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Paul J. Miller, Executive Director

June 29, 2020

Andrew Wheeler, Administrator
U.S. Environmental Protection Agency
1200 Pennsylvania Avenue, NW
Washington, DC 20460

Attention: Docket ID No. EPA-HQ-OAR-2015-0072

Re: *Review of the National Ambient Air Quality Standards for Particulate Matter, Proposed Action*

Dear Administrator Wheeler:

The Northeast States for Coordinated Air Use Management (NESCAUM) offer the following comments on EPA's proposed "Review of the National Ambient Air Quality Standards for Particulate Matter" (PM NAAQS proposal) [85 Fed. Reg. 24094-24144 (April 30, 2020)].

NESCAUM is the regional association of air pollution control agencies representing Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island, and Vermont. Our member state agencies have the primary responsibility in their states for implementing clean air programs that achieve the public health and environmental protection goals of the federal Clean Air Act. Strong, evidence-based NAAQS are essential to the fulfillment of that mission.

EPA's decision to retain the current PM NAAQS violates the Agency's statutory requirement to promulgate primary NAAQS that protect public health with an "*adequate margin of safety*" and secondary NAAQS that "*protect public welfare from any known or anticipated adverse effects*" (Clean Air Act, 42 U.S.C. §7409(b)). Because a wide range of air quality programs are tied to complying with those standards, adoption of or failure to revise an inadequate NAAQS significantly hampers states' abilities to protect the health and welfare of their residents. Note also that because fine particulate matter ($PM_{2.5}$) and its precursors in the ambient air can travel long distances across state lines, states cannot achieve clean air within their own borders without sufficiently protective national requirements.

The comments below address the following issues:

1. EPA's alterations in the NAAQS review process, including the imposition of a highly compressed schedule, hampered the development of strong, evidence-based PM NAAQS.

2. The PM NAAQS review process was critically compromised by EPA's replacement of the entire Clean Air Scientific Advisory Committee (CASAC) and dissolution of the advisory CASAC PM Review Panel (PMRP).
3. EPA should act on the recommendations of the Independent Particulate Matter Review Panel (IPMRP), which is made up of 20 highly-qualified members who served on the CASAC PMRP prior EPA's dissolution of that advisory panel in 2018.
4. Based on the clear preponderance of scientific information as documented by EPA staff, EPA must adopt a more stringent annual average $PM_{2.5}$ NAAQS. The Administrator's decision to retain the current NAAQS in the proposed action is contrary to EPA's long standing regulatory framework and the available science, and has serious implications for public health.

1. EPA's alterations in the NAAQS review process, including the imposition of a highly compressed schedule, hampered the development of a strong, evidence-based PM NAAQS.

In NAAQS reviews, EPA produces a series of sequential documents, each designed to inform the following stages of the review. First, an Integrated Review Plan (IRP) is developed to identify policy-relevant science issues and set forth the schedule and process for the review. EPA then prepares an Integrated Science Assessment (ISA), which forms the scientific foundation for the assessment of whether the NAAQS sufficiently protect public health and welfare. The ISA informs the preparation of a Risk and Exposure Assessment (REA), which presents quantitative estimates of exposures and health risks under defined air quality scenarios. Subsequently, EPA prepares a Policy Assessment (PA), which summarizes information from the ISA and REA and provides the Administrator with options regarding the indicator, averaging time, statistical form, and numerical level (concentration) of the NAAQS.

Because these documents are sequential, EPA has historically provided opportunity for peer review by the statutorily established Clean Air Scientific Advisory Committee (CASAC), as well as public comment, on drafts of each document. EPA would then revise the document to address issues raised in the comments, and, if appropriate, submit a second draft to CASAC for further review prior to finalization. In some cases, a third review of an ISA document was necessary, because of the critical role that this document has in establishing the scientific underpinnings of policy decisions. This long-standing process allowed major issues to be identified and addressed in each document before that information was used in subsequent assessments.

The review schedule in the IRP for the current PM NAAQS review, as finalized in December 2016, was similar to those in previous reviews, allowing for two drafts of the ISA and the REA and issuance of a draft PA concurrent with the second draft of the ISA. However, EPA substantially deviated from that schedule in response to then EPA Administrator Scott Pruitt's May 2018 "Back-to-Basics" memorandum, which set forth a framework for "streamlining" NAAQS reviews. The new schedule for the PM NAAQS review allowed for only one draft of

the ISA. In addition, due to the accelerated process, a REA was not released prior to preparation of the PA; instead, a risk assessment was included as part of the PA document. This accelerated process did not allow sufficient time for incorporation of additional information supplied by reviewers that would better inform subsequent steps in the review. Although EPA staff did admirable work in the preparation of these documents, the compressed schedule compromised EPA's ability to resolve issues in the ISA identified by CASAC and the public and to obtain comments on a risk assessment before those assessments were used to identify policy options in the PA. In addition, the compressed schedule resulted in the omission of important recent studies from consideration in the final NAAQS, as discussed below.

The Clean Air Act stipulates that "at five-year intervals thereafter, the Administrator shall complete a **thorough review** of … the national ambient air quality standards" (42 U.S.C. §7409(d)(1) [bold added]. NESCAUM agrees that it is important that such reviews be conducted in a timely manner. However, a highly compressed schedule that does not allow adequate time for the sequential preparation and review of the science, risk and policy documents is not consistent with a "*thorough review*." As a result, the public is not assured of a primary NAAQS that provides an "*adequate margin of safety*" and a secondary NAAQS that "*protect[s] public welfare from any known or anticipated adverse effects,*" as required by the Clean Air Act.

2. The PM NAAQS review process was critically compromised by EPA's replacement of the entire Clean Air Scientific Advisory Committee (CASAC) and dissolution of the CASAC PM Advisory Review Panel (PMRP).

The Clean Air Act charges CASAC with the responsibility to review existing primary and secondary NAAQS every five years and to "*recommend to the Administrator any new national ambient air quality standards and revisions of existing criteria and standards as may be appropriate.*" (42 U.S.C. § 7409(d)(2). Early in this cycle of the PM NAAQS review, EPA took the extraordinary action of replacing all seven of the charter members of the CASAC in a one year period, rather than staggering appointments to provide Committee continuity. In addition, in October 2018, EPA dismissed the PMRP in its entirety. These combined actions effectively purged the advisory process of institutional experience and essential expertise necessary for such reviews.

