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INDOOR AIR QUALITY HEALTH RISK ANALYSIS

Anthony V. Nero, Jr.

April 1981

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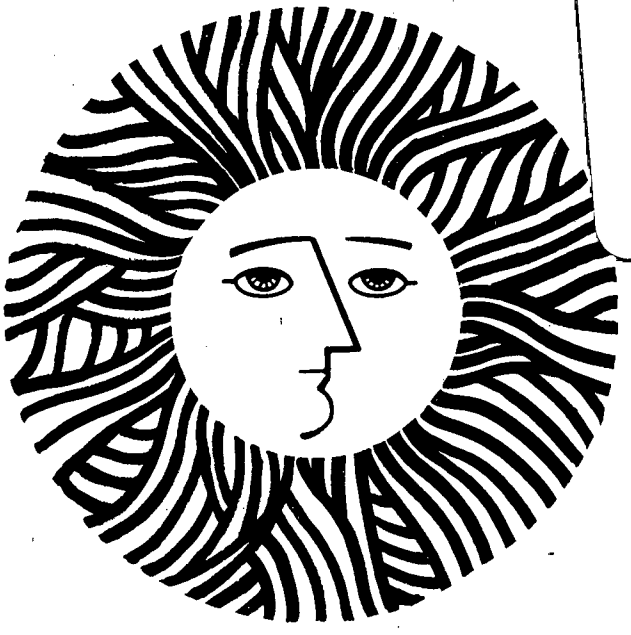

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Transcript of talk presented
at the Workshop on Indoor Air
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April 1981

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Abstract

This talk delineates the principal considerations in assessing the health risk from indoor air pollutants. Two questions may be addressed in the course of such assessment: (1) what is the current risk, i.e., that arising from exposure to current levels of indoor pollutants; and (2) what is the change in the net risk from a particular change in the current situation, which could be caused by a strategy for saving energy or improving air quality in housing. Exposure to radon and its daughters is used as an example, in which case it appears that, in spite of programs to save energy, average exposures could remain unchanged, or even decrease, provided air quality control measures are employed in houses that would otherwise have unusually high radon concentrations.

Keywords: health risk assessment, indoor air quality, radon daughter exposures.

INDOOR AIR QUALITY HEALTH RISK ANALYSIS*

Anthony V. Nero, Jr.

The purpose of this talk is to demonstrate briefly some of the principal considerations in performing indoor air quality (IAQ) health risk analysis. I will indicate these considerations generally and, in addition, use the case of radon and its daughters as an example. Discussion of this case will effectively constitute an extension of the session on radon. However, this shouldn't be taken to imply that radon is necessarily the main pollutant of concern. It is merely the one we will use to demonstrate the principles of risk assessment for indoor air pollutants.

Just to indicate where we might be going, there are two major questions we can ask ourselves in the area of IAQ risk assessment. One is the question of what the current risk is; i.e., the risk from present indoor exposures to air pollutants. The second question, which can be distinguished from the first, is what change in the net risk can be expected from a particular change in the current situation; e.g., a strategy for saving energy or improving air quality in housing.

In trying to examine current risk or changes in it, an array of different pollutants have to be considered. There are several categories into which we can place these different pollutants. I list several categories that arise fairly naturally: smoking products; combustion emissions, which may be considered to include those from smoking; organics, such as formaldehyde, but including all sorts of other materials; radon and its daughters; bacteria; and others that I haven't listed here, simply because I've only included the most familiar categories.

In terms of a health risk assessment, there are several risk categories or health end points that one might examine. Again, I list several classes only as examples. One general class of effects includes respiratory irritation or disease; lung cancer, of course, is a member of this class, but I've singled this out because I will treat it explicitly as we proceed. There are other classes of effects; e.g., acute syndromes associated with carbon monoxide exposures (even leading to death), formaldehyde exposures, and so on. But, in addition to these specifically "health" effects, there is a more general class of "environmental" effects. Some of these effects are those that are ordinarily noted by house occupants; i.e., general comfort parameters, odors, etc. There are, in addition, all sorts of other effects, including direct or indirect effects that might occur outdoors. I'll point out later how these arise as part of risk assessment.

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* Edited transcript of talk presented at session on risk assessment, Workshop on Indoor Air Quality Research Needs, sponsored by the Interagency Research Group on Indoor Air Quality.

