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Do air quality targets really represent safe limits for lung cancer risk?

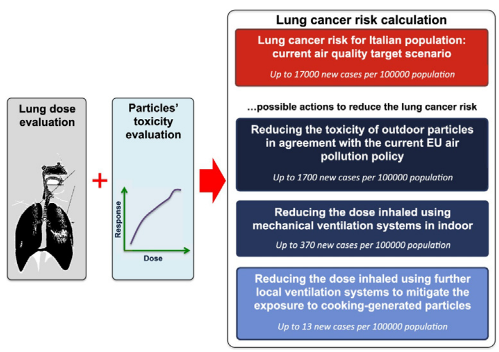
G. Buonanno [a,b,*], L. Stabile [a], L. Morawska [b], G. Giovinco [a], X. Querol [c]

[a] Department of Civil and Mechanical Engineering, University of Cassino and Southern Lazio, Cassino, (FR), Italy
[b] International Laboratory for Air Quality and Health, Queensland University of Technology, Brisbane, Australia
[c] Institute of Environmental Assessment and Water Research (IDÆA), Consejo Superior de Investigaciones Científicas (CSIC), Barcelona, Spain

HIGHLIGHTS

- We evaluated the reliability of air quality targets for lung cancer risk.
- Risk was linked to exposure to polycyclic aromatic hydrocarbons and heavy metals.
- A modified risk-assessment scheme was applied considering sub-micron particles.
- A very high lung cancer risk was related to the actual target levels due to indoor.
- Despite different scenarios applied, risk for the Italian case was not acceptable.

GRAPHICAL ABSTRACT



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ABSTRACT

In order to estimate the lung cancer risk associated to airborne particles, exposure and risk-assessment studies ordinarily use particle mass concentration as dosimetry parameter. Consequently, the corresponding air quality targets are based on this metrics, neglecting the potential impact of ultrafine particles (UFPs) due to their negligible mass. The main purpose of this study was to evaluate the reliability of air quality targets in protecting Italian non-smoking people from lung cancer risk due to exposure to polycyclic aromatic hydrocarbons and some heavy metals associated with particle inhalation. A modified risk-assessment scheme was applied to estimate the cancer risk contribution from both sub-micron (mainly UFPs) and super-micron particles. We found a very high lung cancer risk related to the actual target levels due to the contribution of UFPs, in particular from indoor microenvironments. Therefore, as possible actions to reduce the lung cancer risk, we have hypothesized and tested three different scenarios: a) a reduction of the concentration of carcinogenic chemicals condensed onto particles in agreement with the current EU air pollution policy; b) the use of local ventilation systems to mitigate the exposure to cooking-generated particles; c) the improvement of the overall indoor air quality by considering a mechanical ventilation system instead of the widespread natural ventilation in order to increase the air exchange rates. Even with the simultaneous application of specific actions, performed with the best technologies available, the corresponding estimated lifetime lung cancer risk (ELCR) values for the Italian population for the entire life were equal to 1.25×10^{-4} and 1.23×10^{-4} for males and females, respectively, well higher with respect to the maximum tolerable lifetime cancer risk, 1×10^{-5}.

* Corresponding author at: Department of Civil and Mechanical Engineering, University of Cassino and Southern Lazio, via Di Biasio 43, 03043 Cassino, Italy.
E-mail address: buonanno@unicas.it (G. Buonanno).

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1. Introduction

The World Health Organization (WHO), through the International Agency for Research on Cancer (IARC), has recently classified airborne particles as carcinogenic to humans (Group 1), based on sufficient evidence that exposure is associated with an increased risk of lung cancer (International Agency for Research on Cancer, 2013; Loomis et al., 2013). The potential of particles to produce negative health effects is connected to their ability to enter the lungs, potentially carrying toxic compounds with them. There is not a real consensus in the scientific community, thus far, about which particle size, morphology or chemical components are more associated to the adverse effects on human health and in-depth research in this field is needed (Cassee et al., 2013; World Health Organization, 2013). In terms of particle size, there is an increasing amount of research on ultrafine particles (UFPs, diameter < 100 nm), measured in terms of surface area (Buonanno et al., 2013; Giechaskiel et al., 2009) or particle number concentrations (Buonanno et al., 2014b; Moreno et al., 2015), in respect to mass (PM_{10} or $PM_{2.5}$). In particular, on the basis of toxicity evidence, surface-area is the suitable exposure metric for UFPs (Cauda et al., 2012; Oberdörster et al., 2005; Porstendörfer, 1994; Tran et al., 2000) and also the biological response depends more on the surface-area of particles deposited in the lungs (Brown et al., 2001; Hamoir et al., 2003; Stoeger et al., 2006; Tran et al., 2000) than on other metrics of exposure.