CASAC members have historically been selected using criteria consistent with those identified in a 2003 report from EPA's Science Advisory Board (SAB) entitled "*Implementation Plan for the New Structural Organization of the EPA Science Advisory Board.*" That document states that selection of appointees to the SAB and to EPA advisory committees, like CASAC, should "*tak(e) into account the needed (a) breadth and depth of experience and expertise; (b) balance of scientific perspectives; (c) continuity of knowledge and understanding of EPA missions and*

environmental programs; and (d) diversity factors, including, geographical areas and professional affiliations."[1]

However, in October 2017, then EPA Administrator E. Scott Pruitt issued a memorandum entitled, "*Strengthening and Improving Membership on EPA Federal Advisory Committees (FACs)*" that set forth a different set of principles for identifying committee members, namely: (a) strengthen member participation; (b) increase state, tribal and local government participation; (c) enhance geographic diversity and (d) promote fresh perspectives.[2]

Although the purported objective of this memo is to "*strengthen and improve the composition of EPA's FACs in ways that advance the Agency's mission to protect public health and welfare*," the result was just the opposite. The introductory paragraphs in the memo acknowledge that "*(c)ritical to the integrity of FACs is the selection of qualified and knowledgeable candidates*." However, unlike the SAB report, which lists "*breadth and depth of experience and expertise*" as its first selection criterion, the five principles in the Pruitt memo do not include a consideration of wide and deep scientific qualifications. As a result, the replacement CASAC, appointed after the issuance of this memo, lacks expertise in areas critical to NAAQS reviews, like epidemiology.

Further, the "*strengthen member independence*" principle in the Pruitt memo excludes non-governmental recipients of EPA grants from committee membership. In April 2020, the U.S. Court of Appeals for the D.C. Circuit ruled against this directive, noting that:

> EPA operates pursuant to multiple statutory mandates requiring that its decisions rest on various formulations of "the best available science." 15 U.S.C. § 2625(h). And as EPA's Peer Review Handbook explains, the agency's prior policy—allowing EPA grantees to serve on advisory committees—existed, in part, to "ensure that the scientific and technical bases of its decisions … are based upon the best current knowledge from science, engineering, and other domains of technical expertise; and … are credible."[3] Even the Directive itself agrees that "it is in the public interest to select the most qualified, knowledgeable, and experienced candidates."[4] Yet the Directive nowhere confronts the possibility that excluding grant recipients—that is,

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[1] USEPA Science Advisory Board (2003), "Implementation Plan for the New Structural Organization of the EPA Science Advisory Board," page 8, EPA-SAB-04-002. Available at: https://yosemite.epa.gov/sab/sabproduct.nsf/Web/ImplementReorgSAB/$File/sab04002.pdf.

[2] Memo from E. Scott Pruitt, USEP Administrator dated October 31, 2017. Subject: Strengthening and Improving Membership on EPA Federal Advisory Committees. Available at: https://www.epa.gov/sites/production/files/2017-10/documents/final_draft_fac_memo-10.30.2017.pdf.

[3] *Citing* USEPA Science and Technology Policy Council, Peer Review Handbook, 4th Edition (October 2015), page A-4. Available at: https://www.epa.gov/sites/production/files/2016-03/documents/epa_peer_review_handbook_4th_edition.pdf.

[4] *Citing* Memo from E. Scott Pruitt, USEPA Administrator, dated October 31, 2017. Subject: Strengthening and Improving Membership on EPA Federal Advisory Committees, page 1. Available at: https://www.epa.gov/sites/production/files/2017-10/documents/final_draft_fac_memo-10.30.2017.pdf.

> individuals who EPA has independently deemed qualified enough to receive competitive funding—from advisory committees might exclude those very candidates.[5]

Further, the "promote fresh perspectives" principle in the Pruitt memo was used as a justification for removing all of the charter CASAC members, in clear contradiction of the "*continuity of knowledge*" criterion espoused in the SAB guidance. Those members were largely replaced with less experienced candidates who lacked the breadth and depth of expertise of the previous CASAC. Note that although the memo excluded the participation of recipients of EPA grants, it did not exclude those with ties to regulated industries from membership. In fact, some of the new appointees were industry consultants with established histories questioning generally accepted relationships between air pollution exposures and health.

CASAC's capacity to provide an expert review of the PM NAAQS was further reduced by EPA's abrupt act to disband the CASAC PMRP in October 2018. Historically, EPA has appointed approximately 20 additional scientists to an advisory panel to augment the expertise of the CASAC charter members. This enhanced CASAC's ability to conduct a comprehensive assessment of all aspects of the NAAQS development and allowed CASAC's recommendations to benefit from discussions among scientists with differing perspectives. EPA's abrupt dismissal of the review panel for the PM NAAQS prior to the issuance of the ISA denied the largely inexperienced CASAC charter members the depth and breadth of expertise that those scientists provided.

CASAC acknowledged those limitations in an April 11, 2019 letter to EPA commenting on the first draft of the ISA:

> The CASAC recommends that the EPA reappoint the previous CASAC PM panel (or appoint a panel with similar expertise) as well as adding expertise in biological mechanisms of causation, causal inference, multi-stressor interactions, and potentially others such as: epidemiology, human clinical studies; comparative toxicology, dosimetry, and extrapolation of findings in animals to humans; characterization of sampling errors and biases from continuous ambient PM measurements and satellite remote sensing aerosol optical depth (AOD) analysis; errors and biases in dispersion modeling and photochemical grid modeling; errors-in-variables methods and effects of exposure (and covariate) estimation errors on epidemiologic study results; epidemiology of low-dose causal concentration-response functions; and effects of PM on visibility impairment, climate, and materials. The panel should be appointed in time to review the Second Draft ISA.[6]

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[5] *Physicians for Social Responsibility, et al. v. Wheeler*, D.C. Circuit, No. 19-5104 (decided April 21, 2020). Available at: https://law.justia.com/cases/federal/appellate-courts/cadc/19-5104/19-5104-2020-04-21.html.

[6] Letter from Louis Cox, Jr., CASAC Chair, to EPA Administrator Andrew Wheeler, dated April 11, 2019, Subject: CASAC Review of the EPA's Integrated Science Assessment for Particulate Matter (External Review Draft – October 2018). Available at: https://yosemite.epa.gov/sab/sabproduct.nsf/LookupWebReportsLastMonthCASAC/6CBCBBC3025E13B4852583D90047B352/%24File/EPA-CASAC-19-002+.pdf.

EPA did not reappoint a PM panel but, in a letter dated July 25, 2019, notified CASAC of its intention to:

> Create a pool of subject matter expert consultants that the seven-person chartered CASAC, through the chair, will draw from as needed to support its PM and ozone reviews. The consultants will make themselves available as requested to provide feedback on the scientific and technical aspects of science and policy assessments and related documents. … Requests for feedback from these consultants should be submitted in writing through you, the CASAC's chair, and the CASAC's designated federal official.[7]

While the availability of a "*pool of subject matter expert consultants*" provided CASAC with access to additional expertise, it did not substitute for a review panel. Unlike the former review panels, the subject matter experts were not tasked with review of the EPA draft documents but instead responded only to specific questions submitted by the chartered CASAC members. Historically, CASAC panels deliberated along with the charter members, providing a forum for discussion among scientists with a range of expertise and perspectives on an issue. Written responses to specific CASAC questions by a selected pool of experts did not allow for a similar exchange.

