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Dubious use of fine particle mass-based standards for regulating urban air quality in a hypothermic environment

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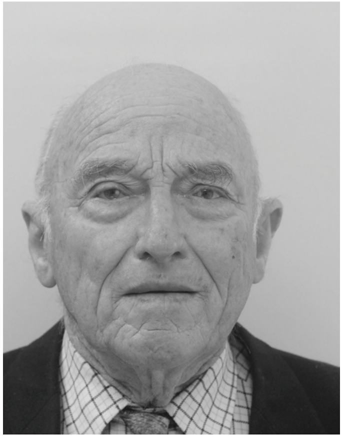


John Hoare studied for his BSc (1957), MSc (1st Class Honours, 1958) and PhD (1962) degrees at Auckland University College, his postgraduate theses being devoted to the chemistry of natural products. During 1961-1964, as a recipient of a Wool Research Organization of New Zealand Inc. Fellowship, he investigated physical and chemical properties of human hair and wool at the University of Leeds, Yorkshire and at the USDA laboratories, Albany, California. During 1964 -1978 he carried out research (mainly at WRONZ's laboratories located at Lincoln, Canterbury) into aspects of wool colour, natural yellowing of wool, bleaching of wool, wool grease recovery/refining, wool scour effluent treatment and allied subjects. From 1978 - 1999 he worked as a technical consultant/engineer for De Spa and Co. Ltd, Woolscourers, Woolston, Christchurch. For the last 14 years he has worked, in retirement, as an active member and Secretary of the Christchurch-based Association for Independent Research (AIR) Inc., aiming, as its stated objective: "*To assess and comment on the scientific basis for public health and resource management policy with particular reference to air quality issues*." The present paper represents, in part, a consequence of such objectives.

Abstract

In New Zealand, outdoor levels of the common air pollutants show considerable regional and seasonal variability; judged by world standards, average values are low. In winter, supplemental space heating using relatively inexpensive solid fuels is often employed domestically. Arbitrarily chosen National Environmental Air Quality Standards (NESAQ), based on a PM_{10} 24 hour average limit of 50 µg/m^3, severely restrict such heating. On a mass/mass basis, the gaseous-volatile/semi-volatile fraction is presumably more injurious, or potentially so, than that comprising the inhalable, essentially non-volatile, particulate matter. Also, in New Zealand regulations controlling urban air pollution define air exclusively as that existing outdoors, ignoring the health consequences of indoor air and/or indoor lifestyles. For these and other reasons, estimates concerning lives that can allegedly be potentially saved by reducing air pollution focused solely on compliance with PM_{10}-based standards are both quantitatively and qualitatively suspect.

Global health

Firstly, what is meant by the term global health? Logically, global health means the collective health of individual human beings amounting, ultimately, to family, community, country and populations worldwide. Consequently, responsible governance pertaining to public health involves encouraging people to, as much as possible, take good care of themselves and each other independently of government , ensuring key natural resources and environments are appropriately managed or controlled and adopting an inherently conservative approach, bearing in mind the steadily evolving nature of scientific knowledge, economies and population dynamics generally.

Air pollution versus air quality

Insofar as the relationship between air quality and public health is concerned, this undoubtedly is a very controversial topic particularly in the context of enforceable policy related to the control and/or regulation of urban air pollution. Typically, suspended fine particulate matter mass of less than 10 and 2.5 µm (PM_{10} and $PM_{2.5}$, respectively) determined outdoors is employed as a surrogate for all the harmful consequences allegedly observed or expected pertaining to likely exposures. Since, compared to the recognised causes of death or ill health, the substantive effect of specific instances of ordinary urban air pollution normally are indeterminate, distinguishing between the *actual* consequences and associated hypothetical mortality/morbidity *estimates* related to reduction of the pollution usually is left unresolved to the detriment of affordable, ethical, public health-implicated policy.

Thus according to the WHO[1]

"*….for 2008, the number of premature deaths attributable to urban outdoor air pollution is estimated to amount to 1.34 million worldwide. Of these, 1.09 million deaths could be avoided if the mean annual Air Quality Guideline values of PM_{10}=20 µg/m^3 and $PM_{2.5}$=10 µg/m^3 were implemented.*"

Clearly this statement is ambiguous and can be taken as meaning either *could*, in the sense of following directly (i.e. would/will) or *could* in the sense of being possible but by no means certain, with no way of knowing which of these is correct or intended by the author of the report in question.

Real, attributable, deaths?

