PROTECTING THE OZONE LAYER PROTECTS EYESIGHT

A REPORT ON CATARACT INCIDENCE IN THE UNITED STATES USING THE ATMOSPHERIC AND HEALTH EFFECTS FRAMEWORK MODEL

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Though every effort was made to ensure accuracy, EPA is solely responsible for any errors in this report.

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Foreword

Cataract is a clouding of the eye's naturally clear lens. Mostly, cataracts appear as we grow older, usually after age 40. Over time, cataract formation in one or both eyes can cause vision impairment and blindness. Age-related cataract has a number of potential causes, but lifelong exposure to ultraviolet radiation from the sun likely plays a significant role. In the 2008 update to the *Vision Problems in the U.S.* report, the National Eye Institute and Prevent Blindness America estimated that cataract affects more than 22 million people, one in six over the age of 40, in the United States.

The only treatment for cataract is removal of the clouded natural lens. Most cataract patients receive an artificial lens, called an intraocular lens (IOL) implant in what is typically a safe and highly effective outpatient procedure. But this treatment can be costly for individuals and for society. Prevent Blindness America estimated in its 2007 *Economic Impact of Vision Problems* report that the direct medical cost of cataract treatment for Americans over the age of 40 totaled $6.8 billion annually. This figure does not include lost productivity from reduced labor force participation and health utility costs related to distress, pain, depression, mobility and social limitations as measured by quality-adjusted life years. These direct and indirect costs will only increase as the U.S. population ages and cataract becomes even more prevalent. The next edition of *Vision Problems in the U.S.*, to include estimates based on 2010 U.S. Census data, is expected to reflect this trend.

The average direct outpatient cost of cataract treatment is $1,268 per patient. For inpatient treatment, the cost rises to $5,689 per patient. Consequently, every case of cataract delayed or avoided entirely will return savings to individuals, our health care delivery system, and society as a whole, not to mention the potential impact in improved quality of life for those who do not have to face vision impairment or surgery.

Protecting the Ozone Layer Protects Eyesight – A Report on Cataract Incidence in the United States Using the Atmospheric and Health Effects Framework Model offers an important reminder of the link between the intensity of ultraviolet radiation and cataract incidence. At Prevent Blindness America, we fully support the Environmental Protection Agency in its efforts to increase public awareness of the consequences for our eye and vision health resulting from UV exposure and the estimated health benefits of domestic and international policies to reduce levels of ozone-depleting substances in the atmosphere. Without the *Montreal Protocol on Substances That Deplete the Ozone Layer* and its amendments and adjustments, the economic and social burden of cataract might well have been much higher for our nation.

As the report emphasizes, cataract is primarily an age-related phenomenon, with risk factors that may vary for individuals depending on where they live, their level of outdoor activity, and the extent to which they take steps to protect their eyes from UV radiation throughout their lives. *Protecting the Ozone Layer Protects Eyesight - Cataract Incidence in the United States Using the Atmospheric and Health Effects Framework Model* sets the stage for additional research to demonstrate the direct economic and societal benefits of ozone layer protection and enables future efforts to tailor more precise public health messaging about UV eye protection that may avoid many more cases of cataract for generations of Americans in the years and decades to come.

Hugh R. Parry

President & CEO

Prevent Blindness America

Preface

The Atmospheric and Health Effects Framework (AHEF) was created in the mid 1980s to assess the adverse human health effects associated with a depleting stratospheric ozone layer. Historically, the AHEF has estimated the probable increases in skin cancer mortality, skin cancer incidence, and cataract incidence in the United States that result from ozone-depleting substance (ODS) emission scenarios relative to a 1979-1980 baseline (i.e., prior to significant ozone depletion). This baseline is defined as the health effects that would have occurred if the ozone concentrations that existed in 1979-1980 had been maintained through the time period modeled. In addition, the AHEF can provide the probable change in incidence and mortality that results from one ODS emission scenario relative to another ODS emission scenario, thereby providing incremental estimates of the potential benefits associated with broad policy scenarios.

The AHEF was significantly updated for the 2006 Peer Review Report to incorporate new research results. A number of revisions occurred, including: (1) recalibration and refinement of stratospheric ozone concentration measurements; (2) updated ODS emission data; (3) improved forecasts of the impact of changing ozone concentrations on ultraviolet (UV) radiation intensity at the Earth's surface; (4) updated information on the biological effects of UV radiation of different wavelengths (action spectra), and how age and year of birth affect the induction of skin cancers and other human health effects; (5) improved estimation of projected skin cancer mortality rates, based on more recent and reliable epidemiological data; (6) revised health effects modeled by the AHEF including removing the cataract module, to more accurately predict only those health effects for which an agreed upon dose-response relationship was available; and (7) updated population data. These updates were tested and presented in the 2006 Peer Review Report, "*Human Health Benefits of Stratospheric Ozone Protection*."

The 2006 Peer Review Report found a weak correlation between state-level average annual UV exposure and cataract incidence (based on data from the 2002 National Eye Institute/Prevent Blindness America report, *Vision Problems in the U.S.: Prevalence of Adult Vision Impairment and Age-Related Eye Disease in America*). It was suggested that aggregated state-level UV data may not have been sufficiently refined to show population–based effects. Based on the findings, the 2006 Peer Review Report identified topics for future research including the possible re-inclusion of the cataract module should additional refinement of population adjusted dose-response information become available. Another area peer reviewers identified for AHEF model improvement was predicting effects by skin types, if possible.

This report discusses the new updates to the AHEF that have occurred since the 2006 Peer Review Report. In particular, this report reintroduces the cataract module into the AHEF given the: (1) improved spatial resolution that provides county-level population projections, and (2) availability of improved information on the biological effects of UV radiation, including dose-response relationships by skin type, to estimate the probable increase in cataract incidence. Although no re-analysis of the weak correlation found between UV radiation exposure and cataract incidence was performed, the availability of county-level data and a more robust action spectrum based on animal eye lenses made such a re-analysis unnecessary.

The changes to the AHEF cataract module are discussed in detail within this report and are intended as a supplement to the 2006 Peer Review Report and, as such, use the same emission scenarios created in 2001. The emission scenarios used in this analysis reflect the state of knowledge for ozone recovery in 2001, i.e., reflect a more optimistic time frame for ozone layer recovery—recovery in the mid 2040s versus the current World Meteorological Organization estimate of 2065. Therefore, it is likely the results in this report underestimate health benefits associated with stratospheric protection programs.

Acronyms

AHEF	Atmospheric and Health Effects Framework
BAF	Biological Amplification Factor
CFC	Chlorofluorocarbon
DU	Dobson Units
EPA	U.S. Environmental Protection Agency
GIS	Geographic Information System
HCFC	Hydrochlorofluorocarbon
NCAR	National Center for Atmospheric Research
NCHS	National Center for Health Statistics
NHANES	National Health and Nutrition Examination Study
ODS	Ozone-Depleting Substances
SEE	Salisbury Eye Evaluation
TOMS	Total Ozone Mapping Spectrometer
TUV	Tropospheric Ultraviolet-Visible Radiation Model
UV	Ultraviolet
WMO	World Meteorological Organization

Executive Summary

Human-made ozone-depleting substances (ODS) such as chlorofluorocarbons (CFCs), halons, methyl bromide, and hydrochlorofluorocarbons (HCFCs) reduce the ozone concentration in the Earth's stratosphere. The ozone layer acts like a protective shield, so damage to it significantly increases the amount of ultraviolet (UV) radiation reaching the Earth's surface. More UV means more adverse human health effects, like skin cancer and cataract. The 1987 *Montreal Protocol on Substances that Deplete the Ozone Layer* (Montreal Protocol) is an international agreement in which governments have acknowledged the harm and agreed to phase out production and import of specific ODS. The U.S. Environmental Protection Agency (EPA) uses the Atmospheric and Health Effects Framework (AHEF) to assess the human health benefits in the U.S. associated with reducing emissions of ODS under the Montreal Protocol and its amendments and adjustments. Previously, the AHEF estimated the skin cancer cases and deaths avoided. This report shows that the AHEF now has the capability to model avoided cataract cases.

The updates that enabled AHEF to model cataract incidence include:

- Improved spatial resolution;
- Updated information on the biological effects of UV radiation, including dose-response data by skin type and gender;
- More recent epidemiological data; and
- Improved calculation of the solar zenith angle.

These updates increase model accuracy and improve model output. This report discusses these updates, improvements, and future work.

EPA uses AHEF to examine how health effects change under different ODS control policy scenarios either relative to the 1979-1980 baseline, or compared to one another. For example, this report estimates that the strengthening of the original Montreal Protocol through the Montreal Amendments of 1997 will result in more than 22 million additional new cataract cases avoided for Americans born between 1985 and 2100. This finding illustrates how reducing ODS leads to increases in stratospheric ozone concentrations, thereby reducing cataract incidence. The results further demonstrate two trends when comparing less protective policies for protecting the ozone layer to more protective policies. First, U.S. counties with many residents older than age 55 have a demonstrably higher cataract incidence than neighboring counties with fewer residents over age 55. Second, because ozone depletion occurs more significantly at higher latitudes, residents of northern counties experience a higher relative increase in exposure to UV radiation than do residents of southern counties.

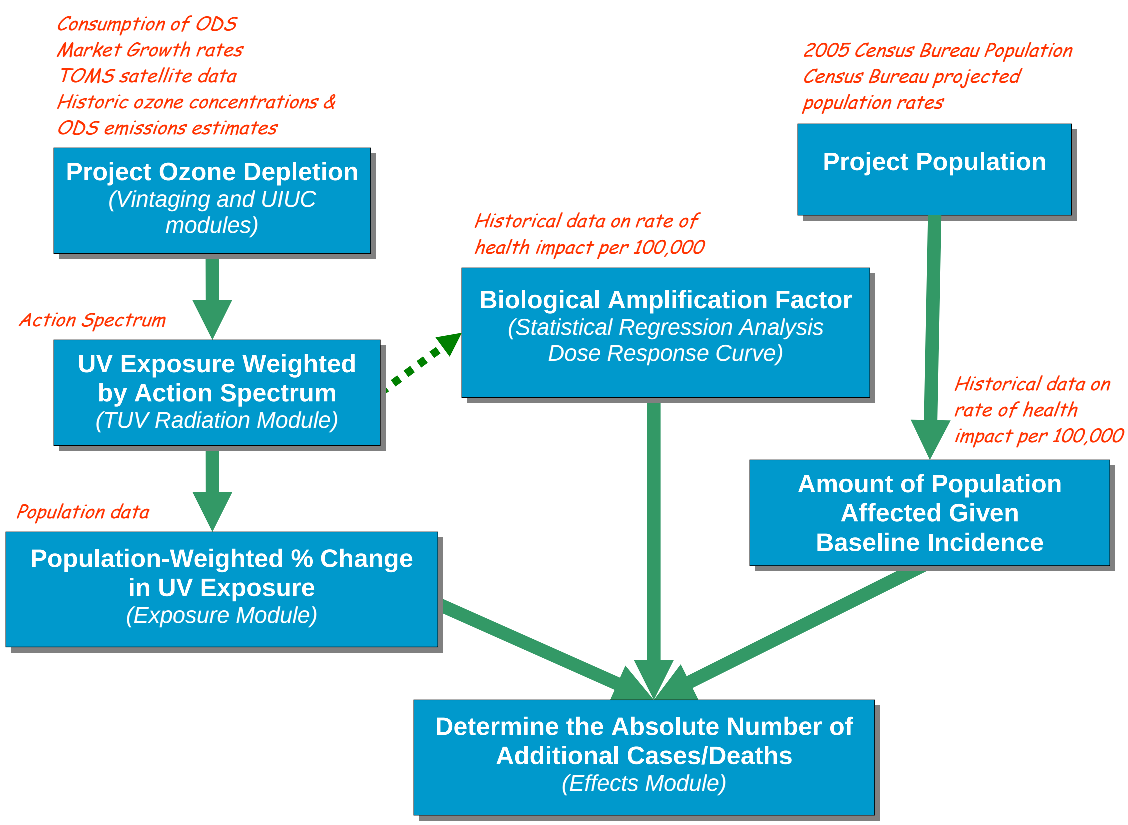
The sensitivity analysis found that changing the biological amplification factor (BAF) as a function of skin type and gender was not highly influential. Overall, the BAFs -- the dose-response relationship between UV radiation intensity and cataract cases caused -- were the greatest source of uncertainty, followed by the choice of action spectrum that relates UV exposure to incidence of cataract.

EPA plans additional updates to AHEF to further improve its capabilities. The emissions scenarios will be updated to reflect current assumptions regarding ODS emissions estimates, including the development of a new emission scenario that represents the Montreal Protocol as adjusted in 2007 and to calculate the health benefits associated with this more aggressive phase out of HCFCs. EPA may also examine avoided costs, and may be able to enhance the model's exposure estimates considering behavior, solar zenith angle, and age.

1. Introduction

The Atmospheric and Health Effects Framework (AHEF) is a series of modules that estimate the health benefit accruing to the U.S. population through the implementation of the 1987 *Montreal Protocol on Substances that Deplete the Ozone Layer* (Montreal Protocol) and the associated amendments and adjustments (see Figure 1).[1] Previously, AHEF provided results calculated for three specific latitude bands covering the U.S. The AHEF has been updated with an enhanced methodology to provide: (1) results at the county scale, and (2) estimates of cataract incidence. This report outlines these updates to the AHEF and presents preliminary results applying the new cataract module.[2]

Figure 1. Schematic Diagram of the AHEF.



Note: Required information for each module is described with red italic text.

The adverse human health effects associated with UV radiation exposure are primarily related to the skin, eyes, and immune system. Eye effects can include cataract, squamous cell cancer of the cornea, conjunctiva, and other damage to the cornea (UNEP 1998; Anduze 1993). Of these, cataract is considered the primary cause of vision loss with approximately two million cataract surgeries performed annually in the U.S. (Smith et al.

[1] See the 2006 AHEF Peer Review Report for more background information on AHEF (EPA 2006).
[2] A glossary of terms is provided at the end of the report.

2005). Studies have shown that UV radiation damages the human eye lens, hastening the deterioration that leads to age-related cataract (Taylor et al. 1988; West et al. 2005). The effectiveness of UV radiation for causing damage to human tissue is wavelength dependent and is characterized by an action spectrum for a particular process. For example, exposure to UV radiation (especially UV-B radiation at 280–320 nm) is an important risk factor for cortical cataract (Oliva and Taylor 2005; Taylor 1989). Additionally, UV-A wavelengths (320-400 nm) and visible radiation have also been implicated in the etiology of cortical cataract in humans (Dillon et al. 1999; Balasubramanian 2000, 2005). Weighting the UV spectrum by the action spectrum for a particular process provides the biologically damaging or biologically effective UV radiation for that process. This study incorporates a new action spectrum and biological amplification factors (BAFs) to provide preliminary projected cataract incidence estimates for the U.S.

2. Modeling Changes in Ultraviolet Radiation Exposure and Health Effects

Until recently, AHEF provided results at three latitude-band resolutions (20–30°N, 30–40°N, and 40–50°N). It is now possible to run the AHEF at county resolution. The AHEF modules updated for county resolution include the exposure module and the effects module. In addition, AHEF was updated to estimate cases of cataract by updating the exposure module to reflect the cataract action spectrum and the effects module to include BAFs by skin type and gender (collectively termed the "cataract module"). The following subsections describe the changes to the AHEF in more detail.

2.1 Changes in the Exposure Module

The exposure module determines the UV exposure for a given health effect as a function of latitude band (20–30°N, 30–40°N, and 40–50°N), year, and action spectrum. The action spectrum is an experimentally-derived weighting function that describes the relative effectiveness of energy at different UV wavelengths to cause a particular biological response, such as cataract.

The normalized sensitivity describes the relative effectiveness of a particular wavelength to produce cataract (the percent change in UV radiation causing a percent change in cataract incidence). The UV exposure weighted by the action spectra are computed using the Tropospheric Ultraviolet-Visible (TUV) radiation model (Madronich 1992, 1993; Madronich and de Gruijl 1993; Madronich et al. 1996, 1998). The cataract incidence action spectrum incorporated in AHEF is in the form of a lookup table providing UV exposure as a function of solar zenith angle and total atmospheric ozone column amount.

