189–198, 2018. Available at https://pubmed.ncbi.nlm.nih.gov/30268459/.

Institute of Medicine (IOM), "Valuing Health for Regulatory Cost-Effectiveness Analysis," The National Academies Press, Washington, DC, 2006. Available at https://doi.org/10.17226/11534.

International Commission on Radiological Protection (ICRP), "1990 Recommendations of the International Commission on Radiological Protection," ICRP Publication 60, *Annals of the ICRP* 21 (1–3), 1991.

ICRP, "Radiation and your patient—A Guide for Medical Practitioners," ICRP Supporting Guidance 2, *Annals of the ICRP* 31 (4), 2001.

ICRP, "The 2007 Recommendations of the International Commission on Radiological Protection," ICRP Publication 103, *Annals of the ICRP* 37 (2–4), 2007.

Jia, H., M. Zack, and W. Thompson, "Population-Based Estimates of Decreases in Quality-Adjusted Life Expectancy Associated with Unhealthy Body Mass Index," *Public Health Reports* 131 (1): 177–184, 2016. Available at https://pubmed.ncbi.nlm.nih.gov/26843684/.

Machina, M., and W. Viscusi, "Handbook of the Economics of Risk and Uncertainty," Elsevier Science, Amsterdam, Netherlands, 2014.

Manning, C., P. Raghavan, and H. Schütze, "Introduction to Information Retrieval," Cambridge University Press, England, 2008.

National Research Council, "Evaluation of Guidelines for Exposures to Technologically Enhanced Naturally Occurring Radioactive Materials," National Academies Press, Washington, DC, 1999.

National Research Council, "Health Risks from Exposure to Low Levels of Ionizing Radiation: BEIR VII Phase 2," The National Academies Press, Washington, DC, 2006. Available at https://nap.nationalacademies.org/catalog/11340/health-risks-from-exposure-to-low-levels-of-ionizing-radiation.

1   Nechyba, T., *Microeconomics: An Intuitive Approach*, 2nd ed., Cengage Learning, Inc., Boston,
2   MA, 2017.
3
4   Siegel, R., K. Miller, and A. Jemal, "Cancer Statistics, 2020," *CA Cancer J Clin* 70 (1): 7–30,
5   2020. Available at https://pubmed.ncbi.nlm.nih.gov/31912902/.
6
7   Tan, W., "Stochastic Models with Applications to Genetics, Cancers, AIDS and Other
8   Biomedical Systems," 2nd ed., *Series on concrete and applicable mathematics,* Volume 19,
9   World Scientific Publishing Co., Singapore, 2015.
10
11 Tolley, K., "What Are Health Utilities?" "What Is . . . ? Series," Hayward Medical Publishing,
12 London, UK, 2009. Available at https://tolleyhealtheconomics.com/wp-
13 content/uploads/2014/09/What-are-health-utilities-Final.pdf.
14
15 United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR),
16 "Hereditary Effects of Radiation: United Nations Scientific Committee on the Effects of Atomic
17 Radiation, UNSCEAR 2001 Report to the General Assembly, with Scientific Annex," New York,
18 NY, 2001.
19
20 U.S. Bureau of Labor Statistics (BLS), "Labor Force Statistics from the Current Population
21 Survey: Household Data Annual Averages," 2021. Accessed March 9, 2021. Available at
22 https://www.bls.gov/cps/demographics.htm.
23
24 U.S. Census Bureau, "Census Bureau Releases 2020 Demographic Analysis Estimates," 2020.
25 Accessed March 9, 2021. Available at https://www.census.gov/newsroom/press-
26 releases/2020/2020-demographic-analysis-estimates.html.
27
28 U.S. Environmental Protection Agency (EPA), "EPA Radiogenic Cancer Risk Models and
29 Projections for the U.S. Population," EPA 402-R-11-001, Washington, DC, 2011.
30
31 U.S. Nuclear Regulatory Commission (NRC), "Reassessment of NRC's Dollar Per Person-Rem
32 Conversion Factor Policy," NUREG-1530, Washington, DC, December 1995. Agencywide
33 Documents Access and Management System (ADAMS) Accession No. ML063470485.
34
35 NRC, "Valuing Nonfatal Cancer Risks in Cost-Benefit Analysis," SECY-20-0074, Washington,
36 DC, August 13, 2020. ADAMS Package Accession No. ML20058C219.
37
38 NRC, "Reassessment of NRC's Dollar Per Person-Rem Conversion Factor Policy: Final
39 Report," NUREG-1530, Revision 1, Washington, DC, February 2022. ADAMS Accession
40 No. ML22053A025.