Given that numbers of deaths cited typically are derived from very small relative risk factors i.e. RR ≈ 1.00 (where RR = 1.00 means zero effect and RRs > 2-3 generally are required if implications of causation are to be taken seriously[2]), not much confidence can be placed in such claims. This is particularly so where, as is usually the case, the crucial exposures are ill-defined, the individuals allegedly affected cannot be identified nor can the substantive causal factors be established with any certainty. In effect, ordinary citizens are being asked to accept the reality of and to fund something they, personally, may never relate to, understand well or benefit from in any substantive way.

Clearly there is a lot at stake here professionally – careers, reputations, industries, economies, statute law, embedded legislation, etc. Whatever the precise explanation, science as a discipline currently is coming a poor second to political expediency employed extensively in the context of urban air quality regulation.[3-5] Thus, for costing purposes, the methodology employed involves i) calculating statistically – from daily mortality data - the number of deaths allegedly attributable to variable (elevated) levels of air pollution and, hence, the number of lives potentially salvable/deaths avoidable in the absence of such pollution and ii) multiplying together such estimates and the monetary value (e.g. NZ$3.56 million; value of a statistical life)[6] ascribed to the average person dying as a result of a road accident. Typically, very large sums of money as potential net positive benefits are estimated thereby leading to calculation of favourable cost/benefit ratios.

Unfortunately, whereas such traffic-related deaths on average involve people aged around 40 years of age, air pollution is most likely to manifestly affect or harm frail, elderly, people.[7] Hence, rather than attempting to justify control of urban air pollution in terms of 'saving' valuable lives, small extensions to (or in some cases detractions from) the lives of already elderly people (cf. population ageing) ought to be accepted instead as a more realistic end result.[8] Also it needs to be acknowledged that such changes are likely to merge more or less seamlessly with the common scenario of steadily increasing life expectancies (2-3 years/decade currently in New Zealand; average life expectancy of approximately 80 years) having little to do with air pollution.

Meanwhile, the situation in Christchurch, New Zealand (population approximately 350,000), exemplifies what can happen when well funded, stridently promoted, authoritatively-couched environmental policies are, nonetheless, ill-conceived and/or mismanaged.[9] Unfortunately, because the topic is complicated, what follows here necessarily deals with only a cross section of the more important aspects.

Confounding issues

Climate

Typically, mortality is highest during the winter virtually everywhere.[7,10] Comparing the North Island of New Zealand (e.g. Auckland averaging 7-15 °C in winter, 15-24 °C in summer) to the South Island (e.g. Christchurch averaging 2-11 °C in winter, 12-23 °C in summer) reveals large variations in climate. Yet identical standards (i.e. NESAQ[11]) for permitted air pollution apply everywhere in NZ irrespective of the different domestic heating options available or other local and regional environmental, economic, and demographic distinctions. Sometimes the prevalence of frost or snow and other circumstances favouring low temperatures or otherwise inclement conditions outdoors ensures that provision of adequate warmth indoors is by no means a simple or assured matter.

It follows, therefore, that excessive environmental or other zeal may be a recipe for genuine personal hardship or worse, particularly in the case of elderly or similarly susceptible people of limited means cf. fuel poverty. Having conceded this point, simple logic in the interests of good governance dictates that:

a) standards for air pollution measured outdoors ought to reflect the fact that many interconnected properties of the local environment are capable of influencing public health both positively and negatively and

b) policy-makers/governments desirous of controlling ordinary urban air pollution need, before taking any major, far-reaching, steps, to as much as possible i) take the wider picture into account ii) provide *full* justification, readily understood by ordinary people, for their actions iii) ensure that if mistakes are made these are able to be rectified quickly and with as little collateral damage as possible.

In recent times, assisted by the implementation of various Regional Natural Resource Management Plans formulated by local and regional government, the need for such commonsensical measures have been ignored or overruled possibly in the interests of promoting, ahead of everything else, a "clean, green, 100% pure" image for New Zealand.

Indoor versus outdoor air

As already indicated, for regulatory purposes Ministry for the Environment (MfE)[12] and Regional Councils such as Environment Canterbury (ECan)[13] define air solely in terms of that found outdoors (i.e. where the measurements are made).