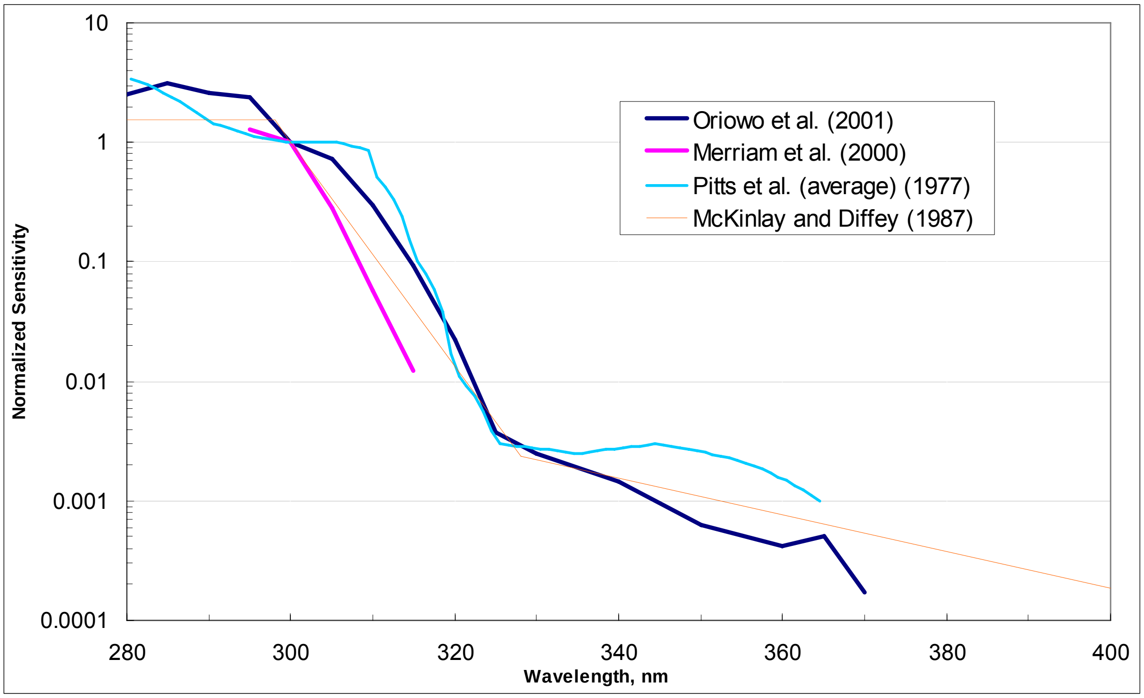
Figure 2 presents four action spectra which were considered for modeling cataract. All of these action spectra exhibit similar behavior demonstrating the strongest sensitivity to the UV-B wavelengths with reducing impact as wavelengths increase. This study uses the most-recently-developed Oriowo action spectrum given both its coverage of optimum wavelengths and the similarity of the pig lens to the human lens in composition and UV response (Oriowo et al. 2001).[3] The Oriowo action spectrum is based on the *in vitro* induction of cataract in whole, cultured pig lenses spanning across wavelengths from 270 to 370 nm, thus extending into the UV-A spectrum (see adjacent textbox and Figure 2).

In Vitro Studies Using a Young Animal Lens in the Absence of a Protective Cornea

- Modeling the impact of UV radiation on the lens in the absence of the protective cornea may overestimate the impact of UV wavelengths between 290 and 300 nm.
- Using a young pig lens to simulate UV damage may underestimate the impact on the older population (as the damage caused by UV-A and UV-B changes with the age of the lens).

[3] In addition, the Oriowo action spectrum appeared in the peer-review journal, *Investigative Ophthalmology & Visual Science*. The Oriowo et al. (2001), Pitts et al. (1997), and Merriam (2000) studies investigate the induction of cataract, while the McKinlay and Diffey (1987) action spectrum represents the induction of erythema.

Figure 2. Action Spectra Considered for Modeling Cataract.



Note: The normalized sensitivity (plotted on the Y-axis) is a log scale. At the normalizing wavelength, every 1 percent change in UV radiation causes a 1 percent change in health effect.

The solar zenith angle is calculated based on location and time of day (other factors such as topography, cloud cover, and surface albedo are not addressed). The newly enhanced AHEF uses a county's area centroid latitude to represent the location. The atmospheric ozone column amounts are provided monthly in Dobson units (DU) at a latitude-band resolution (20–30^{o}N, 30–40^{o}N, and 40–50^{o}N) (see U.S. EPA (2006) for discussion on generating these files). Given that stratospheric ozone perturbations are largely uniform across large regions, a finer resolution for determining the ozone column amounts is not anticipated to provide large differences. The lookup table (see Appendix B) is then used to calculate annual integrated biologically weighted UV irradiance (measured in joules per square meter or J/m^2) by county as a function of the time of day, day of month, and total ozone column amount. The exposure module provides the total UV exposure for each U.S. county at 5- year increments from 1890 to 2100.

There are limitations related to the exposure estimates. In particular, the AHEF cataract exposures are calculated on the basis of available data for persons aged 30 and above; however, during childhood and young adulthood, considerable exposure to UV radiation is likely to occur (see Appendix E.2.1).

2.2 Changes in the Effects Module

The effects module determines the change in cataract incidence that will occur based on a relative change in UV dosage (i.e., the number of cataract cases that occur comparing a scenario case such as the Montreal Protocol as amended and adjusted through 1997[4] relative to the 1979-1980 baseline conditions). While the effects module calculates baseline incidence uniformly across population groups, it uses updated BAFs to investigate cataract risk by skin type and gender.[5] The effects module determines the change in cataract incidence for each U.S. county using Equation 1:

Equation 1.

$$CataractIncidence = (UV_{\exp})(BAF_{ByPopGroup})(BaselineIncidence_{ByPopGroup,Year})(Population_{ByPopGroup,Year})$$

where: *CataractIncidence* is the increase in cataract incidence from scenario to baseline, UV_{exp} is the cumulative percentage increase in UV exposure, $BAF_{ByPopGroup}$ is the biological amplification factor for cataract as a function of population group (skin type and gender), $BaselineIncidence_{ByPopGroup,Year}$ is the baseline incidence estimates of cataract for each population and cohort group, and $Population_{ByPopGroup,Year}$ is the population for each population group by year and age. The cataract baseline incidence estimates are derived from prevalence data presented in Hiller et al. (1983), which in turn are based on a subset of the National Health and Nutrition Examination Study (NHANES) data.[6] The subset consists of 2,225 subjects between the ages of 45 and 74 at 35 different locations across the U.S. Incidence estimates are stratified by location, based on the three latitudinal bands (20–30°N, 30–40°N, and 40–50°N).[7] The methodology used to develop new BAF data by skin type and gender, as well as new population data, is discussed in greater detail below. The results using Equation 1 are at a county resolution which can

> **Cortical Cataract**
>
> Description:
> The outer edges of the lens develop whitish, wedge-shaped opacities or streaks. As the condition worsens, the opacity extends to the center of the lens reducing the light that passes through (provided by the Mayo Clinic website).
>
> Examples of Clinical Definitions:
> - Klein et al. (1998) defines prevalent cortical cataract cases as opacities of 5% or more of the visible lens as documented by a slit lamp photograph.
> - West et al. (1998), used in AHEF, defines cortical cataract as at least one eye being obscured by a grade of 3/16 or higher based on photographically documented cortical opacity.

[4] See Glossary and U.S. EPA (2006) for further description of the respective policy measures discussed in this memorandum.
[5] This is an area for possible future improvement. The cataract baseline incidence used here is the same for light-skinned males, light-skinned females, dark-skinned males, and dark-skinned females. The light-skinned population includes those defined in the U.S. Census Bureau (2009) as *Whites, American Indians, Asians, Pacific Islanders*, or *Other* (including the majority of the Hispanic populations).
[6] NHANES analyzed all three forms of cataract (nuclear, posterior subcapsular, and cortical), but only cortical cataract is clearly associated with UV exposure; much uncertainty exists with regard to the role of UV-B and the other forms of cataract. Thus, by using the NHANES data to develop baseline cataract incidence in the AHEF, this report may overestimate cataract cases avoided. See Appendix A for further explanation of how baseline incidence was calculated.
[7] The baseline incidence assumes zero incidence for populations under 55 years and over 85 years of age. This likely underestimates the overall baseline incidence.

be aggregated to state and national levels. The county results can then be mapped through a postprocessor such as a geographic information system (GIS).

Biological Amplification Factor (BAF)

The action spectrum shows relative weights to be placed on each discrete UV wavelength to reflect the degree to which each wavelength causes biological damage (i.e., UV radiation weighted by action spectrum). It is then possible to describe the relationship between the health effect and the intensity of UV exposure using statistical regression analysis to estimate the dose-response relationship, known as the Biological Amplification Factor, or "BAF." The BAF measures the degree to which changes in UV exposure weighted by the appropriate action spectrum (as measured in W/m^2) produce incremental changes in cataract incidence. The BAF is defined as the percent change in a health effect resulting from a one-percent change in the intensity of UV radiation (weighted by the chosen action spectrum).[8]

If the BAF is equal to 1.1, then a 1.1% change in health effect would occur with a 1% change in the intensity of UV radiation. Previously, AHEF estimated cataract BAFs for all population subgroups based on the number of cataract cases of "watermen" (primarily white males) in the Chesapeake Bay area (Taylor et al. 1988). The updated BAFs incorporated in the new cataract module have been adopted from the Salisbury Eye Evaluation (SEE) project which provided factors for: (1) the entire population, (2) the light-skinned female subgroup, and (3) the dark-skinned subgroup of the population (West et al. 1998, 2005). The SEE findings are based on observations of the Maryland population and therefore the assumption that this population's behaviors influencing sun exposure are representative of that for the entire U.S. is inherent in resultant BAFs. Table 1 shows the BAF values for each population group.

Table 1. Biological Amplification Factors of Cataract Incidence Calculated for Population Subgroups (bold values are provided in West et al. (2005) and West et al. (1998) while the light-skinned male value is provided using Equation 2).

Light-Skinned Male	Light-Skinned Female	Dark-Skinned Male	Dark-Skinned Female
0.197	**0.150**	**0.239**	**0.239**

The bolded values in the table are provided by West et al. (2005) and West et al. (1998) as discussed in the BAF section above. The BAF for light-skinned males is calculated instead using a percent-population weight-based equation:

[8] For this application, a log-log scatterplot of cataract incidence as a function of the yearly amount of UV radiation weighted by the action spectrum is fitted with a regression equation where BAF translates to the slope of the line (i.e., change in cataract incidence divided by the change in yearly amount of weighted UV radiation). Thus, the change in cataract incidence is determined by multiplying the BAF by the calculated population weighted percent change in yearly amount of UV radiation and the baseline incidence. The West et al. (2005) methodology for developing the BAFs takes into account such behavior factors as outdoor activity and UV protection such as wearing hats and/or protective eyewear.

Equation 2.

$$BAF_{NatPop} \cdot Pop_{NatPop} = BAF_{LSM} \cdot Pop_{LSM} + BAF_{LSF} \cdot Pop_{LSF} + BAF_{DSM} \cdot Pop_{DSM} + BAF_{DSF} \cdot Pop_{DSF}$$

where: *BAF* is the biological amplification factor, *Pop* is the population at a given reference year, the subscript "*NatPop*" refers to the national population, as a sum of all subgroups, "*LSM*" refers to light-skinned males, "*LSF*" refers to light-skinned females, "*DSM*" refers to dark-skinned males, and "*DSF*" refers to dark-skinned females. This method weights each BAF by the respective national population subgroup and assumes a value of 0.18 is appropriate for a uniform national BAF estimate (West et al. 1998). The BAF value for light-skinned male, which is not assigned a value in the available literature, is derived using the equation above and 2002 National Center for Health Statistics (NCHS) population dataset to provide a BAF. This method is preferable to simply applying the uniform BAF estimate of 0.18 as it is more likely to reflect and capture the differences for each subpopulation group.

Population

County-level population estimates are incorporated for the years 1985–2050 in five-year increments by age groups, skin type, and gender. Though few U.S. population datasets provide this required level of detail, the National Center of Health Statistics (NCHS) does provide this information for the years 1990, 1995, 2000, and 2005. As the NCHS does not provide this information for 1985, this population dataset is approximated using the 1990 NCHS dataset as discussed below. The following discussion provides the methodology used in creating population datasets for each five year period:

- <u>1985 U.S. county population</u> is developed utilizing both the 1990 NCHS county population dataset by age groups, skin type, and gender and the available 1985 U.S. National Census total national population estimates. First, because 1985 estimates are not available, the 1990 population is "aged backwards" or extrapolated to 1985 (i.e., the population of the age 5–9 group in 1990 becomes the age 0–4 group in 1985; because a child who was 6 years old in 1990 was 1 year old in 1985. This process of "back-casting" was repeated for all age groups).[9] Next the total population of all age groups, skin types, and genders for all U.S. counties is summed and compared to the total national 1985 U.S. National Census population estimate to ensure correlation (U.S. Census Bureau 2000a). The 1985 U.S. National Census population estimate was found to be approximately 3.1 percent higher than the estimate obtained by ageing the 1990 population backward, a difference attributed to mortality and immigration in 1985–1990. In order to reach the official 1985 total population, all population groups are increased by 3.1 percent. This method is likely to over-estimate younger age groups and under-estimate older age groups as mortality is not uniform across all the population groups in 1985–1989; however, this impact is considered to be a small source of error and is unlikely to impact the results.

[9] The 1990 age 0–4 group was dropped because that population group was not born in 1985, and two-thirds of the 85 and older age group was shifted to 80–84, while the remainder was kept in the 85 and older age group.

- 1990 and 1995 county population estimates are adapted from the NCHS (2004) intercensal estimates and address changes that occurred for two U.S. counties: Broomfield County, Colorado and Clifton Forge City, Virginia.[10] Both changes are reflected in the 2000 and 2005 NCHS estimates and in the 2010–2050 projections. To make the 1990 and 1995 county lists compatible with the data for the other years, necessary adjustments were made in a multi-step process.[11]

- 2000 county population estimates are provided by the NCHS (2008).

- 2005–2050 county population uses population estimates and projections (see U.S. EPA (2008) for further detail). These projections are developed using a cohort-component methodology based on the Vintage 2006 July 1, 2005 dataset provided by the National Center for Health Statistics (2007) and the U.S. Census Bureau (2000b).

This integrated approach provides county resolution population data in five-year increments from 1985 through 2050.

[10] In 2001, Broomfield County, Colorado appeared as an independent county (having been created from parts of Adams, Boulder, Jefferson, and Weld counties), while Clifton Forge City, Virginia lost county status, giving up its incorporated city status and subsuming into Allegheny County.
[11] The populations in Clifton Forge City, Virginia were folded into the populations in Allegheny County. The following method was used to shift the populations from surrounding counties of Adams, Boulder, Jefferson, and Weld Counties to Broomfield County, Colorado: (1) the 1990 population of Broomfield County, which is considered a "place" in the 1990 Census, was taken from the 1990 Census (U.S. Census Bureau 2009); (2) the 1995 population is linearly interpolated from the 1990 and 2000 estimates; and (3) the 1990 and 1995 populations are subtracted from the population of the four surrounding counties based on each county's share of the four-county total. While Broomfield is not developed proportionately out of the four counties, it accounts for just 2.5 percent of the total population of the original four counties, so the net effect of this uncertainty on the 1990 and 1995 estimates is assumed to be negligible.

3. Projecting Cataract Incidence

This study uses the updated AHEF county-resolution model to provide a preliminary estimate of cataract incidence for the U.S. with respect to the Montreal Protocol as amended and adjusted through 1997 relative to the 1987 Montreal Protocol as originally agreed. The original Montreal Protocol was signed in 1987 by 27 countries, representing the first international effort to protect stratospheric ozone by reducing production and consumption of CFCs. A number of amendments and adjustments have been adopted since 1987, expanding the number of ODS listed and reducing respective emission levels, and moving from a phasedown of ODS to a complete phaseout. The 1997 Montreal Amendment provided for the phaseout of HCFCs in developing countries and the phaseout of methyl bromide in developed and developing countries by 2005 and 2015, respectively.[12] More recent policy scenarios have yet to be modeled using AHEF, such as the 2007 Montreal Adjustment, which accelerated the phase out of HCFCs and will result in less ozone depletion and more rapid return of ozone levels to pre-depletion levels. In 2009, the Montreal Protocol achieved universal participation, with 196 signatories.

The current version of AHEF reflects no updates to the emissions profiles used for the 2006 Peer Review Report. Therefore, AHEF's ozone recovery estimates differ from those provided in the 2006 World Meteorological Organization (WMO) Scientific Assessment. Using the current version of AHEF, the ozone concentrations projected under the 1997 Montreal Amendment scenario[13] are expected to reach baseline conditions – that is a return to 1979–1980 ozone concentrations – by the mid 2040s, while the ozone concentrations associated with the 1987 Montreal Protocol as originally agreed are projected to be significantly less.

[12] See U.S. EPA (2006) for further discussion of the reductions associated with the 1997 Montreal Amendment. The series of amendments with associated controls of ozone depletion substances are discussed at http://www.epa.gov/Ozone/intpol/history.html.
[13] This scenario includes the controls of all preceding amendments and adjustments.

