# 10.0 QUANTIFIED BENEFITS

## 10.1 Results in Brief

In this section, we calculate monetary benefits for the reductions in ambient PM concentrations resulting from the emission reductions described in Chapters 3 and 9. Benefits related to $PM_{10}$ and $PM_{2.5}$ reductions are calculated using a combination of two approaches: (1) a direct valuation based on air quality analysis of modeled PM and $SO_2$ reductions at specific industrial boilers/process heaters, and (2) a benefits transfer approach which uses dollar per ton values generated from the air quality analysis completed in the first approach to value reductions from non-specific sources. We have used two approaches (Base and Alternative) to provide source benefit estimates from which the benefit transfer values are derived. These approaches differ in their treatment of estimation and valuation of mortality risk reductions and in the valuation of cases of chronic bronchitis. Incremental benefits (in 1999 dollars) from boilers and process heater PM and $SO_2$ emission reductions are presented in Table 10-1.

This benefits analysis does not quantify all potential benefits or disbenefits associated with PM and $SO_2$ reductions. This analysis also does not quantify the benefits associated with reductions in hazardous air pollutants (HAP). The magnitude of the unquantified benefits associated with omitted categories and pollutants, such as avoided cancer cases, damage to ecosystems, or materials damage to industrial equipment and national monuments, is not known. However, to the extent that unquantified benefits exceed unquantified disbenefits, the estimated benefits presented above will be an underestimate of actual benefits. There are many other sources of uncertainty in the estimates of quantified benefits. These sources of uncertainty, along with the methods for estimating monetized benefits for this NESHAP and a more detailed analysis of the results are presented below.

**Table 10-1. Summary of Results: Estimated PM-Related Benefits of the Industrial Boilers and Process Heaters NESHAP**

| Estimation Method | Total Benefits[A, B] (millions 1999$) |
|---|---|
| **Base Estimate:** | |
| MACT Floor: | |
| Using a 3% discount rate | $16 + B |
| Using a 7% discount rate | $15 + B |
| Above the MACT Floor: | |
| Using a 3% discount rate | $17 + B |
| Using a 7% discount rate | $16 + B |
| **Alternative Estimate:** | |
| MACT Floor: | |
| Using a 3% discount rate | $2 + B |
| Using a 7% discount rate | $3 + B |
| Above the MACT Floor: | |
| Using a 3% discount rate | $2 + B |
| Using a 7% discount rate | $3 + B |

[A] Benefits of HAP emission reductions are not quantified in this analysis and, therefore, are not presented in this table. The quantifiable benefits are from emission reductions of $SO_2$ and PM only. For notational purposes, unquantified benefits are indicated with a "B" to represent additional monetary benefits. A detailed listing of unquantified $SO_2$, PM , and HAP related health effects is provided in Table 10-13.

[B] Results reflect the use of two different discount rates; a 3% rate which is recommended by EPA's Guidelines for Preparing Economic Analyses (US EPA, 2000a), and 7% which is recommended by OMB Circular A-94 (OMB, 1992).

## 10.2 Introduction

This chapter presents the methods used to estimate the monetary benefits of the reductions in PM and $SO_2$ emissions associated with control requirements resulting from the Industrial Boilers/Process Heaters NESHAP. Results are presented for the emission controls described in Chapter 2. The benefits that result from the rule include both the primary impacts from application of control technologies or changes in operations and processes, and the secondary effects of the controls. The regulation induced reductions in PM and $SO_2$ emissions also described in Chapter 3 will result in changes in the physical damages associated with exposure to elevated ambient concentrations of PM. These damages include changes in both human health and welfare effects categories. Benefits are calculated for the nation as a whole, assuming that controls are implemented at major sources (sources emitting > 10 tons of a HAP annual, or >25 tons of two or more HAPs annually).

The remainder of this chapter provides the following:

- Subsection 3 provides an overview of the benefits methodology.

- Subsection 4 discusses Phase One of the analysis: modeled air quality change and health effects resulting from a portion of emission reductions at a subset of boiler and process heaters sources

- Subsection 5 discusses Phase Two of the analysis: Benefit transfer valuation of remaining emission reductions

- Subsection 6 discusses total benefit estimated by combining the results of Phases 1 and 2.
- Subsection 7 discusses potential benefit categories that are not quantified due to data and/or methodological limitations, and provides a list of analytical uncertainties, limitations, and biases.

## 10.3 Overview of Benefits Analysis Methodology

This section documents the general approach used to estimate benefits resulting from emissions reductions from boiler and process heater sources. We follow the basic methodology described in the Regulatory Impact Analysis of the Heavy Duty Engine/Diesel Fuel rule [hereafter referred to as the HDD RIA] (US EPA, 2000).

On September 26, 2002, the National Academy of Sciences (NAS) released a report on its review of the Agency's methodology for analyzing the health benefits of measures taken to reduce air pollution. The report focused on EPA's approach for estimating the health benefits of regulations designed to reduce concentrations of airborne particulate matter (PM).

In its report, the NAS said that EPA has generally used a reasonable framework for analyzing the health benefits of PM-control measures. It recommended, however, that the Agency take a number of steps to improve its benefits analysis. In particular, the NAS stated that the Agency should:

- include benefits estimates for a range of regulatory options;
- estimate benefits for intervals, such as every five years, rather than a single year;
- clearly state the project baseline statistics used in estimating health benefits, including those for air emissions, air quality, and health outcomes;
- examine whether implementation of proposed regulations might cause unintended impacts on human health or the environment;
- when appropriate, use data from non-US studies to broaden age ranges to which current estimates apply and to include more types of relevant health outcomes;
- begin to move the assessment of uncertainties from its ancillary analyses into its primary analyses by conducting probabilistic, multiple-source uncertainty analyses. This

assessment should be based on available data and expert judgment.

Although the NAS made a number of recommendations for improvement in EPA's approach, it found that the studies selected by EPA for use in its benefits analysis were generally reasonable choices. In particular, the NAS agreed with EPA's decision to use cohort studies to derive benefits estimates. It also concluded that the Agency's selection of the American Cancer Society (ACS) study for the evaluation of PM-related premature mortality was reasonable, although it noted the publication of new cohort studies that should be evaluated by the Agency.

Several of the NAS recommendations addressed the issue of uncertainty and how the Agency can better analyze and communicate the uncertainties associated with its benefits assessments. In particular, the Committee expressed concern about the Agency's reliance on a single value from its analysis and suggested that EPA develop a probabilistic approach for analyzing the health benefits of proposed regulatory actions. The Agency agrees with this suggestion and is working to develop such an approach for use in future rulemakings.

In this RIA, the Agency has used an interim approach that shows the impact of several important alternative assumptions about the estimation and valuation of reductions in premature mortality and chronic bronchitis. This approach, which was developed in the context of the Agency's Clear Skies analysis, provides an alternative estimate of health benefits using the time series studies in place of cohort studies, as well as alternative valuation methods for mortality and chronic bronchitis risk reductions.

The analysis of benefits of this NESHAP is conducted in two phases. For a portion of the emission reductions expected from this rule, the first phase of analysis models the change in air quality and health effects around specific boiler and process heater sources. The benefits resulting from the changes in air quality are then quantified and monetized. For the remaining set of emission reductions, the specific location of the emission reduction is unknown due to limitations in the data. Therefore, the second phase of our benefits analysis is based on benefits transfer of the modeled changes in air quality and health effects from the location specific emissions reductions achieved in phase one of the analysis. More specifically, the benefit value per ton of emission reduction estimated in phase one is transferred and applied to the emission reductions in phase two of the analysis. Table 10-2 summarizes the emissions reductions associated with the phase one and phase two analyses. Although the NESHAP is expected to result in reductions in emissions of many HAPs as well as PM and $SO_2$, benefits transfer values are generated for only PM and $SO_2$ due to limitations in availability of transfer values, concentration-response functions, or air quality and exposure models for HAPs. For this analysis, we focus on directly emitted PM, and $SO_2$ in its role as a precursor in the formation of ambient particulate matter. Other potential impacts of PM and $SO_2$ reductions not quantified in this analysis, as well as potential impacts of HAPs reductions are described in Chapter 9.

**Table 10-2.**
**Estimate of Emission Reductions for Phases One and Two of the Benefit Analysis**

| Regulatory Option | Total Emission Reductions (tons/yr) | Phase One: Modeled Emission Reductions (tons/yr) | Phase Two: Reductions Applied to Benefit Transfer Values |
|---|---|---|---|
| **MACT Floor:** | | | |
| $SO_2$ | 112,936 | 82,542 | 30,394 |
| $PM_{10}$ | 562,110 | 265,115 | 296,955 |
| $PM_{2.5}$ | 159,196 | 75,095 | 84,101 |
| **Above MACT Floor:** | | | |
| $SO_2$ | 136,733 | 95,361 | 41,372 |
| $PM_{10}$ | 569,229 | 313,947 | 255,282 |
| $PM_{2.5}$ | 171,459 | 94,565 | 76,894 |

The general term "benefits" refers to any and all outcomes of the regulation that contribute to an enhanced level of social welfare. In this case, the term "benefits" refers to the dollar value associated with all the expected positive impacts of the regulation, that is, all regulatory outcomes that lead to higher social welfare. If the benefits are associated with market goods and services, the monetary value of the benefits is approximated by the sum of the predicted changes in consumer (and producer) "surplus." These "surplus" measures are standard and widely accepted measures in the field of applied welfare economics, and reflect the degree of well-being enjoyed by people given different levels of goods and prices. If the benefits are non-market benefits (such as the risk reductions associated with environmental quality improvements), however, other methods of measuring benefits must be used. In contrast to market goods, non-market goods such as environmental quality improvements are public goods, whose benefits are shared by many people. The total value of such a good is the sum of the dollar amounts that all those who benefit are willing to pay.

### 10.3.1 *Methods for Estimating Benefits from Air Quality Improvements*

Environmental and health economists have a number of methods for estimating the economic value of improvements in (or deterioration of) environmental quality. The method used in any given situation depends on the nature of the effect and the kinds of data, time, and resources that are available for investigation and analysis. This section provides an overview of the methods we selected to monetize the benefits included in this RIA.

We note at the outset that EPA rarely has the time or resources to perform extensive new research in the form of evaluating the response in human health effects from specific changes in the concentration of pollutants, or by issuing surveys to collect data of individual's willingness to pay for a particular rule's given change in air quality, which is needed to fully measure the economic benefits of individual rulemakings. As a result, our estimates are based on the best available methods of benefit transfer from epidemiological studies and studies of the economic value of reducing certain health and welfare effects. Benefit transfer is the science and art of adapting primary benefits research on concentration-response functions and measures of the value individuals place on an improvement in a given health effect to the scenarios evaluated for a particular regulation. Thus, we strive to obtain the most accurate measure of benefits for the environmental quality change under analysis given availability of current, peer reviewed research and literature.

In general, economists tend to view an individual's willingness-to-pay (WTP) for a improvement in environmental quality as the most complete and appropriate measure of the value of an environmental or health risk reduction. An individual's willingness-to-accept (WTA) compensation for not receiving the improvement is also a valid measure. Willingness to pay and Willingness to accept are comparable measures when the change in environmental quality is small and there are reasonably close substitutes available. However, WTP is generally considered to be a more readily available and conservative (i.e. more likely to underestimate than overestimate) measure of benefits. Adoption of WTP as the measure of value implies that the value of environmental quality improvements is dependent on the individual preferences of the affected population and that the existing distribution of income (ability to pay) is appropriate.

For many goods, WTP can be observed by examining actual market transactions. For example, if a gallon of bottled drinking water sells for one dollar, it can be observed that at least some persons are willing to pay one dollar for such water. For goods not exchanged in the market, such as most environmental "goods," valuation is not as straightforward. Nevertheless, a value may be inferred from observed behavior, such as sales and prices of products that result in similar effects or risk reductions, (e.g., non-toxic cleaners or bike helmets). Alternatively, surveys may be used in an attempt to directly elicit WTP for an environmental improvement.

One distinction in environmental benefits estimation is between "use values"and "non-use values." Although no general agreement exists among economists on a precise distinction between the two, the general nature of the difference is clear. Use values are those aspects of environmental quality that affect an individual's welfare more or less directly. These effects include changes in product prices, quality, and availability, changes in the quality of outdoor recreation and outdoor aesthetics, changes in health or life expectancy, and the costs of actions taken to avoid negative effects of environmental quality changes.

Non-use values are those for which an individual is willing to pay for reasons that do not relate to the direct use or enjoyment of any environmental benefit, but might relate to existence values and bequest values. Non-use values are not traded, directly or indirectly, in markets. For this reason, the measurement of non-use values has proved to be significantly more difficult than the measurement of use values. The air quality changes produced by this NESHAP cause changes in both use and non-use values, but the monetary benefit estimates are almost exclusively for use values.

More frequently than not, the economic benefits from environmental quality changes are not traded in markets, so direct measurement techniques can not be used. Avoided cost methods are ways to estimate the costs of pollution by using the expenditures made necessary by pollution damage. For example, if buildings must be cleaned or painted more frequently as levels of PM increase, then the appropriately calculated increment of these costs is a reasonable lower bound estimate (under most conditions) of true economic benefits when PM levels are reduced. Avoided costs methods are used to estimate some of the health-related benefits related to morbidity, such as hospital admissions (see the HDD RIA for a detailed discussion of methods to value benefit categories).

Indirect market methods can also be used to infer the benefits of pollution reduction. The most important application of this technique for our analysis is the calculation of the value of a statistical life for use in the estimate of benefits from mortality reductions. There exists no market where changes in the probability of death are directly exchanged. However, people make decisions about occupation, precautionary behavior, and other activities associated with changes in the risk of death. By examining these risk changes and the other characteristics of people's choices, it is possible to infer information about the monetary values associated with changes in mortality risk (see Section 10.4). For measurement of health benefits, this analysis captures the WTP for most use and non-use values, with the exception of the value of avoided hospital admissions, which only captures the avoided cost of illness because no WTP values were available in the published literature.

### 10.3.2 *Methods for Describing Uncertainty*

In any complex analysis using estimated parameters and inputs from numerous models, there are likely to be many sources of uncertainty.[1] This analysis is no exception. As outlined both in this and preceding chapters, there are many inputs used to derive the final estimate of benefits, including

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[1] It should be recognized that in addition to uncertainty, the annual benefit estimates for the Industrial Boilers/Process Heaters NESHAP presented in this analysis are also inherently variable, due to the truly random processes that govern pollutant emissions and ambient air quality in a given year. Factors such as electricity demand and weather display constant variability regardless of our ability to accurately measure them. As such, the estimates of annual benefits should be viewed as representative of the types of benefits that will be realized, rather than the actual benefits that would occur every year.

emission inventories, air quality models (with their associated parameters and inputs), epidemiological estimates of concentration-response (C-R) functions, estimates of values (both from WTP and cost-of-illness studies), population estimates, income estimates, and estimates of the future state of the world (i.e., regulations, technology, and human behavior). Each of these inputs may be uncertain, and depending on their location in the benefits analysis, may have a disproportionately large impact on final estimates of total benefits. For example, emissions estimates are used in the first stage of the analysis. As such, any uncertainty in emissions estimates will be propagated through the entire analysis. When compounded with uncertainty in later stages, small uncertainties in emission levels can lead to much larger impacts on total benefits.

Some key sources of uncertainty in each stage of the benefits analysis are:

- Gaps in scientific data and inquiry;
- Variability in estimated relationships, such as C-R functions, introduced through differences in study design and statistical modeling;
- Errors in measurement and projection for variables such as population growth rates;
- Errors due to mis-specification of model structures, including the use of surrogate variables, such as using $PM_{10}$ when $PM_{2.5}$ is not available, excluded variables, and simplification of complex functions; and
- Biases due to omissions or other research limitations.

Some of the key uncertainties in the benefits analysis are presented in Table 10-3. Information on the uncertainty surrounding particular C-R and valuation functions is provided in the benefits Technical Support Document for the RIA of the Heavy Duty Diesel and Fuel Standard [hereafter referred to as the HDD TSD] (Abt Associates, 2000).

Our estimated range of total benefits should be viewed as an approximate result because of the sources of uncertainty discussed above (see Table 10-3). The total benefits estimate may understate or overstate actual benefits of the rule.

In considering the monetized benefits estimates, the reader should remain aware of the many limitations of conducting these analyses mentioned throughout this RIA. One significant limitation of both the health and welfare benefits analyses is the inability to quantify many of the serious effects discussed in Chapter 9. For many health and welfare effects, such as PM-related materials damage, reliable C-R functions and/or valuation functions are not currently available. In general, if it were possible to monetize these benefits categories, the benefits estimates presented in this analysis would increase. Unquantified benefits are qualitatively discussed in the in Chapter 9 and presented in Table 10-17. The net effect of excluding benefit and disbenefit categories from the estimate of total benefits depends on the relative magnitude of the effects.