Note that 20 members of the former PM review panel dismissed by EPA in October 2018 formed the nongovernmental Independent Particulate Matter Review Panel (IPMRP) and provided their own expert comments to CASAC on drafts of the PM ISA on December 10, 2018 and March 27, 2019. The IPMRP met on October 10-11, 2019, and October 18, 2019 to peer review the draft PA document for the PM NAAQS. A report on recommendations based on those deliberations was submitted to the EPA PA docket and provided to CASAC on October 22, 2019.[8] The recommendations of that group of highly qualified experts are discussed in the following section.

The replacement of all members of the chartered CASAC and dismissal of the PMRP immediately prior to the review of the ISA and PA PM NAAQS documents, combined with the compressed review schedule discussed above, prevented the thorough, independent review of the PM NAAQS required by statute that is essential to the protection of public health and welfare.

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[7] Letter from USEPA Administrator Andrew Wheeler to CASAC Chair Louis Anthony Cox, Jr., dated July 25, 2019. Available at: https://yosemite.epa.gov/sab/sabproduct.nsf/6CBCBBC3025E13B4852583D90047B352/$File/EPA-CASAC-19-002_Response.pdf.

[8] Letter from Christopher Frey, *et al.*, to EPA Administrator Andrew Wheeler dated October 22, 2019, Docket ID No. EPA–HQ–OAR–2015–0072, Subject: Advice from the Independent Particulate Matter Review Panel (formerly EPA CASAC Particulate Matter Review Panel) on EPA's Policy Assessment for the Review of the National Ambient Air Quality Standards for Particulate Matter (External Review Draft – September 2019). Available at: https://yosemite.epa.gov/sab/sabproduct.nsf/81DF85B5460CC14F8525849B0043144B/$File/Independent+Particulate+Matter+Review+Panel+Letter+on+Draft+PA.pdf.

3. EPA should act on the recommendations of the Independent Particulate Matter Review Panel (IPMRP), which is made up of 20 highly-qualified members who served on the CASAC PMRP prior EPA's dissolution of that advisory panel in 2018.

As discussed above, 20 of the members of the PM review panel abruptly disbanded by EPA in October 2018 formed a nongovernmental Independent Particulate Matter Review Panel (IPMRP), which reviewed and submitted comments on EPA's draft PM ISA and PA documents. Seven of the IPMRP members had previously served on a chartered CASAC, three had chaired CASAC review panels, and one was a former CASAC chair. The IPMRP members were subject to a good faith ethics review by the former director of the EPA Science Advisory Board Staff Office.

The IPMRP members represent a wide range of scientific expertise and included multiple experts in key disciplines; such as epidemiology, toxicology, and human clinical studies; in order to provide a diversity of perspectives. As constituted, the IPMRP provided the depth and breadth of experience and expertise identified as critical in the 2003 SAB report,[1] and requested by the current CASAC in its April 11, 2019 letter to EPA.[6] Further, because deliberations involved open discussion among experts, rather than being limited to written responses from a pool of experts, the IPMRP was able to synthesize information from experts representing a range of fields of expertise and a range of perspectives.

The October 22, 2018 IPMRP report includes the following findings concerning the primary fine particulate ($PM_{2.5}$) NAAQS:

- An annual and a 24-hour primary $PM_{2.5}$ NAAQS are both needed in order to protect public health in all areas of the United States.
- The current $PM_{2.5}$ primary NAAQS are not adequate to protect public health; retaining those standards is not scientifically justifiable.
- The annual primary $PM_{2.5}$ NAAQS should be revised to a level between 10 $\mu g/m^3$ and 8 $\mu g/m^3$.
- The 24-hour primary $PM_{2.5}$NAAQS should be revised to a level between 30 $\mu g/m^3$ and 25 $\mu g/m^3$ to provide public health protection in locations where the 24-hour standard, and not the annual standard, is controlling.

NESCAUM respectfully requests that EPA revise the primary $PM_{2.5}$NAAQS to be consistent with the best available science as reflected by the above recommendations.

4. Based on the clear preponderance of scientific information as documented by EPA staff, EPA must adopt a more stringent annual average $PM_{2.5}$ NAAQS, as recommended by EPA staff and by the IPMRP. The Administrator's decision to retain the current NAAQS in the proposed action is contrary to EPA's long standing

regulatory framework and the available science and has serious implications for public health.

The EPA Administrator is proposing retention of the current PM NAAQS, despite clear evidence presented in the ISA and PA that severe adverse health effects, including premature mortality, occur at $PM_{2.5}$ levels below the current annual average NAAQS (12 μg/m^3). EPA staff, writing in the PA, state that:

> When taken together, we reach the conclusion that the available scientific evidence, air quality analyses, and the risk assessment, as summarized above, can reasonably be viewed as calling into question the adequacy of the public health protection afforded by the combination of the current annual and 24-hour primary $PM_{2.5}$ standards.[9]

The PA goes on to provide justification for reducing the annual NAAQS to a level as low as 10 μg/m^3, stating that:

> Key epidemiologic studies indicate consistently positive and statistically significant health effect associations based on air quality distributions with overall long-term mean $PM_{2.5}$ concentrations at and above 8.1 μg/m^3 (8.2 μg/m^3 based on studies that use monitors alone to estimate $PM_{2.5}$ exposures), with mean concentrations at or above 9.6 μg/m^3 in most key studies (10.7 μg/m^3 based on studies that use monitors alone to estimate $PM_{2.5}$ exposures). The ranges of ambient $PM_{2.5}$ concentrations accounting for the bulk of exposures and health data in these studies are expected to extend at least somewhat below the overall long-term mean concentrations reported.[10]

In comments to CASAC in October 2019, the North American Chapter of the International Society for Environmental Epidemiology (ISEE) argued for an even more stringent annual average NAAQS for $PM_{2.5}$, stating that:

> For example, the recent study by Hayes et al. (2019)[11] of the large and well-controlled NIH-AARP cohort has found that there is a statistically significant increase in cardiovascular deaths in the 8 to 12 μg/m^3 fine particulate matter ($PM_{2.5}$) annual average concentration range vs. below 8 μg/m^3 (HR = 1.04 per 10 μg/m^3). Thus, a long-term standard closer to 8 μg/m^3 is needed to more properly protect public health from the severe adverse effects of fine particulate matter.[12]

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[9] USEPA Office of Air Quality Planning and Standards, "Policy Assessment for the Review of the National Ambient Air Quality Standards for Particulate Matter," page 3-99, January 2020. EPA-452/R-20-002. Available at: https://www.epa.gov/sites/production/files/2020-01/documents/final_policy_assessment_for_the_review_of_the_pm_naaqs_01-2020.pdf.