However, because *exposures* of interest often occur elsewhere these may not be reflected well by measurements made on air sampled outdoors. Aware of this, the US Environmental Protection Agency (USEPA)'s definitions of ambient[13] are both self consistent and scientifically robust. Thus:

> ***Ambient Medium*** *(USEPA): Material surrounding or contacting an organism (e.g. outdoor air, indoor air, water, soil, through which chemicals or pollutants can reach the organism).*

Whereas, according to Environment Canterbury:

> ***Ambient air quality*** *is the air quality in a general area, outside buildings and structures. It includes air over a wider area and air subject to localized discharges, e.g. street level discharges. It does not include indoor air,*

air in the workplace, or contaminated air as it is discharged from a source.

How did this difference and confused picture come about? Clearly, air as a natural resource is mostly located outdoors. Hence it would appear influential New Zealand government officials thought that this explained everything and were unaware of, or attached insufficient importance to, the seemingly benign or neutral indoor environment. Also they clearly did *not* have as a primary concern the public health and safety implications of New Zealand's Resource Management Act,[14] the purpose of which is described as follows:

5 Purpose

(1) The purpose of this Act is to promote the sustainable management of natural and physical resources.

*(2) In this Act, **sustainable management** means managing the use, development, and protection of natural and physical resources in a way, or at a rate, which enables people and communities to provide for their social, economic, and cultural well-being and for their health and safety while—*

a) sustaining the potential of natural and physical resources (excluding minerals) to meet the reasonably foreseeable needs of future generations; and

b) safeguarding the life-supporting capacity of air, water, soil, and ecosystems; and

c) avoiding, remedying, or mitigating any adverse effects of activities on the environment.

Either way these same bureaucrats have succeeded in creating fear amongst the population at large that ordinary urban air pollution kills – directly, unambiguously - as many as 182 people each year (approximately 7% of the total deaths)[15] in Christchurch alone even though substantive (i.e. clinical/autopsy) evidence to this effect is completely lacking. But, evidently, not sufficiently "deadly" as to discourage Environment Canterbury from declaring an NESAQ amnesty following a major emergency in Christchurch:

"….The priority for Environment Canterbury over the last two winters has been to ensure people in damaged properties stayed warm and this priority will continue for winter 2013.

….the replacement of older heating sources should reduce particulate air pollution over time. In the short term, however, the need for emergency repairs to heating systems has meant that legislation to prosecute those using polluting older wood burners and open fires has been temporarily relaxed for earthquake damaged homes for the winter of 2011."[16]

But, given that laws embodying the NESAQ still prevail and cannot (legally) be challenged even though the science employed thereto appears to be seriously flawed, not indefinitely!

Origin of acute effects

Regulatory policy focused on PM_{10} 24 hour average (as in New Zealand) assumes that associated *acute* effects are prevalent. Such effects, presumably, are attributable less to elemental carbon, ammonium nitrate, crustal dust, sea salt and similar comparatively inert, non-volatile, material (conveniently determined by weighing) and more to the gaseous (e.g. NO_2, CO, SO_2, O_3) and organic volatile/semi-volatile co-pollutants present.[17]

"Collectable" naturally-occurring substances possessing irritant/allergenic/infectious properties (e.g. pollen, bacteria, viruses, mould etc.) are an exception here. Similarly, various mineral-based dusts, metals, tobacco smoke, etc., potentially contribute to serious illnesses and disorders such as cancer, usually following many years exposure. Typically, however, much uncertainty exists regarding actual causality in such cases, mainly because of the large number of extraneous confounding factors involved. It is simpler, in a regulatory context, to focus on acute exposure-type monitoring assuming this can be done accurately and that the results are relevant to the actual health effects.

Problems related to sampling and monitoring

Being particularly susceptible geographically, Christchurch regularly exhibits "temperature inversion" phenomena during the winter under calm conditions which serves to concentrate the pollutants. Also, because a few, relatively low-lying and hence poorly drained, predominantly residential (St Albans) and/or "industrial" (Woolston) suburbs are especially prone to air pollution attributable to solid-fuelled stoves, boilers and similar equipment, this is where sampling for "worst case scenario" air quality measurement has traditionally been carried out.

Nowadays, such sampling is assumed to reflect maximum (peak) concentrations relevant to NESAQ (PM_{10}) compliance. Generally speaking, other sites of interest (e.g. traffic-related) give little cause for concern ordinarily regarding emissions of CO, SO_2 and NO_2 at any time of the year. Meanwhile it seems fair to conclude that, considering all the suburbs and great diversity of living and working conditions that go to make up the whole city, if the Christchurch "airshed" is to be sampled representatively insofar as personal exposures are concerned, many more sampling sites are needed than just the two or three "outdoor" sampling arrangements currently provided for. Nonetheless, a steady decrease in PM_{10} levels has been observed over the years with peak levels roughly halved compared to 50 years ago.

