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Published Version

Goodman, P., McGillicuddy, E. J., Harrison, R. G. ORCID: https://orcid.org/0000-0003-0693-347X, Rich, D. Q. and Scott, J. A. (2024) Historical research on aerosol number concentrations, classifications of air pollution severity and particle retention: lessons for present day researchers. Air, 2 (4). pp. 439-443. ISSN 2813-4168 doi: https://doi.org/10.3390/air2040025 Available at https://centaur.reading.ac.uk/119772/

To link to this article DOI: http://dx.doi.org/10.3390/air2040025

Publisher: MDPI

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Opinion

Historical Research on Aerosol Number Concentrations, Classifications of Air Pollution Severity and Particle Retention: Lessons for Present-Day Researchers

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Abstract: Research into the adverse health effects of air pollution exposure has repeatedly considered smaller particles, to the point where particle number concentration might be a more relevant metric than mass concentration. Here, we highlight some historical research which developed metrics for air pollution severity based on particle number concentration. Because this work was published in a national journal and prior to the internet and open access, this historical research is not easy to find, and it was more through the history of the aerosol research community in Ireland that this work is now being presented. Multiple online searches for published research papers on "particle number concentrations" and "air pollution severity" were undertaken. Even when specific searches were undertaken using the author names and publication year, these featured papers were not found on any internet search. O'Dea and O'Connor proposed that air pollution severity could be classified based on particle number concentration of condensation nuclei, with 'little' air pollution <50 × 10^3 particles per cm^3, 'mean' 50–70 × 10^3 particles per cm^3, 'strong' 70–100 × 10^3 particles per cm^3, and 'very strong' >100 × 10^3 particles per cm^3. Applying their assumptions on density and mean particle size, equated to mass concentrations for a mean of 6 μgm^{-3}, strong at 8.5 μgm^{-3}, and very strong >10 μgm^{-3}. These are consistent with the current WHO guideline values for $PM_{2.5}$. Additionally, we highlight the 1955 work by Burke and Nolan on the retention of inhaled particles, where ~40% of the inhaled number concentration is retained in the respiratory system. This is also consistent with the more recently published work on particle retention. In summary, the proposed categories of pollution severity, based on number concentrations, could form a basis for the development of future guidelines. This paper highlights that sometimes research has already been published, but it is difficult to find. We challenge researchers to find publications from their own countries which pre-date the WWW to inform current and future research. Additionally, there is scope for a repository for such information on historical publications. We have presented historical research on aerosol number concentrations, classifications of air pollution severity, and particle retention, which present lessons for current researchers.

Keywords: ppollution classification; aerosol concentration; particle retention

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Citation: Goodman, P.; McGillicuddy, E.J.; Harrison, R.G.; Rich, D.Q.; Scott, J.A. Historical Research on Aerosol Number Concentrations, Classifications of Air Pollution Severity and Particle Retention: Lessons for Present-Day Researchers. *Air* **2024**, *2*, 439–443. https://doi.org/10.3390/air2040025

Academic Editor: Ling Tim Wong

Received: 18 October 2024
Revised: 27 November 2024
Accepted: 29 November 2024
Published: 6 December 2024

1. Background to This Paper

The advent of the internet, and more recently the rollout of "open access" journals, has made it easier for researchers all over the world to access research data and to be informed. However, one downside of this is that one can often be overwhelmed by the volume of available published research. It is not possible to reference every single paper on a research topic, and thus researchers are often missing important historical publications.

Another downside of the availability of published research on the internet is that if research was published in national journals, particularly before about 1990, it may not appear on internet searches.

Here, some examples of research related to aerosols/condensation nuclei concentrations and particle retention from historical work published in Ireland are presented. The publications featured are not readily available on the internet. In highlighting this work, the aim is to alert researchers that there is a large body of research that we, and they, may be missing, by solely performing an internet search. We invite other researchers to explore the historical data from within their own countries and research groups.

2. Introduction

Air quality research in Ireland can trace its origins directly back to John Aitken. However, their work has been overlooked, not deliberately, but because the research is difficult to find.

John McClelland worked with Aitken in the United Kingdom and then returned to Ireland where he established the air research group in Dublin. This is outlined by O'Connor [1] in Chapter 4 of "Aerosol Science and Technology: History and reviews" edited by David Ensor 2011 [1] (See Figure 1).