**Table 10-3. Primary Sources of Uncertainty in the Source Benefit Analyses**

| |
|---|
| *1. Uncertainties Associated With Concentration-Response (C-R) Functions* |
| - The value of the PM-coefficient in each C-R function.<br>- Application of a single C-R function to pollutant changes and populations in all locations.<br>- Similarity of future year C-R relationships to current C-R relationships.<br>- Correct functional form of each C-R relationship.<br>- Extrapolation of C-R relationships beyond the range of PM concentrations observed in the study.<br>- Application of C-R relationships only to those subpopulations matching the original study population. |
| *2. Uncertainties Associated With PM Concentrations* |
| - Responsiveness of the models to changes in precursor emissions resulting from the control policy.<br>- Projections of future levels of precursor emissions, especially ammonia and crustal materials.<br>- Model chemistry for the formation of ambient nitrate concentrations. |
| *3. Uncertainties Associated with PM Mortality Risk* |
| - No scientific literature supporting a direct biological mechanism for observed epidemiological evidence.<br>- Direct causal agents within the complex mixture of PM have not been identified.<br>- The extent to which adverse health effects are associated with low level exposures that occur many times in the year versus peak exposures.<br>- The extent to which effects reported in the long-term exposure studies are associated with historically higher levels of PM rather than the levels occurring during the period of study.<br>- Reliability of the limited ambient $PM_{2.5}$ monitoring data in reflecting actual $PM_{2.5}$ exposures. |
| *4. Uncertainties Associated With Possible Lagged Effects* |
| - The portion of the PM-related long-term exposure mortality effects associated with changes in annual PM levels would occur in a single year is uncertain as well as the portion that might occur in subsequent years. |
| *5. Uncertainties Associated With Baseline Incidence Rates* |
| - Some baseline incidence rates are not location-specific (e.g., those taken from studies) and may therefore not accurately represent the actual location-specific rates.<br>- Current baseline incidence rates may not approximate well baseline incidence rates in 2005.<br>- Projected population and demographics may not represent well future-year population and demographics. |
| *6. Uncertainties Associated With Economic Valuation* |
| - Unit dollar values associated with health and welfare endpoints are only estimates of mean WTP and therefore have uncertainty surrounding them.<br>- Mean WTP (in constant dollars) for each type of risk reduction may differ from current estimates due to differences in income or other factors. |
| *7. Uncertainties Associated With Aggregation of Monetized Benefits* |
| - Health and welfare benefits estimates are limited to the available C-R functions. Thus, unquantified or unmonetized benefits are not included. |

## 10.4 Phase One Analysis: Modeled Air Quality Change and Health Effects Resulting from

**a Portion of Emission Reductions at Boiler and Process Heaters Sources**

In phase one of the benefit analysis, we are able to link approximately 50 percent of the emission reductions from this regulation to specific locations of boilers/process heaters. This allows us to evaluate the change in air quality around these sources and the resulting effect on the health of the surrounding population. The analysis performed for the emission reductions evaluated in phase one can be thought of as having three parts, including:

1. Calculation of the impact that our standards will have on the nationwide inventories for PM and $SO_2$ emissions;

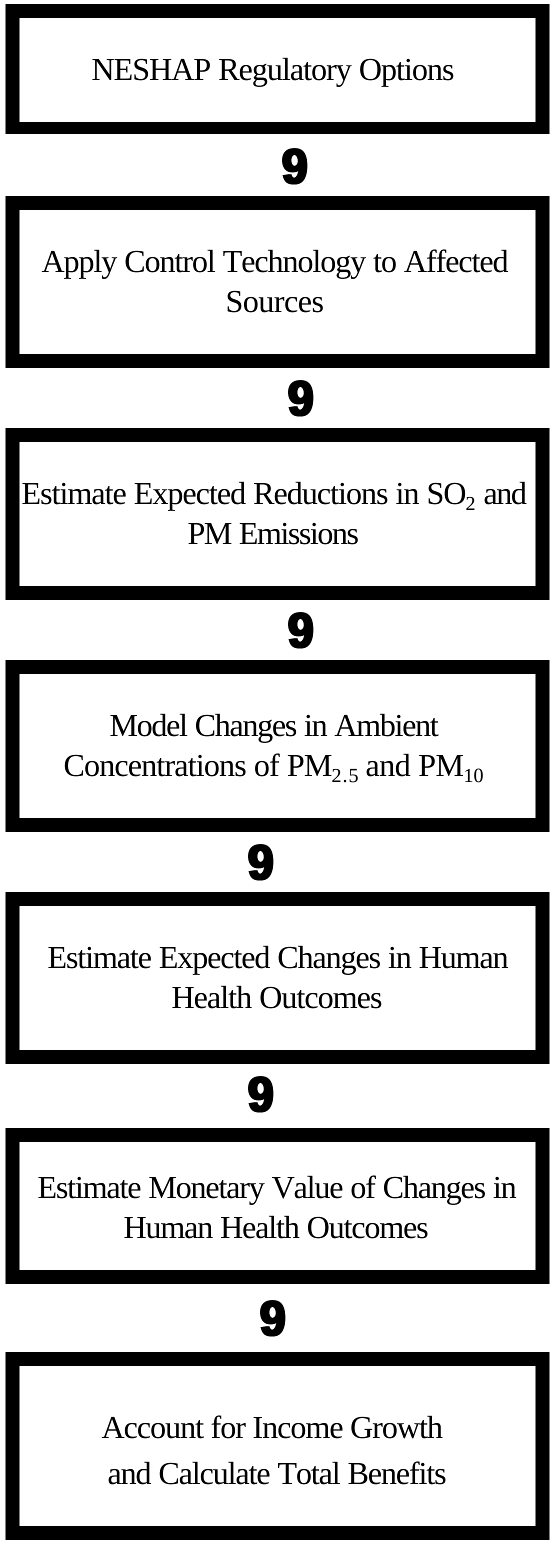
2. Air quality modeling to determine the changes in ambient concentrations of PM that will result from the changes in nationwide inventories of directly emitted PM and precursor pollutants; and

3. A benefits analysis to determine the changes in human health, both in terms of physical effects and monetary value, that result from the changes in ambient concentrations of PM.

Steps 1 and 2 are discussed in previous chapters of this RIA. For step 3, we follow the same general methodology used in the benefits analysis of the Heavy Duty Engine/Diesel Fuel rulemaking. EPA also relies heavily on the advice of its independent Science Advisory Board (SAB) in determining the health and welfare effects considered in the benefits analysis and in establishing the most scientifically valid measurement and valuation techniques.

Figure 10-1 illustrates the steps necessary to link the emission reductions included in the phase one analysis with economic measures of benefits. The first two steps involve the specification and implementation of the regulation. First, the specific regulatory options for reducing air pollution from industrial boilers/process heaters are established. In this chapter, we evaluate the benefits of two regulatory options: the MACT floor and an above the floor option. Next, we determine the changes in boiler and process heater control technology that can be used to meet the level of emissions reductions specified by the regulatory options (see Chapter 2). The changes in pollutant emissions resulting from the required changes in control technology at boilers/process heaters are then calculated, along with predictions of emissions for other industrial sectors in the baseline. The predicted emissions reductions described in Chapter 3 are then used as inputs to air quality models that predict ambient concentrations of pollutants over time and space. These concentrations depend on climatic conditions and complex chemical interactions.

**Figure 10-1. Steps in Phase One of the Benefits Analysis for the Industrial Boilers/Process Heaters NESHAP**



Changes in ambient concentrations will lead to new levels of environmental quality in the U.S., reflected both in human health and in non-health welfare effects. For this analysis, however, we do not evaluate and monetize changes in non-health welfare effects, such as visibility and agricultural yields. To generate estimated health outcomes, projected changes in ambient PM concentrations were input to the Criteria Air Pollutant Modeling System (CAPMS), a customized GIS-based program. CAPMS assigns pollutant concentrations to population grid cells for input into concentration-response functions. CAPMS uses census block population data and changes in pollutant concentrations to estimate changes in health outcomes for each grid cell. For purposes of this analysis, we assume a constant proportion of baseline incidence of the various health effects to the future incidence of health effects.

Our analysis also accounts for expected growth in real income over time. Economic theory argues that WTP for most goods (such as environmental protection) will increase if real incomes increase. The economics literature suggests that the severity of a health effect is a primary determinant of the strength of the relationship between changes in real income and WTP (Alberini, 1997; Miller, 2000; Viscusi, 1993). As such, we use different factors to adjust the WTP for minor health effects, severe and chronic health effects, and premature mortality. Adjustment factors used to account for projected growth in real income from 1990 to 2005 are 1.03 for minor health effects, 1.09 for severe and chronic health effects, and 1.08 for premature mortality[2].

Based on the structure of analysis presented above, Section 10.4.1 provides a description of how we quantify and value changes in individual health effects. Then, in Section 10.4.2 we present quantified estimates of the reductions in health effects resulting from phase one of the benefit analysis.

### 10.4.1 *Quantifying Individual Health Effect Endpoints*

We use the term "endpoints" to refer to specific effects that can be associated with changes in air quality. To estimate these endpoints, EPA combines changes in ambient air quality levels with epidemiological evidence about population health response to pollution exposure. The most significant monetized benefits of reducing ambient concentrations of PM are attributable to reductions in human health risks. EPA's Criteria Document for PM lists numerous health effects known to be linked to ambient concentrations of the pollutant (US EPA, 1996a). The previous chapter described some of these effects. This section describes methods used to quantify and monetize changes in the expected number of incidences of various health effects. For further detail on the methodology used to assess human health benefits such as those included in phase one of this analysis, refer to the HDD RIA and TSD.

The specific PM endpoints that are evaluated in this analysis include:

[2]Details of the calculation of the income adjustment factors are provided in the HDD RIA (U.S. EPA, 2000).

- Premature mortality
- Bronchitis - chronic and acute
- Hospital admissions - respiratory and cardiovascular
- Emergency room visits for asthma
- Asthma attacks
- Lower and upper respiratory illness
- Minor restricted activity days
- Work loss days

As is discussed previously, this analysis relies on concentration-response (C-R) functions estimated in published epidemiological studies relating health effects to ambient air quality. The specific studies from which C-R functions are drawn are included in Table 10-4. Because we rely on methodology used in prior benefit analyses, a complete discussion of the C-R functions used for this analysis and information about each endpoint are contained in the HDD RIA and TSD.

While a broad range of serious health effects have been associated with exposure to elevated PM levels (described more fully in the EPA's PM Criteria Document (US EPA, 1996a), we include only a subset of health effects in this quantified benefit analysis. Health effects are excluded from this analysis for four reasons: (i) the possibility of double counting (such as hospital admissions for specific respiratory diseases); (ii) uncertainties in applying effect relationships based on clinical studies to the affected population; (iii) a lack of an established C-R relationship; or (iv) lack of resources to estimate some endpoints.

Using the C-R functions derived from the studies cited in this table, we apply that same C-R relationship to all locations in the U.S. Although the C-R relationship may in fact vary somewhat from one location to another (for example, due to differences in population susceptibilities or differences in the composition of PM), location-specific C-R functions are generally not available. A single function applied everywhere may result in overestimates of incidence changes in some locations and underestimates in other locations, but these location-specific biases will, to some extent, cancel each other out when the total incidence change is calculated. It is not possible to know the extent or direction of the bias in the total incidence change based on the general application of a single C-R function everywhere.

Recently, the Health Effects Institute (HEI) reported findings by investigators at Johns Hopkins University and others that have raised concerns about aspects of the statistical methodology used in a number of recent time-series studies of short-term exposures to air pollution and health effects (Greenbaum, 2002a). Some of the concentration-response functions used in this benefits analysis were derived from such short-term studies. The estimates derived from the long-term mortality studies, which account for a major share of the benefits in the Base Estimate, are not affected. As discussed in HEI materials provided to sponsors and to the Clean Air Scientific Advisory Committee (Greenbaum, 2002a, 2002b), these investigators found problems in the default "convergence criteria" used in

Generalized Additive Models (GAM) and a separate issue first identified by Canadian investigators about the potential to underestimate standard errors in the same statistical package.[1] These and other investigators have begun to reanalyze the results of several important time series studies with alternative approaches that address these issues and have found a downward revision of some results. For example, the mortality risk estimates for short-term exposure to $PM_{10}$ from NMMAPS were overestimated (the C-R function based on the NMMAPS results used in this benefits analysis uses the revised NMMAPS results).[2] However, both the relative magnitude and the direction of bias introduced by the convergence issue is case-specific. In most cases, the concentration-response relationship may be overestimated; in other cases, it may be underestimated. The preliminary renalyses of the mortality and morbidity components of NMMAPS suggest that analyses reporting the lowest relative risks appear to be affected more greatly by this error than studies reporting higher relative risks (Dominici et al., 2002; Schwartz and Zanobetti, 2002).

Our examination of the original studies used in this analysis finds that the health endpoints that are potentially affected by the GAM issues include: reduced hospital admissions and reduced lower respiratory symptoms in the both the Base and Alternative Estimates; reduced lower respiratory symptoms in both the Base and Alternative Estimates; and reduced premature mortality due to short-term $PM_{10}$ exposures in the Base Estimate[3] and reduced premature mortality due to short-term $PM_{2.5}$ exposures in the Alternative Estimate. While resolution of these issues is likely to take some time, the preliminary results from ongoing reanalyses of some of the studies used in our analyses (Dominici et al, 2002; Schwartz and Zanobetti, 2002; Schwartz, personal communication 2002) suggest a more modest effect of the S-plus error than reported for the NMMAPS $PM_{10}$ mortality study. While we wait for further clarification from the scientific community, we have chosen not to remove these results from the Industrial Boilers and Process Heaters NESHAP benefits estimates, nor have we elected to apply any interim adjustment factor based on the preliminary reanalyses. EPA will continue to monitor the progress of this concern, and make appropriate adjustments as further information is made available.

#### *10.4.1.1 Concentration-Response Functions for Premature Mortality*

Both long and short-term exposures to ambient levels of air pollution have been associated with increased risk of premature mortality. The size of the mortality risk estimates from these epidemiological studies, the serious nature of the effect itself, and the high monetary value ascribed to prolonging life make mortality risk reduction the most important health endpoint quantified in this analysis. Because of the importance of this endpoint and the considerable uncertainty among economists and policymakers as to the appropriate way to value reductions in mortality risks, this section discusses some of the issues surrounding the estimation of premature mortality. For additional discussion on mortality and issues related to estimating risk for other health effects categories, we refer readers to the discussions presented in EPA's HDD RIA (U.S. EPA, 2000b).

Health researchers have consistently linked air pollution, especially PM, with excess mortality. Although a number of uncertainties remain to be addressed by continued research (NRC, 1998), a substantial body of published scientific literature recognizes a correlation between elevated PM concentrations and increased mortality rates. Two types of community epidemiological studies (involving measures of short-term and long-term exposures and response) have been used to estimate PM/ mortality relationships. Short-term studies relate short-term (often day-to-day) changes in PM concentrations and changes in daily mortality rates up to several days after a period of elevated PM concentrations. Long-term studies examine the potential relationship between longer-term (e.g., one or more years) exposure to PM and annual mortality rates. Researchers have found significant associations using both types of studies.

**Table 10-4. PM-related Health Outcomes and Studies Included in the Analysis**

| Health Outcome | Pollutant | Applied Population | Source of Effect Estimate | Source of Baseline Incidence |
|---|---|---|---|---|
| **Premature Mortality** | | | | |
| All-cause premature mortality from long-term exposure (Base Estimate) | $PM_{2.5}$ | > 29 years | Krewski et al., 2000 | U.S. Centers for Disease Control, 1999 |
| Short-term exposure (Alternative Estimate) | $PM_{2.5}$ | < 65 years, $65 years<br>All ages | Schwartz et al. (1996)<br>Schwartz et al. (2000)<br>U.S. Centers for Disease Control, 1999Short-term exposure (Alternative Estimate)<br>$PM_{10}$All agesSamet et al. (2000)<br>Schwartz et al. (2000) | U.S. Centers for Disease Control, 1999 |
| **Chronic Illness** | | | | |
| Chronic Bronchitis (pooled estimate) | $PM_{2.5}$<br><br>$PM_{10}$ | > 26 years<br><br>> 29 years | Abbey et al., 1995<br><br>Schwartz et al., 1993 | Abbey et al., 1993<br><br>Abbey et al., 1993<br>Adams and Marano, 1995 |
| **Hospital Admissions** | | | | |

| | | | | |
|---|---|---|---|---|
| COPD | $PM_{10}$ | > 64 years | Samet et al., 2000 | Graves and Gillum, 1997 |
| Pneumonia | $PM_{10}$ | > 64 years | Samet et al., 2000 | Graves and Gillum, 1997 |
| Asthma | $PM_{2.5}$ | < 65 years | Sheppard et al., 1999 | Graves and Gillum, 1997 |
| Total Cardiovascular | $PM_{10}$ | > 64 years | Samet et al., 2000 | Graves and Gillum, 1997 |
| Asthma-Related ER Visits | $PM_{10}$ | All ages | Schwartz et al., 1993 | Smith et al., 1997 Graves and Gillum, 1997 |
| **Other Effects** | | | | |
| Asthma Attacks | $PM_{10}$ | Asthmatics, all ages | Whittemore and Korn, 1980 | Krupnick, 1988 Adams and Marano, 1995 |
| Acute Bronchitis | $PM_{2.5}$ | Children, 8-12 years | Dockery et al., 1996 | Adams and Marano, 1995 |
| Upper Respiratory Symptoms | $PM_{10}$ | Asthmatic children, 9-11 | Pope et al., 1991 | Pope et al., 1991 |
| Lower Respiratory Symptoms | $PM_{2.5}$ | Children, 7-14 years | Schwartz et al., 1994 | Schwartz et al., 1994 |
| Work Loss Days | $PM_{2.5}$ | Adults, 18-65 years | Ostro, 1987 | Adams and Marano, 1995 |
| Minor Restricted Activity Days (minus asthma attacks) | $PM_{2.5}$ | Adults, 18-65 years | Ostro and Rothschild., 1989 | Ostro and Rothschild, 1989 |

Base Estimate

Over a dozen studies have found significant associations between measures of long-term exposure to PM and elevated rates of annual mortality (e.g. Lave and Seskin, 1977; Ozkaynak and Thurston, 1987). While most of the published studies found positive (but not always significant) associations with available PM indices such as total suspended particles (TSP), fine particles components (i.e. sulfates), and fine particles, exploration of alternative model specifications sometimes found inconsistencies (e.g. Lipfert, 1989). These early "cross-sectional" studies were criticized for a number of methodological limitations, particularly for inadequate control at the individual level for variables that are potentially important in causing mortality, such as wealth, smoking, and diet. More recently, several new long-term studies have been published that use improved approaches and appear to be consistent with the earlier body of literature. These new "prospective cohort" studies reflect a significant improvement over the earlier work because they include information on individuals with respect to measures related to health status and residence. The most extensive study and analyses has been based on data from two prospective cohort groups, often referred to as the Harvard "Six-City study" (Dockery et al., 1993) and the "American Cancer Society or ACS study" ( Pope et al., 1995); these studies have found consistent relationships between fine particle indicators and mortality across multiple locations in the U.S. A third major data set comes from the California based 7$^{th}$ day Adventist study (e.g. Abbey et al, 1999), which reported associations between long-term PM exposure and mortality in men. Results from this cohort, however, have been inconsistent and the air quality results are not geographically representative of most of the US. More recently, a cohort of adult male veterans diagnosed with hypertension has been examined (Lipfert et al., 2000). Unlike previous long-term analyses, this study found some associations between mortality and ozone but found inconsistent results for PM indicators.

Given their consistent results and broad applicability to general US populations, the Six-City and ACS data have been of particular importance in benefits analyses. The credibility of these two studies is further enhanced by the fact that they were subject to extensive reexamination and reanalysis by an independent scientific analysis team (Krewski et al., 2000). The final results of the reanalysis were then independently peer reviewed by a Special Panel of the HEI Health Review Committee. The results of these analyses confirmed and expanded those of the original investigators. This intensive independent reanalysis effort was occasioned both by the importance of the original findings as well as concerns that the underlying individual health effects information has never been made publicly available. The HEI re-examination lends credibility to the original studies but also found unexpected sensitivities concerning (a) which pollutants are most important, (b) the role of education in mediating the association between pollution and mortality, and (c) the magnitude of the association depending on how spatial correlation was handled. Further confirmation and extension of the overall findings using more recent air quality and ACS health information was recently published in the Journal of the American Medical Association (Pope et al., 2002). In general, the risk estimates based on the long-term mortality studies are substantially greater than those derived from short-term studies.

In developing and improving the methods for estimating and valuing the potential reductions in mortality risk over the years, EPA has consulted with a panel of the Science Advisory Board. That panel recommended use of long-term prospective cohort studies in estimating mortality risk reduction (EPA-SAB-COUNCIL-ADV-99-005, 1999). More specifically, the SAB recommended emphasis on Pope, et al. (1995) because it includes a much larger sample size and longer exposure interval, and covers more locations (50 cities as compared to 6 cities in the Harvard data) than other studies of its kind. As explained in the regulatory impact analysis for the Heavy-Duty Engine/Diesel Fuel rule (EPA, 2000b), more recent EPA benefits analyses have relied on an improved specification from this data set that was developed in the HEI reanalysis of this study (Krewski et al., 2000). The particular specification estimated a C-R function based on changes in mean levels of $PM_{2.5}$, as opposed to the function in the original study, which used median levels. This specification also includes a broader geographic scope than the original study (63 cities versus 50). The SAB has recently agreed with EPA's selection of this specification for use in analyzing mortality benefits of PM reductions (EPA-SAB-COUNCIL-ADV-01-004, 2001). For these reasons, the present analysis uses the same C-R function in developing the Base Estimate of mortality benefits related to fine particles.