4. Model Results

The following subsections present the projected changes in cataract incidence for the policy scenarios examined. The AHEF provides results in one of two possible forms: (1) the change in cataract incidence associated with a given policy scenario relative to the 1979-1980 baseline, or (2) the change in cataract incidence associated with a given policy scenario relative to another policy scenario. The results presented here are in a similar fashion as the 2006 Peer Review Report, "*Human Health Benefits of Stratospheric Ozone Protection*," largely demonstrating the cataract incidence cases avoided by strengthening the original 1987 Montreal Protocol through the Montreal Amendments of 1997.

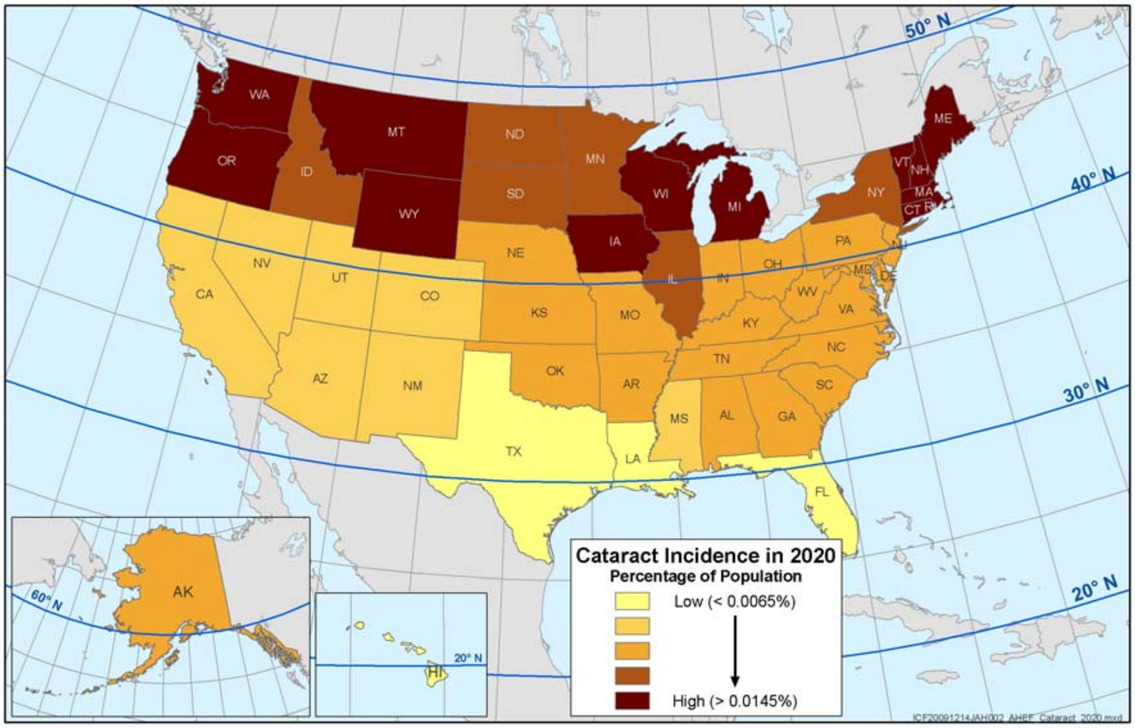
4.1 Results Presented at the County and State Scales

To understand the results discussed in this section (see Figures 3 and 4 for a graphical representation), it is useful to first compare the latitude trends that factor in to the AHEF model. Similar to the findings presented in Table C-1 (see Appendix C), the overall trend in Figure 3 demonstrates an increasing percent change in cataract incidence with increasing (i.e., more northern) latitude. The absolute cataract incidence may still be greater for southern locations; however, the <u>change</u> in incidence associated with a control policy is greater in northern locations due to greater ozone depletion and UV irradiance. Ozone layer thickness varies and is thickest at the equator; ozone layer damage is more severe closer to the poles, allowing for greater transmission of UV to the ground. Figure 3 illustrates the percent change in cataract incidence for all states in 2020 as a percentage of projected state population, comparing the 1987 Montreal Protocol as originally agreed to the 1979-1980 baseline—a healthy ozone layer. This is simply a snapshot for the given year, 2020, and provides coarse level conclusions (i.e., these results may vary with changes in projected year and/or emission scenario). Additional comparisons by latitude and age trends are provided in Appendix C.

As expected, the change in incidence for a given year is very small relative to the total state population and the greatest change in cataract incidence occurs on average for those living in northern states due to the greater reduction in the ozone concentration for the higher latitude bands between the control policy and baseline scenario.[14] Conversely, the northernmost state, Alaska, demonstrates a lower than expected change in incidence per population due to the limited numbers of people at age 55 years and older. The East Coast appears to have a greater risk than the West Coast in acquiring cataract; however, this is misleading as the age of the population is as important as the total number of population. For example, Oklahoma and New Mexico experience similar changes in cataract incidence; however, the Oklahoma population is smaller than the New Mexico population, thereby leading to a greater change in incidence as a percentage of population. This suggests that Oklahoma has a larger projected population group that is 55 years and older than New Mexico. Hence, this figure demonstrates two controlling elements in estimating a state population's changes in cataract incidence when comparing

[14] Incidence is the number of new cataract cases that develop for the 2020 year. Prevalence, on the other hand, is the total number of existing cataract cases during the 2020 year and is not modeled here.

Figure 3. Projected Change in Cataract Incidence Cases for the year 2020 comparing the 1987 Montreal Protocol as Originally Agreed Relative to 1979-1980 Baseline, as a Percentage of Projected State Population.

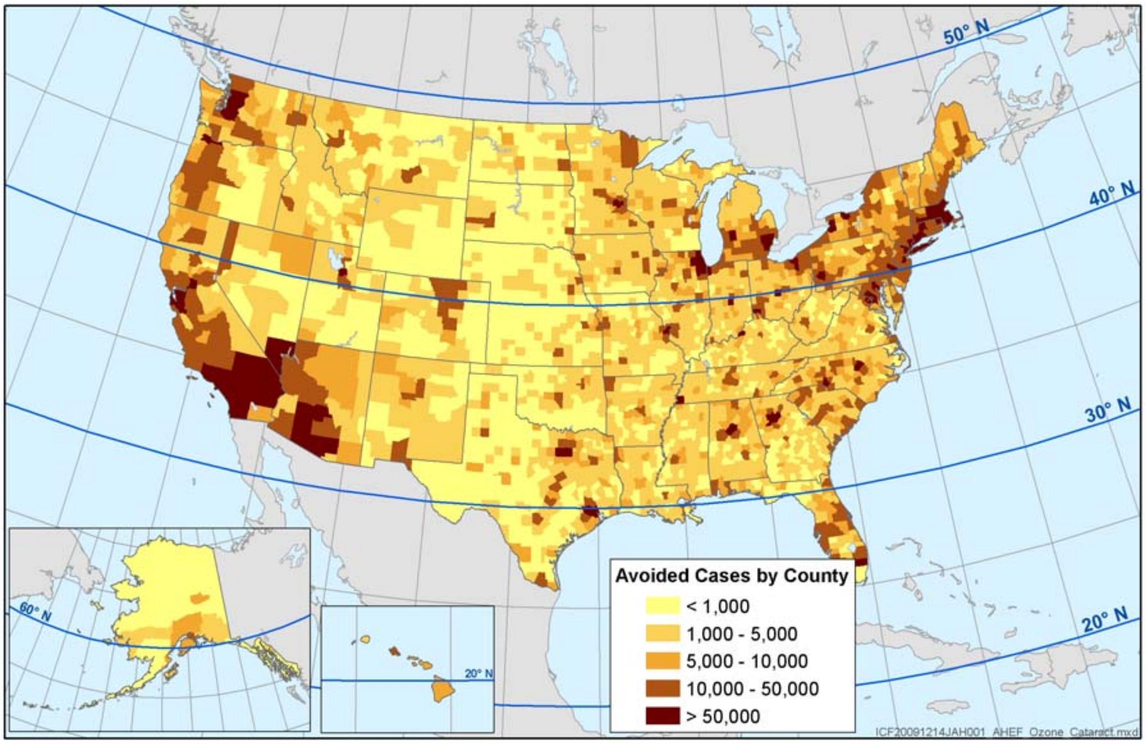


the scenario for the 1987 Montreal Protocol as originally agreed to the scenario for the 1979-1980 baseline: (1) states with a higher percentage of aging populations will display a greater cataract incidence as a percentage of the total population, and (2) the percent increase of harmful UV solar radiation reaching the surface is greater in northern states.

Figure 4 shows the number of avoided cataract cases projected through 2100 by U.S. county when implementing the Montreal Protocol as amended and adjusted through 1997 relative to implementing the 1987 Montreal Protocol as originally agreed. The counties with large population groups older than 55 have a demonstrably greater change in cataract incidence than neighboring counties with smaller population groups older than 55.[15] In addition, since total ozone column amounts decrease by a greater percentage with increasing latitude, northern counties have an increased relative exposure to UV radiation compared to the southern counties. The AHEF results are also aggregated to the state level for further comparison and are displayed in Appendix D.

[15] In 2005, approximately 22% of the U.S. population was older than 55 with West Virginia and Florida representing the highest ratio at approximately 27%, Alaska and Utah representing the lowest ratio at approximately 16%. Within a county, the ratio of older populations can be much larger. Some counties in California, for example, have 32% of the county population older than 55, that is, more than double the ratio of other California counties.

Figure 4. Cataract Incidence Cases Avoided by Implementing the Montreal Protocol as Amended and Adjusted through 1997 Relative to the 1987 Montreal Protocol as Originally Agreed.



4.2 National Results Presented by Policy Scenario

Table 2 provides the incremental number of cataract cases in excess of the baseline (i.e., incidence associated with changes in column ozone concentrations compared to levels observed in 1979–1980) that are projected to occur under the scenario for the 1987 Montreal Protocol as originally agreed and the scenario for the Montreal Protocol as amended and adjusted through 1997.[16] The cataract incidence decreases substantially with the implementation of the more stringent Montreal Protocol as amended and adjusted through 1997. The fourth column in Table 2 shows the avoided number of cataract cases realized when comparing the scenario for the 1987 Montreal Protocol as originally agreed to the scenario for the Montreal Protocol as amended and adjusted through 1997: ODS reduction leads to increases in stratospheric ozone concentrations, thereby reducing cataract incidence levels.

Figure 5 illustrates that as the ODS controls are tightened through policy scenarios like the Montreal Protocol as amended and adjusted through 1997, additional cataract

[16]The results are provided in cohort groups. Each cohort group represents the people born during those years which are grouped together according to the cohort effect as determined from the findings of the AHEF analysis for melanoma induction and which are presented in the 2006 Peer Review report. Cohorts consist of five year intervals, hence, the gap between successive groupings; for example, 1980 represents people born between 1977 and 1982. This study assumes that the time period '1979-1980' represents baseline conditions. A person born in 1890 would not be exposed to changes in UV radiation until 1981 (when the person is 91 years old).

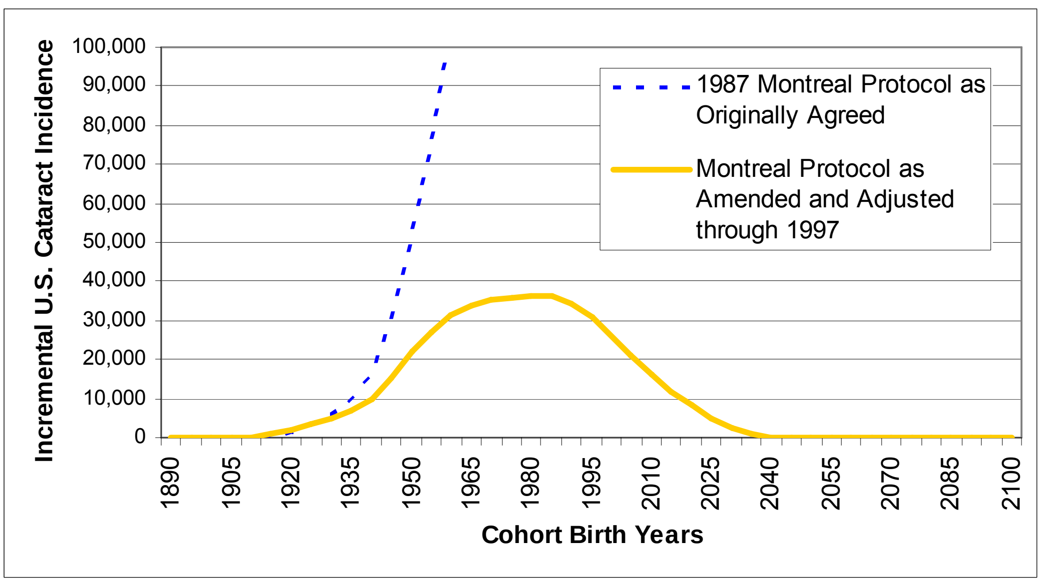
Table 2. Incremental and Total Number of Cataract Incidence Cases.[1]

Birth Years of Cohort Group	Incremental Cataract Incidence (Cases) Compared to Baseline[2]		Cataract Incidence (Cases) Avoided, Comparing Montreal Protocol as Amended/Adjusted through 1997 to 1987 Montreal Protocol as Originally Agreed[3]
	1987 Montreal Protocol as Originally Agreed	Montreal Protocol as Amended/Adjusted through 1997	
1890–1980	1,281,700	263,800	1,018,000
1985–2010	3,131,500	164,500	2,967,000
2015–2050	7,474,300	29,200	7,445,000
2055–2100	11,653,000	0	11,653,000
Total	**23,540,500**	**457,500**	**23,083,000**[4]

[1]These numbers have been rounded. Throughout the report, totals provided may not add up precisely due to rounding.
[2]These numbers indicate the number of cases in excess of the baseline (1979–1980) for each scenario.
[3]These numbers indicate the number of avoided cases from one policy scenario to the other.
[4]When examining the U.S. population born between 1985 and 2100 (i.e., not including the first row of the table), the number of cataract cases avoided is roughly 22 million.

incidence estimates relative to the baseline move closer to that which would be expected if 1979–1980 ozone concentrations had been maintained throughout the time period modeled. The scenario for the 1987 Montreal Protocol as originally agreed, demonstrates the significant number of cataract cases that would have been realized without the more stringent controls of the Montreal Protocol as amended and adjusted through 1997. As illustrated, the cataract incidence in this scenario increases so rapidly that it proves difficult to place both scenarios on the same graph (the incremental U.S. cataract incidence associated with the 1987 Montreal Protocol as originally agreed reaches approximately 900,000 total cases by 2100).

Figure 5. Incremental U.S. Cataract Incidence through 2100 under Two ODS Control Policies.



5. Sensitivity and Uncertainty Analysis

5.1 Sensitivity and Uncertainty to the Biological Amplification Factor

A sensitivity analysis was conducted to compare the AHEF results for the Montreal Protocol as amended and adjusted through 1997 relative to 1979-1980 baseline conditions where the BAF values are varied within reasonable limits. As described in Table 3: Case 1 represents using a uniform BAF value for all populations (West et al. 1998); Case 2 incorporates a BAF value for dark-skinned populations while using the percent-population weight based approximation to calculate an effective BAF for the light-skinned populations (West et al. 2005); and Case 3 is identical to the BAF used in the cataract incidence study (see section 4). Given the small differences in BAF across the three cases - particularly as the higher BAFs are associated with the dark-skinned populations which are currently a smaller-sized population group - it is not expected to produce large differences when comparing resulting cataract incidences.

Table 3. BAF Cases Compared for the Sensitivity Analysis.[17]

Health Effect	Light-Skinned Male	Light-Skinned Female	Dark-Skinned Male	Dark-Skinned Female
Case 1	**0.180**	**0.180**	**0.180**	**0.180**
Case 2	0.170	0.170	**0.239**	**0.239**
Case 3	0.197	**0.150**	**0.239**	**0.239**

Table 4 demonstrates the change in cataract incidence levels for each BAF case as a function of skin type and gender for the Montreal Protocol as amended and adjusted through 1997 scenario with respect to 1979-1980 baseline. The changes in cataract incidence estimates for a given subgroup are directly tied to the BAF value for that case. For example, the change in cataract incidence for the light-skinned males reflects the same pattern as that of the BAF values where the lowest valued BAF and the lowest change in national cataract incidence is realized through Case 2; likewise, the highest valued BAF and the highest change in national cataract incidence is realized for Case 3.

Table 4. National Cataract Incidence by Skin Type and Gender for Each BAF Case Comparing Montreal Protocol as Amended and Adjusted through 1997 with Respect to Baseline for All Cohort Groups.

