Appendix B - Mortality Risk Valuation Estimates

Some U.S. Environmental Protection Agency (EPA) policies are designed to reduce the risk of contracting a potentially fatal health effect such as cancer. Reducing these risks of premature death provides welfare increases to those individuals affected by the policy. These policies generally provide marginal changes in relatively small risks. That is, these policies do not provide assurance that an individual will not die prematurely from environmental exposures; rather, they marginally reduce the probability of such an event. For BCA, analysts generally aggregate these small risks over the affected population to derive the number of statistical lives saved (or the number of statistical deaths avoided) and then use a "value of statistical life" (VSL) to express these benefits in monetary terms.

The risk reductions themselves can generally be classified according to the characteristics of the risk in question (e.g., voluntariness or controllability) and the characteristics of the affected population (e.g., age and health status). These dimensions may affect the *value* of reducing mortality risks. Ideally the VSL would account for all possible risk and demographic characteristics that matter. It would be derived from the preferences of the population affected by the policy, based on the type of risk that the policy is expected to reduce. For example, if a policy were designed to remove carcinogens at a suburban hazardous waste site, the ideal measure would represent the preferences for reduced cancer risks for the exposed population in the area and would reflect the changes in life expectancy that would result. Unfortunately, time and resource constraints make it difficult if not impossible to obtain such unique valuation estimates for each EPA policy. Instead, analysts need to draw from existing VSL estimates obtained using well-established methods (see Chapter 7).

This appendix describes the default VSL estimate currently used by the Agency and its derivation, as well as how analysts should characterize and assess benefit transfer issues that may arise in its application. Benefit transfer considerations that are common to all valuation applications, including the effect of most demographic characteristics of the study and policy populations, are described in Chapter 7 Section 7.3 and will not be repeated here.

B.1 Central Estimate of VSL

Table B.1 contains the VSL estimates that currently form the basis of the Agency's recommended central VSL estimate. Fitting a Weibull distribution to these estimates yields a central estimate (mean) of $10.7 million ($2022) with a standard deviation of $7.2 million.[1, 2] The EPA recommends that the central estimate, updated to the base year of the analysis, be used in all benefits analyses that seek to quantify mortality risk reduction benefits.

This approach was vetted and endorsed by the Agency when the 2000 *Guidelines for Preparing Economic Analyses* were drafted.[3] It remains the EPA's default guidance for valuing mortality risk changes although the Agency has considered and presented alternatives.[4]

B.2 Other VSL Information

For most of mortality risk reductions, the EPA uniformly applies the VSL estimate discussed above. For a period of time (2004-2008), the Office of Air and Radiation (OAR) valued mortality risk reductions using a VSL estimate derived from a limited analysis of some of the available studies. OAR arrived at a VSL using a range of $1 million to $10 million (2000$) consistent with two meta-analyses of the wage-risk literature. The $1 million value represented the lower end of the interquartile range from the Mrozek and Taylor (2002) meta-analysis of 33 studies. The $10 million value represented the upper end of the interquartile range from the Viscusi and Aldy (2003) meta-analysis of 43 studies. The mean estimate of $5.5 million (2000$) was also consistent with the mean VSL of $5.4 million estimated in the Kochi et al. (2006) meta-analysis. However, the Agency neither changed its official guidance on the use of VSL in rulemakings nor subjected the interim estimate to a scientific peer-review process through the Science Advisory Board (SAB) or other peer-review group.

During this time, the Agency continued work to update its guidance on valuing mortality risk reductions. The EPA commissioned a report from meta-analytic experts to evaluate methodological questions raised by the EPA and the SAB on combining estimates from the various data sources. In

1 The VSL was updated from the $4.8 million ($1990) estimate referenced in the 2000 Guidelines by adjusting the individual study estimates for inflation using CPI-U and then fitting a Weibull distribution to the estimates. The updated Weibull parameters are: location = 0, scale = 11.91, shape = 1.51 (updated from location = 0; scale = 5.32; shape = 1.51). The Weibull distribution was determined to provide the best fit for this set of estimates. See U.S. EPA 1997a for more details.

2 This VSL estimate was produced using the Consumer Price Index (CPI). Some economists prefer using the GDP deflator inflation index in some applications. The key issue for EPA analysts is to ensure that the chosen index is used consistently throughout the analysis.

3 The studies listed in Table B.1 were published between 1974 and 1991, and most are hedonic wage estimates that may be subject to considerable measurement error (Black et al. 2003; Black and Kniesner 2003). Although these were the best available data at the time, they are sufficiently dated and may rely on obsolete preferences for risk and income. The Agency is currently considering more recent studies as it evaluates approaches to revise its guidance.