Our Base Estimate also accounts for a lag between reductions in PM 2.5 concentrations and reductions in mortality incidence. It is currently unknown whether there is a time lag (a delay between changes in PM exposures and changes in mortality rates) in the long-term PM2.5/premature mortality relationship. The existence of such a lag is important for the valuation of premature mortality incidences because economic theory suggests that benefits occurring in the future should be discounted. Although there is no specific scientific evidence of the existence or structure of a PM effects lag, current scientific literature on adverse health effects, such as those associated with PM (e.g., smoking-related disease) and the difference in the effect size between chronic exposure studies and daily mortality studies suggest that all incidences of premature mortality reduction associated with a given incremental change in PM exposure probably would not occur in the same year as the exposure reduction. This same smoking-related literature implies that lags of up to a few years are plausible. Adopting the lag structure used in the Tier 2/Gasoline Sulfur RIA, the HDD RIA, and endorsed by the SAB (EPA-SAB-COUNCIL-ADV-00-001, 1999), we assume a five-year lag structure, with 25 percent of premature deaths occurring in the first year (in 2005), another 25 percent in the second year, and 16.7 percent in each of the remaining three years. The mortality incidences across the 5-year period is then discounted back to our year of analysis, 2005.

For reductions in direct emissions of $PM_{10}$, we use a different C-R function, based on the studies of mortality and shorter term exposures to PM. Long-term studies of the relationship between chronic exposure and mortality have not found significant associations with coarse particles or total $PM_{10}$. As discussed earlier in this chapter, concerns have recently been raised about aspects of the statistical methodology used in a number of recent time-series studies of short-term exposures to air pollution and health effects. Due to the "S-Plus" issue identified by the Health Effects Institute, we use as the basis for the Base Estimate the revised relative risk from the NMMAPS study, reported on the website of the Johns

Hopkins School of Public Health[3]. Similar to the $PM_{2.5}$ lag adjustment discussed above, we also include an adjustment for $PM_{10}$ to account for recent evidence that daily mortality is associated with particle levels from a number of previous days. We use the overall pooled NMMAPS estimate of a 0.224 percent increase in mortality for a 10 :g/m3 increase in $PM_{10}$ as the starting point in developing our C-R function. In a recent analysis, Schwartz (2000) found that elevated levels of $PM_{10}$ on a given day can elevate mortality on a number of following days. This type of multi-day model is often referred to as a "distributed lag" model because it assumes that mortality following a PM event will be distributed over a number of days following or "lagging" the PM event[5]. Because the NMMAPS study reflects much broader geographic coverage (90 cities) than the Schwartz study (10 cities), and the Schwartz study has not been reanalyzed to account for the "S-Plus" issue, we choose to apply an adjustment based on the Schwartz study to the NMMAPS study to reflect the effect of a distributed lag model.

The distributed lag adjustment factor is constructed as the ratio of the estimated coefficient from the unconstrained distributed lag model to the estimated coefficient from the single-lag model reported in Schwartz (2000)[4]. The unconstrained distributed lag model coefficient estimate is 0.0012818 and the single-lag model coefficient estimate is 0.0006479. The ratio of these estimates is 1.9784. This adjustment factor is then multiplied by the revised estimated coefficients from the NMMAPS study. The NMMAPS coefficient corresponding to the 0.224 percent increase in mortality risk is 0.000224. The adjusted NMMAPS coefficent is then 0.000224*1.9784 = 0.000444.

Alternative Estimate

To reflect concerns about the inherent limitations in the number of studies supporting a causal association between long-term exposure and mortality, an Alternative benefit estimate was derived from the large number of time-series studies that have established a likely causal relationship between short-term measures of PM and daily mortality statistics. A particular strength of such studies is the fact that potential confounding variables such as socio-economic status, occupation, and smoking do not vary on a day-to-day basis in an individual area. A number of multi-city and other types of studies strongly suggest that these effects-relationships cannot be explained by weather, statistical approaches, or other pollutants. The risk estimates from the vast majority of the short-term studies include the effects of only one or two-day exposure to air pollution. More recently, several studies have found that the practice of examining the effects on a single day basis may significantly understate the risk of short-term exposures (Schwartz, 2000; Zanobetti et al, 2002). These studies suggest that the short-term risk can double when the single-day effects are combined with the cumulative impact of exposures over multiple days to weeks prior to a mortality event.

[3]http://www.biostat.jhsph.edu/biostat/research/update.main.htm

[4]Both the single day and distributed lag models are likely to be affected to the same degree by the S-Plus convergence issue. As such, the ratio of the coefficients from the models should not be affected as much by any changes in the coefficient

The fact that the PM-mortality coefficients from the cohort studies are far larger than the coefficients derived from the daily time-series studies provides some evidence for an independent chronic effect of PM pollution on health. Indeed, the Base Estimate presumes that the larger coefficients represent a more complete accounting of mortality effects, including both the cumulative total of short-term mortality as well as an additional chronic effect. This is, however, not the only possible interpretation of the disparity. Various reviewers have argued that 1) the long-term estimates may be biased high and/or 2) the short-term estimates may be biased low. In this view, the two study types could be measuring the same underlying relationship.

Reviewers have noted some possible sources of upward bias in the long-term studies. Some have noted that the less robust estimates based on the Six-Cities Study are significantly higher than those based on the more broadly distributed ACS data sets. Some reviewers have also noted that the observed mortality associations from the 1980's and 90's may reflect higher pollution exposures from the 1950's to 1960's. While this would bias estimates based on more recent pollution levels upwards, it also would imply a truly long-term chronic effect of pollution.

With regard to possible sources of downward bias, it is of note that the recent studies suggest that the single day time series studies may understate the short-term effect on the order of a factor of two. These considerations provide a basis for considering an Alternative Estimate using the most recent estimates from the wealth of time-series studies, in addition to one based on the long-term cohort studies.

In essence, the Alternative Estimate addresses the above noted uncertainties about the relationship between premature mortality and long-term exposures to ambient levels of fine particles by assuming that there is no mortality effect of chronic exposures to fine particles. Instead, it assumes that the full impact of fine particles on premature mortality can be captured using a concentration-response function relating daily mortality to short-term fine particle levels. Specifically, a concentration-response function based on Schwartz et al. (1996) is employed, with an adjustment to account for recent evidence that daily mortality is associated with particle levels from a number of previous days (Schwartz, 2000), similar to the adjustment for the $PM_{10}$ mortality C-R function described for the Base Estimate.

There are no $PM_{2.5}$ daily mortality studies which report numeric estimates of relative risks from distributed lag models; only $PM_{10}$ studies are available. Daily mortality C-R functions for $PM_{10}$ are consistently lower in magnitude than $PM_{2.5}$-mortality C-R functions, because fine particles are believed to be more closely associated with mortality than the coarse fraction of PM. Given that the emissions reductions under the Industrial Boilers and Process Heaters NESHAP result primarily in reduced ambient concentrations of $PM_{2.5}$, use of a $PM_{10}$ based C-R function results in a significant downward bias in the estimated reductions in mortality. To account for the full potential multi-day mortality impact of acute $PM_{2.5}$ events, we use the same adjustment factor (1.9784) used in developing the $PM_{10}$ mortality C-R function, applied to the $PM_{2.5}$ based C-R function reported in Schwartz et al. (1996).

If most of the increase in mortality is expected to be associated with the fine fraction of $PM_{10}$, then it is reasonable to assume that the same proportional increase in risk would be observed if a distributed lag model were applied to the $PM_{2.5}$ data. There are two relevant coefficients from the Schwartz et al. (1996) study, one corresponding to all-cause mortality, and one corresponding to chronic obstructive pulmonary disease (COPD) mortality (separation by cause is necessary to implement the life years lost approach detailed below). The adjusted estimates for these two C-R functions are:

$$\text{All cause mortality} = 0.001489 * 1.9784 = 0.002946$$
$$\text{COPD mortality} = 0.003246 * 1.9784 = 0.006422$$

Note that these estimates, while approximating the full impact of daily pollution levels on daily death counts, do not capture any impacts of long-term exposure to air pollution. As discussed earlier, EPA's Science Advisory Board, while acknowledging the uncertainties in estimation of a PM-mortality relationship, has repeatedly recommended the use of a study that does reflect the impacts of long-term exposure. The omission of long-term impacts accounts for approximately 40 percent reduction in the estimate of avoided premature mortality in the Alternative Estimate relative to the Base Estimate.

### 10.4.2 *Valuing Individual Health Effect Endpoints*

The appropriate economic value of a change in a health effect depends on whether the health effect is viewed ex ante (before the effect has occurred) or ex post (after the effect has occurred). Reductions in ambient concentrations of air pollution generally lower the risk of future adverse health affects by a fairly small amount for a large population. The appropriate economic measure is therefore ex ante WTP for changes in risk. However, epidemiological studies generally provide
estimates of the relative risks of a particular health effect avoided due to a reduction in air pollution. A convenient way to use this data in a consistent framework is to convert probabilities to units of avoided statistical incidences. This measure is calculated by dividing individual WTP for a risk reduction by the related observed change in risk. For example, suppose a measure is able to reduce the risk of premature mortality from 2 in 10,000 to 1 in 10,000 (a reduction of 1 in 10,000). If individual WTP for this risk reduction is $100, then the WTP for an avoided statistical premature mortality amounts to $1 million ($100/0.0001 change in risk). Using this approach, the size of the affected population is automatically taken into account by the number of incidences predicted by epidemiological studies applied to the relevant population. The same type of calculation can produce values for statistical incidences of other health endpoints.

For some health effects, such as hospital admissions, WTP estimates are generally not available. In these cases, we use the cost of treating or mitigating the effect as a primary estimate. For example, for the valuation of hospital admissions we use the avoided medical costs as an estimate of the value of avoiding the health effects causing the admission. These costs of illness (COI) estimates generally understate the true value of reductions in risk of a health effect. They tend to reflect the direct expenditures related to treatment but not the value of avoided pain and suffering from the health effect. In the HDD RIA and TSD, we describe how the changes in health effects should be valued and indicate the value functions selected to provide monetized estimates of the value of changes in health effects. Table 10-5 below summarizes the value estimates per health effect that we used in this analysis. Note that the unit values for hospital admissions are the weighted averages of the ICD-9 code-specific values for the group of ICD-9 codes included in the hospital admission categories.

**Table 10-5. Unit Values Used for Economic Valuation of Health Endpoints**

| Health or Welfare Endpoint | Estimated Value Per Incidence (1999$) Central Estimate | Derivation of Estimates |
|---|---|---|
| **Premature Mortality (long-term exposure endpoint, Base Estimate)** | $6 million per statistical life | Value is the mean of value-of-statistical-life estimates from 26 studies (5 contingent valuation and 21 labor market studies) reviewed for the Section 812 Costs and Benefits of the Clean Air Act, 1990-2010 (US EPA, 1999). |
| **Premature Mortality (short-term exposure endpoints, Alternative Estimate)** | Varies by age and life years lost | See section on Valuation of Premature Mortality, Alternative Estimate, in text |
| **Chronic Bronchitis (Base Estimate)** | $331,000 | Value is the mean of a generated distribution of WTP to avoid a case of pollution-related CB. WTP to avoid a case of pollution-related CB is derived by adjusting WTP (as described in Viscusi et al., 1991) to avoid a severe case of CB for the difference in severity and taking into account the elasticity of WTP with respect to severity of CB. |
| **Chronic Bronchitis (Alternative Estimate)** | $107,000 | Cost of Illness (COI) estimate based on Cropper and Krupnick (1990). |
| **Hospital Admissions** | | |
| Chronic Obstructive Pulmonary Disease (COPD) (ICD codes 490-492, 494-496) | $12,378 | The COI estimates are based on ICD-9 code level information (e.g., average hospital care costs, average length of hospital stay, and weighted share of total COPD category illnesses) reported in Elixhauser (1993). |
| Pneumonia (ICD codes 480-487) | $14,693 | The COI estimates are based on ICD-9 code level information (e.g., average hospital care costs, average length of hospital stay, and weighted share of total pneumonia category illnesses) reported in Elixhauser (1993). |
| Asthma admissions | $6,634 | The COI estimates are based on ICD-9 code level information (e.g., average hospital care costs, average length of hospital stay, and weighted share of total asthma category illnesses) reported in Elixhauser (1993). |
| All Cardiovascular (ICD codes 390-429) | $18,387 | The COI estimates are based on ICD-9 code level information (e.g., average hospital care costs, average length of hospital stay, and weighted share of total cardiovascular illnesses) reported in Elixhauser (1993). |

**Table 10-5. Unit Values Used for Economic Valuation of Health Endpoints**

| Health or Welfare Endpoint | Estimated Value Per Incidence (1999$) Central Estimate | Derivation of Estimates |
|---|---|---|
| Emergency room visits for asthma | $299 | COI estimate based on data reported by Smith, et al. (1997). |

**Table 10-5. Unit Values Used for Economic Valuation of Health Endpoints**

| Health or Welfare Endpoint | Estimated Value Per Incidence (1999$) Central Estimate | Derivation of Estimates |
|---|---|---|
| **Respiratory Ailments Not Requiring Hospitalization** | | |
| Upper Respiratory Symptoms (URS) | $24 | Combinations of the 3 symptoms for which WTP estimates are available that closely match those listed by Pope, et al. result in 7 different "symptom clusters," each describing a "type" of URS. A dollar value was derived for each type of URS, using mid-range estimates of WTP (IEc, 1994) to avoid each symptom in the cluster and assuming additivity of WTPs. The dollar value for URS is the average of the dollar values for the 7 different types of URS. |
| Lower Respiratory Symptoms (LRS) | $15 | Combinations of the 4 symptoms for which WTP estimates are available that closely match those listed by Schwartz, et al. result in 11 different "symptom clusters," each describing a "type" of LRS. A dollar value was derived for each type of LRS, using mid-range estimates of WTP (IEc, 1994) to avoid each symptom in the cluster and assuming additivity of WTPs. The dollar value for LRS is the average of the dollar values for the 11 different types of LRS. |
| Acute Bronchitis | $57 | Average of low and high values recommended for use in Section 812 analysis (Neumann, et al. 1994) |
| **Restricted Activity and Work Loss Days** | | |
| Work Loss Days (WLDs) | Variable | Regionally adjusted median weekly wage for 1990 divided by 5 (adjusted to 1999$) (US Bureau of the Census, 1992). |
| Minor Restricted Activity Days (MRADs) | $48 | Median WTP estimate to avoid one MRAD from Tolley, et al. (1986) . |

*<u>Adjustments for Growth in Real Income</u>*

Our analysis also accounts for expected growth in real income over time. Economic theory argues that WTP for most goods (such as environmental protection) will increase if real incomes increase. The economics literature suggests that the severity of a health effect is a primary determinant of the strength of the relationship between changes in real income and WTP (Alberini, 1997; Miller, 2000; Viscusi, 1993). As such, we use different factors to adjust the WTP for minor health effects, severe and chronic health effects, and premature mortality. Adjustment factors used to account for projected growth in real income from 1990 to 2005 are 1.03 for minor health effects, 1.09 for severe and chronic health effects, and 1.08 for premature mortality[7].

*10.4.2.1 Valuation of Reductions in Premature Mortality Risk*

Below we present the method for valuing premature mortality in our Base and Alternative Estimates. In both estimates, the values reflect two alternative discount rates, three percent and seven percent, used to estimate the present value of the effect. The choice of a discount rate, and its associated conceptual basis, is a topic of ongoing discussion within the federal government. We adopted a three percent discount rate to reflect reliance on a "social rate of time preference" discounting concept, which is recommended by EPA's *Guidelines for Preparing Economic Analyses* (U.S. EPA, 2000). We also calculate benefits using a seven percent rate consistent with an "opportunity cost of capital" concept to reflect the time value of resources directed to meet regulatory requirements, which is recommended by OMB Circular A-94 (OMB, 1992). In this analysis, the benefit estimates were not significantly affected by the choice of discount rate. Further discussion of this topic appears in EPA's *Guidelines for Preparing Economic Analyses* ( EPA 240-R-00-003, September 2000).

<u>Base Estimate</u>

The monetary benefit of reducing premature mortality risk was estimated using the "value of statistical lives saved" (VSL) approach, although the actual valuation is of small changes in mortality risk experienced by a large number of people. The VSL approach applies information from several published value-of-life studies, which themselves examine tradeoffs of monetary compensation for small additional mortality risks, to determine a reasonable benefit of preventing premature mortality. The mean value of avoiding one statistical death is estimated to be $6 million in 1999 dollars. This represents an intermediate value from a range of estimates that appear in the economics literature, and it is a value the EPA has used in rulemaking support analyses and in the Section 812 Reports to Congress. This estimate is the mean of a distribution fitted to the estimates from 26 value-of-life studies identified in the Section 812 reports as "applicable to policy analysis." The approach and set of selected studies mirrors that of Viscusi (1992) (with the addition of two studies), and uses the same criteria as Viscusi in his review of value-of-life studies. The $6 million estimate is consistent with Viscusi's conclusion (updated to 1999$) that "most of the reasonable estimates of the value of life are clustered in the $3.7 to $8.6 million range." Five of the 26 studies are contingent valuation (CV) studies, which directly solicit WTP information from subjects; the rest are wage-risk studies, which base WTP estimates on estimates of the additional compensation demanded in the labor market for riskier jobs, controlling for other job and employee characteristics such as education and experience. As indicated in the previous section on quantification of premature mortality benefits, we assume for this analysis that some of the incidences of premature mortality related to PM exposures occur in a distributed fashion over the five years following exposure. To take this into account in the valuation of reductions in premature mortality, we apply an annual three percent discount rate to the value of premature mortality occurring in future years.

The economics literature concerning the appropriate method for valuing reductions in premature mortality risk is still developing. The adoption of a value for the projected reduction in the risk of premature mortality is the subject of continuing discussion within the economic and public policy analysis community. Regardless of the theoretical economic considerations, distinctions in the monetary value assigned to the lives saved were not drawn, even if populations differed in age, health status, socioeconomic status, gender or other characteristics.

Following the advice of the EEAC of the SAB, the VSL approach was used to calculate the Base Estimate of mortality benefits (EPA-SAB-EEAC-00-013). While there are several differences between the risk context implicit in labor market studies we use to derive a VSL estimate and the particulate matter air pollution context addressed here, those differences in the affected populations and the nature of the risks imply both upward and downward adjustments. For example, adjusting for age differences between subjects in the economic studies and those affected by air pollution may imply the need to adjust the $6 million VSL downward, but the involuntary nature of air pollution-related risks and the lower level of risk-aversion of the manual laborers in the labor market studies may imply the need for upward adjustments.

Some economists emphasize that the value of a statistical life is not a single number relevant for all situations. Indeed, the VSL estimate of $6 million (1999 dollars) is itself the central tendency of a number of estimates of the VSL for some rather narrowly defined populations. When there are significant differences between the population affected by a particular health risk and the populations used in the labor market studies, as is the case here, some economists prefer to adjust the VSL estimate to reflect those differences.

There is general agreement that the value to an individual of a reduction in mortality risk can vary based on several factors, including the age of the individual, the type of risk, the level of control the individual has over the risk, the individual's attitudes towards risk, and the health status of the individual. While the empirical basis for adjusting the $6 million VSL for many of these factors does not yet exist, a thorough discussion of these uncertainties is included in EPA's Guidelines for Preparing Economic Analyses (U.S. EPA, 2000a). The EPA recognizes the need for investigation by the scientific community to develop additional empirical support for adjustments to VSL for the factors mentioned above.