	Light-Skinned Male	Light-Skinned Female	Dark-Skinned Male	Dark-Skinned Female	Total
BAF Case 1	190,700	223,500	18,900	26,200	459,200
BAF Case 2	180,100	211,000	25,000	34,800	451,000
BAF Case 3	210,200	187,400	25,000	34,800	457,400

Note: These numbers indicate the number of cases in excess of the baseline (1979–1980) for the 1997 Montreal Amendment scenario.

[17] The bolded values in the table are provided by West et al. (2005) and West et al. (1998).

The change in national cataract incidence estimated with the scenario for the Montreal Protocol as amended and adjusted through 1997 relative to 1979-1980 baseline conditions when comparing across the three BAF cases produces minimal differences. There is an overall difference of 2% between Case 1 and Case 2 and an overall difference of 1% between Case 1 and Case 3.

The range of BAF values in Case 3 is used to calculate the BAF uncertainty. The lowest BAF value in Case 3 is 0.150 associated with "Light-skin Female" and the highest BAF value is 0.239 provided for the "Dark-skin Female/Male." The difference in this range is ±0.09. As illustrated in Table 5, this value is added to all skin-type population groups in Case 3 for the high end of the uncertainty analysis and, likewise, is subtracted for the low end.

Table 5. Upper and Lower Bounds of the BAF Uncertainty Analysis.

Range	Light-Skinned Male	Light-Skinned Female	Dark-Skinned Male	Dark-Skinned Female
Lower End	0.107	0.060	0.149	0.149
Higher End	0.287	0.240	0.329	0.329

Table 6 provides estimates of cases based on the lower and upper ends of the range. For this uncertainty analysis, the range is 220,000 to 688,000 additional cases of cataract associated with the Montreal Protocol as amended and adjusted through 1997 scenario relative to 1979-1980 baseline conditions and estimates a theoretical uncertainty of 52%. This range is compared to the 457,500 additional cases of cataract estimated under the Case 3 BAF scenario. Overall, the analysis suggests a change in cataract incidence of 457,500 ± 235,000.

Table 6. National Cataract Incidence by Skin Type and Gender for the Lower and Upper Bounds of the Uncertainty Analysis (using the scenario for the Montreal Protocol as amended and adjusted through 1997 relative to 1979-1980 baseline conditions).

Range	Light-Skinned Male	Light-Skinned Female	Dark-Skinned Male	Dark-Skinned Female	Total
Lower End	107,500	74,900	15,600	21,700	219,700
Higher End	306,200	299,800	34,500	47,900	688,400

5.2 Uncertainty Analysis

AHEF, like other complex modeling frameworks, uses inputs and computational procedures that introduce uncertainty to the results (see U.S. EPA (2006) for a thorough discussion of the methodology in quantifying uncertainty).

Table 7. Quantification of Uncertainty.

Source of Uncertainty	Quantified Uncertainty
Translating column ozone to ground-level UV	
TUV Model	≈ 5%
Translating UV exposure to human health effects	
Uncertainty in the BAFs (cataract incidence)	≈ 52%
Uncertainty with the choice of action spectrum	≈ 27%
Early life exposure vs. whole life exposure	≈ 10%
Total $\sqrt{(5^2 + 52^2 + 27^2 + 10^2)}$	≈ 60%

The uncertainty presented for the choice of BAF is based on the results of the uncertainty analysis (section 5.1). The uncertainty for defining the choice of action spectrum is estimated by comparing the slopes of the action spectra provided in Figure 2 (this value could be refined as research on additional cataract action spectra is undertaken). As mentioned in the methodology for developing population sets, some small errors are reproduced in the population estimates, based on U.S. Census data that are used in this analysis. Additional unquantified uncertainty includes (U.S. EPA 2006):

- Composition of the future atmosphere,
- Future conditions of the ozone layer, effect of climate change on ozone depletion,
- Global compliance with modeled policy scenarios,
- Laboratory techniques and instrumentation for deriving action spectra,
- Demographic and human behavioral changes, and
- Baseline information.

6. Topics for Future Research

There are a number of areas that can be improved upon or would benefit from further research (see U.S. EPA (2006) for further discussion):

- Additional human health endpoints such as the depression of the immune system can likewise be investigated with AHEF as the epidemiological data become available.
- Investigating how climate change variables will stress or relieve human health endpoints is an area of research that is readily available and can be incorporated into AHEF. For instance, projected shifts in human behavior in response to projected climate conditions can be incorporated into the AHEF; or likewise the direct impact of projected climate conditions on estimating the dosage of UV radiation experienced by county-scale populations can be incorporated into the model (e.g., a regional climate model grid of solar radiation to provide a ratio of clear sky/cloudy sky can be transferred to county scale and then incorporated into the AHEF).
- Updates to the latitude-band baseline incidence to provide county resolution incidence and further detailed demographic information would be valuable.
- The BAF and/or exposure weighting functions within AHEF can be updated or introduced as new research becomes available providing factors associated with changes in exposure behavior as a function of travel and/or migration, outdoor activity, and sun protection. These behavior exposure weighting functions may be disaggregated by ethnicity, race, and/or latitude.
- The cataract module can be updated to include an additional UV exposure weighting function based on solar zenith angle once new research becomes available. Specifically, there is initial support in the research community that peak UV exposure to the eye occurs when the solar altitude is around 40 degrees and so exposure could be weighted with the 40 degree maximum for eye exposures (Sasaki et al. 2009).
- Updates to the emission scenarios to be consistent with WMO projections of ozone layer recovery, including the development of an emission scenario reflective of the Montreal Protocol as adjusted in 2007, would align the AHEF results to reflect current assumptions.
- Investigating the effect of early life UV exposure on cataract incidence through updating baseline incidences to include all age groups and/or applying an age-weighting algorithm to account for potential changes in dose-response associated with early life exposures.
- The action spectrum can be updated once a new peer review study becomes available that measures the impact of UV radiation on the lens with the cornea present.

- Developing health cost estimates for the cataract cases avoided would give a more complete understanding of the benefits of different control scenarios.

The AHEF is a flexible model that can be easily manipulated to reflect any relationship between UV dose and response endpoints.

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Glossary

Action Spectrum	Experimentally-derived plots describing the relative effectiveness of each wavelength of UV-A and UV-B radiation in the induction of a specific health effect (e.g., cataract). Action spectra are used as weighting functions in order to estimate the potential of a particular UV exposure to induce adverse health effects.
1979-1980 Baseline	The AHEF defines the "baseline" incidence of cataract as what would be expected to occur in the future if the concentration of stratospheric ozone remained fixed at 1979-1980 levels. The total column observed in the 1979-1980 timeframe is defined as the baseline against which the impacts of future ozone changes are measured. These column ozone levels are assumed in the AHEF to remain constant in the baseline projections.
Biological Amplification Factor (BAF)	BAFs are equal to the slope of the dose-response curve (see "Dose-Response Relationship").
Cataract	A clouding of the eye lens that impacts vision and can lead to blindness.
Cohort Group	Individuals assigned by year of birth into groups for further study. The AHEF uses the results of these birth cohort studies to create and project a baseline estimate of cataract incidence.
Column Ozone	The amount of ozone (measured in Dobson units) contained in a vertical column of air extending from the Earth's surface to an orbiting satellite designed to measure ozone concentrations. Roughly 90 to 95% of column ozone is in the stratosphere with small amounts (5-10%) in the troposphere.
Cortical Cataract	A cataract which forms in the cortex of the eye lens (see page 7 for a more detailed description).
Dobson Unit	A measure of the thickness of the ozone. For a vertical column of ozone compressed at 0 degrees Celsius and 1 atmosphere pressure, a Dobson unit is defined to be 0.01 millimeter thick.

Glossary cont.

Dose Metrics	Measures used to express the amount of UV radiation received over a specific time period (i.e., dose). Examples are peak hour dose, daily dose, or cumulative doses for a month or for an entire year.
Dose-Response Relationship	The relationship between an effect (e.g., cataract) and the exposure (e.g., UV radiation) producing that effect. If plotted on a log-log scale, BAFs are equal to the slope of the dose-response curve.
Incidence	For the purpose of this report, the incidence is defined as the number of new cases of a given health effect that develop each year.
2007 Montreal Adjustment	The 2007 Montreal Adjustment strengthened the Montreal Protocol by requiring a more aggressive phase out of HCFCs in developed and developing countries.
Montreal Amendment (1997)	The 1997 Montreal Amendment strengthened the Montreal Protocol by adding the phase out of HCFCs in developing countries, as well as the phase out of methyl bromide in developed and developing countries by 2005 and 2015, respectively.
Montreal Protocol	*The Montreal Protocol on Substances that Deplete the Ozone Layer* was agreed in 1987 and entered into force in 1989. Today the Montreal Protocol enjoys universal ratification with 196 Parties. The original Montreal Protocol agreement required developed countries to begin phasing down CFCs in 1993 to reach a 50 percent reduction of 1986 consumption levels by 1998.
Normalized Sensitivity	The percent change in UV radiation causing a percent change in cataract incidence (the relative effectiveness of a particular wavelength to produce cataract).
Ozone Column Amount	See “Column Ozone”
Ozone-Depleting Substances	Substances, such as chlorofluorocarbons, halons, methyl bromide, and hydrochlorofluorocarbons, that reduce the ozone concentration in the Earth’s stratosphere.

Glossary cont.

Prevalence	The total number of existing cases of a given health effect, at a specific time, as opposed to new cases ("incidence").
Solar Zenith Angle	The solar zenith angle is the angle of the Sun's position with respect to the local upward vertical, measured in degrees from 0^o (overhead Sun) to 90^o (Sun at the horizon).
Tropospheric Ultraviolet Radiation Model (TUV)	A radiation model which calculates the ultraviolet radiation which travels through the Earth's troposphere (lower layer of the atmosphere) reaching the surface.
Ultraviolet (UV) Radiation	Ultraviolet radiation is a portion of the electromagnetic spectrum with wavelengths shorter than visible light. The Sun produces UV radiation, which is commonly split into three arbitrarily-defined bands: UV-A, UV-B, and UV-C. Because the AHEF relies on action spectra equations to estimate health effects, it is not necessary to define the exact wavelengths that make up each band. UV-A is not absorbed by ozone. UV-B is mostly absorbed by ozone, although some reaches the Earth. UV-C is completely absorbed by ozone and normal oxygen. The AHEF uses the percentage change in UV exposure multiplied by the appropriate BAF and the age-specific baseline incidence or mortality rate to predict future changes in human health effects. Although the AHEF considers only solar UV radiation, UV radiation from artificial sources (e.g., tanning beds, welding, mercury lamps) is also associated with adverse health effects.
UV-A Radiation	A band of ultraviolet radiation with wavelengths from 315-400 nanometers produced by the Sun. UV-A is not absorbed by ozone and is not considered as potent as UV-B in damage-related health effects. This band of radiation has wavelengths just shorter than visible violet light.
UV-B Radiation	A band of ultraviolet radiation with wavelengths from 280-315 nanometers produced by the Sun. UV-B has been associated with human health impacts and is particularly effective at damaging DNA. UV-B has been identified as a cause of melanoma and other types of skin cancer as well as cataract and suppression of the immune system. It has also been linked to damage to some materials, crops, and marine organisms. The ozone layer protects the Earth against most solar UV-B radiation.

Glossary cont.

UV-C Radiation	A band of ultraviolet radiation with wavelengths shorter than 280 nanometers. UV-C is extremely dangerous, and considered significantly more potent compared to UV-B in damage-related health effects. UV-C is completely absorbed by ozone (at wavelengths between 240 and 280 nm) and molecular oxygen (O_2) (at wavelengths between 200 and 280 nm), and hence does not reach the Earth's surface.
UV Irradiance	For the purpose of this report, UV irradiance refers to the UV radiation from the Sun reaching the Earth's surface.
Visible Radiation	A band of wavelengths from 400-700 nanometers produced by the Sun.

Appendix A: Baseline Cataract Incidence

The baseline cataract incidence rates are estimated using cataract incidence data reported in U.S. EPA (1987) and derived from prevalence data presented in Hiller et al. (1983) and based on a subset of the National Health and Nutrition Examination Study (NHANES) data.[18, 19] The subset consisted of 2,225 subjects between the ages of 45 and 74 at 35 difference locations across the U.S.

A-1. Baseline Cataract Incidence for Rates by Age Category (incidence rates assume 1979-1980 ozone levels and are provided per 100,000 people).

	Age Category							
	0-54	55-59	60-64	65-69	70-74	75-79	80-84	85+
Incidence Rates	0	450	450	1,350	1,350	2,750	2,750	0[a]

[a]Given the prevalence (existing cases) of cataract in the 85+ group is the same for the age 75-84 category, incidence (new cases) for the 85+ group is assumed to be zero.

[18] NHANES analyzed all three forms of cataract, but only cortical cataract is clearly associated with UV exposure; much uncertainty exists with regard to the role of UV-B and other forms of cataract. Thus, by using the NHANES data to develop baseline cataract incidence in the AHEF, cataract incidence may be overestimated, although it is unclear by how much.

[19] The NHANES data is developed for the 1971-1972 time period. It is assumed these years adequately represent the 1979-1980 years.

Appendix B: Biologically Weighted Irradiance

This "look-up" table provides the biologically weighted radiation for a given action spectrum as a function of total ozone column, and solar zenith angle.[20] The action spectrum is derived from Oriowo et al. (2001) and provides the eye cataract-inducing irradiance at sea level for cloud-free conditions. The Oriowo action spectrum is based on the induction of cataract in whole cultured pig lenses spanning across wavelengths from 270 to 370 nm, thus extending into the UV-A spectrum. The rows of Table B-1 correspond to the respective ozone column amounts (DU) from 100 DU to 600 DU in 10 DU steps. The columns of Table B-1 represent the cosine of the solar zenith angle from 0.00 to 1.0 in 0.05 steps (the solar zenith angle is 0^o when the Sun is directly overhead). As the Sun progresses across the sky, the amount of radiation reaching the Earth's surface changes according to the cosine of the solar zenith angle, implying the most intensity at solar noon, and lessening intensity before and after noon.

Table B-1. Biologically weighted irradiance (W/m^2) based on the Oriowo et al. 2001 action spectrum.

Ozone Column (Dobson Units)	Cosine of the Solar Zenith Angle																				
	0.00	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.55	0.60	0.65	0.70	0.75	0.80	0.85	0.90	0.95	1.00
100	0.003	0.009	0.022	0.042	0.071	0.112	0.164	0.231	0.312	0.409	0.523	0.655	0.805	0.973	1.160	1.360	1.590	1.840	2.100	2.390	2.690
110	0.003	0.008	0.019	0.037	0.063	0.100	0.148	0.208	0.282	0.371	0.475	0.596	0.733	0.888	1.060	1.250	1.450	1.680	1.930	2.190	2.470
120	0.003	0.008	0.017	0.033	0.057	0.090	0.134	0.189	0.257	0.339	0.435	0.546	0.673	0.815	0.974	1.150	1.340	1.550	1.780	2.020	2.280
130	0.002	0.007	0.016	0.030	0.052	0.082	0.122	0.173	0.236	0.311	0.400	0.503	0.621	0.753	0.901	1.060	1.240	1.440	1.650	1.880	2.120
140	0.002	0.006	0.014	0.027	0.047	0.075	0.112	0.159	0.217	0.287	0.370	0.466	0.575	0.699	0.837	0.988	1.150	1.340	1.540	1.750	1.980
150	0.002	0.006	0.013	0.025	0.043	0.069	0.103	0.147	0.201	0.266	0.343	0.433	0.536	0.651	0.781	0.923	1.080	1.250	1.440	1.640	1.850
160	0.002	0.005	0.012	0.023	0.040	0.064	0.095	0.136	0.186	0.248	0.320	0.404	0.500	0.609	0.731	0.864	1.010	1.180	1.350	1.540	1.740
170	0.002	0.005	0.011	0.021	0.037	0.059	0.088	0.126	0.174	0.231	0.299	0.378	0.469	0.572	0.687	0.813	0.951	1.110	1.270	1.450	1.640
180	0.002	0.004	0.010	0.020	0.034	0.055	0.082	0.118	0.162	0.216	0.280	0.355	0.441	0.538	0.647	0.766	0.898	1.040	1.200	1.370	1.550
190	0.001	0.004	0.009	0.018	0.032	0.051	0.077	0.110	0.152	0.203	0.264	0.334	0.416	0.508	0.611	0.724	0.849	0.988	1.140	1.300	1.470
200	0.001	0.004	0.009	0.017	0.030	0.048	0.072	0.103	0.143	0.191	0.248	0.315	0.393	0.480	0.578	0.686	0.805	0.937	1.080	1.230	1.400

[20] The biologically weighted radiation is the cumulative summation of the product of the action spectrum and the spectral irradiance at each wavelength from 270 to 370 nm. Within the exposure module of AHEF, each ozone policy scenario investigated determines the amount of ozone sunlight travels through to reach the surface at a given county centriod; the county centroid is also used to determine the angle of the sun for a given daylight hour. The biologically weighted radiation is then summed for each daylight hour on the 15th of a given month. This irradiance estimate is then multiplied by 30 to obtain an average irradiance for the whole month.