Taking such things into account, the inhabitants of Christchurch almost certainly are exposed to relatively low levels of potentially harmful air pollution although few would think so considering the admonishments regularly delivered by MfE and ECan, mostly pertaining to NESAQ (PM_{10}) non-compliance.

Basis of regulations - credible or not?

Meanwhile, although compliance with a PM_{10} 24 hour average-based standard is demanded, cost/benefit justification allied to alleged health risks is ultimately based on PM_{10} annual average-type epidemiological studies mainly conducted overseas such as in the USA.[6] Also, the relevant calculations involve a particularly complex mix of assumptions and approximations in any case.[7] All in all, for the various New Zealand Government departments, public bodies and other authorities involved to continue maintaining that the relevant air quality legislation (NESAQ-based) is scientifically valid is to reveal a distinct unwillingness to come to terms with, if not a profound ignorance of, the subject as a whole.

Beginning around 2002, mortality Relative Risk values of around 1.01 based on short-term/acute exposure (i.e. PM_{10} 24 hour average-type epidemiology) were cited as being relevant to Christchurch leading to estimates of 40-70 'premature' deaths each year attributable to PM_{10} air pollution.[18] Subsequently, substantially larger RR values of approximately 1.043[15] and, latterly, approximately 1.07[6] emerged related to long-term or chronic exposure-type epidemiology yielding estimates ranging from 158-182 "premature" deaths annually in those aged 30 years and over. Meanwhile, the method for measuring PM_{10} has also changed resulting in significantly higher results for this pollutant index related to inclusion of and correction for loss of semi-volatiles.

Taking such matters into account, the topic - air quality - clearly has become something amenable to subjective interpretation (i.e. an art rather than a manifestation of good, sound, applied science as normally understood).

Air pollution compliance targets

Christchurch as represented by the St Albans and Woolston monitoring stations currently is unlikely to achieve the present NESAQ requirement of a maximum of 3 exceedances per year of 50µg/m^3 PM_{10} 24 hour average by 2016 let alone the ultimate target of 1 exceedance by 2020.[19] However, it appears to meet the WHO PM_{10} annual average guideline of 20µg/m^3 and seems likely to continue to do so for the foreseeable future.[12] Consequently, considered from the point of view of the city as a whole, the typical exposures to PM_{10} (and to $PM_{2.5}$ with this comprising on average about 60 % of the PM_{10}) would appear to be of little concern judged alongside the standards and guidelines applicable overseas (Table 1).

Furthermore, given that there appears to be little or no connection between measured PM_{10} air pollution and both overall and specific types of respiratory health as recorded in New Zealand[20,21] the wisdom and effectiveness of policies aimed at replacing in short order large numbers of relatively modern (enclosed-type) domestic cord wood-fuelled burners with alternative (mostly electrically-operated) sources of heat has to be seriously questioned.

Nature of the polluting effect

Concerning episodic air pollution as normally experienced in New Zealand, entrapment of "fine" relatively (chemically) inert, essentially non-volatile, material leading to gradual physico-chemical interference of normal respiratory functions (cf. silicosis) would appear to have been the "default" mechanism originally. However, considered in the light of the barely detectable acute effects observed, such modus operandi would appear to be obsolete in a modern context. According to the authors of the latest version of the oft-cited Health and Air Pollution in New Zealand (HAPINZ) reports: [6]

> *Particles of different sizes typically have different sources and different chemical and biological composition. The mechanisms of particle toxicity are complex and still not fully understood. For example, it is not yet certain which of the several classes of toxic effects observed in laboratory experiments are responsible for specific human health effects (Brook* et al. *2010).*

Meanwhile, the main pollutant gases NO_2, CO, SO_2, and O_3, despite being routinely monitored, typically are ignored by epidemiologists and planners. Based on the evidence available, a mechanism reliant upon such "reactive" substances and the (mainly) organic gases/volatiles and semi-volatiles would appear to be entirely feasible in the ordinary urban environment. Indicative, however, of the subtleties involved are the results obtained for one Christchurch sampling site shown in Fig. 1.