4 The EPA engaged the SAB-EEAC on several issues including the use of meta-analysis as a means of combining estimates and approaches for assessing mortality benefits when changes in longevity may vary widely (U.S. EPA 2006d; U.S. EPA 2016). see U.S. EPA 2017 for recent SAB recommendations.

addition, the Agency consulted several times with the SAB Environmental Economics Advisory Committee (SAB-EEAC) on the issue (e.g., U.S. EPA 2017).

Table B.1 - Value of Statistical Life Estimates (mean values in millions of 2022 dollars)

Study	Method	Value of Statistical Life
Kniesner and Leeth (1991 - US)	Labor Market	$1.34
Smith and Gilbert (1984)	Labor Market	$1.57
Dillingham (1985)	Labor Market	$2.02
Butler (1983)	Labor Market	$2.46
Miller and Guria (1991)	Contingent Valuation	$2.69
Moore and Viscusi (1988)	Labor Market	$5.60
Viscusi, Magat, and Huber (1991)	Contingent Valuation	$6.05
Marin and Psacharopoulos (1982)	Labor Market	$7.39
Gegax et al. (1985)	Contingent Valuation	$6.27
Kniesner and Leeth (1991 - Australia)	Labor Market	$7.39
Gerking, de Haan, and Schulze (1988)	Contingent Valuation	$7.61
Cousineau, Lecroix, and Girard (1988)	Labor Market	$8.06
Jones-Lee (1989)	Contingent Valuation	$8.51
Dillingham (1985)	Labor Market	$8.73
Viscusi (1978)	Labor Market	$9.18
R.S. Smith (1976)	Labor Market	$10.30
V.K. Smith (1983)	Labor Market	$10.52
Olson (1981)	Labor Market	$11.64
Viscusi (1981)	Labor Market	$14.55
R.S. Smith (1974)	Labor Market	$16.12
Moore and Viscusi (1988)	Labor Market	$16.35
Kniesner and Leeth (1991 - Japan)	Labor Market	$17.02
Herzog and Schlottman (1987)	Labor Market	$20.38
Leigh and Folsom (1984)	Labor Market	$21.72
Leigh (1987)	Labor Market	$23.29
Garen (1988)	Labor Market	$30.23

Derived from U.S. EPA (1997a) and Viscusi (1992). Updated to 2022$ with CPI-U.

Until updated guidance is available, the Agency determined that a single, peer-reviewed estimate applied consistently best reflects the SAB-EEAC advice received to date. Therefore, the VSL described above that was vetted and endorsed by the SAB should be applied in relevant analyses while the Agency continues its efforts to update its guidance on this issue.

B.3 Benefit Transfer Considerations

Policy analysts valuing mortality risk reductions should account for differences in risk and population characteristics between the policy and study scenarios and their potential effect on the overall results. The ultimate objective of the benefit transfer exercise is to account for all of the factors that significantly affect the value of mortality risk reduction in the context of the policy. Analysts should carefully consider the implications of correcting for some relevant factors, but not for others, recognizing that it may not be feasible to account for all factors.

B.4 Adjustments Associated with Risk Characteristics

Risk characteristics appear to affect the value that people place on risk reduction. A large body of work identifies eight dimensions of risk that affect human risk perception.[5]

1. Voluntary/involuntary
2. Ordinary/catastrophic
3. Delayed/immediate
4. Natural/man-made
5. Old/new
6. Controllable/uncontrollable
7. Necessary/unnecessary
8. Occasional/continuous

Transferring VSL estimates among these categories may introduce bias. There have been some recent efforts attempting to quantitatively assess these sources of bias.[6] These studies generally conclude that voluntariness, control and responsibility affect individual values for safety, although there is no consensus on the direction and magnitude of these effects.

In addition, environmental risks may differ from those that form the basis of VSL estimates in many of these dimensions. Occupational risks, for example, are generally considered to be more voluntary in nature than are environmental risks and may be more controllable. As part of the Agency's review of our mortality risk guidance we are evaluating the literature from which the studies are drawn.

Support for quantitative adjustments in the empirical literature is lacking for most of these factors. The SAB reviewed an Agency summary of the available empirical literature on the effects of risk and population characteristics on WTP for mortality risk reductions (U.S. EPA 2000d). The SAB review concludes that among the demographic and risk factors that might affect VSL estimates, the

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5 A review of issues in risk perception is found in Lichtenstein and Slovic (2006). Other informative sources include Slovic (1987), Rowe (1977), Otway (1977), and Fischoff et al. (1978).

6 Examples include Hammitt and Liu (2004), Sunstein (1997), Mendeloff and Kaplan (1990), McDaniels et al. (1992), Savage (1993), Jones-Lee and Loomes (1994, 1995, 1996), and Covey et al. (1995).

current literature can only support empirical adjustments related to the timing of the risk. The review supports making the following adjustments to primary benefits estimates: (1) adjusting WTP estimates to account for higher future income levels, though not for cross-sectional differences in income; and (2) discounting risk reductions that are brought about in the future by current policy initiatives (that is, after a cessation lag), using the same rates used to discount other future benefits and costs. All other adjustments, if made, should be relegated to sensitivity analyses.