Table B-1 continued.

	Cosine of the Solar Zenith Angle																				
Ozone Column (Dobson Units)	0.00	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.55	0.60	0.65	0.70	0.75	0.80	0.85	0.90	0.95	1.00
210	0.001	0.004	0.008	0.016	0.028	0.045	0.068	0.097	0.135	0.18	0.235	0.298	0.372	0.455	0.548	0.651	0.764	0.891	1.03	1.17	1.33
220	0.001	0.003	0.008	0.015	0.026	0.042	0.064	0.092	0.127	0.17	0.222	0.283	0.352	0.432	0.521	0.619	0.727	0.848	0.978	1.12	1.27
230	0.001	0.003	0.007	0.014	0.025	0.04	0.06	0.087	0.12	0.161	0.21	0.268	0.335	0.411	0.496	0.59	0.693	0.809	0.933	1.07	1.21
240	0.001	0.003	0.007	0.013	0.023	0.037	0.057	0.082	0.114	0.153	0.2	0.255	0.319	0.391	0.473	0.562	0.662	0.773	0.892	1.02	1.16
250	0.001	0.003	0.007	0.013	0.022	0.035	0.054	0.078	0.108	0.145	0.19	0.243	0.304	0.373	0.451	0.537	0.633	0.74	0.854	0.978	1.11
260	0.001	0.003	0.006	0.012	0.021	0.034	0.051	0.074	0.103	0.138	0.181	0.232	0.29	0.356	0.431	0.514	0.606	0.709	0.819	0.938	1.07
270	0.001	0.003	0.006	0.011	0.02	0.032	0.048	0.07	0.098	0.132	0.173	0.221	0.277	0.341	0.413	0.493	0.581	0.68	0.786	0.9	1.02
280	0.001	0.003	0.006	0.011	0.019	0.03	0.046	0.067	0.093	0.126	0.165	0.211	0.265	0.326	0.396	0.472	0.557	0.653	0.755	0.865	0.985
290	0.001	0.002	0.005	0.01	0.018	0.029	0.044	0.064	0.089	0.12	0.158	0.202	0.254	0.313	0.38	0.454	0.535	0.627	0.726	0.833	0.948
300	0.001	0.002	0.005	0.01	0.017	0.028	0.042	0.061	0.085	0.115	0.151	0.194	0.244	0.3	0.365	0.436	0.515	0.604	0.699	0.802	0.913
310	0.001	0.002	0.005	0.009	0.016	0.026	0.04	0.058	0.081	0.11	0.145	0.186	0.234	0.289	0.351	0.419	0.496	0.581	0.674	0.773	0.881
320	0.001	0.002	0.005	0.009	0.016	0.025	0.038	0.056	0.078	0.106	0.139	0.179	0.225	0.278	0.337	0.404	0.477	0.56	0.65	0.746	0.851
330	0.001	0.002	0.005	0.009	0.015	0.024	0.037	0.054	0.075	0.101	0.134	0.172	0.216	0.267	0.325	0.389	0.46	0.541	0.627	0.721	0.822
340	0.001	0.002	0.004	0.008	0.014	0.023	0.035	0.051	0.072	0.098	0.128	0.165	0.208	0.257	0.313	0.375	0.444	0.522	0.606	0.697	0.795
350	0.001	0.002	0.004	0.008	0.014	0.022	0.034	0.049	0.069	0.094	0.124	0.159	0.201	0.248	0.302	0.362	0.429	0.505	0.586	0.674	0.769
360	0.001	0.002	0.004	0.008	0.013	0.021	0.033	0.048	0.067	0.09	0.119	0.153	0.193	0.24	0.292	0.35	0.415	0.488	0.567	0.652	0.744
370	0.001	0.002	0.004	0.007	0.013	0.021	0.031	0.046	0.064	0.087	0.115	0.148	0.187	0.231	0.282	0.338	0.401	0.472	0.549	0.632	0.721
380	0.001	0.002	0.004	0.007	0.012	0.02	0.03	0.044	0.062	0.084	0.111	0.143	0.18	0.224	0.273	0.327	0.388	0.457	0.531	0.612	0.699
390	0.001	0.002	0.004	0.007	0.012	0.019	0.029	0.043	0.06	0.081	0.107	0.138	0.174	0.216	0.264	0.317	0.376	0.443	0.515	0.594	0.678
400	0.001	0.002	0.004	0.007	0.012	0.019	0.028	0.041	0.058	0.078	0.103	0.133	0.169	0.209	0.255	0.307	0.364	0.429	0.5	0.576	0.658
410	0.001	0.002	0.004	0.007	0.011	0.018	0.027	0.04	0.056	0.076	0.1	0.129	0.163	0.203	0.248	0.298	0.353	0.417	0.485	0.559	0.64
420	0.001	0.002	0.003	0.006	0.011	0.017	0.026	0.039	0.054	0.073	0.097	0.125	0.158	0.196	0.24	0.289	0.343	0.404	0.471	0.543	0.621
430	0.001	0.002	0.003	0.006	0.011	0.017	0.026	0.037	0.052	0.071	0.094	0.121	0.153	0.19	0.233	0.28	0.333	0.393	0.457	0.528	0.604
440	0.001	0.002	0.003	0.006	0.01	0.016	0.025	0.036	0.051	0.069	0.091	0.117	0.149	0.185	0.226	0.272	0.323	0.382	0.445	0.513	0.588
450	0.001	0.001	0.003	0.006	0.01	0.016	0.024	0.035	0.049	0.067	0.088	0.114	0.144	0.179	0.219	0.264	0.314	0.371	0.432	0.499	0.572
460	0.001	0.001	0.003	0.006	0.01	0.015	0.023	0.034	0.048	0.065	0.086	0.111	0.14	0.174	0.213	0.257	0.305	0.361	0.421	0.486	0.557
470	0	0.001	0.003	0.006	0.009	0.015	0.023	0.033	0.046	0.063	0.083	0.107	0.136	0.169	0.207	0.25	0.297	0.351	0.409	0.473	0.542
480	0	0.001	0.003	0.005	0.009	0.015	0.022	0.032	0.045	0.061	0.081	0.104	0.132	0.165	0.201	0.243	0.289	0.342	0.399	0.461	0.528
490	0	0.001	0.003	0.005	0.009	0.014	0.022	0.031	0.044	0.059	0.079	0.101	0.129	0.16	0.196	0.236	0.281	0.333	0.388	0.449	0.515

Table B-1 continued.

	Cosine of the Solar Zenith Angle																				
Ozone Column (Dobson Units)	0.00	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.55	0.60	0.65	0.70	0.75	0.80	0.85	0.90	0.95	1.00
500	0	0.001	0.003	0.005	0.009	0.014	0.021	0.03	0.042	0.058	0.076	0.099	0.125	0.156	0.191	0.23	0.274	0.324	0.379	0.438	0.502
510	0	0.001	0.003	0.005	0.009	0.014	0.02	0.03	0.041	0.056	0.074	0.096	0.122	0.152	0.186	0.224	0.267	0.316	0.369	0.427	0.49
520	0	0.001	0.003	0.005	0.008	0.013	0.02	0.029	0.04	0.055	0.072	0.094	0.119	0.148	0.181	0.218	0.26	0.308	0.36	0.417	0.478
530	0	0.001	0.003	0.005	0.008	0.013	0.019	0.028	0.039	0.053	0.071	0.091	0.116	0.144	0.176	0.213	0.254	0.301	0.351	0.407	0.467
540	0	0.001	0.003	0.005	0.008	0.013	0.019	0.027	0.038	0.052	0.069	0.089	0.113	0.14	0.172	0.208	0.248	0.293	0.343	0.397	0.456
550	0	0.001	0.003	0.005	0.008	0.012	0.018	0.027	0.037	0.051	0.067	0.087	0.11	0.137	0.168	0.203	0.242	0.286	0.335	0.388	0.445
560	0	0.001	0.003	0.005	0.008	0.012	0.018	0.026	0.036	0.049	0.065	0.085	0.107	0.134	0.164	0.198	0.236	0.28	0.327	0.379	0.435
570	0	0.001	0.002	0.004	0.007	0.012	0.018	0.025	0.036	0.048	0.064	0.083	0.105	0.13	0.16	0.193	0.231	0.273	0.319	0.37	0.425
580	0	0.001	0.002	0.004	0.007	0.012	0.017	0.025	0.035	0.047	0.062	0.081	0.102	0.127	0.156	0.189	0.225	0.267	0.312	0.362	0.416
590	0	0.001	0.002	0.004	0.007	0.011	0.017	0.024	0.034	0.046	0.061	0.079	0.1	0.124	0.153	0.184	0.22	0.261	0.305	0.354	0.407
600	0	0.001	0.002	0.004	0.007	0.011	0.017	0.024	0.033	0.045	0.059	0.077	0.098	0.122	0.149	0.18	0.215	0.255	0.299	0.346	0.398

Appendix C: Comparison of Atmospheric and Health Effects Framework Variables

The variables contributing to estimating cataract incidence, namely, age, UV irradiance, latitude, and policies in place to protect the ozone layer are discussed here to assist in explaining the trends discussed in section 4.1 (see Figures 3 and 4 for graphical representation of trends). Table C-1 presents estimates of cataract incidence under the 1979-1980 Baseline, the 1987 Montreal Protocol as Originally Agreed, and the Montreal Protocol as Amended and Adjusted through 1997 for a southern state (Florida) and a northern state (Illinois) in 2020. Both states have relatively large populations aged 55 to 84.[21]

Table C-1 presents the amount of UV radiation reaching the Earth's surface (annual average UV irradiance) for each of the scenarios reviewed. The UV irradiance decreases as we compare the 1987 Montreal Protocol as originally agreed, the Montreal Protocol as amended and adjusted through 1997, and the 1979-1980 Baseline, as expected. This trend mirrors the reduction in concentrations of ozone-depleting substances associated with each control policy.[22] Geographically, the southern state, Florida, has a much higher average annual UV irradiance when compared to Illinois. That is, more UV reaches the Earth's surface in the southern states.

Table C-1 also displays the absolute cataract incidence by state and control policy in the year 2020. As would be expected, as the amount of average annual UV irradiance increases so does the estimated cataract incidence. The absolute incidence number is directly proportional to the average annual UV irradiance.

The difference between cataract incidence for each control policy and the 1979-1980 baseline is represented in Table C-1 as the "incremental cataract incidence relative to 1979-1980 baseline." The greater the reduction in total ozone column amount compared to the 1979-1980 baseline, the larger the incremental cataract incidence. Greater ozone damage occurs under the original Montreal Protocol than under the more stringent Amendments of 1997. Under both control policies, the total ozone column amount is smaller than the 1979-1980 baseline. This table demonstrates that although the UV radiation reaching the surface is greater in a southern location (leading to a greater absolute number of cataract incidence), the difference in cataract incidence between control policy and 1979-1980 baseline is greater for the northern location. This is because

[21] The projected Illinois total population in 2020 is 14,570,102 of which 3,989,644 are aged between 55 and 84. The projected Florida total population is 19,245,129 of which 5,793,586 are aged between 55 and 84.

[22] We see an increase in ozone concentrations moving from the 1987 Montreal Protocol as originally agreed to the Montreal Protocol as Amended and Adjusted through 1997, approaching the concentrations under the Baseline scenario.

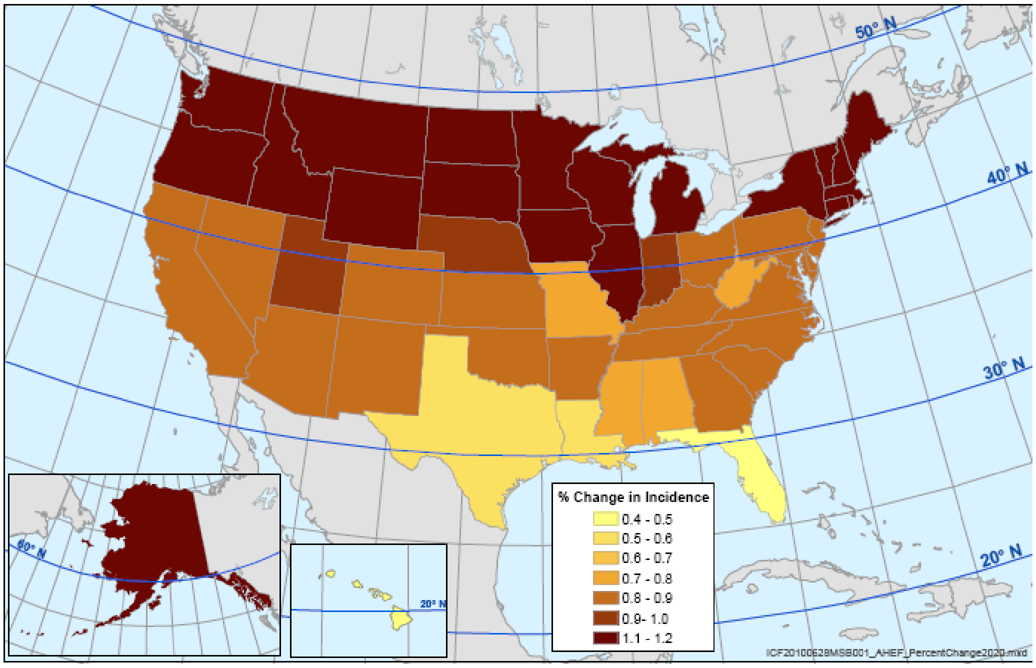
ozone layer damage is greater closer to the poles and further from the equator. This relationship is further illustrated in Figures 3 and 4 in section 4.1.

Table C-1. Comparison of UV and cataract-related variables for Illinois and Florida for the population between ages 55 and 84 in the year 2020.

	Illinois			**Florida**		
	1979-1980 Baseline	**1987 Montreal Protocol as Originally Agreed**	**Montreal Protocol as Amended and Adjusted through 1997**	**1979-1980 Baseline**	**1987 Montreal Protocol as Originally Agreed**	**Montreal Protocol as Amended and Adjusted through 1997**
Annual Integrated Biologically Weighted UV Irradiance (kJ/m^2)	3,319	4,187	3,463	4,817	5,429	4,932
Absolute Cataract Incidence	31,980	32,350	32,150	36,480	36,650	36,570
Incremental Cataract Incidence Relative to 1979-1980 Baseline		370	180		170	85
% Change in Cataract Incidence per 1979-1980 Baseline Cataract Incidence		1.20%	0.56%		0.47%	0.25%

Figure C-1 illustrates the percent change in cataract incidence for all states in 2020, comparing the 1987 Montreal Protocol as originally agreed to the 1979-1980 baseline. Similar to the findings presented in Table C-1, the overall trend in this figure demonstrates an increasing percent change in cataract incidence with increasing (i.e., more northern) latitude. The absolute cataract incidence may still be greater for southern locations; however, the change in incidence associated with a control policy is greater in northern locations.

Figure C-1. Projected % Change in Cataract Incidence Cases for the year 2020 comparing the 1987 Montreal Protocol as Originally Agreed to the 1979-1980 Baseline.



Appendix D: Avoided Cataract Incidence by State

Table D-1 provides the estimated avoided cataract incidence by state projected through the end of the century. Overall, those states with a large number of people older than 55 are at increased risk for cataract, assuming similar exposure behavior. Areas traditionally with an aging population and with greater increases in UV exposure (such as northern cities) demonstrate larger changes in cataract incidence when moving from the 1987 Montreal Protocol as Orginally Agreed to the more stringent Montreal Protocol as Amended and Adjusted through 1997. These data complement the data in section 4.1.

Table D-1. Avoided Cataract Incidence Cases through the year 2100 by Implementing the Montreal Protocol as Amended and Adjusted through 1997 Relative to the 1987 Montreal Protocol as Originally Agreed.