In practice, determination of PM_{10} via FDMS involves the following:

i) sampling the air under the prevailing (outdoor) ambient conditions

ii) obtaining, simultaneously, a sub-sample representative of the "fine" particle fraction ≤ 10 mm e.g. via a "50 % efficiency/cut" cyclone

iii) collecting the suspended, moisture free, particulate matter on a filter while weighing it at a temperature of 30^o C

iv) repeating the weighing step under conditions facilitating calculation/compensation for concomitant loss of attendant "volatiles" whence

v) the permanent (largely inorganic) gases are not taken into account/recorded as PM

vi) the more volatile of the volatiles/semi-volatiles (possibly mainly organic) fraction are not taken into account/recorded as such

vii) the less volatile of the volatiles/semi-volatiles (largely organic) fraction presumably are partly taken into account/recorded

viii) significant amounts of relatively inert "fine" particulate matter are taken into account/recorded as potentially harmful material simply from a mass perspective

ix) potential toxicity associated with the "coarse" particle fraction is disregarded/downplayed.

Hence, considering all of the above it seems fair to conclude that monitoring of urban air quality in the interests of public health, as presently carried out, leaves a lot to be desired.

Precautionary Principle

The Precautionary Principle[22] states that:

> *".....if an action or policy has a suspected risk of caus-*

ing harm to the public or to the environment, in the absence of scientific consensus that the action or policy is not harmful, the burden of proof that it is not harmful falls on those taking an action... "

Application of the principle appears to have led, in New Zealand at least, to overly stringent standards for PM (Table 1).

Comparing the shown data above, New Zealand's PM_{10}-based standard is seen to be much more stringent than the equivalent standards favoured by USEPA and the EU. Also, considering that the individual limits, etc. are largely arbitrary, use of the term "standard" in a regional context is contentious. Consistent with this viewpoint, WHO prefers to promulgate limits described as guidelines rather

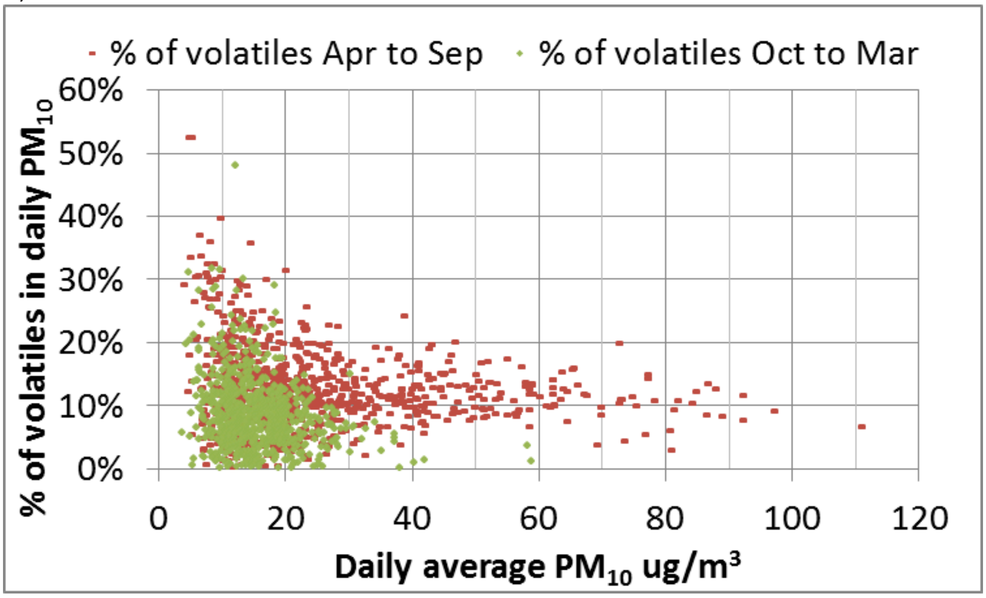
Table 1 Ambient air quality standards: comparison of allowable air pollution (PM) limits and exceedances (reproduced with permission: Hoare, J.L. New Directions: Questions surrounding suspended particle mass used as a surrogate for air quality and for regulatory control of ambient urban air pollution, *Atmospheric Environment*, **2014**, *91*, 175–177).