[10] Ibid. page 3-113.

[11] Hayes RB, Lim C, Zhang Y, Cromar K, Shao Y, Reynolds HR, Silverman DT, Jones RR, Park Y, Jerrett M, Ahn J, Thurston GD. PM2.5 air pollution and cause-specific cardiovascular disease mortality. International Journal of Epidemiology, 2019, 1–11. Available at: https://www.cchaeha.com/assets/hayes+ije.pdf.

[12] Letter from George Thurston on behalf of the ISEE North American Chapter to CASAC, Subject: Comments for the October 22, 2019 CASAC Teleconference. Available at:

Environmental justice is also an important consideration in setting a $PM_{2.5}$ NAAQS that provides an adequate margin of safety. People with heart or lung diseases, children, and older adults have long been identified as groups that "*are the most likely to be affected by particle pollution exposure.*"[13] Recent research involving very large study populations provides strong evidence that gender, race and socioeconomic status are also essential factors in increased sensitivity to $PM_{2.5}$. For instance, in a subgroup analyses evaluating 247,682,367 person-years of data for Medicare recipients that resided in ZIP codes with annual average $PM_{2.5}$ concentrations below the current 12 $\mu g/m^3$ NAAQS, Di *et al.* (2017) found that:

> [M]en; black, Asian, and Hispanic persons; and persons who were eligible for Medicaid (i.e., those who had low socioeconomic status) had a higher estimated risk of death from any cause in association with $PM_{2.5}$ exposure than the general population … Among black persons, the effect estimate for $PM_{2.5}$ was three times as high as that for the overall population.[14]

As discussed above, EPA staff clearly state in the PA that currently available data call into question the adequacy of the public health protection provided by the existing $PM_{2.5}$ NAAQS and provide justification for an annual average standard as low as 10 $\mu g/m^3$. However, the current NAAQS proposal states that "*the Administrator proposes to conclude that the available scientific evidence and technical information continue to support the current annual and 24-hour $PM_{2.5}$ standards.*" (page 24121)

To justify this decision, the Administrator invokes uncertainties in the use of epidemiological studies to derive standards in the absence of experimental studies conducted at similar exposure levels, saying:

> In the absence of evidence from experimental studies that $PM_{2.5}$ exposures typical of areas meeting the current annual and 24-hour standards can activate biological pathways that plausibly contribute to serious health outcomes, the Administrator is cautious about placing too much weight on reported $PM_{2.5}$ health effect associations for air quality meeting those standards. He concludes that such associations alone, without supporting experimental evidence at similar $PM_{2.5}$ concentrations, leave important questions unanswered regarding the degree to which the typical $PM_{2.5}$ exposures likely to occur in areas meeting the current standards can cause the mortality or morbidity outcomes reported in epidemiologic studies. Given this concern, the Administrator does not think that recent epidemiologic studies reporting health effect associations at $PM_{2.5}$ air

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https://yosemite.epa.gov/sab/sabproduct.nsf/71AC3DD0F61B5D178525849B0046580F/$File/ISEE-10-22-19-CASACstatement.pdf.

[13] USEPA, Health and Environmental Effects of Particulate Matter (PM) webpage. https://www.epa.gov/pm-pollution/health-and-environmental-effects-particulate-matter-pm.

[14] Di, Q, Wang, Y, Zanobetti, A, Wang, Y, Koutrakis, P, Choirat, C, Dominici, F and Schwartz, JD (2017). "Air pollution and mortality in the Medicare population." New England Journal of Medicine 376(26): 2513-2522 Available at: https://www.nejm.org/doi/full/10.1056/NEJMoa1702747.

> quality concentrations likely to have met the current primary standards support revising those standards. Rather, he judges that the overall body of evidence, including controlled human exposure and animal toxicological studies, in addition to epidemiologic studies, indicates continuing uncertainty in the degree to which adverse effects could result from $PM_{2.5}$ exposures in areas meeting the current annual and 24-hour standards. (page 21420)

This conclusion is in direct contradiction to the ISA evaluation of the degree to which uncertainty issues have been addressed by recent studies. Based on its assessment of currently available studies, the ISA concludes that positive associations between long-term $PM_{2.5}$ exposures and mortality are robust across studies with a variety of study designs, approaches to estimating $PM_{2.5}$ exposures, analyses of co-pollutants, approaches to controlling for confounders, geographic regions and populations, and temporal periods.[15]

Studies published since the ISA was compiled provide further substantial support of the causal relationship between low level $PM_{2.5}$ exposure and mortality. A list of such studies is attached to these comments. These publications include a recent EPA study that evaluated the impact of incremental exposure to 1 $\mu g/m^3$ of $PM_{2.5}$ on the mortality rate for people with heart failure, adjusting for age, race, sex, distance to the nearest air pollution monitor, and socioeconomic status indicators. The study concluded that, "*(e)levated $PM_{2.5}$ exposures result in substantial years of life lost even at concentrations below current national standards*."[16]

The compressed NAAQS review schedule, which, as discussed above, allowed for only one draft of the ISA and PA, contributed to the lack of consideration of these studies. The Clean Air Act clearly requires that "*(a)ir quality criteria for an air pollutant shall accurately reflect the latest scientific knowledge useful in indicating the kind and extent of all identifiable effects on public health or welfare which may be expected from the presence of such pollutant in the ambient air*." (Clean Air Act, 42 U.S.C. §7408(a)(2)). Therefore, EPA should thoroughly assess all relevant recent studies not evaluated in the ISA, including those on the attached list, and publish a

[15] USEPA Office of Research and Development, "Integrated Science Assessment for Particulate Matter," Chapter 11, December 2019, EPA/660/R-19/188. Available at: https://cfpub.epa.gov/ncea/isa/recordisplay.cfm?deid=347534#tab-3.

[16] Ward-Caviness C, AM Weaver, M Buranosky, ER Pfaff, LM Neas, RB Devlin, J Schwartz, Q Di, WE Cascio, D Diaz-Sanchez. 2020. Associations Between Long-Term Fine Particulate Matter Exposure and Mortality in Heart Failure Patients. Journal of the American Heart Association. 2020;9. https://www.ahajournals.org/doi/10.1161/JAHA.119.012517.