State	Avoided Cataract Incidence	State	Avoided Cataract Incidence
AL	315,050	MT	107,370
AK	71,290	NC	643,830
AR	195,090	ND	65,460
AZ	421,370	NE	156,690
CA	2,860,380	NH	151,290
CO	322,850	NJ	633,580
CT	424,870	NM	133,620
DC	54,360	NV	175,950
DE	63,750	NY	1,750,210
FL	544,990	OH	979,710
GA	689,850	OK	205,050
HI	51,740	OR	446,390
IA	307,990	PA	947,500
ID	144,230	RI	123,980
IL	1,338,400	SC	324,400
IN	503,170	SD	80,490
KS	184,080	TN	430,970
KY	291,860	TX	1,124,410
LA	192,440	UT	145,570
MA	822,530	VA	577,120
MD	423,340	VT	75,940
ME	155,800	WA	696,800
MO	397,290	WI	289,430
MI	1,134,260	WV	132,000
MN	562,300	WY	23,010
MS	188,950	Total	23,083,000

Appendix E: Responses to Peer Review Comments

The Atmospheric and Health Effects Framework (AHEF) was created in the mid 1980s to assess the adverse human health effects associated with a depleting stratospheric ozone layer. Historically, the AHEF has estimated the probable increases in skin cancer mortality, skin cancer incidence, and cataract incidence in the United States that result from ozone-depleting substance (ODS) emission scenarios relative to a 1979-1980 baseline (i.e., prior to significant ozone depletion). In addition, the AHEF can estimate the relative change in incidence and mortality when comparing one ODS emission scenario to another, thereby providing incremental estimates of the benefits among policy options (e.g., more aggressive phaseout targets or inclusion of additional ODS). The AHEF was significantly updated in 2006 to incorporate new research results (e.g., recalibration and refinement of stratospheric ozone concentration measurements, updated ODS emission data, updated information on the biological effects of UV radiation of different wavelengths). These updates were tested and presented in the 2006 Peer Review Report, "*Human Health Benefits of Stratospheric Ozone Protection*."

The current study incorporates several new updates to the AHEF that have occurred since the 2006 Peer Review Report (U.S. EPA 2006) including re-introducing the cataract module given the availability of improved information on the biological effects of UV radiation and dose-response relationships by skin type, to estimate the probable increase in cataract incidence. In addition, the AHEF's spatial resolution has been improved to allow disaggregation at the county-level. It was felt that the incorporation of this new information warranted an updated peer review to focus on the new cataract module methodology and data. The process for and outcome of that review are described in the remainder of this appendix.

E.1 Peer Review Process

This section outlines the overall logistics of the peer review process and provides short biographies of each reviewer.

E.1.1 Selection of Peer Reviewers

The objective of the peer review was to compile a group of diverse reviewers with expertise in the areas where improvements have been made to the AHEF since the 2006 Peer Review Report, "*Human Health Benefits of Stratospheric Ozone Protection*." In order to meet this objective, a well-rounded pool of experts was compiled with representatives from academia, government, and industry. This section describes the step-by-step process in which the peer review panel was selected.

1. The panel selection criteria were developed to ensure a robust and comprehensive identification of review candidates. The selection criteria included:

    - Well-known, respected experts with at least one of the following areas of expertise:
        - UV dose-response relationships (ideally cataract)
        - Causation of cataract incidence
        - UV health modeling particularly as a function of population growth and demographics;
    - Experience in providing peer reviews for similar types of UV health and/or cataract modeling;
    - No association with the AHEF cataract report;
    - No expectation of gain from a favorable or unfavorable outcome of the peer review;
    - Availability to participate in the peer review of the cataract module of AHEF; and
    - Enthusiasm for participating in the peer review of the cataract module of AHEF.

2. A preliminary list of 50 potential reviewers was compiled through canvassing the grey literature, journal articles, and internet searches. A list of industry experts was also collected based on direct communication with companies specializing in protective eyewear and lists of committee members for eyewear standards produced by the American National Standards Institute.

3. The candidates were evaluated against the selection criteria, giving those with recent publications in their respective field priority. The list was narrowed to two to three of the strongest candidates per expertise category with an additional category added for industry experts for a total of 10 candidates. Throughout the process, every effort was made to ensure the panel represented a range of expertise and professional backgrounds.

4. Reviewers were contacted, resulting in five peer reviewers available for a discussion describing the report, the review expectations, and the timeline.

E.1.2 Peer Reviewers

The peer review selection process was designed to identify a diverse group of experts that could provide comments on various aspects of the report.

Ultimately, five peer reviewers were confirmed to provide comments on the draft report, "*Cataract Incidence in the United States Using the Atmospheric Health and Effects Framework Model,*" dated March 26, 2010.

Short biographies of the five participating peer reviewers are as follows:

Dr. James Dillon, Northern Illinois University
James Dillon, Ph.D. is an adjunct professor in the Chemistry and Biochemistry department at Northern Illinois University. Until December, 2009, he was the Director of the Photobiology Laboratory in the Department of Ophthalmology of the College of Physicians and Surgeons of Columbia University. His research interests include ocular aging, photochemistry, lens, retina, cataract, and macular degeneration. In particular, his research focuses on the molecular mechanisms of cataracts and retinal diseases, investigating how ultraviolet light and oxidation contribute to the formation of cataracts in the lens and how visible light contributes to age-related macular degeneration. Dr. Dillon has published numerous articles and was awarded the Alcon Research Institute Award for outstanding contributions in the field of vision research.

Dr. Barbara E. K. Klein, University of Wisconsin
Barbara Klein, M.D., M.P.H, is a Professor in the Ophthalmology and Visual Sciences department at the University of Wisconsin. Her research interests include prevalence and incidence of age-related cataract, macular degeneration, and diabetic retinopathy; incidence of eye complications associated with diabetes; and genetic correlation to ocular diseases. Dr. Klein is a co-director of the Beaver Dam Eye Study, which collects information on the prevalence and incidence of common eye diseases in the aging population and examines other aging issues, such as overall health, quality-of-life, and environmental and medicinal exposures.

Dr. John C. Merriam, Edward S. Harkness Eye Institute
John Merriam, M.D., is a Clinical Professor of Ophthalmology at Columbia University and an attending ophthalmologist at the Columbia-Presbyterian Medical Center. His expertise includes astigmatism, cataract, macular degeneration, and plastic surgery, for which he has authored numerous articles. He is a member of the American Academy of Ophthalmology, American Society of Cataract and Refractive Surgery, Association for Research in Vision and Ophthalmology, and the American Ophthalmologic Society among others. Dr. Merriam was named a Castle Connolly Top Doctor in the New York metropolitan area from 1999-2008.

Dr. Cristina Schnider, Johnson and Johnson Vision Care
Dr. Schnider, O.D., M.Sc., M.B.A., is Senior Director of Professional and Medical Affairs at Johnson & Johnson Vision Care. Dr. Schnider is also the lead person on case reports for the Section on Cornea, Contact Lenses and Refractive Technologies of the American Academy of Optometry Leadership.

Prior to joining Johnson & Johnson, Dr. Schnider served as Director of Medical Affairs and Manager of Claims Substantiation and Product Assessment at Vistakon and Associate Professor at the Pacific University College of Optometry. In 2004, Dr. Schnider was recognized by Vision Monday as one of the "Most Influential Women in Optical."

Dr. Jeffrey L. Weaver, American Optometric Association
Dr. Weaver, O.D., M.B.A., M.S., is the Executive Director of the American Board of Optometry. Dr. Weaver is also Chief of Optometry of the U.S. Army Reserve; Reserve Optometry Consultant to the Surgeon General; Adjunct Professor at the University of Missouri, St. Louis College of Optometry, where he instructs the course on Environmental Vision and teaches in the Primary Care Clinic; and Diplomate in Public Health and Environmental Vision of the American Academy of Optometry. He is a member of the American Optometric Association Commission on Ophthalmic Standards. Dr. Weaver is Board Certified in Healthcare Management as a Fellow of the American College of Healthcare Executives.

E.1.3 Review Process

Once reviewers agreed to participate in the process, charge questions were provided to the peer reviewers which directed focus to certain parts of the report based on the expertise of individual reviewers. Reviewers were also asked for comments across the entire report, if reviewers wished to do so. The reviewers were provided with a copy of the report, "*Cataract Incidence in the United States Using the Atmospheric Health and Framework Model*," the 2006 Peer Review Report, "*Human Health Benefits of Stratospheric Ozone Protection*," and additional studies of interest for their review.

Peer review comments led to a number of actionable items including additions and clarifications to the report, and the incorporation of additional modeling results (see section E.2).

E.2 Responses to Peer Review Comments

The peer review comments are presented in this section by charge question. Each reviewer received only the charge questions best fitting his or her expertise; however, reviewers were asked to review the entire report and provide comment(s) as necessary. The reviewer comments to each charge question have been collectively summarized. Each of these points is represented below the respective charge question and given an alphanumeric number. A response and any actionable item(s) taken follows each point. In response to the peer review comments, the report has been updated with clarifications, new results discussion, and additional items for future work.

E.2.1. Responses to Charge Questions

Charge Question 1: There are a number of studies available that discuss prevalence of cataract. This report bases the biological amplification factor (BAF) on the Salisbury Eye Evaluation (SEE) Project as it is a regional-based study in the United States, provides the biological amplification factors in published literature, and provides dose-response relationships by gender and skin-type. Do you find this study sound for the purpose of this work?

Key Point(s) for Discussion: The following points were raised by the reviewers requiring further discussion and/or action items:

(1a) It is difficult to measure UV exposure directly on the lens given the eye's complex structure.

- Response: The BAF estimates the increase in eye damage associated with an increase in UV exposure. The action spectrum (see charge question 5) provides the measurements of damage on the lens caused by UV. The SEE study, which provides BAF for this work, does factor in UV ocular exposure based on a series of measurements made on local residents in the course of their day. However, it is understood that such measurements are uncertain. AHEF is a flexible model that can be updated as new BAFs become available.

- Action Item(s): The following bullet has been added to Section 6, under *Topics for Future Research*: "The BAF and/or exposure weighting functions within AHEF can be updated or introduced as new research becomes available providing factors associated with changes in exposure behavior as a function of travel and/or migration, outdoor activity, and sun protection. These behavior exposure weighting functions may be disaggregated by ethnicity, race, and/or latitude."

(1b) A reasonable attempt to account for behavior has been included in the SEE model.

- Response: The SEE study includes factors for UV protection such as wearing hats and/or protective eyewear as well as outdoor activity. These factors are internal to their model and are used in determining the BAFs. As new studies become available, AHEF is able to be updated with new research.

- Action Item(s): The following text has been added to the end of the footnote on page 8: "The West et al. (2005) methodology for developing the BAFs takes into account such behavior factors as outdoor activity and UV protection such as wearing hats and/or protective eyewear."

(1c) The SEE study does not account for variations in exposure due to travel and migration, and does assume the behaviors in sun protection that are accounted for in the SEE study remains constant across the United States and into the future.

- Response: The application of the SEE study in AHEF does assume that the behavior of the population groups in the SEE study are representative of the populations groups across the United States. As stated on page 8 of the report, "The SEE findings are based on observations of the Maryland population and therefore the assumption that this population's behaviors influencing sun exposure are representative of that for the entire U.S. is inherent in resultant BAFs." It is difficult to include changes in exposure associated with travel and/or migration. AHEF does not account for this.

- Action Item(s): The following bullet has been added to Section 6, under *Topics for Future Research*: "The BAF and/or exposure weighting functions within AHEF can be updated or introduced as new research becomes available providing factors associated with changes in exposure behavior as a function of travel and/or migration, outdoor activity, and sun protection. These behavior exposure weighting functions may be disaggregated by ethnicity, race, and/or latitude."

(1d) An investigation of the change in cortical cataract before and after the Montreal Protocol was adapted would give credence to the SEE model.

- Response: Given the potential long-term cumulative UV exposure associated with acquiring cortical cataract, it does not seem a change in cataract prevalence before and after the Montreal Protocol would be readily applicable in determining SEE model accuracy. The adoption of the Montreal Protocol was not immediately implemented by all countries; as such, the ozone-depleting substance concentrations in the stratosphere may not have realized a significant drop within a short time frame. In addition, the cataract prevalence data available may not be well-suited for such a study as the prevalence of cortical cataract is not provided separately (e.g., NEI/PBA 2002).

- Action Item(s): No action item.

(1e) Using cataract surgery as a surrogate measure for cataract prevalence may be misleading because cortical cataract is the least likely of three types of age-related cataract to precede cataract surgery.

- Response: The SEE model bases the number of people in its study with cortical cataract using eye exams and medical records. It investigates the three forms of cataract (nuclear, posterior subcapsular, and cortical) and determines cortical cataract is a form that can be linked to UV radiation.

- Action Item(s): No action item.

Charge Question 2: A new set of population estimates is required for the AHEF given the new county resolution. Does the methodology for projecting population growth discussed in section 2.2 appear sound?

(2a) This study assumes differences in cataract incidence are a function of age, skin type, and UV exposure. It is suggested to broaden this study to include differences as a function of ethnicities.

- Response: Currently, there are no biological amplification factors available as a factor of ethnicity; however, if such data becomes available, AHEF can be updated with the new BAFs and population data for ethnicities as defined by the U.S. census bureau. Given the current literature, it appears the differences in exposure between ethnic groups may be related to sun protection and exposure behavior, as opposed to any anatomical differences in the eye structure. This leads to another option for accounting for ethnicities, that is, updating the cataract module with a behavior weighting factor that would represent change in UV exposure based on changes in behavior as a function of ethnicity.

- Action Item(s): The following bullet has been added to Section 6, under *Topics for Future Research*: "The BAF and/or exposure weighting functions within AHEF can be updated or introduced as new research becomes available providing factors associated with changes in exposure behavior as a function of travel and/or migration, outdoor activity, and sun protection. These behavior exposure weighting functions may be disaggregated by ethnicity, race, and/or latitude."

Charge Question 3: In general, this report finds the greatest cataract incidence will occur for states with populations with a higher percentage of aging populations and for northern states due to the greater reduction in ozone concentration. Are these modeling conclusions supported by the current literature on cataract incidence after correcting for migratory and behavioral factors?

Key Point(s) for Discussion: This question should be clarified. It is not the absolute UV irradiance that is greater in the northern states, but the change in UV irradiance estimated when comparing a control policy scenario to the 1979-1980 Baseline. The report requires similar clarifications. The following comparison of the difference in incremental change of UV irradiance between Illinois (northern state) and Florida (southern state) has been inserted into Appendix C of the report:

"*The variables contributing to estimating cataract incidence, namely, age, UV irradiance, latitude, and policies in place to protect the ozone layer are discussed here to assist in explaining the trends discussed in section 4.1 (see Figures 3 and 4 for graphical representation of trends). Table C-1 presents estimates of cataract incidence under the 1979-1980 Baseline, the 1987 Montreal Protocol as Originally Agreed, and the Montreal Protocol as Amended and Adjusted through 1997 for a southern state (Florida) and a northern state (Illinois) in 2020. Both states have relatively large populations aged 55 to 84.*[23]

Table C-1 presents the amount of UV radiation reaching the Earth's surface (annual average UV irradiance) for each of the scenarios reviewed. The UV irradiance decreases as we compare the 1987 Montreal Protocol as originally agreed, the Montreal Protocol as amended and adjusted through 1997, and the 1979-1980 Baseline, as expected. This trend mirrors the reduction in concentrations of ozone-depleting substances associated with each control policy.[24] *Geographically, the southern state, Florida, has a much higher average annual UV irradiance when compared to Illinois. That is, more UV reaches the Earth's surface in the southern states.*

Table C-1 also displays the absolute cataract incidence by state and control policy in the year 2020. As would be expected, as the amount of average annual UV irradiance increases so does the estimated cataract incidence. The absolute incidence number is directly proportional to the average annual UV irradiance.

The difference between cataract incidence for each control policy and the 1979-1980 baseline is represented in Table C-1 as the "incremental cataract incidence relative to 1979-1980 baseline." The greater the reduction in total ozone column amount compared to the 1979-1980 baseline, the larger the

[23] The projected Illinois total population in 2020 is 14,570,102 of which 3,989,644 are aged between 55 and 84. The projected Florida total population is 19,245,129 of which 5,793,586 are aged between 55 and 84.
[24] We see an increase in ozone concentrations moving from the 1987 Montreal Protocol as originally agreed to the Montreal Protocol as Amended and Adjusted through 1997, approaching the concentrations under the Baseline scenario.

incremental cataract incidence. Greater ozone damage occurs under the original Montreal Protocol than under the more stringent Amendments of 1997. Under both control policies, the total ozone column amount is smaller than the 1979-1980 baseline. This table demonstrates that although the UV radiation reaching the surface is greater in a southern location (leading to a greater absolute number of cataract incidence), the difference in cataract incidence between control policy and 1979-1980 baseline is greater for the northern location. This is because ozone layer damage is greater closer to the poles and further from the equator. This relationship is further illustrated in Figures 3 and 4 in section 4.1.

