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DEVELOPING A CONCEPTUAL FRAMEWORK FOR EVALUATING ENVIRONMENTAL RISKS AND CONTROL STRATEGIES: THE CASE OF INDOOR AIR

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ABSTRACT

The health risks estimated for indoor air pollutants are often substantially larger than those for similar pollutants in outdoor air and water supplies, yet comparable to accident risks in homes and automobiles. This suggests the need to examine the premises and expectations for limiting risks in different environments - indoor, outdoor, and occupational - as a basis for evaluating the importance of risks, and formulating risk-limiting objectives, for indoor air pollutants. These environments differ in who benefits from each setting or activity, who is affected by associated exposures, who has control or responsibility, and so on. A principal conclusion from examining such issues is that not only are the nature and magnitude of risk important for choosing objectives, but also the context. A properly developed conceptual framework can thus greatly influence the form and detail of control objectives and strategies.

INTRODUCTION

Human exposures to several classes of indoor air pollutants are substantially larger than exposures to similar pollutants from outdoor air or water supplies (1). The health risks estimated for these classes often therefore exceed ordinarily considered "environmental" risks, and are sometimes comparable to risks associated with exposures of industrial workers (2). For example, estimated lifetime risks of premature cancer death for exposures to radon (and its decay products), tobacco smoke, and VOCs in indoor air are on the order of 0.1% for average concentrations. Estimates for asbestos are somewhat less, but still large compared with protective criteria that consider any risk greater than, say, 0.001% or even 0.0001% to be significant, or that even suggest goals of zero exposure. In the case of radon, the estimated risks appear to equal or exceed 1% for people who are highly-exposed or who smoke, as indicated in Figure 1.

In view of such risks, initial efforts have sometimes aimed at reducing levels as much as possible in every circumstance, often using strategies that later proved ineffective, ill-founded, difficult to implement, or extremely costly. In the United States, the strategy for controlling asbestos - implemented by the Environmental Protection Agency (EPA) (3) - might be described in all of these ways, given its perhaps $100 billion cost and questionable scientific basis (4). The control of formaldehyde has illustrated, in contrast, that a particular strategy - setting indoor concentration limits for the housing stock itself - may be impractical, especially as compared with strategies controlling the manufacture of source materials (5). And, although most countries with programs controlling radon have aimed initially to reduce exposures that approach occupational radiation limits, the EPA has had as its primary objective the reduction of the average exposure in U.S. homes (6). However, choosing this objective arises from a conceptual framework developed primarily for outdoor pollutants, not for the indoor environment, and may have delayed efforts to identify and fix homes having concentrations much greater than average (7).

These cases indicate the need for explicit development of a conceptual framework for evaluating risks in the indoor environment, and serving as the basis for choosing risk-limiting objectives of prospective control strategies. The absence of such a framework appears to have led to the missteps of the past, typically from evaluating a new situation - indoor exposures - within a framework developed for another situation, i.e., exposures from outdoor air. Since risks of premature death on the order of 0.1% or even 1% are typical of the settings (indoor and occupational) where people spend most of their time (cf. Figure 1), these could as easily be the reference levels for considering risks from indoor air pollutants. Evidently, formulating an appropriate conceptual framework requires careful examination of the premises and expectations that underlie our efforts to avoid risk in the indoor and other settings.

A complete control strategy entails three major elements, discussed previously in some detail for the case of radon (8):

- a system of risk-limiting guidelines;
- a methodology for identifying the buildings (or classes or components thereof) needing implementation of control measures; and
- a scheme for choosing the control measures appropriate to the circumstances at hand.