Provisional Assessment of Recent Studies prior to finalization of the PM NAAQS decision, as has been done in previous PM reviews.[17,18]

The issue is further addressed in the testimony of Elizabeth A. Sheppard, Ph.D. at the October 2019 CASAC meeting. Dr. Sheppard is a Professor in the Departments of Biostatistics and Environmental and Occupational Health Sciences at the University of Washington, a former member of the chartered CASAC and of several CASAC NAAQS review panels, and a member of the IPMRP. In her testimony, Dr. Sheppard stated the following:

> Most, but far from all the weight of evidence for $PM_{2.5}$ health effects comes from epidemiologic studies. The epidemiologic evidence is vast, particularly in terms of the geographic domain and number of subjects included; it provides an overall consistent scientific basis, supported by coherence with controlled human and toxicological studies, for finding that the current primary $PM_{2.5}$ standards are not protective of public health. All these studies have been conducted and analyzed using accepted scientific methods.
> …
> In fact, requiring a hazard assessment to be conducted at typical exposure levels will often require enormous sample sizes and thus will mandate unaffordable human exposure or animal toxicological studies.[19]

The Administrator's decision to disregard the wealth of epidemiological study data available, in concert with data from supporting studies, in setting a primary $PM_{2.5}$ NAAQS is inconsistent with the weight of evidence based scientific framework that has long been used in regulatory decisions. By requiring untenable experimental studies, EPA is establishing an unattainable burden of proof that seriously hamstrings informed public health decisions, including the setting of protective NAAQS.

Conclusion

The Administrator should reverse his proposed decision to retain the PM NAAQS and follow expert recommendations to promulgate an annual average $PM_{2.5}$ NAAQS that is no higher than 10 $\mu g/m^3$ in order to provide the level of public health protection intended by the Clean Air Act. In addition, the Administrator should adopt 24-hour primary $PM_{2.5}$ NAAQS that is no higher

[17] USEPA Office of Research & Development, "Provisional Assessment of Recent Studies on Health Effects of Particulate Matter Exposure," July 2006, EPA/600/R-06/063. Available at: https://cfpub.epa.gov/ncea/risk/recordisplay.cfm?deid=151826.
[18] USEPA Office of Research & Development, "Provisional Assessment of Recent Studies on Health Effects of Particulate Matter Exposure," December 2012, EPA/600/R-12/056F. Available at; https://www3.epa.gov/ttn/naaqs/standards/pm/data/20121213psa.pdf.
[19] Testimony of Elizabeth A. Sheppard, Ph.D., to the October 22, 2019 Public Teleconference of the Chartered Clean Air Scientific Advisory Committee (CASAC) on Particulate Matter. Available at: https://yosemite.epa.gov/sab/sabproduct.nsf/2BB1EC27AAA58C558525849B006E848C/$File/Sheppard+Oral+Comments.pdf.

than 30 µg/m^3 to protect public health in locations where the 24-hour standard is controlling. The NESCAUM states rely on EPA to establish NAAQS that are protective of public health and welfare, and national standards are especially important for pollutants like $PM_{2.5}$, which have a large regional component influenced by interstate pollutant transport.

Despite a highly compressed schedule, EPA staff prepared comprehensive ISA and PA documents. However, review and revision of those documents were hampered both by the compressed schedule, which prevented a complete review of drafts of those documents in sequence, and the lack of continuity in knowledge among the CASAC membership caused by EPA's replacement of the entire CASAC and abrupt dismissal of the CASAC PM review panel prior to issuance of the ISA. EPA should act on the recommendations from the IPMRP, which is composed of highly qualified and experienced scientists representing the areas of expertise necessary for a comprehensive review of the issues in those documents, and has the continuity of CASAC knowledge that the current CASAC lacks.

The Administrator's decision to retain the current PM NAAQS contradicts clear evidence documented in the ISA and PA of serious public health effects, including premature mortality, at $PM_{2.5}$ levels below the current annual average standard for that pollutant. The failure to establish an appropriate $PM_{2.5}$ NAAQS jeopardizes the public's health. Further, the Administrator's justification of this flawed decision, which deviates sharply from EPA's long standing regulatory framework and requires an unattainable burden of proof, has serious implications for future public health decision-making.

The Administrator's decision to retain the current $PM_{2.5}$ NAAQS is not protective of public health and does not comport with the informed decision-making requirements of the Clean Air Act. As such, it must be withdrawn.

Sincerely,

Paul J. Miller
Executive Director

Attachment: Listing of Recent Causal Particulate Matter Mortality Studies

cc: NESCAUM Directors
NESCAUM Air Toxics and Public Health Committee
NESCAUM Attainment Planning Committee
Lynne Hamjian, EPA R1
Richard Ruvo, EPA R2

Recent Causal Particulate Matter Mortality Studies

Full articles have been submitted to the docket separately.

Recent causality studies not included in the Integrated Science Assessment (ISA) and Policy Assessment (PA)

Abu Awad Y, Q Di, Y Wang, X Choirat, B Coull, A Zanobetti, J Schwartz. 2019. Change in PM2.5 exposure and mortality among Medicare recipients. Environmental Epidemiology 3:e054. doi: 10.1097/EE9.0000000000000054. https://journals.lww.com/environepidem/Fulltext/2019/08000/Change_in_PM2_5_exposure_and_mortality_among.2.aspx

We consider the sub-population of Medicare enrollees who moved residence from one ZIP Code to another from 2000 to 2012. We used Cox proportional hazards models stratified on original ZIP Code with inverse probability weights (IPW) to control for individual and ecological confounders at the new ZIP Code. The distribution of covariates appeared to be randomized by change in exposure at the new locations as standardized differences were mostly near zero. Using IPW, per 10 µg/m3 increase in PM2.5, the hazard ratio was 1.21 (95% confidence interval [CI] = 1.20, 1.22] among whites and 1.12 (95% CI = 1.08, 1.15) among blacks. This study provides evidence of likely causal effects at concentrations below current limits of PM2.5.

Bennett JE, H Tamura-Wicks H, RM Parks, RT Burnett, CA Pope 3rd, MJ Bechle, et al. 2019. Particulate matter air pollution and national and county life expectancy loss in the USA: A spatiotemporal analysis. PLoS Med 16(7): e1002856https://doi.org/10.1371/journal.pmed.1002856

We used four Bayesian spatiotemporal models, with different adjustments for other determinants of mortality, to directly estimate mortality and life expectancy loss due to current PM2.5 pollution and the benefits of reductions since 1999, nationally and by county.