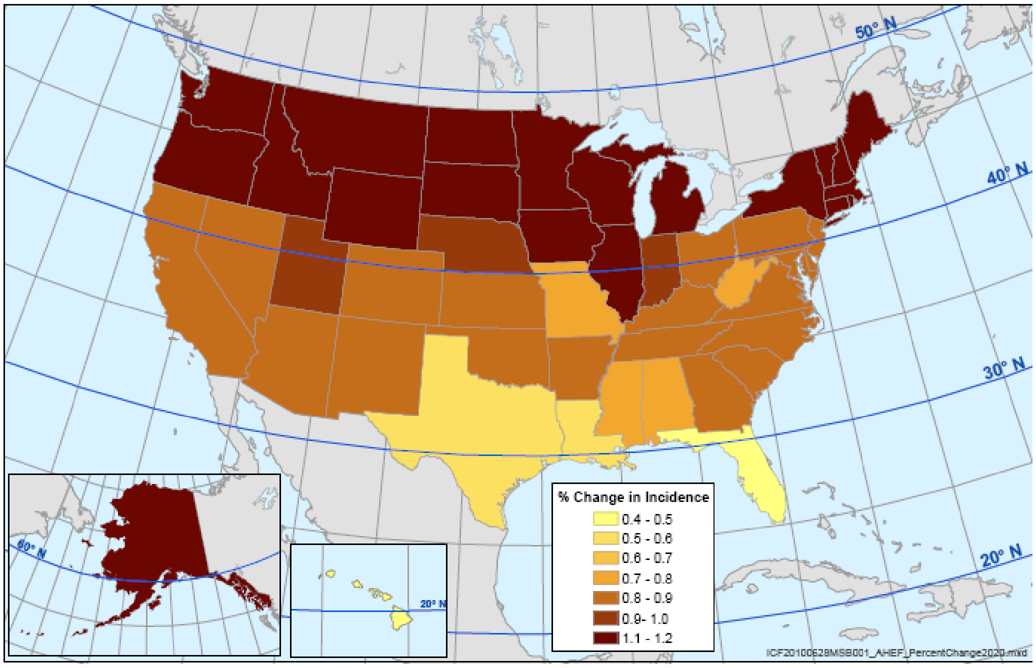
Table C-1. Comparison of UV and cataract-related variables for Illinois and Florida for the population between ages 55 and 84 in the year 2020.

	Illinois			**Florida**		
	1979-1980 Baseline	**1987 Montreal Protocol as Originally Agreed**	**Montreal Protocol as Amended and Adjusted through 1997**	**1979-1980 Baseline**	**1987 Montreal Protocol as Originally Agreed**	**Montreal Protocol as Amended and Adjusted through 1997**
Annual Integrated Biologically Weighted UV Irradiance (kJ/m^2)	3,319	4,187	3,463	4,817	5,429	4,932
Absolute Cataract Incidence	31,980	32,350	32,150	36,480	36,650	36,570
Incremental Cataract Incidence Relative to 1979-1980 Baseline		370	180		170	90
% Change in Cataract Incidence per 1979-1980 Baseline Cataract Incidence		1.20%	0.56%		0.47%	0.25%

Figure C-1 illustrates the percent change in cataract incidence for all states in 2020, comparing the 1987 Montreal Protocol as originally agreed to the 1979-

1980 baseline. Similar to the findings presented in Table C-1, the overall trend in this figure demonstrates an increasing percent change in cataract incidence with increasing (i.e., more northern) latitude. The absolute cataract incidence may still be greater for southern locations; however, the <u>change</u> in incidence associated with a control policy is greater in northern locations."

Figure C-1. Projected % Change in Cataract Incidence Cases for the year 2020 comparing the 1987 Montreal Protocol as Originally Agreed to the 1979-1980 Baseline.



The following points were raised by the reviewers requiring further discussion and/or action items:

(3a) Increased risk of cataract illustrated for those living in northern states may also be due to the unique nature of the ocular UV exposure occurring due to the anatomy of the orbit. Current research is underway that finds peak UV exposure to the eye occurs when the solar altitude is around 40 degrees.

- <u>Response</u>: Current research suggests the eye exposure to UV is at a maximum when the solar altitude is around 40 degrees. This suggests those living outside of the tropics are more susceptible to eye damage. As studies become available, this information can be used in AHEF either to inform the development of the biologically weighted irradiances or to be added as a weighting factor as a function of solar zenith angle.

- Action Item(s): The following bullet has been added to Section 6, *Topics for Future Research*: "The cataract module can be updated to include an additional UV exposure weighting function based on solar zenith angle once new research becomes available. Specifically, there is initial support in the research community that peak UV exposure to the eye occurs when the solar altitude is around 40 degrees and so exposure could be weighted with the 40 degree maximum for eye exposures (Sasaki et al. 2009)."

(3b) The current observations demonstrate the change in ozone concentrations are decreasing at a greater rate with increasing latitudes; alternatively, the amount of UV reaching the surface increases as latitudes decrease. There is no evidence that the increase due to ozone reduction is greater than the decrease due to latitude.

- Response: Please see discussion directly below this charge question. The results of the projected incremental change of cataract incidence are not based on absolute UV irradiance, but on the incremental change in UV irradiance estimated between a control policy scenario and the 1979-1980 baseline. The minimal reduction in ozone-depleting substances associated with the original Montreal Protocol, for example, results in significant change in stratospheric ozone concentrations. The Northern latitudes realize this change in reduced concentration earlier and with greater severity.

- Action Item(s): No action item.

(3c) Populations in higher latitudes likely spend less time outdoors and thereby receive less UV exposure than their southern counterparts. This may be offset to some degree by the usage of protective eyewear.

- Response: The AHEF includes the use of UV protection such as wearing hats and/or protective eyewear as well as outdoor activity in the BAFs that are estimated for Maryland population groups. These behaviors are assumed to be representative of the nation; hence, AHEF does not allow for variations across the country. AHEF is readily able to include weighting factor(s) which would represent UV protection based on county latitude.

- Action Item(s): The following bullet has been added to Section 6, under *Topics for Future Research*: "The BAF and/or exposure weighting functions within AHEF can be updated or introduced as new research becomes available providing factors associated with changes in exposure behavior as a function of travel and/or migration, outdoor activity, and sun protection. These behavior exposure weighting functions may be disaggregated by ethnicity, race, and/or latitude."

(3d) While the modeling assumptions made in the AHEF model seem reasonable, any assumptions made relating to migration patterns are questionable as there are multiple migration trends between demographics.

- Response / Action Item(s): Please see Response / Action Item (s) associated with charge question (1c).

Charge Question 4: This report investigates the sensitivity of the cataract incidence results to varying biological amplification factors (see section 5.1 in the report). The cataract incidence results are not found to be very sensitive to varying the biological amplification factor as a function of gender and skin-type. Is the methodology in the sensitivity analysis described by section 5.1 sound?

Key Point(s) for Discussion: The following points were raised by the reviewers requiring further discussion and/or action items:

(4a) Given there is no known dramatic anatomical difference in the refracting structures of the eye amongst races, variation of cataract incidence by race based on the physical attributes should not be significant. However, behavior such as UV protection and outdoor activity may be a function of race and/or ethnicity.

- Response: Currently, there are no biological amplification factors available as a function of ethnicity; however, if such data becomes available, AHEF can be updated with population data for race or ethnicities as defined by the U.S. census bureau. Given the current literature, it appears the differences in exposure between ethnic groups may be related to sun protection and exposure behavior as opposed to any anatomical differences in the eye structure.

- Action Item(s): The following bullet has been added to section 6, under *Topics for Future Research*: "The BAF and/or exposure weighting functions within AHEF can be updated or introduced as new research becomes available providing factors associated with changes in exposure behavior as a function of travel and/or migration, outdoor activity, and sun protection. These behavior exposure weighting functions may be disaggregated by ethnicity, race, and/or latitude."

(4b) It is suggested to validate SEE's statement that SEE has "shown similar risks of cataract with UVB exposure for Caucasians and African

Americans" by using Census data and a measure of cataract prevalence and incidence to investigate cataract incidence as a factor of pigmentation compared to exposure.

- Response / Action Item(s): Please see Response / Action Item(s) of charge question (1d).

Charge Question 5: The Oriowo et al. (2001) spectrum was used given both its coverage of optimum wavelengths and that the pig cornea is similar in composition and UV response to the human cornea. Given your expertise, is the Oriowo et al. (2001) action spectrum used to represent cataract response to UV radiation a sound choice?

Key Point(s) for Discussion: The following points were raised by the reviewers requiring further discussion and/or action items:

(5a) The porcine study, which provides the cataract action spectrum for the AHEF model, may be acceptable for the older populations based on the main absorbing chromophore. It is also noted that older humans with an aging lens will be more susceptible to increases in UV-B than predicted by the Oriowo et al. study.

- Response: The AHEF model currently assumes zero baseline incidence for populations below 55 years of age. If this age threshold is lowered to allow younger populations to acquire cataract, then a transparent discussion of limitations associated with using the Oriowo et al. study for young populations groups would need to be included. The caveat associated with this study as outlined above will be added to the report.

- Action Item(s): The following text has been added to the text box on page 5 discussing the Oriowo et al. (2001) action spectrum: "Using a young pig lens to simulate UV damage may underestimate the impact on the older population (as the damage caused by UV-A and UV-B changes with the age of the lens)." The following text has been added as a bullet to section 6, *Topics for Future Research*: "Investigating the effect of early life UV exposure on cataract incidence through updating baseline incidences to include all age groups and/or applying an age-weighting algorithm to account for potential changes in dose-response associated with early life exposures."

(5b) Using this study for the cataract action spectrum is not likely to introduce a 50% probable error.

- Response: The uncertainty analysis on page 18 provides an approximate quantification of uncertainty associated with the action spectrum of 50%. As mentioned in the text, this number is associated with the uncertainty of skin cancer and, upon further reflection, is not appropriate to include in this study. There is no quantification of the uncertainty associated with using the Oriowo et al. (2001) action spectrum available. However, a comparison of the slopes of the action spectra illustrated in Figure 2 suggests an uncertainty of 27%. Continuing to quantify uncertainty across action spectrum can be developed once additional research of action spectrum across like wavelengths has been conducted.

- Action Item(s): There are two action items. Firstly, page 19, section 5.2, the "~50%" quantified uncertainty associated with "uncertainty with the choice of action spectrum" has been replaced with "27%." Secondly, the following text "The uncertainty for defining the choice of action spectrum is very likely overestimated and is based on skin cancer results (EPA 2006)," has been replaced with "The uncertainty for defining the choice of action spectrum is estimated by comparing the slopes of the action spectra illustrated in Figure 2."

(5c) It is likely the pig cornea is similar to the human cornea. The Oriowo et al. study investigates impact of UV on the lens without a cornea present. However, if the cornea were present, the adverse impact of the shorter UV wavelengths would be reduced. The impact of UV-B may be overestimated given the Oriowo et al. (2001) action spectrum was developed based on the eye lens without a protective cornea. The human cornea filters UV below about 293 nm. It is suggested than an "effective" action spectrum could be used that would take into account both the filtering that would occur if a cornea was present and the absorption spectrum of the lens.

- Response: As noted, the Oriowo et al. study uses in vitro pig lenses in the absence of the protective cornea. In application of this to the AHEF model, the National Center for Atmospheric Research's (NCAR) radiative transfer model TUV (Tropospheric Ultraviolet-Visible) uses the action spectrum to provide the biologically weighted irradiance "lookup table." This table is based on the wavelengths from 270 to 370 nm. Most of the UV wavelengths below 290 nm are absorbed in the upper atmosphere. As Figure E-1 demonstrates, as the total ozone column near 300 DU decreases by 1%, an increase in UV irradiance occurs. There is not a significant change in the shorter wavelengths particularly as the solar zenith angle increases.

Figure E-1. Increases in UV radiation in response to 1% decrease in total ozone column near 300 DU (Madronich et al. 1995).[25]

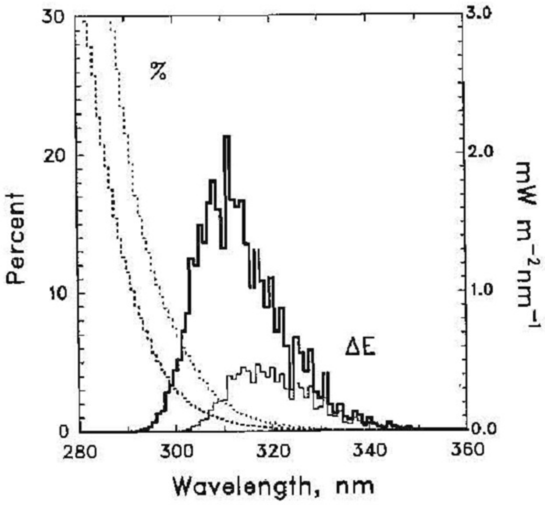


Figure 1. Increases in UV radiation in response to a 1% decrease in the total ozone column near 300 DU (1 DU = 2.69 x 10^{16} molec cm^{-2}). Solid lines (right scale) give spectral irradiance changes, dotted lines (left scale) give percent changes. Values are for overhead sun (thick lines) and for a solar zenith angle of 70° (thin lines). From Madronich (1).

Given this, the inclusion of a protective cornea when estimating the action spectrum against shorter wavelengths may not have a noticeable impact on the AHEF results (which are based on the difference in cataract incidence between control policies and the 1979-1980 Baseline). Though the suggested "effective" action spectrum is an interesting route to artificially address these wavelengths, it is preferred to use a peer reviewed action spectrum directly from the literature for the AHEF model and, as such, the Oriowo et al. action spectrum will be used until a new action spectrum which tests the damage on both the cornea and the lens across the UV wavelength band becomes available.

- <u>Action Item(s):</u> There are two action items. Firstly, the following text box on page 5, discussing the Oriowo action spectrum has been added: "Modeling the impact of UV radiation on the lens in the absence of the protective cornea may overestimate the impact of UV wavelengths between 290 and 300 nm." Secondly, the following text has been added as a bullet to section 6, *Topics for Future Research*: "The action spectrum can be updated once a new peer

[25] Madronich, S., R. McKenzie, M. Caldwell, and L. Bjorn (1995). "Changes in Ultraviolet Radiation Reaching the Earth's Surface." A*mbio*, Vol. 24 No. 3, 143-152

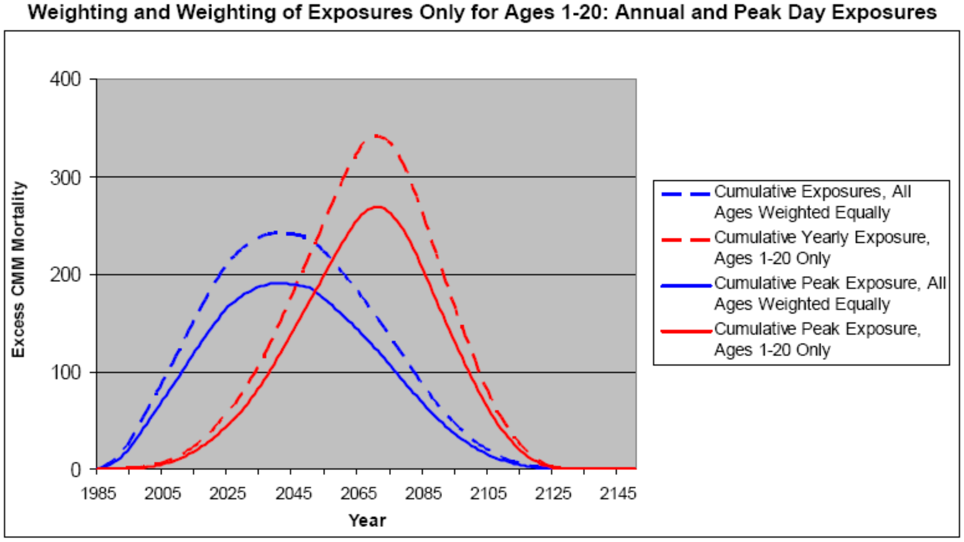
review study becomes available that measures the UV impact on the lens with the cornea present."

(5d) Recent research suggests a window of UV-B wavelengths can transmit through the cornea and lens, hitting the retina during childhood (pre-puberty years); that is, injury to the lens is more likely cumulative from an early age.

- Response: The AHEF model assumes populations aged below 55 years of age do not acquire UV-induced cataract. The cataract baseline incidence used in the AHEF model is drawn from observed populations. As such, the cumulative impacts of UV that contribute to the baseline incidence inherently reflect child exposure. However, it is interesting to note that this suggests an increase in cataract incidence later in life may be associated with poor protective behavior during childhood. AHEF does allow for weighting of UV exposures by age and by type of exposure (e.g., peak day exposure and annual exposure). The cataract module can be adapted to include both a baseline incidence for all age groups and an age-weighting of UV exposure. For example, a similar discussion of the cumulative UV exposure over a lifetime for cutaneous malignant melanoma (CMM) skin cancer was included in Section 8.2 of the 2006 Peer Review Report. Figure E-2 provides results when using annual or peak day exposures. The exposures are either weighted equally over a person's lifetime, or by weighting only the exposures received between age one and age twenty.

Figure E-2. (EPA 2006)

Figure 8. Excess CMM Mortality for the Montreal Adjustments Scenario for Equal Age Exposure Weighting and Weighting of Exposures Only for Ages 1-20: Annual and Peak Day Exposures



These simulations illustrate that cutaneous malignant melanoma (CMM) mortality may change by up to 11% when the age-weighting exposure assumptions are changed.