1.1. Particle toxicity and risk model

The toxicity of particles is clearly associated to the compounds that are attached to them, several of which have been classified by the IARC in the Group 1 carcinogens (i.e. there is "sufficient evidence" of carcinogenicity in humans, such that a causal relationship has been established between exposure to these agents and human cancer). Among these, PAHs and some metals (As, Cd, Ni) could be considered major contributors to human exposure through the respiratory tract. The occurrence of PAHs and heavy metals in ambient air is of particular concern due to the variability of the exposure and the size of at-risk populations. Anyway, for >25% of the EU-28 population, an annual mean value of BaP higher than 1 ng m^{-3} was found from 2011 to 2013 (EEA Report, 2015). Human exposure to As, Cd and Ni ambient air concentrations above the target values is considered to be a local problem, restricted to a few areas in Europe, and caused by specific industrial plants or areas (EEA Report, 2015). Although European (outdoor) air quality seems to improve also as a consequence of the implementation of existing legislation (EEA Report, 2015), a reliable estimation of the effectiveness of the current air quality targets to limit the lung cancer risk of European population in the exposure to airborne particles is far to be achieved mainly because of the large uncertainties of the methodologies to estimate the real risk of the population (Dong et al., 2015). Using limited risk models cannot support policymakers to scientifically plan further efforts to reduce emissions of air pollutants for the protection of human health and the environment. Indeed, the lung cancer risk models currently available only take into account for the super-micron particle (PM fractions) contribution. As an example, Hamra et al. (2014) performed a systematic review on the relationship between PM and lung cancer showing, on the basis of 7 cohort studies investigated, a significant correlation also for non-smoker population. Nonetheless, super-micron particle toxicity (U.S. Environmental Protection Agency, 2005) solely cannot justify the actual lung cancer risk evaluated through epidemiological studies (Albert et al., 1983): thus, the lung cancer risk related to the exposure to UFPs could be likely higher than the super-micron particle one (Liao et al., 2011; Sze-To et al., 2012). Besides particle toxicity, the excess lifetime lung cancer risk (ELCR) also depends on the dose, namely the surface area (for UFPs) and the mass (for super-micron particles) deposited in the respiratory system. In our previous paper, Buonanno et al. (2015) estimated the ELCR for the Italian population by applying a risk assessment scheme modified from an existing risk model, which was designed to consider the lung cancer risk associated with both UFPs and super-micron particles (Sze-To et al., 2012). To this end (i) the particle concentration measurement data in the microenvironments where people are exposed to were considered, and (ii) the daily exposure of people of different age groups to polycyclic aromatic hydrocarbons (PAHs) and regulated metals (As, Cd, Ni) were estimated on the basis of time activity patterns reported in the Italian Human Activity Pattern Survey. The research showed that the median annual average concentrations of PAH (expressed as BaP equivalent concentration), As, Cd, and Ni in PM_{10} whose people are exposed resulted equal to 0.36, 0.66, 0.20, and 5.54 ng m^{-3}, respectively. The resulting average ELCR for the Italian population was equal to of 1.90×10^{-2}: i.e. much larger than the acceptable level of 10^{-5} to 10^{-6}, based on the cancer risk decision points used for lifetime exposure of the general population.

1.2. Air quality standards

From a regulatory point of view, Environmental Protection Agencies (EPAs) in Western countries measure daily average mass-based concentration (PM_{10}, $PM_{2.5}$) at an outdoor fixed sampling point (FSP). The number and position of such FSPs is only determined as a function of the size of the population (European Parliament and Council of the European Union, 2008; National Environmental Protection Council, 1998; U.S. Environmental Protection Agency, 2006). Nevertheless, the evaluation of risk related with real exposure is particularly difficult because: a) FSP data are not representative of real outdoor exposure (due to the high particle concentration decay with respect to distance from the source (Buonanno et al., 2011a; Kumar et al., 2014)); b) the long sampling base (24-h basis) (Manigrasso et al., 2013); c) outdoor exposure commonly represents a modest contribution to personal integrated exposure since individuals spend most of time in indoor moving through multiple indoor microenvironments (Buonanno et al., 2012; Morawska et al., 2013; Schweizer et al., 2006); d) no air quality standards considering other particle metrics (number and, above all, surface area) are taken into account (Buonanno et al., 2009; Buonanno et al., 2010a; Buonanno et al., 2010b; Reche et al., 2015); and e) consolidated risk models for chemicals use mass as the dosimetry to assess the health effect (Hamra et al., 2014). Therefore, adverse health effects related to UFPs are not estimated when assessing exposure to particulate matter and, consequently, air quality monitoring data and time activity patterns are not adequate for policymakers to develop accurate risk analysis, estimate the major contributions, define high-risk sub-groups, and carry out efficient risk reduction measures.

As regards PAH concentration, the target value for the protection of human health, expressed as annual mean, for BaP is set at 1 ng m^{-3} in PM_{10} (European Parliament and Council of the European Union, 2004) as reported in an extensive body of legislation establishing health-based standards for PAHs in the air. The corresponding estimated lifetime lung cancer risk due to PAHs is 8.7 cases in a population of 10^5 with chronic inhalational exposure to 1 ng m^{-3} of BaP over a lifetime of 70 years. Because the estimated ELCR is higher with respect to the acceptable risk (lower than 1×10^{-5}), the UK Government's Expert Panel on Air Quality Standards (EPAQS) (Expert Panel on Air Quality Standards, 1999) and the Swedish Governmental Commission on Environmental Health (Commission on Environmental Health, 1996) recommended standards of 0.25 ng m^{-3} and 0.1 ng m^{-3}, respectively, as the long-term average target values for BaP in order to have a corresponding theoretical lifetime cancer risk of 1×10^{-5} (Bostrom et al., 2002). On the basis, once again, of an acceptable risk of 1×10^{-5}, an estimated reference level is presented (0.12 ng m^{-3}).

From a regulatory point of view, the main threats to human health from heavy metals are associated with exposure to arsenic, cadmium and nickel. These compounds have been classified by the IARC as Group 1: namely there is "sufficient evidence" of carcinogenicity in humans. Therefore, As, Cd and Ni have been extensively studied and