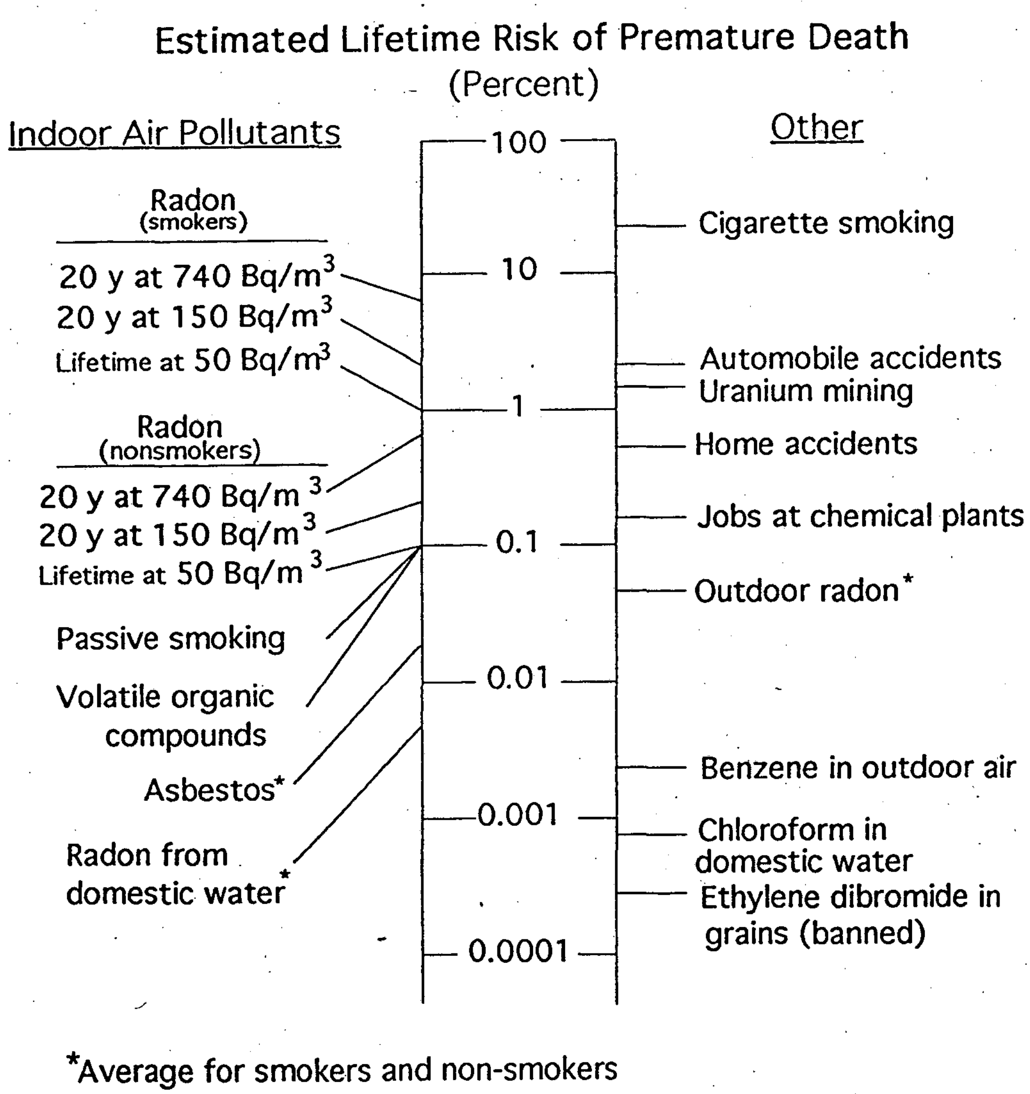

Fig. 1. Risks from indoor pollutants and other exposures. All risks are for the whole population, except where indicated. Radon estimates presume a ten-fold difference between smoker and nonsmoker risks due to synergism, but this ratio is not known exactly. (Figure adapted from Ref. 7.)

Each of these elements, and particularly the guidelines (which may take many forms), is influenced substantially by the risk-limiting objectives identified and chosen on the basis of our conceptual picture of the indoor environment. Hence the importance of developing this picture for formulating the main elements of control strategies for indoor pollutants.

QUANTITATIVE AND QUALITATIVE FEATURES OF RISKS AND SETTINGS

Risk assessment itself yields information on the nature, magnitude, and uncertainty of risks. But interpreting and utilizing this information requires an evaluation framework that embodies premises about the acceptability of risk and expectations about limiting risk. Examining some of the differing features of risk in different settings can illuminate the dimensions of risk acceptability and control, and contribute to formulating a framework for evaluating risks and strategies for their control.

Absolute versus relative magnitude of risks

As indicated, it is not the absolute estimated risk alone, compared with some universal risk-limiting criterion, that suffices for decisions on a particular exposure. Examination of risks typically associated with the setting in question, as contrasted with other situations, can help develop a perspective on risk-limiting expectations for that setting, in this case inside non-industrial buildings, primarily homes. This can provide a basis for determining the appropriateness or acceptability of risks of various magnitudes in the setting of interest. Thus, just as use of risk-limiting criteria developed for the occupational setting may not be suitable for evaluating risks due to pollution in public water supplies, criteria developed for water or outdoor air may not be suitable for consideration of risks from indoor air pollution. Indeed, examination of relative risks in different settings may help identify issues underlying the acceptability and control of risks in different settings, a matter of more general interest than just for indoor air quality.

Distribution of risk among the population

The distribution of indoor exposures in a population spans a wide range, often represented adequately by a lognormal distribution. Some of the population therefore experience substantially higher risks than average. Hence risk-limiting objectives may be aimed at controlling or reducing either the average exposure or those substantially higher than average, or both (2, 8). For example, concentration limits might be chosen primarily to avoid very large individual exposures, while building codes might aim primarily at reducing the average exposure over the long term. The concentration limits would have only modest effects on average exposures, but would avoid accumulation of exposures at rates exceeding some criterion for unacceptable individual risk (such as occupational limits).