As further support for the Base benefits estimate, the SAB-EEAC advised in their recent report that the EPA "continue to use a wage-risk-based VSL as its Base Estimate, including appropriate sensitivity analyses to reflect the uncertainty of these estimates," and that "the only risk characteristic for which adjustments to the VSL can be made is the timing of the risk"(EPA-SAB-EEAC-00-013). In developing the Base Estimate of the benefits of premature mortality reductions, we have discounted over the lag period between exposure and premature mortality. However, in accordance with the SAB advice, we use the VSL in the Base Estimate.

Alternative Estimate

The Alternative Estimate reflects the impact of changes to key assumptions associated with the valuation of mortality. These include: 1) the impact of using wage-risk and contingent valuation-based value of statistical life estimates in valuing risk reductions from air pollution as opposed to contingent valuation-based estimates alone, 2) the relationship between age and willingness-to-pay for fatal risk reductions, and 3) the degree of prematurity in mortalities from air pollution.

The Alternative Estimate addresses the first issue by using an estimate of the value of statistical life that is based only on the set of five contingent valuation studies included in the larger set of 26 studies recommended by Viscusi (1992) as applicable to policy analysis. The mean of the five contingent valuation based VSL estimates is $3.7 million (1999$), which is approximately 60 percent of the mean value of the full set of 26 studies. The second issue is addressed by assuming that the relationship between age and willingness-to-pay for fatal risk reductions can be approximated using an adjustment factor derived from Jones-Lee (1989). The SAB has advised the EPA that the appropriate way to account for age differences is to obtain the values for risk reductions from the age groups affected by the risk reduction. Several studies have found a significant effect of age on the value of mortality risk reductions expressed by citizens in the United Kingdom (Jones-Lee et al., 1985; Jones-Lee, 1989; Jones-Lee, 1993).

Two of these studies provide the basis to form ratios of the WTP of different age cohorts to a base age cohort of 40 years. These ratios can be used to provide Alternative age-adjusted estimates of the value of avoided premature mortalities. One problem with both of the Jones-Lee studies is that they examine VSL for a limited age range. They then fit VSL as a function of age and extrapolate outside the range of the data to obtain ratios for the very old. Unfortunately, because VSL is specified as quadratic in age, extrapolation beyond the range of the data can lead to a very severe decline in VSL at ages beyond 75.

A simpler and potentially less biased approach is to simply apply a single age adjustment based on whether the individual was over or under 65 years of age at the time of death. This is consistent with the range of observed ages in the Jones-Lee studies and also agrees with the findings of more recent studies by Krupnick et al. (2000) that the only significant difference in WTP is between the over 70 and under 70 age groups. To correct for the potential extrapolation error for ages beyond 70, the adjustment factor is selected as the ratio of a 70 year old individual's WTP to a 40 year old individual's WTP, which is 0.63, based on the Jones-Lee (1989) results and 0.92 based on the Jones-Lee (1993) results. To show the maximum impact of the age adjustment, the Alternative Estimate is based on the Jones-Lee (1989) adjustment factor of 0.63, which yields a VSL of $2.3 million for populations over the age of 70. Deaths of individuals under the age of 70 are valued using the unadjusted mean VSL value of $3.7 million (1999$). Since these are acute mortalities, it is assumed that there is no lag between reduced exposure and reduced risk of mortality.

Jones-Lee and Krupnick may understate the effect of age because they only control for income and do not control for wealth. While there is no empirical evidence to support or reject hypotheses regarding wealth and observed WTP, WTP for additional life years by the elderly may in part reflect their wealth position vis a vis middle age respondents.

The third issue is addressed by assuming that deaths from chronic obstructive pulmonary disease (COPD) are advanced by 6 months, and deaths from all other causes are advanced by 5 years. These reductions in life years lost are applied regardless of the age at death. Actuarial evidence suggests that individuals with serious preexisting cardiovascular conditions have a remaining life expectancy of around 5 years. While many deaths from daily exposure to PM may occur in individuals with cardiovascular disease, studies have shown relationships between all cause mortality and PM, and between PM and mortality from pneumonia (Schwartz, 2000). In addition, recent studies have shown a relationship between PM and non-fatal heart attacks, which suggests that some of the deaths due to PM may be due to fatal heart attacks (Peters et al., 2001). And, a recent meta-analysis has shown little effect of age on the relative risk from PM exposure (Stieb et al., 2002), which suggests that the number of deaths in non-elderly populations (and thus the potential for greater loss of life years) may be significant. Indeed, this analysis estimates that 21 percent of non-COPD premature deaths avoided are in populations under 65. Thus, while the assumption of 5 years of life lost may be appropriate for a subset of total avoided premature mortalitites, it may over or underestimate the degree of life shortening attributable to PM for the remaining deaths.

In order to value the expected life years lost for COPD and non-COPD deaths, we need to construct estimates of the value of a statistical life year. The value of a life year varies based on the age at death, due to the differences in the base VSL between the 65 and older population and the under 65 population. The valuation approach used is a value of statistical life years (VSLY) approach, based on amortizing the base VSL for each age cohort. Previous applications have arrived at a single value per life year based on the discounted stream of values that correspond to the VSL for a 40 year old worker (EPA, 1999a). This assumes 35 years of life lost is the base value associated with the mean VSL value of $3.7 million (1999$). The VSLY associated with the $3.7 million VSL is $163,000, annualized assuming EPA's guideline value of a 3 percent discount rate, or $270,000, annualized assuming OMB's guideline value of a 7 percent discount rate. For example, using the 3 percent discount rate, the VSL applied in this analysis is then built up from that VSLY by taking the present value of the stream of life years. Thus, if you assume that a 40 year-old dying from pneumonia would lose 5 years of life, the VSL applied to that death would be $0.79 million. For populations over age 65, we then develop a VSLY from the age-adjusted base VSL of $2.3 million. Given an assumed remaining life expectancy of 10 years, this gives a VSLY of $258,000, assuming a 3 percent discount rate. A similar calculation is used to derive the VSLY estimate using a 7% discount rate. Again, the VSL is built based on the present value of 5 years of lost life, so in this case, we have a 70 year old individual dying from pneumonia losing 5 years of life, implying an estimated VSL of $1.25 million. As a final step, these estimated VSL values are multiplied by the appropriate adjustment factors to account for changes in WTP over time, as outlined above.

Applying the VSLY approach to the four categories of acute mortality results in four separate sets of values for an avoided premature mortality based on age and cause of death. Non-COPD deaths for populations aged 65 and older are valued at $1.4 million per incidence in 2010, and $1.6 million in 2020. Non-COPD deaths for populations aged 64 and younger are valued at $0.88 million per incidence in 2010, and $1.0 million in 2020. COPD deaths for populations aged 65 and older are valued at $0.15 million per incidence in 2010, and $0.17 million in 2020. Finally, COPD deaths for populations aged 64 and younger are valued at $0.096 million per incidence in 2010, and $0.11 million in 2020. The implied VSL for younger populations is less than that for older populations because the value per life year is higher for older populations. Since we assume that there is a 5 year loss in life years for a PM related mortality, regardless of the age of person dying, this necessarily leads to a lower VSL for younger populations.

Note that the NMMAPS study used to derive the C-R function for $PM_{10}$ did not provide separate estimates for different causes of death, so we are unable to determine the proportion of $PM_{10}$ deaths that are attributable to COPD or other causes. In the Base analysis, such distinctions are unnecessary, as all reductions in incidence of premature mortality are valued equally, regardless of age at death or remaining life expectancy. In the alternative estimate, the value of avoided incidences of premature mortality is determined by age and remaining life expectancy, so cause of death and age are important. Given the lack of data on cause of death, we assume all deaths from $PM_{10}$ are equivalent (within an age category) and result in the same number of life years lost, assumed to be equal to 5 years.

#### *10.4.2.2 Valuation of Reductions in Chronic Bronchitis*

Base Estimate

The best available estimate of WTP to avoid a case of chronic bronchitis (CB) comes from Viscusi, et al. (1991). The Viscusi, et al. study, however, describes a severe case of CB to the survey respondents. We therefore employ an estimate of WTP to avoid a pollution-related case of CB, based on adjusting the Viscusi, et al. (1991) estimate of the WTP to avoid a severe case. This is done to account for the likelihood that an average case of pollution-related CB is not as severe. The adjustment is made by applying the elasticity of WTP with respect to severity reported in the Krupnick and Cropper (1992) study. Details of this adjustment procedure can be found in the Heavy-Duty Engine/Diesel Fuel RIA and its supporting documentation, and in the most recent Section 812 study (EPA 1999).

We use the mean of a distribution of WTP estimates as the central tendency estimate of WTP to avoid a pollution-related case of CB in this analysis. The distribution incorporates uncertainty from three sources: (1) the WTP to avoid a case of severe CB, as described by Viscusi, et al.; (2) the severity level of an average pollution-related case of CB (relative to that of the case described by Viscusi, et al.); and (3) the elasticity of WTP with respect to severity of the illness. Based on assumptions about the distributions of each of these three uncertain components, we derive a distribution of WTP to avoid a pollution-related case of CB by statistical uncertainty analysis techniques. The expected value (i.e., mean) of this distribution, which is about $331,000 (1999$), is taken as the central tendency estimate of WTP to avoid a PM-related case of CB.

Alternative Estimate

For the Alternative Estimate, a cost-of illness value is used in place of willingness-to-pay to reflect uncertainty about the value of reductions in incidences of chronic bronchitis. In the Base Estimate, the willingness-to-pay estimate was derived from two contingent valuation studies (Viscusi et al., 1991; Krupnick and Cropper, 1992). These studies were experimental studies intended to examine new methodologies for eliciting values for morbidity endpoints. Although these studies were not specifically designed for policy analysis, the SAB (EPA-SAB-COUNCIL-ADV-00-002, 1999) has indicated that the severity-adjusted values from this study provide reasonable estimates of the WTP for avoidance of chronic bronchitis. As with other contingent valuation studies, the reliability of the WTP estimates depends on the methods used to obtain the WTP values. In order to investigate the impact of using the CV based WTP estimates, the Alternative Estimate relies on a value for incidence of chronic bronchitis using a cost-of-illness estimate based on Cropper and Krupnick (1990) which calculates the present value of the lifetime expected costs associated with the illness. The current cost-of-illness (COI) estimate for chronic bronchitis is around $107,000 per case, compared with the current WTP estimate of $330,000.

### 10.4.3 *Results of Phase One Analysis: Benefits Resulting from a Portion of Emission Reductions at a Subset of Boiler and Process Heater Sources*

Applying the C-R and valuation functions described above to the estimated changes in PM from phase one of our analysis yields estimates of the number of avoided incidences (i.e. premature mortalities, cases, admissions, etc.) and the associated monetary values for those avoided incidences. In Tables 10-6(a) and (b), we provide the results for the Base Estimate and the Alternative Estimate of the MACT floor option resulting from the phase one analysis. Tables 10-7(a) and (b) present the results for the Base Estimate and the Alternative Estimate of the above the MACT floor option resulting from the phase one analysis. To obtain a total benefit estimate, we aggregate dollar benefits associated with each of the health effects examined, such as hospital admissions, assuming that none of the included health and welfare effects overlap. All of the monetary benefits are in constant 1999 dollars.

As we have discussed, not all known PM-related health and welfare effects could be quantified or monetized. These unmonetized benefits are indicated in Tables 10-6 and 10-7 by place holders, labeled $B_1$ and $B_2$. In addition, unmonetized benefits associated with HAP reductions are indicated by the placeholder $B_3$. Unquantified reduce incidences of physical effects are indicated by $U_1$ and $U_2$. The estimate of total monetized health benefits is thus equal to the subset of monetized PM-related health benefits plus $B_H$, the sum of the unmonetized health benefits.

**Table 10-6(a). Phase One Analysis: Base Estimate of Annual Benefits Associated with Approximately 50% of the Emission Reductions from the Industrial Boilers/Process Heaters NESHAP (MACT Floor Regulatory Option in 2005) Using Air Quality Modeling & the CAPMS Benefit Model[A, B]**

| Endpoint | Avoided Incidence[C] (cases/year) | Monetary Benefits[D] (millions 1999$, adjusted for growth in real income) |
|---|---|---|
| Premature mortality[E,F] (long-term exposure, adults 30 and over) | | |
| -Using a 3% discount rate | 1,170 | $7,325 |
| -Using a 7% discount rate | 1,170 | $6,880 |
| Chronic bronchitis (adults, 26 and over, WTP valuation) | 2,340 | $845 |
| Hospital Admissions – Pneumonia (adults, over 64) | 500 | $5 |
| Hospital Admissions – COPD (adults, 64 and over) | 420 | $5 |
| Hospital Admissions – Asthma (65 and younger) | 120 | $1 |
| Hospital Admissions – Cardiovascular (adults, over 64) | 1,230 | $25 |
| Emergency Room Visits for Asthma (65 and younger) | 930 | <$1 |
| Asthma Attacks (asthmatics, all ages) | 79,020 | $B_1$ |
| Acute bronchitis (children, 8-12) | 2,430 | <$1 |
| Lower respiratory symptoms (children, 7-14) | 26,470 | <$1 |
| Upper respiratory symptoms (asthmatic children, 9-11) | 89,480 | $5 |
| Work loss days (adults, 18-65) | 205,400 | $20 |
| Minor restricted activity days (adults, age 18-65) | 1,011,200 | $50 |
| Other PM-related health effects[G] | $U_1$ | $B_2$ |
| HAP health effects[G] | $U_2$ | $B_3$ |
| **Total Monetized Health-Related Benefits**[F] | | |
| -Using a 3% discount rate | — | $8,280+**$B_H$** |
| -Using a 7% discount rate | — | $7,835+**$B_H$** |

[A]The results presented in this table are based on those $SO_2$ and PM emission reductions identified for specific sources included in the Inventory Database. This includes approximately 50% of all emission reductions estimated by the rule. The location of all other emission reductions (i.e. non-inventory reductions) cannot be determined specifically and hence cannot be modeled in an air quality model. See Section 10.5 and Appendix D for benefit estimation of non-inventory emission reductions.

[B] The results presented in this table reflect the outcome of the combination of PM and $SO_2$ model runs. See Appendix D for a presentation of results for each pollutant independently.

[C] Incidences are rounded to the nearest 10 and may not add due to rounding. Incidences of unquantified endpoints are indicated with a U.

[D] Dollar values are rounded to the nearest 5 million and may not add due to rounding. The value of unquantified endpoints are indicated with a B.

[E] Note that the estimated value for PM-related premature mortality assumes the 5 year distributed lag structure described in detail in the Regulatory Impact Analysis of Heavy Duty Engine/Diesel Fuel rule.
[F] Monetized benefits are presented using two different discount rates. Results calculated using 3 percent discount rate are recommended by EPA's *Guidelines for Preparing Economic Analyses* (U.S. EPA, 2000a). Results calculated using 7 percent discount rate are recommended by OMB Circular A-94 (OMB, 1992).
[G] A detailed listing of unquantified PM and HAP related health effects is provided in Table 10-17.

**Table 10-6(b). Phase One Analysis: Alternative Estimate of Annual Benefits Associated with Approximately 50% of the Emission Reductions from the Industrial Boilers/Process Heaters NESHAP (MACT Floor Regulatory Option in 2005) Using Air Quality Modeling & the CAPMS Benefit Model[A, B]**

| Endpoint | Avoided Incidence[C] (cases/year) | Monetary Benefits[D] (millions 1999$, adjusted for growth in real income) |
|---|---|---|
| Premature mortality (short-term exposure, all ages)[E] | | |
| -Using a 3% discount rate | 702 | $780 |
| -Using a 7% discount rate | 702 | $900 |
| Chronic bronchitis (adults, 26 and over, COI valuation) | 2,340 | $275 |
| Hospital Admissions – Pneumonia (adults, over 64) | 500 | $5 |
| Hospital Admissions – COPD (adults, 64 and over) | 420 | $5 |
| Hospital Admissions – Asthma (65 and younger) | 120 | $1 |
| Hospital Admissions – Cardiovascular (adults, over 64) | 1,230 | $25 |
| Emergency Room Visits for Asthma (65 and younger) | 930 | <$1 |
| Asthma Attacks (asthmatics, all ages) | 79,020 | $B_1$ |
| Acute bronchitis (children, 8-12) | 2,430 | <$1 |
| Lower respiratory symptoms (children, 7-14) | 26,470 | <$1 |
| Upper respiratory symptoms (asthmatic children, 9-11) | 89,480 | $5 |
| Work loss days (adults, 18-65) | 205,400 | $20 |
| Minor restricted activity days (adults, age 18-65) | 1,011,200 | $50 |
| Other PM-related health effects[F] | $U_1$ | $B_2$ |
| HAP health effects[F] | $U_2$ | $B_3$ |
| **Total Monetized Health-Related Benefits[E]** | | |
| -Using a 3% discount rate | — | \$1,165+$\mathbf{B_H}$ |
| -Using a 7% discount rate | — | \$1,290+$\mathbf{B_H}$ |

[A] The results presented in this table are based on those $SO_2$ and PM emission reductions identified for specific sources included in the Inventory Database. This includes approximately 50% of all emission reductions estimated by the rule. The location of all other emission reductions (i.e. non-inventory reductions) cannot be determined specifically and hence cannot be modeled in an air quality model. See Section 10.5 and Appendix D for benefit estimation of non-inventory emission reductions.

[B] The results presented in this table reflect the outcome of the combination of PM and $SO_2$ model runs. See Appendix D for a presentation of results for each pollutant independently.

[C] Incidences are rounded to the nearest 10 and may not add due to rounding. Incidences of unquantified endpoints are indicated with a U.

[D] Dollar values are rounded to the nearest 5 million and may not add due to rounding. The value of unquantified endpoints are indicated with a B.

[E] Monetized benefits are presented using two different discount rates. Results calculated using 3 percent discount rate are recommended by EPA's *Guidelines for Preparing Economic Analyses* (U.S. EPA, 2000a). Results calculated using 7 percent discount rate are recommended by OMB Circular A-94 (OMB, 1992).
[F] A detailed listing of unquantified PM and HAP related health effects is provided in Table 10-17.

Thus, our Base Estimate of total monetized benefits for phase one of the Industrial Boilers/Process Heaters NESHAP benefit analysis associated with the MACT floor is approximately \$8 billion + $B_H$ (using either a 3% or 7% discount rate). The Alternative Estimate is approximately \$1 billion + $B_H$ (using either a 3% or 7% discount rate). The benefits of phase one in combination with the phase two estimate of benefits will serve as the basis for our estimate of the total benefits of the regulation.

For the Above the MACT Floor option of this NESHAP, Table 10-7 indicates that the Base Estimate of total monetized benefits for phase one of the analysis is approximately \$10 billion + $B_H$ using a 3% discount rate (or approximately \$9.5 billion using a 7% discount rate). The Alternative Estimate of total monetized benefits associated with phase one of the analysis is \$1.5 billion using a 3% discount rate (using either a 3% or 7% discount rate).