Carone M, F Dominici, L Sheppard. 2020. In Pursuit of Evidence in Air Pollution Epidemiology, Epidemiology: 31(1): 1-6. doi: 10.1097/EDE.0000000000001090. https://journals.lww.com/epidem/Fulltext/2020/01000/In_Pursuit_of_Evidence_in_Air_Pollution.1.aspx

In our view, causal inference methods should not be used as another opportunity to weaponize science against itself. Policymakers cannot wait for the data, study designs, and analytic tools that will ensure unarguable causal inferences: stalling until perfect evidence arises is irresponsible and does not protect public health.

Corrigan AE, MM Becker, LM Neas, WE Cascio, AG Rappold. 2018. Fine particulate matters: the impact of air quality standards on cardiovascular mortality. Environ Res 161:364–69. https://doi.org/10.1016/j.envres.2017.11.025
We examined the change in cardiovascular (CV) mortality rate and the association between change in PM2.5 and change in CV-mortality rate before (2000–2004) and after implementation of the 1997 annual PM2.5 NAAQS (2005–2010) among U.S. counties. We further examined how the association varied with respect to two factors related to NAAQS compliance: attainment status and design values (DV). We used difference-in-differences and linear regression models, adjusted for sociodemographic confounders.

Danesh Yazdi M, Y Wang, Q Di, A Zanobetti, J Schwartz. 2019. Long-term exposure to PM2.5 and ozone and hospital admissions of Medicare participants in the southeast USA. Environ Int 130:104879. https://doi.org/10.1016/j.envint.2019.05.073
We examined the association between average annual fine particulate matter ($PM_{2.5}$) and ozone and first hospital admissions of Medicare participants for stroke, chronic obstructive pulmonary disease (COPD), pneumonia, myocardial infarction (MI), lung cancer, and heart failure (HF). Annual average $PM_{2.5}$ and ozone levels were estimated using high-resolution spatio-temporal models. We fit a marginal structural Cox proportional hazards model, using stabilized inverse probability weights (IPWs) to account for the competing risk of death and confounding. Analyses were then repeated after restricting to exposure levels below the current U.S. standards. The results showed that $PM_{2.5}$ was significantly associated with an increased hazard of admissions for all studied outcomes; the highest observed being a 6.1% (95% CI: 5.9%–6.2%) increase in the hazard of admissions with pneumonia for each $\mu g/m^3$ increase in particulate levels. The hazard of pneumonia increased by 3.0% (95% CI: 2.9%–3.1%) for each ppb increase in the ozone level. Our results reveal a need to regulate long-term ozone exposure, and that associations persist below current $PM_{2.5}$ standards.

Dominici F, C Zigler. 2017. Best practices for gauging evidence of causality in air pollution epidemiology. American Journal of Epidemiology 186(12): 1303–1309, https://doi.org/10.1093/aje/kwx307
Using 3 prominent air pollution studies as examples, we review good practices for how to critically evaluate the extent to which an air pollution study provides evidence of causality. We argue that evidence of causality should be gauged by a critical evaluation of design decisions such as 1) what actions or exposure levels are being compared, 2) whether an adequate comparison group was constructed, and 3) how closely these design decisions approximate an idealized randomized study.

Henneman LRF, C Choirat, C Zigler, M Corwin. 2019. Accountability Assessment of Health Improvements in the United States Associated with Reduced Coal Emissions Between 2005 and 2012, Epidemiology: July 2019 - Volume 30 - Issue 4 - p 477-485 doi: 10.1097/EDE.0000000000001024, https://journals.lww.com/epidem/Abstract/2019/07000/Accountability_Assessment_of_Health_Improvements.3.aspx
We associate changes in 10 health outcome rates among approximately 30 million US Medicare beneficiaries with exposure changes between 2005 and 2012 using two difference-in-difference regression approaches designed to mitigate observed and unobserved confounding. Rates per 10,000 person–years of six cardiac and respiratory health outcomes—all cardiovascular disease, chronic obstructive pulmonary disorder, cardiovascular stroke, heart failure, ischemic heart disease, and respiratory tract infections—decreased by between 7.89 and 1.95 per μg/m^3decrease in PM2.5, with comparable decreases in coal exposure leading to slightly larger rate decreases.

Higbee JD. JS Lefler, RT Burnett, M Ezzati, JD Marshall, S-Y Kim, M Bechle, AL Robinson, CA Pope 3rd. 2020. Estimating long-term pollution exposure effects through inverse probability weighting methods with Cox proportional hazards models. Environmental Epidemiology 4(2): e085. doi: 10.1097/EE9.0000000000000085.
https://journals.lww.com/environepidem/FullText/2020/04000/Estimating_long_term_pollution_exposure_effects.5.aspx
Twenty-nine years of data from the National Health Interview Survey was compiled and linked to modeled annual average outdoor $PM_{2.5}$ concentration and restricted-use mortality data. A series of Cox proportional hazards models, adjusted using inverse probability weights, yielded causal risk estimates of long-term exposure to ambient $PM_{2.5}$ on all-cause and cardiopulmonary mortality.

Liu C, Chen R, F Sera, AM Vicedo-Cabrera, Y Guo, S Tong, et al. 2019. Ambient particulate air pollution and daily mortality in 652 cities. New Engl J Med 381:705-715.
https://www.nejm.org/doi/10.1056/NEJMoa1817364
We evaluated the associations of inhalable particulate matter (PM) with an aerodynamic diameter of 10 μm or less (PM_{10}) and fine PM with an aerodynamic diameter of 2.5 μm or less ($PM_{2.5}$) with daily all-cause, cardiovascular, and respiratory mortality across multiple countries or regions. The pooled concentration-response curves showed a consistent increase in daily mortality with increasing PM concentration, with steeper slopes at lower PM concentrations.

Miles CH, J Schwartz, EJ Tchetgen Tchetgen. 2018. A class of semiparametric tests of treatment effect robust to confounder classical measurement error. Statistics in Medicine, 37(24):3403-3416. doi: 10.1002/sim.7852. Epub 2018 Jun 25.
https://onlinelibrary.wiley.com/doi/abs/10.1002/sim.7852
We develop a large class of semiparametric test statistics of an exposure causal effect which are completely robust to additive unbiased measurement error of a subset of confounders.

Pope, A, JS Lefler, M Ezzati, JD Higbee, JD Marshall, S-Y Kim, M Bechle, et al. 2019. Mortality risk and fine particulate air pollution in a large, representative cohort of U.S. sdults. Environmental Health Perspectives 127(7): 077007. https://ehp.niehs.nih.gov/doi/10.1289/ehp4438
Cox proportional hazards models were used to estimate PM2.5–mortality hazard ratios for all-cause and specific causes of death while controlling for individual risk factors and regional and urban versus rural differences. In general, PM2.5–mortality associations were consistently positive for all-cause and cardiopulmonary mortality across key modeling choices and across subgroups of sex, age, race-ethnicity, income, education levels, and geographic regions.