A different issue arises among people with differing smoking histories. Since the risk from a particular pollutant may act synergistically with smoking, as for radon and asbestos, smokers may suffer significantly greater risks than nonsmokers. In fact, the bulk of the population risk may occur among smokers, who have however accepted a very large risk from the smoking itself. In the case of radon, this suggests the need to differentiate, to the extent possible, between the risks for people with differing smoking histories, and perhaps to distinguish between associated objectives for any control strategy, both for average and high radon concentrations. Such a distinction can alter the apparent importance of risks associated with radon exposures, as seen in Figure 1. For example, if a relative risk model can be applied directly, implying a roughly ten-fold difference in the "radon" risk for smokers and those who have not smoked, then 20-year occupancy of a home with an average indoor radon concentration of 200 Bq/m^3 implies an added risk of premature death for nonsmokers of perhaps 0.2%, in the range of risks from other indoor pollutants. The added (radon) risk for smokers would be much greater, in the vicinity of 2%, about the chance of being killed in an auto accident for U.S. residents. (For comparison, the risk from smoking alone exceeds 20%.)

Issues of responsibility, control or choice, and benefit

Examining risks from different situations indicates the substantial importance, not only of the physical nature and source of the exposure, but of who experiences the exposure (e.g., the working population versus a mix of ages), who (if anyone) is the cause of the exposure, who can control it, who benefits from the circumstances, and who has to pay for control. Outdoor air quality standards, for example, implicitly constitute much stricter limits on exposures or risks caused by someone else (such as an industry or the automobile fleet) than on those associated with activities of individuals themselves. Conversely, an individual often accepts, willingly or from economic need, significant exposures associated with his or her work, exposures that are often much larger than would be permitted by environmental agencies for the general population. In effect, the occupational economic benefit offsets the associated risks. The indoor environment differs from the outdoor and occupational settings, but may be closer to the latter. In both cases, direct benefits and often a modicum of control are usually involved, in contrast to exposures from pollutants in outdoor environmental media, such as air and water, where individuals have little control or direct benefit. The residential setting is one where, at least in most developed countries, occupants derive substantial personal benefits in terms of health, comfort, and convenience. Viewed pragmatically, in the indoor and occupational (including industrial) settings estimated lifetime risks of premature death of order 0.1% are the norm, and reducing these very substantially would be extremely difficult if not impossible. In contrast, environmental agencies (e.g., in developed countries) can realistically employ trigger levels a hundred times lower for many exposures from the outdoor environment. Finally, questions of responsibility, control and benefit (in this case, personal enjoyment) become acute in considering the synergism between, for example, radon and smoking.

Application of cost-effectiveness criteria in different settings

Different settings have typically different exposures and estimated risks, as noted, and the nature of factors affecting exposures - such as source behavior and pollutant transport - can differ substantially. Thus, even if similar cost-benefit criteria are applied to controlling exposures in these different circumstances, substantially different exposure limitations, or reductions to be sought, can result. Thus a numerical limit that is developed properly for one setting may not be suitable for another. Furthermore, different cost-benefit criteria may be adopted in different circumstances, whether explicitly or implicitly and purposefully or inadvertently, arising from differences in the qualitative features of these settings, as discussed above. A different criterion can of itself result in substantially different exposure limitations. Thus risks estimated for different circumstances may be evaluated differently, either because of differing underlying (cost-benefit) criteria, or because of differing results of applying the same criterion to situations having different exposures and technical features. Such evaluation, explicit or not, should precede the actual adoption of guidelines, and recognizing this is important in considering new situations. Otherwise, by trying to apply a numerical guideline or cost-benefit criterion developed for one setting to a new circumstance, superficial consistency can hide underlying inconsistency in cost-benefit analyses or more fundamental differences in the evaluation of risk in these different circumstances.

In considering the effectiveness of alternative guidelines or strategies, it is also important to differentiate between the risk attributable to the exposure of concern and the risk that is actually affected, i.e., the fraction of attributable risk that is eliminated. Though a commitment may be motivated by a large attributable risk, the actual scale and nature of a program, or selection of guidelines, should be determined by the fraction of the risk - or of those at high risk - that can actually be affected.