		Country		
Pollution index	Averaging period	United States of America[23]	European Union[24]	New Zealand[11]
PM_{10}	24 hours	150*; 1/yr as a 3 yr average	50*; 35/yr	50*; 1/yr (aiming for full compliance by 2020**)
PM_{10}	Annual	N/A	40*	N/A (WHO guideline of 20* currently met virtually everywhere)
$PM_{2.5}$	24 hours	35*; 98th percentile averaged over 3 yr.		
$PM_{2.5}$	Annual	12*; (averaged over 3 yr.) Primary 15*; (averaged over 3 yr.) Secondary	25* 20*; (exposure, averaged over 3 yr.) by 2015 18*; (exposure, averaged over 3 yr.) by 2020	N/A (currently ≤15* assuming PM_{10} annual avg. is ≤ 20* and 70% of PM_{10} is $PM_{2.5}$)

* Measured in µg/cubic metre

** In some towns and cities in NZ, especially those situated in regions experiencing relatively cold winters, exceedances/yr currently exceed the standard by a considerable margin

A)



B)

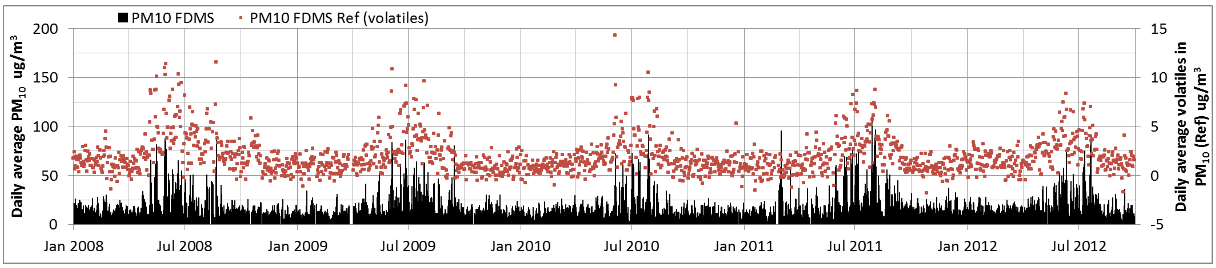


Fig. 1. 24 hour average PM_{10} via Filter Dynamics Measurement System (FDMS), showing seasonal variations in PM and % "volatiles" for Christchurch. (A) Average PM_{10} % volatiles: cooler months (red), 12%; warmer months (green), 8%. (B) Variations in daily average PM_{10} (black) and daily average volatiles in PM_{10} (red). Average volatiles for 2008 - 2012, 11%; "Exceedances"/yr = 20 approximately (graph B reproduced with permission: Hoare, J.L. *New Directions: Questions surrounding suspended particle mass used as a surrogate for air quality and for regulatory control of ambient urban air pollution*, Atmospheric Environment, **2014**, *91*, 175–177).

than legally enforceable standards stated as follows:

> "…governments should consider their own local circumstances carefully before using the guidelines directly as legal standards." [25]

Conclusions

Pursuit in an urban context of perfectly clean and/or pure air is unrealistic and impractical. Instead, a reasonable compromise corresponding as much as possible to the likely actual exposures and confirmed risks related to achievable air quality in all its guises is preferable.

Where local supplies of solid fuels are assured, relatively inexpensive and sustainable compared to alternative sources of available energy (e.g. electricity and/or gas) it makes good sense to allow and encourage effective and efficient use of such methods of heating domestically (e.g. as a back-up and/or during very cold or otherwise inclement weather).

Arbitrarily-chosen limits (guidelines) for the individual gaseous inorganic and volatile/semi-volatile organic pollutant categories possibly would be more suitable for regulatory purposes than the epidemiologically-arrived at, PM-based, "standards" currently employed.

Particle-related toxicity probably resides principally in an adsorbed volatile/semi-volatile sub-component; tolerably stable therein provided the ambient temperature is low enough.

Such material probably is capable, at least partly, of being volatilised/desorbed at temperatures approaching "blood heat" (approximately 37 °C) thereby assisting the transfer of otherwise relatively harmless, occluded, material deeper into the lungs.

Probably all airborne particles (i.e. particles ≤ approximately 100 mm in diameter) should be regarded as potentially significant contributors to the acute effects, the latter being mainly attributable to the "permanent" gases and volatiles with additional contributions from the adsorbed semi-volatile and volatile material.

In practice, global health is a composite of that enjoyed by individuals and as such is best tackled from a local/regional perspective.

Compared to the US and EU standards for PM_{10} 24 hour average, the equivalent New Zealand standard (NESAQ) permitting no more than 1 exceedance of 50 mg/m^3 per year is particularly stringent with accrued benefits likely to be small or unclear relative to the substantive overall costs incurred. Given that the Government appears unwilling to modify its stance enabling a more realistic/straightforward/honest approach to the science involved, a sense of injustice prevails.

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