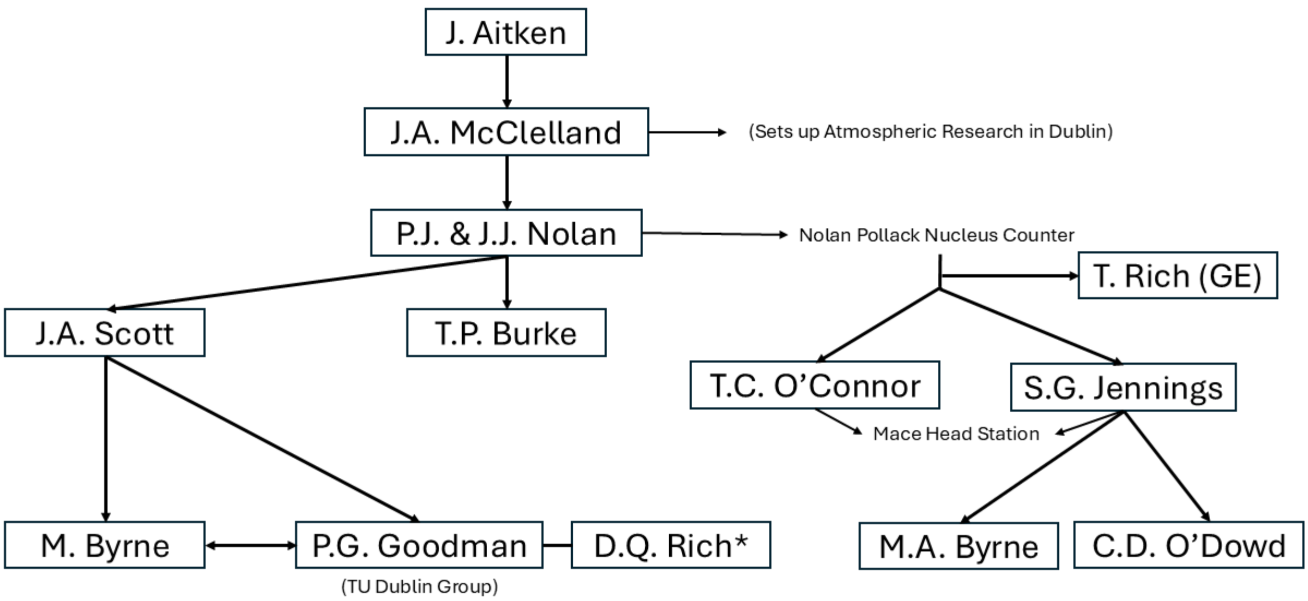

Figure 1. Historical Schematic.

The interest in air pollution and its impact on health is not new. Brimblecombe [2] gives an interesting account of historical references to air pollution and its adverse health effects, going back over many centuries. In recent years, the World Health Organization (WHO), the United States Environmental Protection Agency (USEPA), and the European Union (EU) [3–5] all provide limit values, national ambient air quality standards, or guidelines for ambient particle concentrations in units of $\mu g/m^3$. Initially, particles were measured by a system known as the "Black Smoke" method [6], where the size cut-off was 4.5 µm [7]. More recently, air pollution levels are presented as the mass concentrations in micrograms m^{-3} for the size fractions PM_{10} (particulate matter < 10 µm in aerodynamic diameter) and $PM_{2.5}$ (<2.5 µm) [3–5].

From a population health perspective, Dockery and Pope [8] suggest that the adverse health effects of ambient air pollution exposure are associated with $PM_{2.5}$. This raises the question as to whether the mass concentration of particles is the most appropriate metric to use. Recently Thém and Salma [9] have highlighted this very fact, where they have reviewed the evidence and suggest that particle number concentrations might be more relevant. Oberdöster et al. [10] have also reviewed and highlighted the importance of particle numbers and toxicity from a health research perspective. This is where the historical work becomes relevant, as it has not featured in any of the key publications in this area.

It is fortunate that due to the relatively close-knit air quality research community in Ireland, researchers are familiar with some of the historical research work. O'Dea and O'Connor (1984) [11] proposed a classification of the severity of air pollution based on particle number concentrations. Because this publication was in an Irish journal, and because it effectively predates the WWW, it is not readily found on any internet search.

3. Methodology

We used Web of Science, SOCPUS, PUBMED, and Google Scholar to search for relevant publications. We used the search terms "particle number concentration" AND "air pollution", which failed to find O'Dea and O'Connor (1984) [11], or any paper which referenced their work. The same internet search approach was used in relation to Burke and Nolan (1955) [12], where "particle retention" and "particle deposition" were used as search terms. These failed to find Burke and Nolan (1955) [12] or any paper which referenced this work. O'Dea and O Connor (1984) [11] proposed the following air pollution classification;

In addition to suggested classifications of particulate air pollution based on particle number concentrations, O'Dea and O'Connor (1984) [11] also provided an estimate of particle mass concentration, using a density of 1 g/cm^3. O'Dea and O'Connor considered an "average" particle of radius, r = 3 × 10^{-8} m. This gives an average particle volume of ~1 × 10^{-22} m^3. Then, applying the density of 1 g/cm^3 as proposed by O'Dea and O'Connor, this gives an average particle a mass of ~1 × 10^{-19} kg. This is the mass per particle we used to calculate the mass in µm^{-3}, taking the midpoint number of particles, from the particle number concentrations for each category as proposed by O'Dea and O'Connor and in Table 1 [11].

Table 1. Aerosol number concentration and pollution severity from O'Dea and O'Connor (1984) [11].