**Table 10-7(a). Phase One Analysis: Base Estimate of Annual Benefits Associated with Approximately 50% of the Emission Reductions from the Industrial Boilers/Process Heaters NESHAP (Above the MACT Floor Regulatory Option in 2005) Using Air Quality Modeling & the CAPMS Benefit Model[A, B]**

| Endpoint | Avoided Incidence[C] (cases/year) | Monetary Benefits[D] (millions 1999$, adjusted for growth in real income) |
|---|---|---|
| Premature mortality[E,F] (long-term exposure, adults, 30 and over) | | |
| -Using a 3% discount rate | 1,390 | $8,740 |
| -Using a 7% discount rate | 1,390 | $8,210 |
| Chronic bronchitis (adults, 26 and over, WTP valuation) | 2,860 | $1,030 |
| Hospital Admissions – Pneumonia (adults, over 64) | 610 | $10 |
| Hospital Admissions – COPD (adults, 64 and over) | 500 | $5 |
| Hospital Admissions – Asthma (65 and younger) | 140 | $1 |
| Hospital Admissions – Cardiovascular (adults, over 64) | 1,480 | $25 |
| Emergency Room Visits for Asthma (65 and younger) | 1,140 | <$1 |
| Asthma Attacks (asthmatics, all ages) | 97,060 | $B_1$ |
| Acute bronchitis (children, 8-12) | 2,870 | <$1 |
| Lower respiratory symptoms (children, 7-14) | 31,290 | <$1 |
| Upper respiratory symptoms (asthmatic children, 9-11) | 110,370 | $5 |
| Work loss days (adults, 18-65) | 243,870 | $25 |
| Minor restricted activity days (adults, age 18-65) | 1,196,500 | $60 |
| Other PM-related health effects[F] | $U_1$ | $B_2$ |
| HAP health effects[G] | $U_2$ | $B_3$ |
| **Total Monetized Health-Related Benefits**[F] | | |
| -Using a 3% discount rate | — | $9,905+**$B_H$** |
| -Using a 7% discount rate | — | $9,375+**$B_H$** |

[A]The results presented in this table are based on those $SO_2$ and PM emission reductions identified for specific sources included in the Inventory Database. This includes approximately 50% of all emission reductions estimated by the rule. The location of all other emission reductions (i.e. non-inventory reductions) cannot be determined specifically and hence cannot be modeled in an air quality model. See Section 10.5 and Appendix D for benefit estimation of non-inventory emission reductions.

[B] The results presented in this table reflect the outcome of the combination of PM and $SO_2$ model runs. See Appendix D for a presentation of results for each pollutant independently.

[C] Incidences are rounded to the nearest 10 and may not add due to rounding. Incidences of unquantified endpoints are indicated with a U.

[D] Dollar values are rounded to the nearest 5 million and may not add due to rounding. The value of unquantified endpoints are indicated with a B.

[E] Note that the estimated value for PM-related premature mortality assumes the 5 year distributed lag structure described in detail in the Regulatory Impact Analysis of Heavy Duty Engine/Diesel Fuel rule.
[E] Monetized benefits are presented using two different discount rates. Results calculated using 3 percent discount rate are recommended by EPA's *Guidelines for Preparing Economic Analyses* (U.S. EPA, 2000a). Results calculated using 7 percent discount rate are recommended by OMB Circular A-94 (OMB, 1992).
[F] A detailed listing of unquantified PM and HAP related health effects is provided in Table 10-17.

**Table 10-7(b). Phase One Analysis: Alternative Estimate of Annual Benefits Associated with Approximately 50% of the Emission Reductions from the Industrial Boilers/Process Heaters NESHAP (Above the MACT Floor Regulatory Option in 2005) Using Air Quality Modeling & the CAPMS Benefit Model[A, B]**

| Endpoint | Avoided Incidence[C] (cases/year) | Monetary Benefits[D] (millions 1999$, adjusted for growth in real income) |
|---|---|---|
| Premature mortality[E] (short-term exposure, all ages) | | |
| -Using a 3% discount rate | 860 | $955 |
| -Using a 7% discount rate | 860 | $1,100 |
| Chronic bronchitis (adults, 26 and over, COI valuation) | 2,860 | $335 |
| Hospital Admissions – Pneumonia (adults, over 64) | 610 | $10 |
| Hospital Admissions – COPD (adults, 64 and over) | 500 | $5 |
| Hospital Admissions – Asthma (65 and younger) | 140 | $1 |
| Hospital Admissions – Cardiovascular (adults, over 64) | 1,480 | $25 |
| Emergency Room Visits for Asthma (65 and younger) | 1,140 | <$1 |
| Asthma Attacks (asthmatics, all ages) | 97,060 | $B_1$ |
| Acute bronchitis (children, 8-12) | 2,870 | <$1 |
| Lower respiratory symptoms (children, 7-14) | 31,290 | <$1 |
| Upper respiratory symptoms (asthmatic children, 9-11) | 110,370 | $5 |
| Work loss days (adults, 18-65) | 243,870 | $25 |
| Minor restricted activity days (adults, age 18-65) | 1,196,500 | $60 |
| Other PM-related health effects[F] | $U_1$ | $B_2$ |
| HAP health effects[F] | $U_2$ | $B_3$ |
| **Total Monetized Health-Related Benefits**[E] | | |
| -Using a 3% discount rate | — | $1,425+$\mathbf{B_H}$ |
| -Using a 7% discount rate | — | $1,570+$\mathbf{B_H}$ |

[A] The results presented in this table are based on those $SO_2$ and PM emission reductions identified for specific sources included in the Inventory Database. This includes approximately 50% of all emission reductions estimated by the rule. The location of all other emission reductions (i.e. non-inventory reductions) cannot be determined specifically and hence cannot be modeled in an air quality model. See Section 10.5 and Appendix D for benefit estimation of non-inventory emission reductions.

[B] The results presented in this table reflect the outcome of the combination of PM and $SO_2$ model runs. See Appendix D for a presentation of results for each pollutant independently.

[C] Incidences are rounded to the nearest 10 and may not add due to rounding. Incidences of unquantified endpoints are indicated with a U.

[D] Dollar values are rounded to the nearest 5 million and may not add due to rounding. The value of unquantified endpoints are indicated with a B.

[E] Monetized benefits are presented using two different discount rates. Results calculated using 3 percent discount rate are recommended by EPA's *Guidelines for Preparing Economic Analyses* (U.S. EPA, 2000a). Results calculated using 7 percent discount rate are recommended by OMB Circular A-94 (OMB, 1992).
[F] A detailed listing of unquantified PM and HAP related health effects is provided in Table 10-17.

## 10.5 Phase Two Analysis: Benefit Transfer Valuation of Remaining Emission Reductions

As is mentioned previously, only a portion of the expected emission reductions of the rule can be mapped to specific locations and hence modeled to determine the change in air quality (e.g., change in ambient PM concentrations). For approximately 50% of the PM reductions and approximately 30% of the $SO_2$ reductions, the lack of location-specific data prevents us from utilizing the S-R Matrix to determine air quality changes and the CAPMS model to estimate total benefits. We can assume, however, that these reductions are achieved uniformly throughout the country because the location of boilers/process heaters in the U.S. is spread fairly evenly across all states. To estimate benefits for these reductions, we use the results of the air quality and benefit analysis provided in phase one to infer the average benefit value per ton of emission reduction for each pollutant - PM and $SO_2$. The benefit transfer values for PM and $SO_2$ are then applied to all remaining emission reductions to approximate total benefits of phase two of this analysis.

Before determining the benefit value to transfer to these reductions, one consideration must first be made. The total benefits that result from the air quality analysis of phase one is due to the combination of both direct PM reductions and $SO_2$ reductions that transform into secondary PM. Without knowledge of the percent of the total benefits in phase one that can be attributed to direct PM versus the percent of phase one benefits attributed to $SO_2$, we cannot accurately assign the monetized benefits to the tons reduced of each pollutant. To correctly apportion the total benefit value from phase one to the respective PM and $SO_2$ reductions, we performed two additional S-R Matrix model runs of the reductions valued in phase one; one evaluation of the benefits of the PM reductions alone (holding $SO_2$ unchanged), and one run of the benefits of the $SO_2$ reductions alone (holding PM reductions unchanged). This allows us to determine the appropriate benefit transfer value for each individual pollutant. Because the combined effect of reducing both PM and $SO_2$ simultaneously at one location would result in a larger change in the concentration of PM, it can be expected that the air quality analyses of each pollutant alone will result in lower changes in concentrations and hence lower calculated benefits. The air quality and benefit assessment of the individual pollutants are again performed for each regulatory option: the MACT floor, and the Above the MACT Floor option. The detailed results of the additional air quality and benefit model runs are reported in Appendix D.

These data, along with the set of C-R and valuation functions contained in CAPMS, constitute the input set for the benefits transfer value function. The benefits transfer function for each pollutant is specified as:

$$Transfer\ Value = \frac{Benefits}{Emission\ Reductions}$$

The numerator in the transfer value formula is total monetary benefits, which is determined by applying the same economic valuation functions specified in Table 10-5 to changes in incidences of human health endpoints resulting from the air quality modeling of each pollutant separately. In Appendix

D, we show the calculated benefit transfer value of the total monetized benefits of PM alone and $SO_2$ alone and also for each individual endpoint included in this analysis.

A similar calculation is also done for the number of incidences associated with each endpoint. From the air quality assessments of PM and $SO_2$ alone, we divide total incidences of an endpoint by the total emission reductions included in the air quality scenario. Therefore, we determine a measure of the number of incidences of each health effect that can result from a ton of pollutant reductions (for example, 0.10 fewer asthma cases per ton reduced). This allows us to transfer the incidence per ton reduced to the remaining set of emission reductions of the phase two analysis.

Note that for both dollar and incidence per ton estimates, we assume that each ton of pollutant has the same impact, so that subnational applications are inappropriate as the national application requires assuming populations are uniformly distributed throughout the U.S.

Once all transfer values are determined for each endpoint and total benefits, we apply them to the set of phase two emission reductions. Finally, we combine our phase two estimates of benefits with the phase one calculated benefits to provide an estimate of total benefits for each endpoint and determine the total monetized benefits associated with the rule.

Sections 10.5.1 and 10.5.2 provide further detail on the transfer values obtained for $SO_2$ and PM in this analysis.

### 10.5.1 $SO_2$ *Benefits Transfer Values*

Using the results of the air quality analysis of $SO_2$ reductions alone (holding PM unchanged) from phase one, we can extract information on the total number of incidences and total benefit value of each endpoint to estimate the $SO_2$ benefit transfer values. As an example of the calculation consider the following: the total $SO_2$ emission reductions applied in the S-R matrix analysis for phase one of this analysis are 82,542 tons. Under the MACT floor, the Base Estimate yields approximately 240 fewer premature deaths at a total value of $1.5 billion (see Appendix D for details). Therefore, the benefit transfer value to apply to $SO_2$ emission reductions in the phase two analysis associated with the mortality endpoint would on average be $18,385 per ton reduced. This procedure is repeated for each endpoint and for the total benefits estimate associated with $SO_2$ reductions alone. Further, based on these results it can be estimated that $SO_2$ reductions from the MACT floor on average result in 0.003 fewer incidences of mortality per ton reduced (240 incidences/82,542 tons).

The following tables present the incidence and benefits data necessary to calculate the benefits transfer values for $SO_2$. Table 10-8(a) and (b) present the benefit transfer values for the Base Estimate and the Alternative Estimate of the MACT floor option, while Table 10-9(a) and (b) presents benefit transfer values associated with the Base and Alternative Estimates for the Above the MACT floor option. The benefits transfer values for $SO_2$ emission reductions are reported in 1999 dollars. Differences in benefit/ton estimates between the MACT floor option and the Above the Floor option may be due to differences in the location of emission reductions and other factors. In particular, while PM reductions from process heaters are not expected to accrue at the MACT Floor level of control, approximately 18,300 tons are estimate for the Above the Floor option. The Inventory Database provides information on the location of the majority of process heaters and thus we can apply a large percentage of these reductions directly into the air quality and benefit analysis. In addition, the process heaters affected by this proposal are largely found at large facilities located near large cities, thus the changes in air quality are applied to the populated areas around the cities.

## Table 10-8(a). Base Estimate: $SO_2$ Benefit Transfer Values Based on Data From Phase One Analysis

*MACT Floor Regulatory Option*[A]

| Endpoint | Avoided Incidence[B] (cases/year) | Incidence Per Ton Reduced[C] | Monetary Benefits[D] (millions 1999$, adjusted for growth in real income) | Total Benefit Per Ton Reduced[C] ($/ton) |
|---|---|---|---|---|
| Premature mortality[E] (long-term exposure, adults 30 and over) | | | | |
| -Using a 3% discount rate | 240 | 0.0029 | $1,520 | $18,385 |
| -Using a 7% discount rate | 240 | 0.0029 | $1,425 | $17,270 |
| Chronic bronchitis (adults, 26 and over, WTP valuation) | 320 | 0.0039 | $115 | $1,400 |
| Hospital Admissions – Pneumonia (adults, over 64) | 60 | 0.0008 | $1 | $10 |
| Hospital Admissions – COPD (adults, 64 and over) | 50 | 0.0006 | $1 | $5 |
| Hospital Admissions – Asthma (65 and younger) | 20 | 0.0003 | <$1 | <$5 |
| Hospital Admissions – Cardiovascular (adults, over 64) | 150 | 0.0018 | $5 | $30 |
| Emergency Room Visits for Asthma (65 and younger) | 130 | 0.0016 | <$1 | <$1 |
| Asthma Attacks (asthmatics, all ages) | 11,120 | 0.1347 | $B_1$ | $B_1$ |
| Acute bronchitis (children, 8-12) | 490 | 0.0059 | <$1 | <$1 |
| Lower respiratory symptoms (children, 7-14) | 5,330 | 0.0645 | <$1 | $1 |
| Upper respiratory symptoms (asthmatic children, 9-11) | 12,980 | 0.1572 | <$1 | $5 |
| Work loss days (adults, 18-65) | 42,611 | 0.5162 | $5 | $55 |
| Minor restricted activity days (adults, age 18-65) | 214,592 | 2.5998 | $10 | $130 |
| Other PM-related health effects[F] | $U_1$ | ----- | $B_2$ | $B_2$ |
| HAP-related health effects[F] | $U_2$ | ----- | $B_3$ | $B_3$ |
| **Total Benefits of $SO_2$-Related Reductions**[E] | | | | |
| -Using a 3% discount rate | — | ----- | $1,650 | $20,030+$\mathbf{B_H}$ |
| -Using a 7% discount rate | — | ----- | $1,560 | $18,910+$\mathbf{B_H}$ |

[A] Results of the phase one benefit analysis of $SO_2$ emission reductions are presented in Appendix D, and replicated in columns 2 and 4 of this table.

[B] Incidences are rounded to the nearest 10 and may not add due to rounding. Incidences of unquantified endpoints are indicated with a U.

[C] Total $SO_2$ emission reductions included in the phase one analysis and applied to derive the benefit transfer values of this table are 82,542 tons.

[D] Dollar values are rounded to the nearest 5 million and may not add due to rounding. The value of unquantified endpoints are indicated with a B.
[E] Monetized benefits are presented using two different discount rates. Results calculated using 3 percent discount rate are recommended by EPA's *Guidelines for Preparing Economic Analyses* (U.S. EPA, 2000a). Results calculated using 7 percent discount rate are recommended by OMB Circular A-94 (OMB, 1992).

## Table 10-8(b). Alternative Estimate: $SO_2$ Benefit Transfer Values Based on Data From Phase One Analysis

*MACT Floor Regulatory Option*[A]

| Endpoint | Avoided Incidence[B] (cases/year) | Incidence Per Ton Reduced[C] | Monetary Benefits[D] (millions 1999$, adjusted for growth in real income) | Total Benefit Per Ton Reduced[C] ($/ton) |
|---|---|---|---|---|
| Premature mortality (short-term exposure, all ages)<br>-Using a 3% discount rate | 160 | 0.0019 | $180 | $2,170 |
| -Using a 7% discount rate | 160 | 0.0019 | $205 | $2,505 |
| Chronic bronchitis (adults, 26 and over, COI valuation) | 320 | 0.0039 | $35 | $455 |
| Hospital Admissions – Pneumonia (adults, over 64) | 60 | 0.0008 | $1 | $10 |
| Hospital Admissions – COPD (adults, 64 and over) | 50 | 0.0006 | $1 | $5 |
| Hospital Admissions – Asthma (65 and younger) | 20 | 0.0003 | <$1 | <$5 |
| Hospital Admissions – Cardiovascular (adults, over 64) | 150 | 0.0018 | $5 | $30 |
| Emergency Room Visits for Asthma (65 and younger) | 130 | 0.0016 | <$1 | <$1 |
| Asthma Attacks (asthmatics, all ages) | 11,120 | 0.1347 | $B_1$ | $B_1$ |
| Acute bronchitis (children, 8-12) | 490 | 0.0059 | <$1 | <$1 |
| Lower respiratory symptoms (children, 7-14) | 5,330 | 0.0645 | <$1 | $1 |
| Upper respiratory symptoms (asthmatic children, 9-11) | 12,980 | 0.1572 | <$1 | $5 |
| Work loss days (adults, 18-65) | 42,611 | 0.5162 | $5 | $55 |
| Minor restricted activity days (adults, age 18-65) | 214,592 | 2.5998 | $10 | $130 |
| Other PM-related health effects | $U_1$ | ----- | $B_2$ | $B_2$ |
| HAP-related health effects | $U_2$ | ----- | $B_3$ | $B_3$ |
| **Total Benefits of $SO_2$-Related Reductions**<br>-Using a 3% discount rate | — | ----- | $235 | $2,870+$\mathbf{B_H}$ |
| -Using a 7% discount rate | — | ----- | $265 | $ 3,200+$\mathbf{B_H}$ |

[A] Results of the phase one benefit analysis of SO2 emission reductions are presented in Appendix D, and replicated in columns 2 and 4 of this table.

[B] Incidences are rounded to the nearest 10 and may not add due to rounding. Incidences of unquantified endpoints are indicated with a U.
[C] Total SO2 emission reductions included in the phase one analysis and applied to derive the benefit transfer values of this table are 82,542 tons.
[D] Dollar values are rounded to the nearest 5 million and may not add due to rounding. The value of unquantified endpoints are indicated with a B.