Let me turn first to the problem of assessing the current risk from radon daughters, just as an example of the assessment process. In order to assess the risk, several kinds of information are needed. One clearly needs information on exposures, and even this is divided into two kinds of information as I frame it here. The first is data on average exposures, and the second is information on the distribution of exposures; i.e., how many people are getting exposures of various sizes. In order to understand this distribution, one has to have information on concentrations of pollutants, in this case the radon daughters; one also has to have information on patterns with which people use their houses or are present in their houses.

I should make two comments in passing that I'll elaborate on in a few minutes. One is that the average exposure is not known to be better than about a factor of 2. One can argue about the precise uncertainty, but I'll use this factor in what follows, indicating where it comes from. A second point that I would make is that the exposure distribution is not known well at all. For example, the question of how many people are receiving exposures above any specific level cannot be answered with any certainty. We cannot characterize exposures adequately either on the basis of direct measurements of concentrations or on the basis of an understanding of what the sources of radon are and how radon gets into buildings - we don't have that information, nor do we know much about the behavior of radon daughters indoors. So our information base on daughter exposures is not very good. However, unlike other indoor air pollutants, radon information is still good enough to make rough estimates of the kind I'll indicate below.

The second class of information required for risk assessment is what the health effects of a given exposure are. This information was discussed in a fair amount of detail by William Ellett, in the session on radon, so that I will not discuss the basis of the dose-response information that we have. However, as I go along I'll use some of that information, as you'll see. In any case the range of uncertainty is large - about a factor of 10 from low estimates to high - or a factor of 3 around the geometric mean. Now, in using such information, it is very important to remember that there are two kinds of health risk estimates that one might make. First is an estimate of the total population risk, which information can be used for certain purposes. A second kind of estimate that one could make is what the risk is to those who are exposed to relatively large concentrations. These people are at the highest risk, and one might want to devote more attention to them than to people who are at lower risk.

Let us turn now to actually making a risk estimate, beginning with the question of what the average concentrations might be. I show you a large table, not so that you should remember the specific data, but merely to indicate what the state of information is. The total number of houses in which radon or radon daughter concentrations have been measured in this country is of the order of hundreds. Most of these arise from studies in which 10 to 100 houses were monitored. There have actually been more studies than indicated in the table, because I've excluded studies of only one or two houses and generally speaking I have only included studies that had about 10 or more houses. In any case, the information base is not very large and,

because the distribution of exposures is very large, we don't really have much information about either the average or the distributions.

However, I suggest in the next figure that we do have some information, although the figure must be taken only as suggestive. This curve is only schematic and is not an attempt to represent the actual data. Nevertheless, we could say that a typical concentration of radon daughters, given in the usual units; i.e., working level (WL), is probably on the order of 0.005 WL. I emphasize the word "typical." The average concentration in houses is probably not far from that number. It could be virtually anywhere in the range between 0.001 (or 0.002) and 0.01 WL. So I've written down that the average concentration is about 0.003 WL, with an uncertainty factor of 3.

Another question of substantial interest is what highly exposed individuals might be encountering. What I've indicated both by the tail that extends very far out, far above the average of the distribution, and by the number that I've cited, is that there are probably some people in the United States who are exposed routinely to concentrations of the order of 0.05 WL - a factor of 10 above the average. However, we don't know how many people they are. It would be interesting to know.

Given information on concentrations, we can calculate a typical exposure, which I've written down in the usual unit, working level months (WLM), the definition of which isn't needed to follow the discussion. But in terms of this unit, the average exposure could be about 0.15 WLM per year and the "maximally exposed" individuals we have just mentioned would be receiving a factor of 10 greater exposure than this.

Knowing these exposures and the kind of dose-response information presented at the radon session, we can make an estimate of the risk from indoor radon. From the data discussed in that session (see Table 2), we can see that the dose-response factor, assuming a linear dependence of effect on dose, has been estimated by various entities to have values ranging over a factor of 10. Each one of those estimates itself has, of course, some uncertainty. But loosely speaking, we might say that we know the dose-response factor to within a factor of 3 about some mean. I've written down the dose-response coefficient as 300 cases per million WLM exposure among a population; the usual unit is "person-WLM."