Qiu X, Y Wei, Y Wang, Q Di, T Sofer, J Schwartz. 2020. Inverse probability weighted distributed lag effects of short-term exposure to PM2.5 and ozone on CVD hospitalizations in New England Medicare participants - exploring the causal effects. Environmental Research 182:109095. https://doi.org/10.1016/j.envres.2019.109095
Application of causal distributed lag modeling showed harmful effects of short-term $PM_{2.5}$ exposure on CVD hospitalizations in a causal way among elderly population. Each 10 $\mu g/m^3$ increase in lag0-lag5 cumulative $PM_{2.5}$ exposure on average increased the AMI, CHF, IS hospital admission rate by 4.3%, 3.9% and 2.6% among New England Medicare participants.

Sanders NJ, AI Barreca. MJ Neidell. 2020. Estimating causal effects of particulate matter regulation on mortality. Epidemiology 31(2):160-167. doi: 10.1097/EDE.0000000000001153. https://journals.lww.com/epidem/Abstract/2020/03000/Estimating_Causal_Effects_of_Particulate_Matter.2.aspx
Based on estimates from log-linear difference-in-differences models, our results indicate after the CAAA designation for PM2.5 in 2005, PM2.5 levels decreased 1.59 $\mu g/m^3$ (95% CI = 1.39, 1.80) and mortality rates among those 65 and older decreased by 0.93% (95% CI = 0.10%, 1.77%) in nonattainment counties, relative to attainment ones. Results are robust to a series of alternate models, including nearest-neighbor matching based on propensity score estimates.

Schwartz JD, Y Wang, I Kloog, M Yitshak-Sade, F Dominici, A Zanobetti. 2018. Estimating the effects of PM 2.5 on life expectancy using causal modeling methods. Environmental Health Perspectives 126(12): 127002. https://ehp.niehs.nih.gov/doi/10.1289/EHP3130
We derived nonparametric estimates of the distribution of life expectancy as a function of PM2.5 using data from 16,965,154 Medicare beneficiaries in the Northeastern and mid-Atlantic region states (129,341,959 person-years of follow-up and 6,334,905 deaths). The estimated mean age at death for a population with an annual average PM2.5 exposure of 12 $\mu g/m^3$ (the 2012 National Ambient Air Quality Standard) was 0.89 years less (95% CI: 0.88, 0.91) than estimated for a counterfactual PM2.5 exposure of 7.5 $\mu g/m^3$.

Schwartz J, K Fong, A Zanobetti. 2018. A national multicity analysis of the causal effect of local pollution, NO_2, and PM2.5 on mortality. Environmental Health Perspectives 126, (8): 087004. https://ehp.niehs.nih.gov/doi/10.1289/EHP2732
We used three methods which, under different assumptions, provide causal marginal estimates of effect: a marginal structural model, an instrumental variable analysis, and a negative exposure control. Causal-modeling techniques, each subject to different assumptions, demonstrated causal effects of locally generated pollutants on daily deaths with effects at concentrations below the current EPA daily PM2.5 standard.

Vodonos A, Y Abu Awad, J Schwartz. 2018. The concentration-response between long-term $PM_{2.5}$ exposure and mortality; A meta-regression approach. Environmental Research 166:677-689. https://doi.org/10.1016/j.envres.2018.06.021
We systematically searched all published cohort studies examining the association between long term exposure to $PM_{2.5}$ and mortality. We applied multivariate linear random effects meta-analysis with random effects for cohort, and study within cohort. Meta-regression techniques were used to test whether study population or analytic characteristics modify the $PM_{2.5}$ -mortality association and to estimate the shape of the concentration-response curve.

Ward-Caviness C, AM Weaver, M Buranosky, ER Pfaff, LM Neas, RB Devlin, J Schwartz, Q Di, WE Cascio, D Diaz-Sanchez. 2020. Associations Between Long-Term Fine Particulate Matter Exposure and Mortality in Heart Failure Patients. Journal of the American Heart Association. 2020;9. https://www.ahajournals.org/doi/10.1161/JAHA.119.012517
We used Cox proportional hazards models to evaluate the association of annual average fine particulate matter (PM2.5) exposure at the time of initial heart failure diagnosis with all-cause mortality, adjusted for age, race, sex, distance to the nearest air pollution monitor, and socioeconomic status indicators. Elevated PM2.5 exposures result in substantial years of life lost even at concentrations below current national standards.

Wei Y, Y Wang, X Wu, Q Di, L Shi, P Koutrakis, et al. 2020. Causal effects of air pollution in Massachusetts. Am J Epidemiol kwaa098, https://doi.org/10.1093/aje/kwaa098
Implementing a generalized propensity score adjustment approach with 3.8 billion person-days of follow-up, we simultaneously assessed causal associations of long- (one-year moving average) and short-term (two-day moving average) PM2.5, O3, and NO2 exposures with all-cause mortality on additive scale among Medicare beneficiaries in Massachusetts, 2000–2012. We found long- and short-term PM2.5, O3, and NO2 were all associated with increased mortality risk. Mortality associated with long-term PM2.5 and O3 increased substantially at low levels. The findings suggest air pollution was causally associated with mortality, even at levels below national standards.

Wu X, D Braun, MA Kioumourtzoglou, C Choirat, Q Di, F Dominici. 2019. Causal inference in the context of an error prone exposure: air pollution and mortality. Ann Appl Stat 13:520-547. doi: 10.1214/18-AOAS1206. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6812524/
We propose a new approach for estimating causal effects when the exposure is measured with error and confounding adjustment is performed via a generalized propensity score (GPS). Using validation data, we propose a regression calibration (RC)-based adjustment for a continuous error-prone exposure combined with GPS to adjust for confounding (RC-GPS). Under assumptions of noninterference and weak unconfoundedness, using matching we found that exposure to moderate levels of PM2.5 (8 < PM2.5 ≤ 10 μg/m3) causes a 2.8% (95% CI: 0.6%, 3.6%) increase in all-cause mortality compared to low exposure (PM2.5 ≤ 8 μg/m3).

Wu X, D Braun, J Schwartz, MA Kioumourtzoglou, F Dominci. 2020. Evaluating the impact of long-term exposure to fine particulate matter on mortality among the elderly. Science Advances 26 Jun 2020: eaba5692. DOI: 10.1126/sciadv.aba5692.
https://advances.sciencemag.org/content/early/2020/06/26/sciadv.aba5692
Leveraging 16 years of data—68.5 million Medicare enrollees and 570 million observations—we provide strong evidence of the causal link between long-term $PM_{2.5}$ exposure and mortality under a set of assumptions necessary for causal inference. Using five distinct statistical approaches, we found that a decrease of 10 $\mu g/m^3$ $PM_{2.5}$ leads to a statistically significant 6%–7% decrease in mortality risk. Based on these models, lowering the air quality standard to 10 $\mu g/m^3$ would save 143,257 lives (95% confidence interval 115,581–170,645) in one decade.