Particle Number Concentration (Particles/cm^3)	Degree of Pollution
<50	Little
50–70	Mean
70–100	Strong
>100	Very strong

This gives approximate mass values of concentrations for 'mean' at 6 µg/m^3, 'strong' at 8.5 µg/m^3, and 'very strong' at >10 µg/m^3. These are consistent with the current WHO guideline values for $PM_{2.5}$ [3].

4. Discussion

In Table 2, the classifications of particle number concentrations related to the type of location being monitored are presented. The suggestions of O'Dea and O'Connor (1984) [11] are compared with the more recent work by Morawska et al. (2009) [13], which they based on data from a review of multiple studies. There is consistency between the work of the two papers. Furthermore, Morawska et al. (1999) [14] report that mean densities of particles typically vary between about 1.2 and 1.8 g/cm^3. However, even making calculations based on these values still yields results that are close to the WHO guideline values and consistent with those from O'Dea and O'Connor (1984) [11].

Table 2. Aerosol number concentration and classification of the region, comparison of the O'Dea and O'Connor with that of Morawska et al.

O'Dea and O'Connor (1984) [11]		Morawska et al. (2009) [13]	
Identification	**Particle Number Concentration (Particles/cm³)**	**Identification**	**Particle Number Concentration (Particles/cm³)**
Remote unpopulated	3000	Rural	3000
		Clean background	3000
Rural sparsely populated	10,000	Urban background	9000
Surburban residential	30,000		
Urban residential light commercial	50,000	Roadside	46,000
Urban commercial industry	100,000	Road tunnel	100,000
City center heavy industry	700,000		

We also considered a second paper which discussed particle deposition in the human lungs [12]. We again used the same internet search tools and methodology. This paper by Burke and Nolan [12] on entrapment of aerosols within the human respiratory tract reported a difference of ~40% in the number of particles in the air inhaled compared to the number exhaled. However, Morawska et al. (2005) also reported a mean retention of particle numbers in the respiratory tract of 40% [15]. This again highlights that the earlier work, which is not found on internet searches, is consistent with current research values. Chalupa et al. (2004) [16] report even higher retention during exercise in asthmatics, but again do not mention the work of Burke and Nolan (1955) [12].

What we have highlighted here is that previous research, published before the internet (WWW), proposed classification of air quality, based on particle number concentrations. The classifications based on particle number concentrations, and the type of monitoring location, such as remote, urban background, etc., as proposed by O'Dea and O'Connor (1984) [11] are very consistent with the work of Morawaska et al. [13] (2009) (Table 2).

From a health perspective, particle retention work by Burke and Nolan (1955) [12] is again consistent with more recent research conducted 50 years later [15,16]. We have reviewed many publications in this area of research, but none have referenced the work of Burke and Nolan (1955) [12].

When we consider Burke and Nolan (1955) [12] in the area of particle deposition/retention, and O'Dea and O'Connor (1984) [11] in the area of pollution severity, based on particle number concentrations, they are consistent with more recent research. The particle retention values are consistent with the work of Morawska et al. (2005) [15], while the classification of pollution severity is consistent with Morawska et al. (2009) [13]. We also expect to have missed some key publications, and that is why we have sought to highlight this point. We in no way criticize any of the authors of any of the papers referenced here; it was the unique knowledge of the historical work which allowed us to find these historical publications and to consider them in the context of more recent work in these respective aspects of aerosol science. Finally, we take the opportunity to highlight the contribution of O'Connor to the development of the Mace Head site on the West coast of Ireland [17].

5. Conclusions

We hope that it has been demonstrated that while the internet is an excellent resource for researchers, many important older contributions to "air pollution research" can be missed or overlooked. Further, we have shown that O'Dea and O'Connor (1984) [11] proposed possible classifications of air pollution severity based on particle number concentrations 40 years ago; these proposed concentrations, linked to pollution severity, are still relevant today. We have also shown that Burke and Nolan in 1955 [12] demonstrated that ~40% of particles, based on particle number density, are trapped in the human respiratory system, which is still consistent with research conducted 50 years later. This paper challenges researchers the world over to explore the archives within their own countries and research groups to discover what valuable insights have been overlooked by common internet searches. We also suggest that this is an opportunity to establish a repository to collect and make available such historical research papers which would otherwise be lost to the modern scientific community in this area.

Author Contributions: The current Research Team and their linkages are as follows. J.A.S.: worked with Nolan and Burke, was involved in the development of the ionization smoke alarm, and developed the Irish Young Scientist exhibition with Burke. P.G.: trained with J.A.S. and has published on the Dublin coal ban and Irish workplace smoking ban, etc.; PI of the TU Dublin Air Quality research group and has collaborated with DQ Rich on health effects of air pollution. R.G.H.: Department of Meteorology, University of Reading, UK. Aerosol and atmospheric electricity scientist, and retriever of archive historical pollution data. E.J.M.: joint PI of TU Dublin Air Quality research group. D.Q.R.: epidemiologist at the University of Rochester, New York, United States of America; he is a grand-nephew of T. Rich who collaborated with Noland and Pollack on the automation of the Condensation Nucleus counter (See page 423 from Ref. [1]). All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

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