Using this dose-response factor, together with exposure information, we can make a risk estimate. What we obtain from the values indicated is a radon-daughter induced lung-cancer incidence of approximately 45 cases per million people per year among the U.S. population. But the range is large because of the factors of 3 uncertainty in exposures and dose-response. What the overall uncertainty is depends on how these factors of 3 are folded together. One purely statistical approach would yield, overall, a factor of 5 in either direction. On the other hand, the extremes yield a factor of 9 in either direction. Taking the first approach, the estimated average risk among the U.S. population is 9 to 225 cases per million per year.

We would get a somewhat different number for the individual risk of those who are exposed continuously to an exposure of 0.05 WL, the number we cited earlier for those at higher risk. Estimating the risk of an individual living in that concentration for a lifetime, based on our dose-response factor, yields the result that such an individual has an added lifetime chance of getting lung cancer of about 4 percent. Now again, the uncertainty in the dose-response factor, a factor of 3 in either direction, would cause us to modify this to about 1 to 10 percent. This is a very large risk.

This is the kind of procedure one could go through in examining this particular facet of current indoor air quality risks. If we look at the mean radon-related lung cancer incidence that I have written down, 45 cases per million per year, this turns out to be very close to the lung cancer incidence among those who don't smoke; roughly within a factor of 2. The uncertainty in this radon-related estimate is of course large. Increasing it by a factor of 5 to 225 cases per million per year (the estimate associated with the upper end of the uncertainty range) yields an estimate that exceeds the observed lung cancer incidence among nonsmokers. If we take the other end of the range of risk estimates, 9 per million per year, we obtain a much smaller number. But it is still more than a thousand lung cancer cases per year in the United States. This is significant.

Let us now go on to the next major point. If we understand what the current risk is from current exposures to radon or other indoor pollutants, how do we understand the health effects of a change in the building stock. Such a change could be due either to an interest in energy conservation or to an interest in indoor air quality. In either case we would like to know what the net change in the risk would be. There are several possible sources for a change in the risk. It is possible to change the source strength of the individual pollutants; it is possible, by implementing energy conservation or indoor air quality measures, to change the infiltration or ventilation rate; it is possible to clean the air actively. Any of these changes could effect a change in the net risk.

There are several broad considerations that have to be kept in mind. There are, in fact, many indoor air pollutants. For each of them, we would need exposure information and dose response information. In effecting a change, for example a change in energy use in buildings, we would not only change indoor concentrations; we would also change outdoor exposures to some pollutants. These pollutants could come from the individual houses, from energy production facilities that supply energy to those houses, and so on. I'll explain this further in a moment.

As I stressed, we are interested, in questions of population average both exposures or risks and of individual risks. Moreover, just to emphasize a point that is obvious to anyone who has been looking at risk assessment, a great danger is to emphasize those parts of the risk that we are able to quantify and to ignore those that we aren't able to quantify, even when the latter are comparable in importance, or even more important.

As I've said, one of the possible factors that might cause a change in indoor air quality risks is the implementation of measures to save energy. In order to understand the change in net risk from a saving of energy, we have to consider both the effect on indoor air quality and other effects. In fact, we have to look at the entire energy system that supplies the energy for, as an example, space heating and cooling. I don't want to explore this in detail, but merely to indicate through a rather complex figure the kind of things we might consider. I've tried to indicate on the left the energy supply technologies and, on the right, the points of use of different energy supplies. In considering energy use for space heating and cooling, the end uses are at the lower right. But in order to consider the net effect of a change in end use, we have to look at the effect on the entire system. Let me just indicate what this means in another way, using a simpler figure indicating classes of enviromental effects. In a house one has what we could call "internal" risks due to exposures indoors. One would also induce "external" risks; for example, burning oil, gas, or anything else (wood?) in the house that results in emission of pollutants into the (outdoor) air. This can affect people outside the house. In addition, if energy is supplied from some centralized energy technology, there are risks associated with using that technology, including what I call external risks; i.e., risks due to emissions into the external environment, and also occupational risks that are internal to that technology. These may appear to be obvious things, but it is important that they not be neglected when performing an assessment aimed at estimating changes in the net risk.

Finally, let us return to the case of a change in the infiltration rate, considering in particular the effect on radon daughter exposures. The effect of a change in infiltration rate on radon daughter exposures is itself not simple, depending as it does on how the change is brought about and on what control technologies are associated with it. In addition, any complete risk analysis would have to include other indoor pollutants, some of which are identified, but many of which have not yet been associated quantitatively with risks. Moreover, the externalities that I have referred to would have to be considered.