Yitshak-Sade M, R Nethery, Y Abu Awad, F Mealli, F Dominici, I Kloog, et al. 2020. Lowering air pollution levels in Massachusetts may prevent cardiovascular hospital admissions. J Am Coll Cardiol 75:2642-2644.
https://www.sciencedirect.com/science/article/abs/pii/S0735109720347495
We estimated the number of cause-specific CVD hospital admissions—all CVD, myocardial infarction, ischemic stroke, and congestive heart failure—attributable to high levels of 2-day exposure to PM2.5 using a causal modeling approach. We found significant numbers of CVD admissions among the elderly population in Massachusetts that were attributable to short-term exposure to PM2.5.

Yitshak-Sade M, I Kloog, A Zanobetti, JD Schwartz. 2019. Estimating the causal effect of annual PM2.5 exposure on mortality rates in the Northeastern and mid-Atlantic states. Environmental Epidemiology 3(4): e052.
https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6693936/
We obtained records of Medicare beneficiaries 65 years of age or more who reside in the Northeastern or mid-Atlantic states from 2000 to 2013 and followed each participant from the year of enrollment to the last year of follow-up. We estimated the causal effect of annual $PM_{2.5}$ exposure on mortality rates using the difference-in-differences approach in the Poisson survival analysis. We controlled for individual confounders, for spatial differences using dummy variables for each ZIP code and for time trends using a penalized spline of year. The interquartile range (IQR) of the annual $PM_{2.5}$ concentration was 3 $\mu g/m^3$, and the mean annual $PM_{2.5}$ concentration ranged between 6.5 and 14.5 $\mu g/m^3$ during the study period. An IQR

incremental increase in $PM_{2.5}$ was associated with a 4.04% increase (95% CI = 3.49%, 4.59%) in mortality rates.

Zigler CM, C Choira, F Dominici. 2018. Impact of National Ambient Air Quality Standards nonattainment designations on particulate pollution and health. Epidemiology 29(2):165-172. doi: 10.1097/EE9.0000000000000052.
https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5792368/
We employ causal inference methods and a spatial hierarchical regression model to characterize the extent to which a designation of "nonattainment" with the 1997 National Ambient Air Quality Standard for ambient fine particulate matter (PM2.5) in 2005 causally affected ambient PM2.5 and health outcomes among over 10 million Medicare beneficiaries in the Eastern US in 2009–2012.

Causality study cited in the ISA, but not in PA

Makar M, J Antonelli, Q Di, D Cutler, J Schwartz, F Dominici. 2017. Estimating the causal effect of fine particulate matter levels on death and hospitalization: are levels below the safety standards Harmful? Epidemiology 28(5): 627-634. doi: 10.1097/EDE.0000000000000690.
https://journals.lww.com/epidem/Abstract/2017/09000/Estimating_the_Causal_Effect_of_Low_Levels_of_Fine.1.aspx
We constructed a cohort of 32,119 Medicare beneficiaries residing in 5138 US ZIP codes who were interviewed as part of the Medicare Current Beneficiary Survey (MCBS) between 2002 and 2010 and had 1 year of follow-up. We found that increasing exposure to $PM_{2.5}$ from levels lower than 12 $\mu g/m^3$ to levels higher than 12 $\mu g/m^3$ is associated with increases in all-cause admission rates of 7% (95% CI = 3%, 10%) and in circulatory admission hazard rates of 6% (95% CI = 2%, 9%). When we restricted analysis to enrollees with exposure always lower than 12 $\mu g/m^3$, we found that increasing exposure from levels lower than 8 $\mu g/m^3$ to levels higher than 8 $\mu g/m^3$ increased all-cause admission hazard rates by 15% (95% CI = 8%, 23%), circulatory by 18% (95% CI = 10%, 27%), and respiratory by 21% (95% CI = 9%, 34%).

Recent causality studies referenced in the final ISA and PA

Schwartz J, M-A Bind, P Koutrakis. 2017. Estimating causal effects of local air pollution on daily deaths: effect of low levels. Environmental Health Perspectives 125(1): 23-29.
https://ehp.niehs.nih.gov/doi/full/10.1289/EHP232
Using an instrumental variable approach, we developed an instrument for variations in local pollution concentrations that is unlikely to be correlated with other causes of death, and examined its association with daily deaths in the Boston, Massachusetts, area. We also used Granger causality to assess whether omitted variable confounding existed.

Schwartz J, E Austin, M-A Bind, A Zanobetti, P Koutrakis. 2015. Estimating causal associations of fine particles with daily deaths in Boston. American Journal of Epidemiology 182(7): 644-650. https://doi.org/10.1093/aje/kwv101
Author's response to comments: Schwartz J, P Koutrakis, M-A Bind. 2016. Three authors reply. American Journal of Epidemiology 183(6):595-596. https://doi.org/10.1093/aje/kww024
We used an instrumental variable approach, including back trajectories as instruments for variations in PM2.5 uncorrelated with other predictors of death. We also used propensity score as an alternative causal modeling analysis. We found a causal association of $PM_{2.5}$ *with mortality, with a 0.53% (95% confidence interval: 0.09, 0.97) and a 0.50% (95% confidence interval: 0.20, 0.80) increase in daily deaths using the instrumental variable and the propensity score, respectively.*

Wang Y, I Kloog, BA Coull, A Kosheleva, Aa Zanobetti, JD Schwartz. 2016. Estimating causal effects of long-term PM2. 5 exposure on mortality in New Jersey. Environmental Health Perspectives 124(8): 1182-1188. https://ehp.niehs.nih.gov/doi/full/10.1289/ehp.1409671
We applied a variant of the difference-in-differences approach, which serves to approximate random assignment of exposure across the population and hence estimate a causal effect. Under the assumption of the difference-in-differences approach, we identified a causal effect of long-term PM2.5 exposure on mortality that was modified by seasonal temperatures and ecological socioeconomic status.

Wang Y, M Lee, P Liu, L Shi, Z Yu, Y Abu Awad, A Zanobetti, JD Schwartz,. (2017). Doubly Robust Additive Hazards Models to Estimate Effects of a Continuous Exposure on Survival. *Epidemiology (Cambridge, Mass.)*, *28*(6), 771–779. https://doi.org/10.1097/EDE.0000000000000742
The proposed approaches improve the robustness of the additive hazards model and produce a novel additive causal estimate of PM2.5 on survival and several additive effect modifications, including social inequality.