Increases in income over time. The economics literature shows that the income elasticity of WTP to reduce mortality risk is positive, based on cross-sectional data. As a result, benefits estimates of reduced mortality risk accruing in future years may be adjusted to reflect anticipated income growth, using the range of income elasticities (0.08, 0.40 and 1.0) employed in *The Benefits and Costs of the Clean Air Act, 1990-2010.*[7] Recent EPA analyses have assumed a triangular distribution from these values and used the results in a probabilistic assessment of benefits.[8] At the time of this writing, the EPA is engaged in a consultation with the SAB-EEAC on the appropriate range of income elasticities and will update this guidance as needed.

Timing of reduced exposure and reduced risk. Many environmental policies are targeted at reducing the risk of effects such as cancer, where there may be an extended period of time between the reduced exposure and the reduction in the risk of death from the disease.[9] This delay between the change in exposure and realization of the reduced risk may affect the value of that risk reduction. Most existing VSL estimates are based on risks of relatively immediate fatalities making them an imperfect fit for a benefits analysis of many environmental policies. Economic theory suggests that reducing the risk of a delayed health effect will be valued less than reducing the risk of a more immediate one, when controlling for other factors.

B.5 Effects on WTP Associated with Demographic Characteristics

Two population characteristics are particularly noteworthy for their potential effect on mortality risk valuation estimates: age and health status of the exposed population. In September 2006, the Agency requested an additional advisory from the SAB-EEAC on issues related to valuing changes in life expectancy for which age and baseline health status are close correlates.[10] Because the outcome of this review is not yet available, we focus here on previous advice received from the SAB on related questions.

Age. It has sometimes been posited that older individuals should have a lower WTP for changes in mortality risk given the fewer years of life expectancy remaining compared to younger individuals. This hypothesis may be confounded, however, by the finding that older persons reveal a greater

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7 For details see Kleckner and Neuman (2000).

8 See, for example, pp. 6-84 of the Final Economic Analysis for the Stage 2 Disinfection Byproducts Rule (DBPR) (U.S. EPA 2005d).

9 Although latency is defined here as the time between exposure and fatality from illness, alternative definitions may be used in other contexts. For example, "latency" may refer to the time between exposure and the onset of symptoms. These symptoms may be experienced for an extended period of time before ultimately resulting in fatality.

10 U.S. EPA (2006d) summarizes much of the literature related to the effects of age and health status on WTP for changes in mortality risk and includes the charge questions put to the SAB-EEAC on these issues.

demand for reducing mortality risks and hence have a greater implicit value of a life year (Ehrlich and Chuma 1990). Several authors have attempted to explore potential differences in mortality risk valuation estimates associated with differences in the average age of the affected population using theoretical models of life-cycle consumption.[11] In general, this literature has shown that the relationship between age and WTP for mortality risk changes is ambiguous, requiring strong assumptions to even sign the relationship.[12] Empirical evidence is also mixed. A number of empirical studies (mostly hedonic wage studies) suggest that the VSL follows a consistent "inverted-U" life-cycle, peaking in the region of mean age.[13] Others find no such statistically significant relationship and still others show WTP increasing with age.[14] Stated preference results are also mixed, with some studies showing declining WTP for older age groups and others finding no statistically significant relationship between age and WTP.[15]

In spite of the ambiguous relationship between age and WTP, two alternative adjustment techniques have been derived from this literature. The first technique, *value of statistical life-years (VSLY)*, is derived by dividing the estimated VSL by expected remaining life expectancy. This is by far the most common approach and presumes that: (1) the VSL equals the sum of discounted values for each life year; and (2) each life year has the same value. This method was applied as an alternative case in an effort to evaluate the sensitivity of the benefits estimates prepared for the EPA's retrospective and prospective studies of the costs and benefits of the Clean Air Act (U.S. EPA 1997a; U.S. EPA 1999).

A second technique is to apply a distinct value or suite of values for mortality risk reduction depending on the age of incidence. However, there is relatively little available literature upon which to base such adjustments.[16]

Neither approach enjoys general acceptance in the literature as they both require large assumptions to be made, some of which have been contradicted in empirical studies. Since published support is lacking, neither approach is recommended at this time.

Analysts are advised to note the age distribution of the affected population when possible, especially when children are found to be a significant portion of the affected population.[17] Although

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11 See, for example, Shepard and Zeckhauser (1982), Rosen (1988), Cropper and Sussman (1988, 1990), and Johansson (2002).