**Table 10-9(a). Base Estimate: $SO_2$ Benefit Transfer Values Based on Data From Phase One Analysis**
*Above the MACT Floor Regulatory Option*[A]

| Endpoint | Avoided Incidence[B] (cases/year) | Incidence Per Ton Reduced[C] | Monetary Benefits[D] (millions 1999$, adjusted for growth in real income) | Total Benefit Per Ton Reduced[C] ($/ton) |
|---|---|---|---|---|
| Premature mortality (long-term exposure, adults, 30 and over) | | | | |
| -Using a 3% discount rate | 310 | 0.0032 | $1,935 | $20,305 |
| -Using a 7% discount rate | 310 | 0.0032 | $1,820 | $19,070 |
| Chronic bronchitis (adults, 26 and over, WTP valuation) | 400 | 0.0042 | $145 | $1,500 |
| Hospital Admissions – Pneumonia (adults, over 64) | 70 | 0.0007 | $1 | $10 |
| Hospital Admissions – COPD (adults, 64 and over) | 60 | 0.0006 | $1 | $10 |
| Hospital Admissions – Asthma (65 and younger) | 30 | 0.0003 | <$1 | <$5 |
| Hospital Admissions – Cardiovascular (adults, over 64) | 170 | 0.0018 | $5 | $35 |
| Emergency Room Visits for Asthma (65 and younger) | 150 | 0.0015 | <$1 | <$1 |
| Asthma Attacks (asthmatics, all ages) | 12,250 | 0.1284 | $B_1$ | $B_1$ |
| Acute bronchitis (children, 8-12) | 660 | 0.0069 | <$1 | <$1 |
| Lower respiratory symptoms (children, 7-14) | 7,170 | 0.0752 | <$1 | $1 |
| Upper respiratory symptoms (asthmatic children, 9-11) | 14,160 | 0.1485 | <$1 | $5 |
| Work loss days (adults, 18-65) | 54,980 | 0.5765 | $5 | $60 |
| Minor restricted activity days (adults, age 18-65) | 279,760 | 2.9337 | $15 | $145 |
| Other PM-related health effects | $U_1$ | ----- | $B_2$ | $B_2$ |
| HAP-related health effects | $U_2$ | ----- | $B_3$ | $B_3$ |

| | | | | |
|---|---|---|---|---|
| **Total Benefits of $SO_2$-Related Reductions** | | | | |
| -Using a 3% discount rate | — | ----- | $2,105 | $22,070+$\mathbf{B_H}$ |
| -Using a 7% discount rate | — | ----- | $1,990 | $20,840+$\mathbf{B_H}$ |

[A] Results of the phase one benefit analysis of $SO_2$ emission reductions are presented in Appendix D, and replicated in columns 2 and 4 of this table.

[B] Incidences are rounded to the nearest 10 and may not add due to rounding. Incidences of unquantified endpoints are indicated with a U.

[C] Total $SO_2$ emission reductions included in the phase one analysis and applied to derive the benefit transfer values of this table are 95,361 tons.

[D] Dollar values are rounded to the nearest 5 million and may not add due to rounding. The value of unquantified endpoints are indicated with a B.

## Table 10-9(b). Alternative Estimate: $SO_2$ Benefit Transfer Values Based on Data From Phase One Analysis

*Above the MACT Floor Regulatory Option*[A]

| Endpoint | Avoided Incidence[B] (cases/year) | Incidence Per Ton Reduced[C] | Monetary Benefits[D] (millions 1999$, adjusted for growth in real income) | Total Benefit Per Ton Reduced[C] ($/ton) |
|---|---|---|---|---|
| Premature mortality (short-term exposure, all ages) | | | | |
| -Using a 3% discount rate | 185 | 0.0019 | $205 | $2,150 |
| -Using a 7% discount rate | 185 | 0.0019 | $235 | $2,470 |
| Chronic bronchitis (adults, 26 and over, COI valuation) | 400 | 0.0042 | $45 | $490 |
| Hospital Admissions – Pneumonia (adults, over 64) | 70 | 0.0007 | $1 | $10 |
| Hospital Admissions – COPD (adults, 64 and over) | 60 | 0.0006 | $1 | $10 |
| Hospital Admissions – Asthma (65 and younger) | 30 | 0.0003 | <$1 | <$5 |
| Hospital Admissions – Cardiovascular (adults, over 64) | 170 | 0.0018 | $5 | $35 |
| Emergency Room Visits for Asthma (65 and younger) | 150 | 0.0015 | <$1 | <$1 |
| Asthma Attacks (asthmatics, all ages) | 12,250 | 0.1284 | $B_1$ | $B_1$ |
| Acute bronchitis (children, 8-12) | 660 | 0.0069 | <$1 | <$1 |
| Lower respiratory symptoms (children, 7-14) | 7,170 | 0.0752 | <$1 | $1 |
| Upper respiratory symptoms (asthmatic children, 9-11) | 14,160 | 0.1485 | <$1 | $5 |
| Work loss days (adults, 18-65) | 54,980 | 0.5765 | $5 | $60 |
| Minor restricted activity days (adults, age 18-65) | 279,760 | 2.9337 | $15 | $145 |
| Other PM-related health effects | $U_1$ | ----- | $B_2$ | $B_2$ |
| HAP-related health effects | $U_2$ | ----- | $B_3$ | $B_3$ |
| **Total Benefits of $SO_2$-Related Reductions** | | | | |
| -Using a 3% discount rate | — | ----- | $275 | $2,910+$\mathbf{B_H}$ |
| -Using a 7% discount rate | — | ----- | $305 | $3,225+$\mathbf{B_H}$ |

[A] Results of the phase one benefit analysis of $SO_2$ emission reductions are presented in Appendix D, and replicated in columns 2 and 4 of this table.

[B] Incidences are rounded to the nearest 10 and may not add due to rounding. Incidences of unquantified endpoints are indicated with a U.

[C] Total $SO_2$ emission reductions included in the phase one analysis and applied to derive the benefit transfer values of this table are 95,361 tons.

[D] Dollar values are rounded to the nearest 5 million and may not add due to rounding. The value of unquantified endpoints are indicated with a B.

10.5.2 *PM Benefits Transfer Values*

The transfer values for PM are developed using the same basic approach as for the $SO_2$ reductions. However, the PM benefits analysis conducted for this RIA includes health benefits associated with reductions in both $PM_{2.5}$ and $PM_{10}$. Therefore, the benefit transfer values for endpoints associated with $PM_{2.5}$ alone will be established using an estimate of the portion of total PM reductions that are likely to be $PM_{2.5}$. Likewise the benefit endpoints associated with $PM_{10}$ alone require an estimate of $PM_{10}$ emission reductions to derive the benefit transfer value for such endpoints. Fortunately, the S-R Matrix model has a component that can approximate $PM_{2.5}$ emissions from a total change in PM. Based on this approximation, of the 265,155 tons of $PM_{10}$ emission reductions included in the air quality analysis of the MACT floor from phase one, approximately 75,095 tons are $PM_{2.5}$.[5]

The endpoints associated with $PM_{2.5}$ are long-term mortality, minor restricted activity days (MRAD), and acute respiratory symptoms. All other endpoints are associated with $PM_{10}$ reductions. For the MACT floor option, Tables 10-9(a) and (b) present the total incidence and benefits data for each endpoint from the phase one analysis for the Base and Alternative Estimates, and the calculated the benefits transfer values for PM that are to be applied for the phase two analysis. Table 10-10(a) and (b) present similar data for the Above the MACT floor regulatory option.

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[5] Reductions in $PM_{2.5}$ are derived as a function of the estimated $PM_{10}$ reductions. The S-R matrix model contains coefficients that relate reductions in both directly emitted $PM_{10}$ and directly emitted $PM_{2.5}$. At the time the S-R matrix was being developed in the early 1990s, a nationwide inventory of directly emitted $PM_{2.5}$ emissions was not available, so the author developed a method for crudely estimating $PM_{2.5}$ emissions from $PM_{10}$ emissions. The air quality changes predicted by the model for direct $PM_{2.5}$ were then developed from these crude emissions estimates. A full discussion of the derivation of $PM_{2.5}$ estimates is provided in E.H. Pechan (1994 and 1996), and Latimer and Associates(1996). The PM Calculator Tool can also be found on the Internet at www.epa.gov/chief/software/pmcalc/index.html.

## Table 10-10(a). Base Estimate: PM Benefit Transfer Values Based on Data From Phase One Analysis

*MACT Floor Regulatory Option*[A]

| Endpoint | Avoided Incidence[B] (cases/year) | Incidence Per Ton Reduced[C] | Monetary Benefits[D] (millions 1999$, adjusted for growth in real income) | Total Benefit Per Ton Reduced[C] ($/ton) |
|---|---|---|---|---|
| Premature mortality (long-term, adults, 30 and over)<br>-Using a 3% discount rate | 900 | 0.01202 | $5,675 | $75,595 |
| -Using a 7% discount rate | 900 | 0.01202 | $5,330 | $71,005 |
| Chronic bronchitis (adults, 26 and over, WTP valuation) | 2,360 | 0.0089 | $850 | $3,195 |
| Hospital Admissions – Pneumonia (adults, over 64) | 510 | 0.0019 | $10 | $30 |
| Hospital Admissions – COPD (adults, 64 and over) | 420 | 0.0016 | $5 | $20 |
| Hospital Admissions – Asthma (65 and younger) | 90 | 0.0012 | $1 | $10 |
| Hospital Admissions – Cardiovascular (adults, over 64) | 1,230 | 0.0046 | $25 | $85 |
| Emergency Room Visits for Asthma (65 and younger) | 950 | 0.0036 | <$1 | $1 |
| Asthma Attacks (asthmatics, all ages) | 80,700 | 0.3043 | $B_1$ | $B_1$ |
| Acute bronchitis (children, 8-12) | 1,870 | 0.0248 | <$1 | $1 |
| Lower respiratory symptoms (children, 7-14) | 20,370 | 0.2712 | <$1 | $5 |
| Upper respiratory symptoms (asthmatic children, 9-11) | 91,620 | 0.3455 | $5 | $10 |
| Work loss days (adults, 18-65) | 158,560 | 2.1115 | $20 | $225 |
| Minor restricted activity days (adults, age 18-65) | 760,870 | 10.132 | $40 | $500 |
| Other PM-related health effects | $U_1$ | ----- | $B_2$ | $B_2$ |
| HAP-related health effects | $U_2$ | ----- | $B_3$ | $B_3$ |
| **Total Benefits of PM-Related Reductions**<br>-Using a 3% discount rate) | — | ----- | $6,620 | $88,120+$\mathbf{B_H}$ |
| -Using a 7% discount rate | — | ----- | $6,275 | $83,530+$\mathbf{B_H}$ |

[A] Results of the phase one benefit analysis of PM emission reductions are presented in Appendix D, and replicated in columns 2 and 4 of this table.

[B] Incidences are rounded to the nearest 10 and may not add due to rounding. Incidences of unquantified endpoints are indicated with a U.

[C] Total $PM_{10}$ and $PM_{2.5}$ emission reductions included in the phase one analysis and applied to derive the benefit transfer values of this table are 265,155 tons and 75,095 tons, respectively.

[D] Dollar values are rounded to the nearest 5 million and may not add due to rounding. The value of unquantified endpoints are indicated with a B.

**Table 10-10(b). Alternative Estimate: PM Benefit Transfer Values Based on Data From Phase One Analysis**

*MACT Floor Regulatory Option*[A]

| Endpoint | Avoided Incidence[B] (cases/year) | Incidence Per Ton Reduced[C] | Monetary Benefits[D] (millions 1999$, adjusted for growth in real income) | Total Benefit Per Ton Reduced[C] ($/ton) |
|---|---|---|---|---|
| Premature mortality (short-term, all ages) | | | | |
| -Using a 3% discount rate | 550 | 0.00727 | $610 | $8,090 |
| -Using a 7% discount rate | 550 | 0.00727 | $705 | $9,365 |
| Chronic bronchitis (adults, 26 and over, COI valuation) | 2,360 | 0.0089 | $275 | $1,035 |
| Hospital Admissions – Pneumonia (adults, over 64) | 510 | 0.0019 | $10 | $30 |
| Hospital Admissions – COPD (adults, 64 and over) | 420 | 0.0016 | $5 | $20 |
| Hospital Admissions – Asthma (65 and younger) | 90 | 0.0012 | $1 | $10 |
| Hospital Admissions – Cardiovascular (adults, over 64) | 1,230 | 0.0046 | $25 | $85 |
| Emergency Room Visits for Asthma (65 and younger) | 950 | 0.0036 | <$1 | $1 |
| Asthma Attacks (asthmatics, all ages) | 80,700 | 0.3043 | $B_1$ | $B_1$ |
| Acute bronchitis (children, 8-12) | 1,870 | 0.0248 | <$1 | $1 |
| Lower respiratory symptoms (children, 7-14) | 20,370 | 0.2712 | <$1 | $5 |
| Upper respiratory symptoms (asthmatic children, 9-11) | 91,620 | 0.3455 | $5 | $10 |
| Work loss days (adults, 18-65) | 158,560 | 2.1115 | $20 | $225 |
| Minor restricted activity days (adults, age 18-65) | 760,870 | 10.132 | $40 | $500 |
| Other PM-related health effects | $U_1$ | ----- | $B_2$ | $B_2$ |
| HAP-related health effects | $U_2$ | ----- | $B_3$ | $B_3$ |
| **Total Benefits of PM-Related Reductions** | | | | |
| -Using a 3% discount rate | — | ----- | $975 | $13,000+$\mathbf{B_H}$ |
| -Using a 7% discount rate | — | ----- | $1,075 | $14,275+$\mathbf{B_H}$ |

A Results of the phase one benefit analysis of PM emission reductions are presented in Appendix D, and replicated in columns 2 and 4 of this table.

B Incidences are rounded to the nearest 10 and may not add due to rounding. Incidences of unquantified endpoints are indicated with a U.

C Total PM10 and PM2.5 emission reductions included in the phase one analysis and applied to derive the benefit transfer values of this table are 265,155 tons and 75,095 tons, respectively.

D Dollar values are rounded to the nearest 5 million and may not add due to rounding. The value of unquantified endpoints are indicated with a B.

**Table 10-11(a). Base Estimate: PM Benefit Transfer Values Based on Data From Phase One Analysis**

*Above the MACT Floor Regulatory Option*[A]

| Endpoint | Avoided Incidence[B] (cases/year) | Incidence Per Ton Reduced[C] | Monetary Benefits[D] (millions 1999$, adjusted for growth in real income) | Total Benefit Per Ton Reduced[C] |
|---|---|---|---|---|
| Premature mortality (long-term exposure, adults, 30 and over) | | | | |
| -Using a 3% discount rate | 1,090 | 0.0115 | $6,835 | $72,290 |
| -Using a 7% discount rate | 1,090 | 0.0115 | $6,420 | $67,900 |
| Chronic bronchitis (adults, 26 and over, WTP valuation) | 2,680 | 0.0085 | $965 | $3,070 |
| Hospital Admissions – Pneumonia (adults, over 64) | 570 | 0.0018 | $10 | $30 |
| Hospital Admissions – COPD (adults, 64 and over) | 470 | 0.0015 | $5 | $20 |
| Hospital Admissions – Asthma (65 and younger) | 110 | 0.0012 | $1 | $10 |
| Hospital Admissions – Cardiovascular (adults, over 64) | 1,390 | 0.0044 | $25 | $80 |
| Emergency Room Visits for Asthma (65 and younger) | 1,070 | 0.0034 | <$1 | $1 |
| Asthma Attacks (asthmatics, all ages) | 90,940 | 0.2897 | $B_1$ | $B_1$ |
| Acute bronchitis (children, 8-12) | 2,230 | 0.0236 | <$1 | $1 |
| Lower respiratory symptoms (children, 7-14) | 24,330 | 0.2572 | <$1 | $5 |
| Upper respiratory symptoms (asthmatic children, 9-11) | 103,400 | 0.3294 | $5 | $10 |
| Work loss days (adults, 18-65) | 190,370 | 2.0131 | $20 | $215 |
| Minor restricted activity days (adults, age 18-65) | 918,650 | 9.7144 | $45 | $485 |
| Other PM-related health effects | $U_1$ | ----- | $B_2$ | $B_2$ |
| HAP-related health effects | $U_2$ | ----- | $B_3$ | $B_3$ |
| **Total Benefits of PM-Related Reductions** | | | | |
| -Using a 3% discount rate | — | ----- | $7,910 | $83,645+$\mathbf{B_H}$ |
| -Using a 7% discount rate | — | ----- | $7,495 | $79,255+$\mathbf{B_H}$ |

[A] Results of the phase one benefit analysis of PM emission reductions are presented in Appendix D, and replicated in columns 2 and 4 of this table.

[B] Incidences are rounded to the nearest 10 and may not add due to rounding. Incidences of unquantified endpoints are indicated with a U.

[C] Total $PM_{10}$ and $PM_{2.5}$ emission reductions included in the phase one analysis and applied to derive the benefit transfer values of this table are 313,947 tons and 94,565 tons, respectively.

[D] Dollar values are rounded to the nearest 5 million and may not add due to rounding. The value of unquantified endpoints are indicated with a B.

**Table 10-11(b). Alternative Estimate: PM Benefit Transfer Values Based on Data From Phase One Analysis**

*Above the MACT Floor Regulatory Option*[A]

| Endpoint | Avoided Incidence[B] (cases/year) | Incidence Per Ton Reduced[C] | Monetary Benefits[D] (millions 1999$, adjusted for growth in real income) | Total Benefit Per Ton Reduced[C] |
|---|---|---|---|---|
| Premature mortality (short-term exposure, all ages) | | | | |
| -Using a 3% discount rate | 675 | 0.0071 | $750 | $7,950 |
| -Using a 7% discount rate | 675 | 0.0071 | $870 | $9,200 |
| Chronic bronchitis (adults, 26 and over, COI valuation) | 2,680 | 0.0085 | $315 | $1,000 |
| Hospital Admissions – Pneumonia (adults, over 64) | 570 | 0.0018 | $10 | $30 |
| Hospital Admissions – COPD (adults, 64 and over) | 470 | 0.0015 | $5 | $20 |
| Hospital Admissions – Asthma (65 and younger) | 110 | 0.0012 | $1 | $10 |
| Hospital Admissions – Cardiovascular (adults, over 64) | 1,390 | 0.0044 | $25 | $80 |
| Emergency Room Visits for Asthma (65 and younger) | 1,070 | 0.0034 | <$1 | $1 |
| Asthma Attacks (asthmatics, all ages) | 90,940 | 0.2897 | $B_1$ | $B_1$ |
| Acute bronchitis (children, 8-12) | 2,230 | 0.0236 | <$1 | $1 |
| Lower respiratory symptoms (children, 7-14) | 24,330 | 0.2572 | <$1 | $5 |
| Upper respiratory symptoms (asthmatic children, 9-11) | 103,400 | 0.3294 | $5 | $10 |
| Work loss days (adults, 18-65) | 190,370 | 2.0131 | $20 | $215 |
| Minor restricted activity days (adults, age 18-65) | 918,650 | 9.7144 | $45 | $485 |
| Other PM-related health effects | $U_1$ | ----- | $B_2$ | $B_2$ |
| HAP-related health effects | $U_2$ | ----- | $B_3$ | $B_3$ |
| **Total Benefits of PM-Related Reductions** | | | | |
| -Using a 3% discount rate | — | ----- | $1,175 | $12,425+$\mathbf{B_H}$ |
| -Using a 7% discount rate | — | ----- | $1,295 | $13,670+$\mathbf{B_H}$ |

[A] Results of the phase one benefit analysis of PM emission reductions are presented in Appendix D, and replicated in columns 2 and 4 of this table.

[B] Incidences are rounded to the nearest 10 and may not add due to rounding. Incidences of unquantified endpoints are indicated with a U.

[C] Total $PM_{10}$ and $PM_{2.5}$ emission reductions included in the phase one analysis and applied to derive the benefit transfer values of this table are 313,947 tons and 94,565 tons, respectively.

[D] Dollar values are rounded to the nearest 5 million and may not add due to rounding. The value of unquantified endpoints are indicated with a B.

10.5.3 *Application of Benefits Transfer Values to Phase Two Emission Reductions*

Emission reductions included in phase two of our benefit analysis are summarized in Table 10-2. These reductions will be applied to the benefit transfer values developed in the previous section. These emission reductions are derived by simply subtracting the emission reductions including in the phase one analysis from the total emission reductions anticipated from this NESHAP.