- Action Item(s): The following text has been added as a bullet to section 6, *Topics for Future Research*: "Investigating the effect of early life UV exposure on cataract incidence through updating baseline incidences to include all age groups and/or applying an age-weighting algorithm to account for potential changes in dose-response associated with early life exposures."

(5e) The Oriowo et al. (2001) study provides the action spectrum for the pig lens not the pig cornea.

- Response: This is incorrect in the report, this will be corrected.

- Action Item(s): Page 5, Section 2.1, "similarity of the pig cornea to the human cornea in composition and UV response" has been replaced with "similarity of the pig lens to the human lens in composition and UV response." And "pig cornea is similar in composition and UV response to the human cornea" has been replaced with "pig lens is similar in composition and UV response to the human lens."

(5f) Laboratory experiments use brief, relatively intense doses of UV radiation. However, cumulative human exposure to UV radiation occurs over decades at much lower doses. As such, laboratory experiments may not represent whole life exposure scenarios.

- Response: As it is considered unethical to conduct UV dose-response experiments on humans and difficult to monitor long-term doses, animal experiments for determining action spectra are the best currently available relationships that exist. To the extent that better models become available: for example, primate studies or long term human monitoring studies, dose-response relationships used in the AHEF can be updated.

- Action Item(s): No action item.

(5g) References for the action spectrum listed in Figure 2 are missing in the reference section for all but the Oriowo et al. (2001) study.

- Response: This will be corrected.

- Action Item(s): Missing references have been added to the reference section.

(5h) The risk of acquiring cataract has been demonstrated to increase with decreasing latitude given sunlight, on average, travels through less atmosphere. These observations suggest the solar UV radiation affects the human lens.

- Response: It has been documented in a number of studies that UV radiation is a likely contributor to cortical cataract. Please see the discussion directly beneath charge question 3.

- Action Item(s): No action item.

(5i) It is not known how the sensitivity of the human lens varies with age. However, without any data on the age-dependent sensitivity of the human lens to UV radiation, it is not possible to know the true long-term impact of ozone depletion and recovery on the U.S. population of any state.

- Response: The AHEF cataract module assumes cumulative exposure of UV and allows cataract incidence to occur at a threshold age of 55. The modeled baseline incidence for cataract is a function of age for individuals between from 55 to 85 years in 5 year cohorts Although early life exposures may add to the population weighted cataract burden, it is expected to be a second order correction and would be difficult to separate this source of morbidity from overall cataract incidence. It would be possible, as a proxy, however, to weight early life exposures more heavily in the AHEF model and to generate incidence estimates based on this weighting. Several reviewers suggested such age weighting based on the consideration that the younger lens may be more vulnerable to UV impact contributing to cataract incidence that may occur later in life.

- Action Item(s): The following text has been added as a bullet to section 6, *Topics for Future Research*: "Investigating the effect of early life UV exposure on cataract incidence through updating baseline incidences to include all age groups and applying an age-weighting algorithm to account for potential changes in dose response associated with early life exposures."

(5j) The draft report suggests that the depletion of stratospheric ozone creates greater risk for populations living in the northern states compared to those living in the southern states. There is a question as to whether this data corrected for total UV radiation.

- Response/Action Item(s): Please see the discussion, and Responses/Action Item(s) to Charge Question 3.

Charge Question 6: The solar zenith angle calculation has been updated from a latitude band resolution to a county resolution. The stratospheric ozone column amounts continue to be provided at the latitude band resolution as a finer resolution for determining the ozone column amounts is not anticipated to provide large differences. Do you agree?

Key Point(s) for Discussion: The following points were raised by the reviewers requiring further discussion and/or action items:

(6a) It is suggested to investigate the ozone variations along a specific latitude to test the applicability of using a latitude band resolution for ozone column amounts.

- Response: AHEF determines monthly total ozone column amounts for a given policy scenario at 10 degree latitude band resolution. These values are then used to estimate the biologically weighted irradiance at a given U.S. county and time of day, assuming clear-sky conditions. The Nimbus satellite[26] provides monthly images of ozone column amounts at 25 DU increments, which is a resolution of about 10% relative to the total column ozone. Variability in ozone concentrations by topography and time of year is also observed to be on the order of 25 DU in mountainous terrain. Additionally, total column ozone estimates are comprised to some degree of tropospheric ozone contributions that vary according to location and associated local air quality. These factors all affect instantaneous or averaged column ozone levels, but importantly, are present in both the baseline and modeled scenario output, and hence, tend to cancel each other out. It is also worth noting that the relative differences between scenarios, and the associated uncertainty, would tend to be a second order effect and within the range of measurement resolution.

- Action Item(s): No action item.

Charge Question 7: Research has shown that the use of sunglasses or protective eyewear reduces UV impact. Have you found in your research, or are you aware of research in the literature or not yet published, that protective eyewear is a significant deterrent to cataract incidence?

Key Point(s) for Discussion: The following points were raised by the reviewers requiring further discussion and/or action items:

(7a) There is significant evidence that suggests protective eyewear reduces UV radiation into the eye. Research has not been adequately conducted

[26] ftp://toms.gsfc.nasa.gov/pub/nimbus7/images/monthly_averages/ozone/

that tests the effect of protective eyewear on reducing incidence of UV-related eye disease.

- Response: Though it is unlikely a research study focused on this question will be conducted, the anecdotal understanding suggests that sunglasses are a deterrent to cataracts. The BAF used in this study incorporate estimates of long-term sun protection behavior such as sunglasses, hats, and outdoor activity. The AHEF can include this new research as it becomes available.

- Action Item(s): The following bullet has been added to section 6, under *Topics for Future Research*: "The BAF and/or exposure weighting functions within AHEF can be updated or introduced as new research becomes available providing factors associated with changes in exposure behavior as a function of travel and/or migration, outdoor activity, and sun protection. These behavior functions may be disaggregated by ethnicity and/or latitude."

(7b) The use of protective eyewear may vary with time of day. The greatest usage of protective eyewear may occur midday; however, it has been shown that more damaging UV impact on the eye occurs when the solar zenith angle is larger. Hence, the timing of optimum protective behavior (e.g., wearing sunglasses) may not actually correspond to the degree of potential UV impact.

- Response: The solar zenith angle, based on location and time of day, is calculated by the AHEF model and used in determining the biologically weighted irradiance. The current action spectrum equates the effectiveness of each UV wavelength to harm the lens of the eye. Two weightings based on time of day could be applied to both to simulate increased UV dose and the use of protective eyewear. A study could be conducted to determine if the UV dose associated with varying solar zenith angles could also be represented by a weighting factor.

- Action Item(s): The following bullet has been added to section 6, under *Topics for Future Research*: "The cataract module can be updated to include an additional UV exposure weighting function based on solar zenith angle once new research becomes available. Specifically, there is initial support in the research community that peak UV exposure to the eye occurs when the solar altitude is around 40 degrees and so exposure could be weighted with the 40 degree maximum for eye exposures (Sasaki et al. 2009)."

(7c) Due to the peripheral light focusing effect, wearing sunglasses that block rays from the front of the eye can have virtually zero impact on preventing ocular damage associated with potentially the most relevant UV radiation. UV contact lenses and wrap-around sunglasses can block these damaging rays, but reports on UV contact lens use are unreliable.

- o Response: This suggests that the form of eyewear protection is important. This is relevant to any future behavioral studies where the use of eye protection would be included in the cataract module as a weighting factor. This factor would likely require a comprehensive study that accounts for this variation in eye protection.

- o Action Item(s): The following bullet has been added to section 6, under *Topics for Future Research*: “The BAF and/or exposure weighting functions within AHEF can be updated or introduced as new research becomes available providing factors associated with changes in exposure behavior as a function of travel and/or migration, outdoor activity, and sun protection. These behavior exposure weighting functions may be disaggregated by ethnicity, race, and/or latitude.”

(7d) It is nearly impossible to prove direct causality of the use of protective eyewear to the reduction of cataract incidence because of (1) the small incidence of cataract and (2) length of time of UV exposure required to develop cataracts. However, based on other evidence, it is appropriate to recommend UV protective eyewear to the population regardless of location.

- o Response: Though it is unlikely a research study focused on this question will be conducted, the anecdotal understanding suggests that sunglasses are a deterrent to cataracts. The AHEF can include this new research as it becomes available.

- o Action Item(s): The following bullet has been added to section 6, *Topics for Future Research*, “The BAF and/or exposure weighting functions within AHEF can be updated or introduced as new research becomes available providing factors associated with changes in exposure behavior as a function of travel and/or migration, outdoor activity, and sun protection. These behavior exposure weighting functions may be disaggregated by ethnicity, race, and/or latitude.”

Charge Question 8: If protective eyewear is a deterrent, does cataract incidence vary depending on whether eye protection begins at younger ages?

Key Point(s) for Discussion: The following points were raised by the reviewers requiring further discussion and/or action items:

(8a) As significant exposure of UV radiation occurs before 19 years of age, early protection against cumulative exposure is crucial. Overall, the lower the lifetime exposure of the eye to solar radiation, the less total or cumulative exposure leading to cataract incidence.

- Response/Action Item(s): Please see Response/Action Item(s) to charge question 5d.

(8b) Studies have shown that the lens' effectiveness in blocking UV increases with age; children have very large pupils and before age 20, the lens is very clear and lacks the biochemical elements to effectively block UV.

- Response: An exposure weighting factor as a function of age can be introduced into AHEF once the research has become available; this would allow for greater weighting of exposure for younger years. Please see Response/Action Item(s) to charge question 5d.

- Action Item(s): The following text has been added as a bullet to section 6, *Topics for Future Research*: "Investigating the effect of early life UV exposure on cataract incidence through updating baseline incidences to include all age groups and/or applying an age-weighting algorithm to account for potential changes in dose-response associated with early life exposures."

Charge Question 9: If protective eyewear is a deterrent, does research suggest that the behavior of using eye protection varies by population type?

Key Point(s) for Discussion: The following points were raised by the reviewers requiring further discussion and/or action items:

(9a) Based on personal experience, the behavior of using eye protection does vary by population type and, in many cases, may be entrenched in the society's culture.

- Response: Currently, the AHEF estimates BAFs for cataract as a function of skin type. If the behavior of eyewear protection is shown to vary by ethnicity, or other population type, AHEF is able to be updated to include this data.

- Action Item(s): The following bullet has been added to section 6, under *Topics for Future Research*: "The BAF and/or exposure weighting functions within AHEF can be updated or introduced as new research becomes available providing factors associated with changes in exposure behavior as a function of travel and/or migration, outdoor activity, and sun protection. These behavior exposure weighting functions may be disaggregated by ethnicity, race, and/or latitude."

(9b) In many cases, protective eyewear is worn in response to glare. Fair-skinned populations with light eyes tend to be more affected by glare due to the retinal and iris pigment levels and may, therefore, be more apt to use protection. However, due to lack of consistent sun protective measures by dark-skinned persons, who experience less glare, dark-skinned persons are in effect more vulnerable to primary ophthalmohelioses.

- Response: Currently, the AHEF model estimates cataract biological amplification factors (BAFs) for light-skinned and dark-skinned populations. AHEF is a flexible model that can include new or additional BAFs for different behavioral population types as new research becomes available.

- Action Item(s): The following bullet has been added to section 6, under *Topics for Future Research*: "The BAF and/or exposure weighting functions within AHEF can be updated or introduced as new research becomes available providing factors associated with changes in exposure behavior as a function of travel and/or migration, outdoor activity, and sun protection. These behavior functions may be disaggregated by ethnicity and/or latitude."

(9c) Studies may not be available that specifically suggest that the behavior of using eye protection varies by population type. However, there are studies on sun protection attitudes and behaviors which could potentially be used to quantify protective eyewear behavior.

- Response: Currently, AHEF estimates biological amplification factors (BAFs) for cataract as a function of skin type. If the behavior of eyewear protection is shown to vary by ethnicity, or other population type, AHEF is able to be updated to include this data.

- Action Item(s): Add the following bullet to section 6, under *Topics for Future Research*: "The BAF and/or exposure weighting functions within AHEF can be updated or introduced as new research becomes available providing factors associated with changes in exposure behavior as a function of travel and/or migration, outdoor activity, and sun protection. These behavior exposure weighting functions may be disaggregated by ethnicity, race, and/or latitude."

E.2.2. Additional comments on the report

One reviewer questioned whether the cataract baseline incidence rates are, in fact, prevalence data.

- Response: This prevalence data provides cataract cases by 5-year age groups. A difference in the prevalence between two immediate age groups provides an estimate of new baseline incidence for the older age group. It is recognized in section 6, under *Topics for Future Research*, new baseline incidence values for 1979-1980 would be valuable.

One reviewer suggested the following: The trends in cataract incidence provided in this report may be due to cohort effects other than changes in UV-B that may have occurred in the 40 years since the NHANES. The potential confounding by cohorts should be mentioned in this report.

- Response: The NHANES data is used to provide baseline cataract incidence (i.e., for the 1979-1980 timeframe). Because the AHEF is concerned only with changes in UV-mediated cataract incidence and extrapolates this solely from the baseline incidence data, confounding cohort effects (e.g., changes in smoking habits or diabetes incidence that affect the incidence of various forms of cataract) are not relevant. To the extent that confounding effects may influence the baseline data, upon which the analysis is based, this limitation has been acknowledged in the report (see footnote 5 in section 2.2 on page 7) and because only incremental cases associated with incremental changes in UV are assessed, any additional uncertainty would be of the second order.

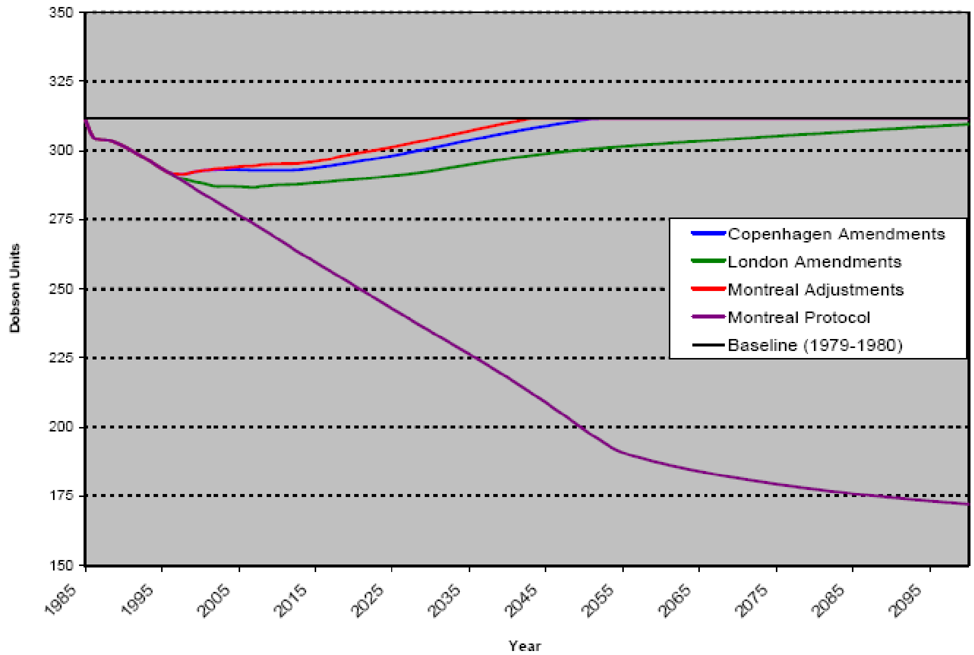
One reviewer questioned the report's clinical definition of cataract.

- Response: We have included a new textbox describing two clinical definitions of cortical cataract used by cross-sectional surveys, including the West et al. (2005) study which provides the BAFs used in this report.

One reviewer questioned the reasonableness of 23 million fewer cases of cataract in response to the implementation of the Montreal Protocol.

- Response: This number of cases applies to the total population born between 1890 to 2100. The greatest impacts accrue to those segments of the population born between 1995 and 2045 when the Earth's protective layer is most depleted, as illustrated below for the 30^{o} to 40^{o}N latitude band (reproduced from Figure 2 of the 2006 Peer Review Report, "*Human Health Benefits of Stratospheric Ozone Protection*") for various ozone control policies.

Figure E-3. Projected Ozone Column Amounts for 30° to 40°N latitude band for various ozone control policies (EPA 2006).



The implications for cataract incidence based on these scenarios are the subject of the dose-response relationships used in the AHEF. One study estimates a 1% reduction in stratospheric ozone would correspond to an additional 0.5% increase in cataract.[27]

[27] UNEP assessment as cited by http://www.ozonedepletion.info/education/part2/ozoneimpact.html.