12 See Evans and Smith (2006) for a recent summary.

13 See Jones-Lee et al. (1985), Aldy and Viscusi (2008), Viscusi and Aldy (2007a, 2007b), and Kniesner et al. (2006).

14 Viscusi and Aldy (2003) review more than 60 studies of mortality risk estimates from 10 countries and discuss eight hedonic wage studies that explicitly examine the age-WTP relationship. Only five of the eight studies found a statistically significant, negative relationship between age and the return to risk. Smith et al. (2004) and Kniesner et al. (2006) find that WTP increases with age.

15 Krupnick et al. (2002) report that WTP for mortality risk reductions changes significantly with age after age 70. Alberini et al. (2004) find no difference in the WTP for younger age groups and find a 20% reduction for those aged 70 and older. However, this difference was not statistically significant.

16 This second approach was illustrated in one EPA study (U.S. EPA 2002) for valuation of air pollution mortality risks, drawing upon adjustments measured in Jones-Lee et al. (1985).

17 See U.S. EPA (2003a) for more information on the valuation of children's health risks. OMB's Circular A-4 advises agencies to use estimates of mortality risk valuation for children that are at least as large as those used for adult populations (OMB 2003).

the literature on the valuation of children's health risks is growing, there is still not enough information currently to derive age-specific valuation estimates.

Health status. Individual health status may also affect WTP for mortality risk reduction. This is an especially relevant factor for valuation of environmental risks because individuals with impaired health are often the most vulnerable to mortality risks from environmental causes. For example, particulate air pollution appears to disproportionately affect individuals in an already impaired state of health. Health status is distinct from age (a "quality versus quantity" distinction) but the two factors are clearly correlated and therefore must be addressed jointly when considering the need for an adjustment. Again, both the theoretical and empirical literatures on this point are mixed with some studies showing a declining WTP for increased longevity with a declining baseline health state (Desvousges et al. 1996) and other studies showing no statistically significant effects (Krupnick et al. 2002).[18]

Application of existing VSLY approaches implicitly assumes a linear relationship in which each discounted life year is valued equally. As Office of Management and Budget (OMB) (1996) notes "current research does not provide a definitive way of developing estimates of VSLY that are sensitive to such factors as current age, latency of effect, life years remaining, and social valuation of different risk reductions." The second alternative, applying a suite of values for these risks, lacks broad empirical support in the economics literature. However, the potential importance of this benefit transfer factor suggests that analysts consider sensitivity analysis when risk data — essentially risk estimates for specific age groups — are available. An emerging literature on the value of life expectancy extensions, based primarily on stated preference techniques, is beginning to help establish a basis for valuation in cases where the mortality risk reduction involves relatively short extensions of life.[19]

B.6 Conclusion

Due to current limitations in the existing economic literature, these *Guidelines* conclude that, for the present time, the appropriate default approach for valuing these benefits is provided by the central VSL estimate described earlier. However, analysts should carefully present the limitations of this estimate. Economic analyses should also fully characterize the nature of the risk and populations affected by the policy action and should confirm that these parameters are within the scope of the situations considered in these *Guidelines*. While a qualitative discussion of these issues is generally warranted in EPA economic analyses, analysts should also consider a variety of quantitative sensitivity analyses on a case-by-case basis as data allow. The analytical goal is to characterize the impact of key attributes that differ between the policy and study cases. These attributes, and the

18 The fields of health economics and public health often account for health status through the use of quality-adjusted life years (QALYs) or disability adjusted life years (DALYs). These measures have their place in evaluating the cost-effectiveness of medical interventions and other policy contexts but have not been fully integrated into the welfare economic literature on risk valuation. More information on QALYs can be found in Gold et al. (1996) and additional information on DALYs can be found in Murray (1994).

19 It should be noted that many observers have expressed reservations over adjusting the value of mortality risk reduction on the basis of population characteristics such as age. One of the ethical bases for these reservations is a concern that adjustments for population characteristics imply support for variation in protection from environmental risks. Another consideration is that existing economic methods may not capture social WTP to reduce health risks. Chapter 9 details how some these considerations may be informed by a separate assessment of equity.

degree to which they affect the value of risk reduction, may vary with each benefit transfer exercise, but analysts should consider the characteristics described above (e.g., age, health status, voluntariness of risk and latency) and values arising from altruism.

As the economic literature in this area evolves, WTP estimates for mortality risk reductions that more closely resemble those from environmental hazards may support more precise benefit transfers. Literature on the specific methods available to account for individual benefit-transfer considerations will also continue to develop. In addition, The EPA will continue to conduct periodic reviews of the risk valuation literature and will reconsider and revise the recommendations in these *Guidelines* accordingly. The EPA will seek advice from the SAB as guidance recommendations are revised.

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