Thus, in the final step of the phase two analysis, the transfer values calculated in section 10.5.3 are multiplied by the emission reductions associated with the phase two analysis. Appendix D provides tables showing the benefit estimation for each pollutant (PM and $SO_2$) separately. In the tables below, we combine the total $SO_2$ benefits of phase two with the total PM benefits of phase two from Appendix D to provide a summary of total benefits associated with phase two of this analysis for each regulatory option analyzed.

**Table 10-12(a). Phase Two Analysis: Base Estimate of Annual Health Benefits Associated with Non-Inventory Emission Reductions of the Industrial Boilers/Process Heaters NESHAP - MACT Floor Regulatory Option in 2005, Using Benefit Transfer Values[A]**

| Endpoint | Avoided Incidence[B] (cases/year) | Monetary Benefits[C] (millions 1999$, adjusted for growth in real income) |
|---|---|---|
| Premature mortality[D] (long-term exposure, adults, 30 and over) | | |
| -Using a 3% discount rate | 1,100 | $6,920 |
| -Using a 7% discount rate | 1,110 | $6,495 |
| Chronic bronchitis (adults, 26 and over, WTP valuation) | 2,760 | $990 |
| Hospital Admissions – Pneumonia (adults, over 64) | 590 | $10 |
| Hospital Admissions – COPD (adults, 64 and over) | 490 | $5 |
| Hospital Admissions – Asthma (65 and younger) | 110 | $1 |
| Hospital Admissions – Cardiovascular (adults, over 64) | 1,430 | $25 |
| Emergency Room Visits for Asthma (65 and younger) | 1,110 | <$1 |
| Asthma Attacks (asthmatics, all ages) | 94,470 | $B_1$ |
| Acute bronchitis (children, 8-12) | 2,270 | <$1 |
| Lower respiratory symptoms (children, 7-14) | 24,770 | <$1 |
| Upper respiratory symptoms (asthmatic children, 10-11) | 107,380 | <$5 |
| Work loss days (adults, 18-65) | 193,270 | $20 |
| Minor restricted activity days (adults, age 18-65) | 931,140 | $45 |
| Other PM-related health effects[E] | $U_1$ | $B_2$ |
| HAP-related health effects[E] | $U_2$ | $B_3$ |
| **Total Monetized Health-Related Benefits** | | |
| -Using a 3% discount rate | — | $8,020+$\mathbf{B_H}$ |
| -Using a 7% discount rate | — | $7,600+$\mathbf{B_H}$ |

[A] The results presented in this table reflect the outcome of the combination of PM and $SO_2$ benefit estimates from the application of benefit transfer values applied in the phase two analysis. See Appendix D for a presentation of results for each pollutant independently.
[B] Incidences are rounded to the nearest 10 and may not add due to rounding. Incidences of unquantified endpoints are indicated with a U.
[C] Dollar values are rounded to the nearest 5 million and may not add due to rounding. The value of unquantified endpoints are indicated with a B.
[D] Note that the estimated value for PM-related premature mortality assumes the 5 year distributed lag structure described in detail in the Regulatory Impact Analysis of Heavy Duty Engine/Diesel Fuel rule.
[E] A detailed listing of unquantified PM and HAP related health effects is provided in Table 10-16.

### Table 10-12(b). Phase Two Analysis: Alternative Estimate of Annual Health Benefits Associated with Non-Inventory Emission Reductions of the Industrial Boilers/Process Heaters NESHAP - MACT Floor Regulatory Option in 2005, Using Benefit Transfer Values[A]

| Endpoint | Avoided Incidence[B] (cases/year) | Monetary Benefits[C] (millions 1999$, adjusted for growth in real income) |
|---|---|---|
| Premature mortality (short-term exposure, all ages) | | |
| -Using a 3% discount rate | 670 | $750 |
| -Using a 7% discount rate | 670 | $865 |
| Chronic bronchitis (adults, 26 and over, COI valuation) | 2,760 | $320 |
| Hospital Admissions – Pneumonia (adults, over 64) | 590 | $10 |
| Hospital Admissions – COPD (adults, 64 and over) | 490 | $5 |
| Hospital Admissions – Asthma (65 and younger) | 110 | $1 |
| Hospital Admissions – Cardiovascular (adults, over 64) | 1,430 | $25 |
| Emergency Room Visits for Asthma (65 and younger) | 1,110 | <$1 |
| Asthma Attacks (asthmatics, all ages) | 94,470 | $B_1$ |
| Acute bronchitis (children, 8-12) | 2,270 | <$1 |
| Lower respiratory symptoms (children, 7-14) | 24,770 | <$1 |
| Upper respiratory symptoms (asthmatic children, 10-11) | 107,380 | <$5 |
| Work loss days (adults, 18-65) | 193,270 | $20 |
| Minor restricted activity days (adults, age 18-65) | 931,140 | $45 |
| Other PM-related health effects[E] | $U_1$ | $B_2$ |
| HAP-related health effects[E] | $U_2$ | $B_3$ |
| **Total Monetized Health-Related Benefits** | | |
| -Using a 3% discount rate | — | $1,180+$\mathbf{B_H}$ |
| -Using a 7% discount rate | — | $1,300+$\mathbf{B_H}$ |

[A] The results presented in this table reflect the outcome of the combination of PM and $SO_2$ benefit estimates from the application of benefit transfer values applied in the phase two analysis. See Appendix D for a presentation of results for each pollutant independently.
[B] Incidences are rounded to the nearest 10 and may not add due to rounding. Incidences of unquantified endpoints are indicated with a U.
[C] Dollar values are rounded to the nearest 5 million and may not add due to rounding. The value of unquantified endpoints are indicated with a B.
[D] Note that the estimated value for PM-related premature mortality assumes the 5 year distributed lag structure described in detail in the Regulatory Impact Analysis of Heavy Duty Engine/Diesel Fuel rule.

[E] A detailed listing of unquantified PM and HAP related health effects is provided in Table 10-16.

## Table 10-13(a). Phase Two Analysis: Base Estimate of Annual Health Benefits Associated with Non-Inventory Emission Reductions of the Industrial Boilers/Process Heaters NESHAP - Above the MACT Floor Regulatory Option in 2005, Using Benefit Transfer Values[A]

| Endpoint | Avoided Incidence[B] (cases/year) | Monetary Benefits[C] (millions 1999$, adjusted for growth in real income) |
|---|---|---|
| Premature mortality[D] (long-term exposure, adults, 30 and over) | | |
| -Using a 3% discount rate | 1,020 | $6,400 |
| -Using a 7% discount rate | 1,020 | $6,010 |
| Chronic bronchitis (adults, 26 and over, WTP valuation) | 2,350 | $850 |
| Hospital Admissions – Pneumonia (adults, over 64) | 500 | $10 |
| Hospital Admissions – COPD (adults, 64 and over) | 410 | $5 |
| Hospital Admissions – Asthma (65 and younger) | 100 | $1 |
| Hospital Admissions – Cardiovascular (adults, over 64) | 1,200 | $20 |
| Emergency Room Visits for Asthma (65 and younger) | 930 | <$1 |
| Asthma Attacks (asthmatics, all ages) | 79,260 | $B_1$ |
| Acute bronchitis (children, 8-12) | 2,100 | <$1 |
| Lower respiratory symptoms (children, 7-14) | 22,890 | <$1 |
| Upper respiratory symptoms (asthmatic children, 10-11) | 90,220 | <$5 |
| Work loss days (adults, 18-65) | 178,650 | $20 |
| Minor restricted activity days (adults, age 18-65) | 868,360 | $45 |
| Other PM-related health effects[E] | $U_1$ | $B_2$ |
| HAP-related health effects[E] | $U_2$ | $B_3$ |
| **Total Monetized Health-Related Benefits** | | |
| -Using a 3% discount rate | — | $7,350+$\mathbf{B_H}$ |
| -Using a 7% discount rate | — | $6,960+$\mathbf{B_H}$ |

[A] The results presented in this table reflect the outcome of the combination of PM and $SO_2$ benefit estimates from the application of benefit transfer values applied in the phase two analysis. See Appendix D for a presentation of results for each pollutant independently.
[B] Incidences are rounded to the nearest 10 and may not add due to rounding. Incidences of unquantified endpoints are indicated with a U.
[C] Dollar values are rounded to the nearest 5 million and may not add due to rounding. The value of unquantified endpoints are indicated with a B.
[D] Note that the estimated value for PM-related premature mortality assumes the 5 year distributed lag structure described in detail in the Regulatory Impact Analysis of Heavy Duty Engine/Diesel Fuel rule.
[E] A detailed listing of unquantified PM and HAP related health effects is provided in Table 10-16.

**Table 10-13(b). Phase Two Analysis: Alternative Estimate of Annual Health Benefits Associated with Non-Inventory Emission Reductions of the Industrial Boilers/Process Heaters NESHAP - Above the MACT Floor Regulatory Option in 2005, Using Benefit Transfer Values[A]**

| Endpoint | Avoided Incidence[B] (cases/year) | Monetary Benefits[C] (millions 1999$, adjusted for growth in real income) |
|---|---|---|
| Premature mortality[D] (short-term exposure, all ages) | | |
| -Using a 3% discount rate | 625 | $580 |
| -Using a 7% discount rate | 625 | $670 |
| Chronic bronchitis (adults, 26 and over, COI valuation) | 2,350 | $275 |
| Hospital Admissions – Pneumonia (adults, over 64) | 500 | $10 |
| Hospital Admissions – COPD (adults, 64 and over) | 410 | $5 |
| Hospital Admissions – Asthma (65 and younger) | 100 | $1 |
| Hospital Admissions – Cardiovascular (adults, over 64) | 1,200 | $20 |
| Emergency Room Visits for Asthma (65 and younger) | 930 | <$1 |
| Asthma Attacks (asthmatics, all ages) | 79,260 | $B_1$ |
| Acute bronchitis (children, 8-12) | 2,100 | <$1 |
| Lower respiratory symptoms (children, 7-14) | 22,890 | <$1 |
| Upper respiratory symptoms (asthmatic children, 10-11) | 90,220 | <$5 |
| Work loss days (adults, 18-65) | 178,650 | $20 |
| Minor restricted activity days (adults, age 18-65) | 868,360 | $45 |
| Other PM-related health effects[E] | $U_1$ | $B_2$ |
| HAP-related health effects[E] | $U_2$ | $B_3$ |
| **Total Monetized Health-Related Benefits** | | |
| -Using a 3% discount rate | — | $960+$\mathbf{B_H}$ |
| -Using a 7% discount rate | — | $1,150+$\mathbf{B_H}$ |

[A] The results presented in this table reflect the outcome of the combination of PM and $SO_2$ benefit estimates from the application of benefit transfer values applied in the phase two analysis. See Appendix D for a presentation of results for each pollutant independently.

[B] Incidences are rounded to the nearest 10 and may not add due to rounding. Incidences of unquantified endpoints are indicated with a U.

[C] Dollar values are rounded to the nearest 5 million and may not add due to rounding. The value of unquantified endpoints are indicated with a B.

[D] Note that the estimated value for PM-related premature mortality assumes the 5 year distributed lag structure described in detail in the Regulatory Impact Analysis of Heavy Duty Engine/Diesel Fuel rule.
[E] A detailed listing of unquantified PM and HAP related health effects is provided in Table 10-16.

## 10.6 Total Benefits of the Industrial Boilers/Process Heaters NESHAP

Given the estimates of benefits from phases one and two of this analysis, this section combines those results to present our Base and Alternative Estimates of total benefits of the NESHAP. To obtain this estimate, we aggregate dollar benefits associated with each of the effects examined, such as hospital admissions, into a total benefits estimate assuming that none of the included health and welfare effects overlap. The Base Estimate of the total benefits associated with the health and welfare effects is the sum of the separate effects estimates. Total monetized benefits associated with the MACT floor regulatory option of the Industrial Boilers/Process Heaters NESHAP are listed in Table 10-14(a) and (b), along with a breakdown of benefits by endpoint. Table 10-15(a) and (b) provides total annual benefits of the above the MACT floor option.

Again, note that the value of endpoints known to be affected by PM that we are not able to monetize are assigned a placeholder value (e.g., $B_1$, $B_2$, etc.). Unquantified physical effects are indicated by a U. The estimate of total benefits is thus the sum of the monetized benefits and a constant, B, equal to the sum of the unmonetized benefits, $B_1+B_2+...+B_n$.

A comparison of the incidence column to the monetary benefits column reveals that there is not always a close correspondence between the number of incidences avoided for a given endpoint and the monetary value associated with that endpoint. For example, under the MACT floor option there are over 75 times more asthma attacks than premature mortalities, yet these asthma attacks account for only a very small fraction of total monetized benefits. This reflects the fact that many of the less severe health effects, while more common, are valued at a lower level than the more severe health effects. Also, some effects, such as asthma attacks, are valued using a proxy measure of WTP. As such the true value of these effects may be higher than that reported in Table 10-14(a) and (b) and Table 10-15(a) and (b).

Our Base Estimate of total monetized benefits for the MACT floor is $16.3 billion when using a 3 percent discount rate (or $15.4 billion when using a 7 percent discount rate). Of this total, $14.2 billion (or $13.4 billion) are the benefits of reduced premature mortality risk from PM exposure. Total monetized benefits are dominated by the benefits of reduced mortality risk, accounting for 87 percent of total monetized benefits, followed by chronic bronchitis totaling $1.8 billion, which represents 11 percent of the total. Following chronic bronchitis, minor restricted activity days (MRADs) is the next largest quantified benefit category totaling $100 million, and it also presents the category with the largest number of incidences at 1,942,340 per year. MRADs in combination with lost work days and avoided hospital admissions from cardiovascular-related illness account for $140 million of total benefits. For the asthma-related endpoints, we note that the MACT floor will result in approximately 173,000 fewer asthma attacks, more than 2,000 fewer visits to the emergency room of hospitals for asthma, and 200 fewer hospital admissions for asthma-related effects.

For the Alternative Estimate, the total monetized benefits of the MACT floor is $2.3 billion when using a 3 percent discount rate (or $2.6 billion when using a 7 percent discount rate), of which

$1.5 billion (or $1.8 billion) are the benefits of reduced premature mortality risk from PM exposure, followed by chronic bronchitis totaling $595 million. Other endpoints are equivalent to the Base Estimate.

Total annual benefits of the above the MACT floor regulatory option are $17.2 billion under the Base Estimate when using a 3 percent discount rate (or $16.3 billion when using a 7 percent discount rate). Similar to the MACT floor results, the mortality endpoint accounts for the majority of benefits at $15.1 billion (or $14.2 billion) under the Base Estimate, followed by chronic bronchitis at $1.9 billion. MRADs account for $100 million in benefits and 2,064,854 fewer incidences. The monetized benefits of MRADs combined with lost work days and cardiovascular-related hospital admissions account for $180 million of benefits. For the asthma-related endpoints, we note that the above the MACT floor option will result in approximately 82,000 fewer asthma attacks, more than 2,000 fewer visits to the emergency room of hospitals for asthma, and about 240 fewer hospital admissions for asthma-related effects.

For the Alternative Estimate, the total monetized benefits of the above the MACT floor option is $2.3 billion when using a 3 percent discount rate (or $2.6 billion when using a 7 percent discount rate). Of the total $1.6 billion (or $1.7 billion) are the benefits of reduced premature mortality risk from PM exposure, followed by chronic bronchitis totaling $610 million. Other endpoints are equivalent to the Base Estimate.

## Table 10-14(a). Base Estimate of Total Annual Benefits of the Industrial Boilers/Process Heaters NESHAP [A]

*MACT Floor Regulatory Option*

| Endpoint | Avoided Incidence[B] (cases/year) | Monetary Benefits[C] (millions 1999$, adjusted for growth in real income) |
|---|---|---|
| Premature mortality[D] (long-term exposure, adults, 30 and over) | | |
| -Using a 3% discount rate | 2,270 | $14,240 |
| -Using a 7% discount rate | 2,270 | $13,375 |
| Chronic bronchitis (adults, 26 and over, WTP valuation) | 5,100 | $1,835 |
| Hospital Admissions – Pneumonia (adults, over 64) | 1,100 | $15 |
| Hospital Admissions – COPD (adults, 64 and over) | 900 | $10 |
| Hospital Admissions – Asthma (65 and younger) | 230 | <$5 |
| Hospital Admissions – Cardiovascular (adults, over 64) | 2,660 | $50 |
| Emergency Room Visits for Asthma (65 and younger) | 2,040 | <$1 |
| Asthma Attacks (asthmatics, all ages) | 173,490 | $B_1$ |
| Acute bronchitis (children, 8-12) | 4,700 | <$1 |
| Lower respiratory symptoms (children, 7-14) | 51,240 | $1 |
| Upper respiratory symptoms (asthmatic children, 10-11) | 196,860 | $5 |
| Work loss days (adults, 18-65) | 398,670 | $40 |
| Minor restricted activity days (adults, age 18-65) | 1,942,340 | $100 |
| Other PM-related health effects[E] | $U_1$ | $B_2$ |
| HAP-related health effects[E] | $U_2$ | $B_3$ |
| **Total Monetized Health-Related Benefits[F]** | | |
| -Using a 3% discount rate | — | $16,300+$\mathbf{B_H}$ |
| -Using a 7% discount rate | — | $15,430+$\mathbf{B_H}$ |

[A] The results presented in this table include all emission reductions including those identified for specific sources included in the Inventory Database included in the Phase One analysis and the remaining reductions not included in the Inventory Database included in the Phase Two analysis

[B] Incidences are rounded to the nearest 10 and may not add due to rounding. Incidences of unquantified endpoints are indicated with a U.

[C] Dollar values are rounded to the nearest 5 million and may not add due to rounding. The value of unquantified endpoints are indicated with a B.

[D] The estimated value for PM-related premature mortality assumes a 5-year distributed lag structure and discounted at a 3% rate, which is described in the HDD RIA.

[E] A detailed listing of unquantified PM and HAP related health effects is provided in Table 10-16.

## Table 10-14(b). Alternative Estimate of Total Annual Benefits of the Industrial Boilers/Process Heaters NESHAP [A]

*MACT Floor Regulatory Option*

| Endpoint | Avoided Incidence[B] (cases/year) | Monetary Benefits[C] (millions 1999$, adjusted for growth in real income) |
|---|---|---|
| Premature mortality (short-term exposure, all ages) | | |
| -Using a 3% discount rate | 1,370 | $1,530 |
| -Using a7% discount rate | 1,370 | $1,765 |
| Chronic bronchitis (adults, 26 and over, COI valuation) | 5,100 | $595 |
| Hospital Admissions – Pneumonia (adults, over 64) | 1,100 | $15 |
| Hospital Admissions – COPD (adults, 64 and over) | 900 | $10 |
| Hospital Admissions – Asthma (65 and younger) | 230 | <$5 |
| Hospital Admissions – Cardiovascular (adults, over 64) | 2,660 | $50 |
| Emergency Room Visits for Asthma (65 and younger) | 2,040 | <$1 |
| Asthma Attacks (asthmatics, all ages) | 173,490 | $B_1$ |
| Acute bronchitis (children, 8-12) | 4,700 | <$1 |
| Lower respiratory symptoms (children, 7-14) | 51,240 | $1 |
| Upper respiratory symptoms (asthmatic children, 10-11) | 196,860 | $5 |
| Work loss days (adults, 18-65) | 398,670 | $40 |
| Minor restricted activity days (adults, age 18-65) | 1,942,340 | $100 |
| Other PM-related health effects[E] | $U_1$ | $B_2$ |
| HAP health effects[E] | $U_2$ | $B_3$ |
| **Total Monetized Health-Related Benefits** [F] | — | $2,350+$\mathbf{B_H}$ |
| -Using a 3% discount rate | | |
| -Using a 7% discount rate | — | $2,585+$\mathbf{B_H}$ |

[A] The results presented in this table include all emission reductions including those identified for specific sources included in the Inventory Database included in the Phase One analysis and the remaining reductions not included in the Inventory Database included in the Phase Two analysis

[B] Incidences are rounded to the nearest 10 and may not add due to rounding. Incidences of unquantified endpoints are indicated with a U.