Reductions in exposures in the near term versus the long term

An important matter in choosing objectives, guidelines, and strategies, is the ordering of activities in time, in effect the issue of setting priorities. Thus it is thought by many that radon control efforts should be devoted initially to the identification and remediation of the homes with the highest levels, with the definition of this class depending on the overall distribution for the country or region being considered and other practical matters. However, efforts aimed at high pollutant exposures, while rapidly assisting those at greatest risk, may have little effect on the population's average exposure. Hence, if the latter are of concern, corresponding strategic elements are needed. The most effective of these in both absolute and monetary terms are those implemented over a substantial period of time; many control measures are more effectively implemented as buildings are constructed than as remedial measures, e.g., incorporation of pressed-wood products with lower formaldehyde emissions than a decade ago or of radon control techniques involving sub-slab ventilation. This implies that near and long term strategies may adopt different numerical guidelines, based on differing objectives, and that differing cost-effectiveness may be achieved. Hence guidelines and control strategies are likely to have a complex structure in exposure and in time, as well as in location.

Other features of risks, settings, or control strategies

Other important considerations apply. One measure of success of a program, particularly one aimed at situations with high indoor concentrations, is its comprehensiveness, i.e., to what degree all or most of the high-concentration buildings will be found and fixed. Another issue is use of conservative risk estimates, which - paradoxically - may not be suitable for the indoor environment, since the large risks and great cost of control programs make it important that realistic estimates be used. Further, it appears important - especially in considering indoor exposures - to recognize the absurdity of presuming that health-based criteria exclude those based also on practicality (and cost); all guidelines or standards for pollutants affecting human health are inherently health based, and no criterion can be applied sensibly without considering practicalities. Finally, many of the considerations above may lead to different conclusions, depending on the circumstances in various countries, a particularly important distinction being that between developed and developing countries. Frameworks for environmental and occupational protection are typically more fully developed in the former, and people in less developed countries tend to suffer larger risks in all settings - outdoor, indoor, and occupational - than those in developed countries, so that the importance of a modest pollutant risk may be less because life expectancies are greatly shortened by a high frequency of "premature" deaths from more important causes.

DISCUSSION

The considerations mentioned above assume differing importance in different settings. This accounts in large part for the fact that the overall regime for occupational protection is not accepted as the basis for more general "environmental" protection. Similarly, the conceptual framework developed for the latter appears ill suited for indoor environmental protection. And the regime developed for occupational radiation protection - while it can be stretched to include environmental radiation, and even radon in the indoor environment - is strained to take proper account of identifiable aspects of the indoor environment. What is needed, instead, is a conceptual framework that, while taking account of the knowledge and experience in developing other protective regimes, will be based squarely - and not peripherally - on the specific features of the indoor environment.

This development cannot be instantaneous. Nor can it be accomplished by a single part of society - scientific, governmental, or private - and certainly not by a single representative of one of those parts, e.g., a single agency or professional society. It will, instead, require the cooperative and open examination of the issues underlying risk acceptability and control - including those mentioned above - by a variety of societal agents, supported by analyses that go well beyond merely understanding how to assess risks. An obvious outcome of these efforts will be fuller recognition that it is not only the type and magnitude of risk that is important in adopting objectives and control strategies, as has been suggested in a consideration of chemical versus radiation risks (9), but also the setting.

Even before this conceptual framework is completed, however, preliminary examination of the main issues can help in the selection of principal near-term objectives. The most obvious are programs to avoid situations with very high exposures, and identification of measures that are low-cost or cost-free for reducing average concentrations in future housing.

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REFERENCES

1. Spengler JD, Sexton K. Indoor air pollution: A public health perspective. Science 1983;221:9-17.
2. Nero AV. Controlling indoor air pollution. Sci Am 1988 May; 258:42-8.
3. Environmental Protection Agency. Guidance for Controlling Asbestos-Containing Materials in Buildings. Washington, DC: Environmental Protection Agency, 1985.
4. Mossman BT, Bignon J, Corn M, Seaton A, Gee JBL. Asbestos: scientific developments and implications for public policy. Science 1990;247:294-301.
5. van der Kolk J. Minimum ventilation requirements and health criteria for products used indoors. In: Berglund B, Lindvall T, Sundell J, eds. Indoor Air. v. 1. Stockholm, Sweden: Swedish Council for Building Research, 1984:245-50.
6. Puskin JS, Nelson CB. EPA's perspective on risks from residential radon exposure. J Air Waste Manage Assoc 1989;39:915-20.
7. Nero AV. A national strategy for indoor radon. Issues in Science and Technology 1992(Fall):33-40.
8. Nero AV. Elements of a strategy for control of indoor radon. In: Nazaroff WW, Nero AV, eds. Radon and its Decay Products in Indoor Air. New York: Wiley, 1988:459-87.
9. Kocher DC, Hoffman FO. Regulating environmental carcinogens: Where do we draw the line? Environ Sci Technol 1991;25:1986-9.

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