[C] Dollar values are rounded to the nearest 5 million and may not add due to rounding. The value of unquantified endpoints are indicated with a B.

[D] The estimated value for PM-related premature mortality assumes a 5-year distributed lag structure and discounted at a 3% rate, which is described in the HDD RIA.

[E] A detailed listing of unquantified PM and HAP related health effects is provided in Table 10-16.

## Table 10-15(a). Base Estimate of Total Annual Benefits of the Industrial Boilers/Process Heaters NESHAP [A]

*Above the MACT Floor Regulatory Option*

| Endpoint | Avoided Incidence[B] (cases/year) | Monetary Benefits[C] (millions 1999$, adjusted for growth in real income) |
|---|---|---|
| Premature mortality[D] (long-term exposure, adults, 30 and over) | | |
| -Using a 3% discount rate | 2,410 | $15,135 |
| -Using a 7% discount rate | 2,410 | $14,220 |
| Chronic bronchitis (adults, 26 and over, WTP valuation) | 5,220 | $1,875 |
| Hospital Admissions – Pneumonia (adults, over 64) | 1,110 | $15 |
| Hospital Admissions – COPD (adults, 64 and over) | 910 | $10 |
| Hospital Admissions – Asthma (65 and younger) | 240 | <$5 |
| Hospital Admissions – Cardiovascular (adults, over 64) | 2,680 | $50 |
| Emergency Room Visits for Asthma (65 and younger) | 2,080 | <$1 |
| Asthma Attacks (asthmatics, all ages) | 82,130 | $B_1$ |
| Acute bronchitis (children, 8-12) | 4,970 | <$1 |
| Lower respiratory symptoms (children, 7-14) | 54,190 | $1 |
| Upper respiratory symptoms (asthmatic children, 10-11) | 200,590 | $5 |
| Work loss days (adults, 18-65) | 275,710 | $30 |
| Minor restricted activity days (adults, age 18-65) | 2,064,850 | $100 |
| Other PM-related health effects[E] | $U_1$ | $B_2$ |
| HAP-related health effects[E] | $U_2$ | $B_3$ |
| Total Monetized Health-Related Benefits | | |
| -Using a 3% discount rate | — | $17,230+$\mathbf{B_H}$ |
| -Using a 7% discount rate | — | $16,310+$\mathbf{B_H}$ |

[A] The results presented in this table include all emission reductions including those identified for specific sources included in the Inventory Database and the remaining reductions not included in the Inventory Database.

[B] Incidences are rounded to the nearest 10 and may not add due to rounding. Incidences of unquantified endpoints are indicated with a U.

[C] Dollar values are rounded to the nearest 5 million and may not add due to rounding. The value of unquantified endpoints are indicated with a B.

[D] The estimated value for PM-related premature mortality assumes a 5-year distributed lag structure and discounted at a 3% rate, which is described in the HDD RIA.

[E] A detailed listing of unquantified PM and HAP related health effects is provided in Table 10-16.

## Table 10-15(b). Alternative Estimate of Total Annual Benefits of the Industrial Boilers/Process Heaters NESHAP [A]

*Above the MACT Floor Regulatory Option*

| Endpoint | Avoided Incidence[B] (cases/year) | Monetary Benefits[C] (millions 1999$, adjusted for growth in real income) |
|---|---|---|
| Premature mortality (short-term exposure, all ages) | | |
| -Using a 3% discount rate | 1,480 | $1,535 |
| -Using a 7% discount rate | 1,480 | $1,771 |
| Chronic bronchitis (adults, 26 and over, COI valuation) | 5,220 | $610 |
| Hospital Admissions – Pneumonia (adults, over 64) | 1,110 | $15 |
| Hospital Admissions – COPD (adults, 64 and over) | 910 | $10 |
| Hospital Admissions – Asthma (65 and younger) | 240 | <$5 |
| Hospital Admissions – Cardiovascular (adults, over 64) | 2,680 | $50 |
| Emergency Room Visits for Asthma (65 and younger) | 2,080 | <$1 |
| Asthma Attacks (asthmatics, all ages) | 82,130 | $B_1$ |
| Acute bronchitis (children, 8-12) | 4,970 | <$1 |
| Lower respiratory symptoms (children, 7-14) | 54,190 | $1 |
| Upper respiratory symptoms (asthmatic children, 10-11) | 200,590 | $5 |
| Work loss days (adults, 18-65) | 275,710 | $30 |
| Minor restricted activity days (adults, age 18-65) | 2,064,850 | $100 |
| Other PM-related health effects[E] | $U_1$ | $B_2$ |
| HAP health effects[E] | $U_2$ | $B_3$ |
| Total Monetized Health-Related Benefits | | |
| -Using a 3% discount rate | — | $2,380+$\mathbf{B_H}$ |
| -Using a 7% discount rate | — | $2,620+$\mathbf{B_H}$ |

[A] The results presented in this table include all emission reductions including those identified for specific sources included in the Inventory Database and the remaining reductions not included in the Inventory Database.
[B] Incidences are rounded to the nearest 10 and may not add due to rounding. Incidences of unquantified endpoints are indicated with a U.
[C] Dollar values are rounded to the nearest 5 million and may not add due to rounding. The value of unquantified endpoints are indicated with a B.
[D] The estimated value for PM-related premature mortality assumes a 5-year distributed lag structure and discounted at a 3% rate, which is described in the HDD RIA.
[E] A detailed listing of unquantified PM and HAP related health effects is provided in Table 10-16.

## 10.7 Limitations of the Analysis

### 10.7.1 *Uncertainties and Assumptions*

Significant uncertainties and potential biases are inherent in any benefits analysis based on benefits transfer techniques. This analysis uses two forms of benefit transfer, (1) the transfer of dose-response functions and valuation estimates from published articles, and (2) the transfer of value per ton reduced from the monetized estimate in the phase one analysis. The degree of uncertainty and bias depends on how divergent the reality of the policy situation is from the state of the world assumed in the benefits transfer approaches.

For this analysis, several key assumptions may lead to over or underestimation of benefits. Table 10-8 lists these assumptions, and where possible indicate the expected direction of the bias. This is by no means an exhaustive list, but captures what we have identified as key assumptions. In addition to these uncertainties and biases, there are uncertainties and biases embedded in the original benefits analyses from which the transfer values were generated. Some of these potential biases and assumptions are discussed in the preceding sections. For a full discussion of these uncertainties, see the RIA for the Heavy Duty Engine/Diesel Fuel rule, as well as the Section 812 report to congress on the Benefits and Costs of the Clean Air Act 1999 to 2010.

**Table 10-16.**
**Significant Uncertainties and Biases Associated with the Industrial Boilers/Process Heaters Benefit Analysis**

| Assumption | Direction of Bias[A] |
|---|---|
| Omission of HAP effects, and PM effects associated with visibility and materials damage benefit categories | Downward |
| Estimated emission reductions accurately reflect conditions in 2005 | Unknown |
| Future meteorology well-represented by modeled meteorology | Unknown |
| Benefits from source studies do not include all benefits and disbenefits | Unknown |
| Population, demographics, exposures, and air quality included in phase one analysis is representative for the transfer to the phase two analysis | Unknown |
| Linear extrapolation of future populations | Unknown |
| Accuracy of S-R Matrix representativeness of secondary PM formation chemistry | Unknown |

[A] A downward bias is an indicator that total benefits are underestimated. An upward bias is an indicator that total benefits are overestimated. In several cases, the direction of the bias is unknown and can potential be an underestimate or an overestimate of total benefits.

### 10.7.2 *Unquantified Effects*

In addition to the monetized benefits presented in the above tables, it is important to recognize that many benefit categories associated with HAP, $SO_2$, and PM reductions are not quantified or monetized for this analysis. With respect to the benefits of reducing exposure to HAPs, EPA has developed a rudimentary risk analysis focusing only on cancer risks. As discussed above, this analysis suggests that the proposed rule would reduce cancer incidence by roughly tens of cases per year if it were implemented at all affected boiler and process heater facilities. Placing a value on these impacts would increase the economic benefits of the rule. This analysis carries significant assumptions, uncertainties, and limitations. EPA is working with the SAB to develop better methods for analyzing the cancer and non-cancer benefits of HAP reductions. EPA will include a monetized estimate of the benefits of reducing HAP emissions with the analysis for the final rule if it is able to develop better methods before promulgation of this rule. Other potentially important unquantified benefit categories are listed in Table 10-17. For a more complete discussion of unquantified benefits and disbenefits, see the RIA for the Heavy Duty Engine/Diesel Fuel rule.

**Table 10-17. Unquantified Benefit Categories**

| | Unquantified Benefit Categories Associated with HAPs | Unquantified Benefit Categories Associated with PM |
|---|---|---|
| **Health Categories** | Airway responsiveness<br>Pulmonary inflammation<br>Increased susceptibility to respiratory infection<br>Acute inflammation and respiratory cell damage<br>Chronic respiratory damage/ Premature aging of lungs<br>Emergency room visits for asthma | Changes in pulmonary function<br>Morphological changes<br>Altered host defense mechanisms<br>Cancer<br>Other chronic respiratory disease<br>Emergency room visits for asthma<br>Emergency room visits for non- asthma respiratory and cardiovascular causes<br>Lower and upper respiratory symptoms<br>Acute bronchitis<br>Shortness of breath<br>Increased school absence rates |
| **Welfare Categories** | Ecosystem and vegetation effects<br>Damage to urban ornamentals (e.g.,grass, flowers, shrubs, and trees in urban areas)<br>Commercial field crops<br>Fruit and vegetable crops<br>Reduced yields of tree seedlings, commercial and non-commercial forests<br>Damage to ecosystems<br>Materials damage | Materials damage<br>Damage to ecosystems (e.g., acid sulfate deposition)<br>Nitrates in drinking water<br>Visibility in recreational and residential areas |

## 10.8 Benefit-Cost Comparison

This Regulatory Impact Analysis (RIA) provides cost, economic impact, and benefit estimates that are potentially useful for evaluating regulatory alternatives for the proposed industrial boilers and process heaters rule. Benefit-cost analysis provides a systematic framework for assessing and comparing such alternatives. According to economic theory, the efficient alternative maximizes net benefits to society (i.e., social benefits minus social costs). However, there are practical limitations for the comparison of benefits to costs in this analysis. In particular, the inability to quantify the primary HAP related benefits of the rule, as well as the inability to quantify the disbenefits of increased electricity generation related emissions introduces biases into our estimate of benefits that make comparison with costs less meaningful. Executive Order 12866 clearly indicates that unquantifiable or nonmonetizable categories of both costs and benefits should not be ignored. There are many important unquantified and unmonetized costs and benefits associated with reductions in $PM_{10}$ and $PM_{2.5}$ emissions, including many health and welfare effects. Potential PM benefit categories that have not been quantified and monetized are listed in Table 10-18 of this chapter. It is also important to recall that this analysis is only of the monetizable benefits associated with $PM_{10}$ and $PM_{2.5}$ reductions. The proposed rule is designed to reduce HAP emissions. By achieving these HAP reductions, the rule reduces the risks associated with exposures to those chemicals, including the risk of fatal cancers. It is likely the monetized benefit estimates presented in this chapter are expected to underestimate total benefits of the rule.

In addition to categories that cannot be included in the calculated net benefits, there are also practical limitations for the comparison of benefits to costs in this analysis, which have been discussed throughout this chapter. Several specific limitations deserve to be mentioned again here:

- The state of atmospheric modeling is not sufficiently advanced to provide a workable "one atmosphere" model capable of characterizing ground-level pollutant exposure for all pollutants of interest (e.g., ozone, particulate matter, carbon monoxide, nitrogen deposition, etc). Therefore, the EPA must employ several different pollutant models to characterize the effects of alternative policies on relevant pollutants. Also, not all atmospheric models have been widely validated against actual ambient data. In particular, since a broad-scale monitoring network is in the early stages of development for fine particulate matter ($PM_{2.5}$), atmospheric models designed to capture the effects of alternative policies on $PM_{2.5}$ are not fully validated. Additionally, significant shortcomings exist in the data that are available to perform these analyses. While containing identifiable shortcomings and uncertainties, EPA believes the models and assumptions used in the analysis are reasonable based on the available data and evidence.

- Qualitative and more detailed discussions of the above and other uncertainties and limitations are included in detail in earlier sections. In particular, the fact that only half of the sources expected to be affected by this proposed rule are actually covered in these analysis contributes to the uncertainty of the benefits estimates (as well those of the costs and economic impacts, as well). Data limitations prevent an overall quantitative estimate of the uncertainty associated with final estimates. Nevertheless, the reader should keep all of these uncertainties and limitations in mind when reviewing and interpreting the results.

- The Base and Alternative PM benefit estimates do not include the monetary value of several known PM-related welfare effects, including recreational and residential visibility, household soiling, and materials damage.

Nonetheless, if one is mindful of these limitations, the relative magnitude of the benefit-cost comparison presented here can be useful information. Thus, this section summarizes the benefit and cost estimates that are potentially useful for evaluating the efficiency of the proposed Industrial Boilers and Process Heaters proposed rule.

The estimated social cost of implementing the proposed NESHAP at the MACT floor is approximately $837 million (1999$) in third year after issuance of this rule. The Base Estimate of monetized benefits of the MACT floor are $16.3 billion when using a 3 percent discount rate (or approximately $15.4 billion when using a 7 percent discount rate). The Alternative Estimate of benefits totals $2.3 billion when using a 3 percent discount rate (or approximately $2.6 billion when using a 7 percent discount rate). Keeping in mind that no primary HAP-related benefits are quantified, comparison with costs indicates that our Base Estimate of monetized benefits of ancillary $PM_{10}$ and $SO_2$ reductions alone exceed the compliance costs by nearly a factor of 20.

For the above the floor option (also called "Option 1A" in this RIA), the estimated social cost is $1.9 billion (1999$) in third year after issuance of this rule. The Base Estimate of monetized benefits of the above the floor option are $17.2 billion when using a 3 percent discount rate (or approximately $16.3 billion when using a 7 percent discount rate). The Alternative Estimate of benefits for the above the floor option totals $2.4 billion when using a 3 percent discount rate (or approximately $2.6 billion when using a 7 percent discount rate). Thus, our Base Estimate of benefits of the above the floor option exceed the costs by a factor of 8.

It is also useful to consider the incremental costs and benefits of moving from the MACT floor to the above the floor option. The incremental net benefits of going to the above the floor option from the proposed NESHAP (the MACT floor alternative) is -$160 million under the Base Estimate (using a 3 percent discount rate), or $-1,060 million under the Alternative Estimate (using a 3 percent discount rate). Hence, the MACT floor alternative can be considered a more efficient alternative to society than the above the floor option from the standpoint of maximizing net benefits. Note that while monetized benefits of $PM_{10}$ and $SO_2$ reductions are large in this instance, they account for only a portion of the benefits of this rule. Notable omissions include all benefits of HAPs and VOC reductions, including reduced cancer incidences, central nervous system and cardiovascular system effects, and ozone related benefits. It is also important to note that not all benefits of $PM_{10}$ reductions have been monetized. Categories which have contributed significantly to monetized benefits in past analyses (see the Heavy Duty Engine/Diesel Fuel RIA) include recreational and residential visibility and household soiling. Table 10-17 lists known unquantified benefits associated with PM and HAP reductions. Table 10-18 summarizes the costs, benefits, and net benefits for the rule and the above the floor option, and shows a comparison of the two option.

We did not attempt to estimate welfare benefits associated with PM reductions for this rule because of the difficulty in developing acceptable benefit transfer values for these effects. The SAB has recently reviewed existing studies valuing improvements in residential visibility and reductions in household soiling and advised that these studies do not provide an adequate basis for valuing these effects in cost-benefit analyses (EPA-SAB-COUNCIL-ADV-00-002, 1999; EPA-SAB-Council-ADV-003, 1998). Reliable methods do exist for valuing visibility improvements in Federal Class I areas, however, the benefits transfer method outlined above does not allow for predictions of changes in visibility at specific Class I areas. These predictions are necessary to estimate Class I area visibility benefits. As such we have left this potentially important endpoint unquantified for this analysis. Given the proximity of some sources to national parks in the Northwest (Mt. Ranier, Olympic, and Crater Lake), Northern Rockies (Glacier), and Maine (Acadia), these omitted benefits may be significant.

**Table 10-18. Annual Net Benefits of the Industrial Boilers and Process Heaters NESHAP in 2005**

| | MACT Floor (Million 1999$) | Above the MACT Floor (Million 1999$) |
|---|---|---|
| **Social Costs**[B] | $837 | $1,923 |
| **Social Benefits**[B, C, D]**:** | | |
| **HAP-related health and welfare benefits** | Not monetized | Not monetized |
| **PM-related welfare benefits** | Not monetized | Not monetized |
| **SO2- and PM-related health benefits:** | | |
| **Base Estimate** | | |
| **-Using 3% Discount Rate** | $16,300 + B | $17,230 + B |
| **-Using 7% Discount Rate** | $15,430 + B | $16,310 + B |
| **Alternative Estimate** | | |
| **-Using 3% Discount Rate** | $2,350 + B | $2,380 + B |
| **-Using 7% Discount Rate** | $2,585 + B | $2,620 + B |
| **Net Benefits (Benefits - Costs)**[C, D]**:** | | |
| **Base Estimate** | | |
| **-Using 3% Discount Rate** | $15,465 | $15,305 + B |
| **-Using 7% Discount Rate** | $14,595 | $14,385 + B |
| **Alternative Estimate** | | |
| **-Using 3% Discount Rate** | $1,515 | $455 + B |
| **-Using 7% Discount Rate** | $1,750 | $700 + B |

[A] All costs and benefits are rounded to the nearest $5 million. Thus, figures presented in this table may not exactly equal benefit and cost numbers presented in earlier sections of the chapter.

[B] Note that costs are the total costs of reducing all pollutants, including HAPs as well as $SO_2$ and $PM_{10}$. Benefits in this table are associated only with PM and $SO_2$ reductions.

[C] Not all possible benefits or disbenefits are quantified and monetized in this analysis. Potential benefit categories that have not been quantified and monetized are listed in Table 8-13. B is the sum of all unquantified benefits and disbenefits.

[D] Monetized benefits are presented using two different discount rates. Results calculated using 3 percent discount rate are recommended by EPA's *Guidelines for Preparing Economic Analyses* (U.S. EPA, 2000a). Results calculated using 7 percent discount rate are recommended by OMB Circular A-94 (OMB, 1992).

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