For the case of indoor radon, let me just indicate two key points. First, by changing the infiltration rate, we can have a highly variable effect on radon daughter concentrations, depending on how that change is accomplished. I show some data from a house in Maryland in which the ventilation rate was controlled by use of a mechanical ventilation system with an air-to-air heat exchanger. The upper figure shows the variation in the radon concentration as a function of time over a 2-week period. During that 2-week period, the ventilation rate was maintained at about five different values. The equilibrium radon concentration corresponds pretty well, as we would expect, to the inverse of the ventilation rate. However, the daughter concentration, which is shown on the lower figure, is much more complicated. A variety of different kinds of mechanisms can remove daughters, including not only ventilation but also filtration and adhesion to various surfaces in the house and the air circulation system. The point is that predicting the effect of a particular change in the building stock on radon daughter exposures is not a simple question.

The second point on indoor radon is indicated in the final very schematic figure, which in fact presumes we know something about the effect of ventilation rate reduction. What I want to indicate conceptually is the kind of trends we might expect from different strategies beginning now, i.e., in the year 1980. What I've tried to plot schematically is the average population exposure to radon daughters over a period extending from the year 1900 through 1980 to some time in the future. What I've suggested in the figure is that there has probably been a modest increase in radon daughter exposures during this century. This presumption, based not on experimental evidence, but on conjecture, assumes some decrease in infiltration rate from tightening of houses over the years.

Whether or not this has actually occurred, the present point of interest is what might happen in the future, say for the next 20 years and beyond. Changing the housing stock is a relatively slow process. Considering the energy-saving measures that might be employed in existing houses and the related practices that might be employed in building new housing, I suggest that if we employed no explicit control concepts or specific control technologies, radon daughter exposures could increase by about 25 percent over the next 20 years. Taking this conjecture for the sake of argument, we can consider what else might happen. If we give some explicit attention to the question of radon exposures, e.g., if we try to identify those areas or individuals that have particularly high exposure, we could effectively cut the tail off the exposure distribution that I showed you, eliminating much of the risk to the highly exposed portion of the population. Moreover, if we also employ control technologies in very tight houses, we would be avoiding a large amount of associated exposures. With such attention, we could hold radon daughter exposures below the trend of the last century or so, and even decrease average exposures. These are, of course, just two examples of what might happen.

I close by summarizing what we have been talking about: broadly speaking, the role of indoor air quality risk assessment. One purpose is to quantify the current risk, both to identify problems that we don't understand very well and as a basis for understanding what research might be done to improve our information base. A related interest is to indicate the need for development of control technologies. The other purpose of risk assessment is to understand the effect of a particular action, whether a program to save energy or a decision to employ a control technology, on the total risk. Such assessment involves the risk both indoors and outdoors, arising both from the end use and from the rest of the energy system. Risk assessment is an important tool for understanding what priorities we might set in trying to increase our information base and doing research relevant to it. It is also important as a tool for understanding the health effect of decisions we might make to change buildings in the United States.

Acknowledgement

This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Building Energy Research and Development, Building Systems Division, and by the Director, Office of Energy Research, Office of Health and Environmental Research, Human Health and Assessments Division and Pollutant Characterization and Safety Research Division of the U.S. Department of Energy under Contract No. W-7405-ENG-48.

INDOOR HEALTH RISK ASSESSMENT

MAJOR QUESTIONS:

- RISK FROM CURRENT INDOOR EXPOSURES
- CHANGES IN NET RISK FROM VARIOUS STRATEGIES

MAJOR INDOOR POLLUTANTS:

- SMOKING
- COMBUSTION EMISSIONS
- ORGANICS
- RADON
- BACTERIA.....?

MAJOR POTENTIAL HEALTH EFFECTS:

- RESPIRATORY IRRITATION OR DISEASE
- ACUTE SYNDROMES, INCLUDING DEATH
- LUNG CANCER

OTHER ENVIRONMENTAL EFFECTS:

- INDOORS - ODORS, COMFORT
- OUTDOORS - INDIRECT EFFECTS

ASSESSING PRESENT RISK FROM RADON DAUGHTERS

EXPOSURE AVERAGE AND DISTRIBUTION:

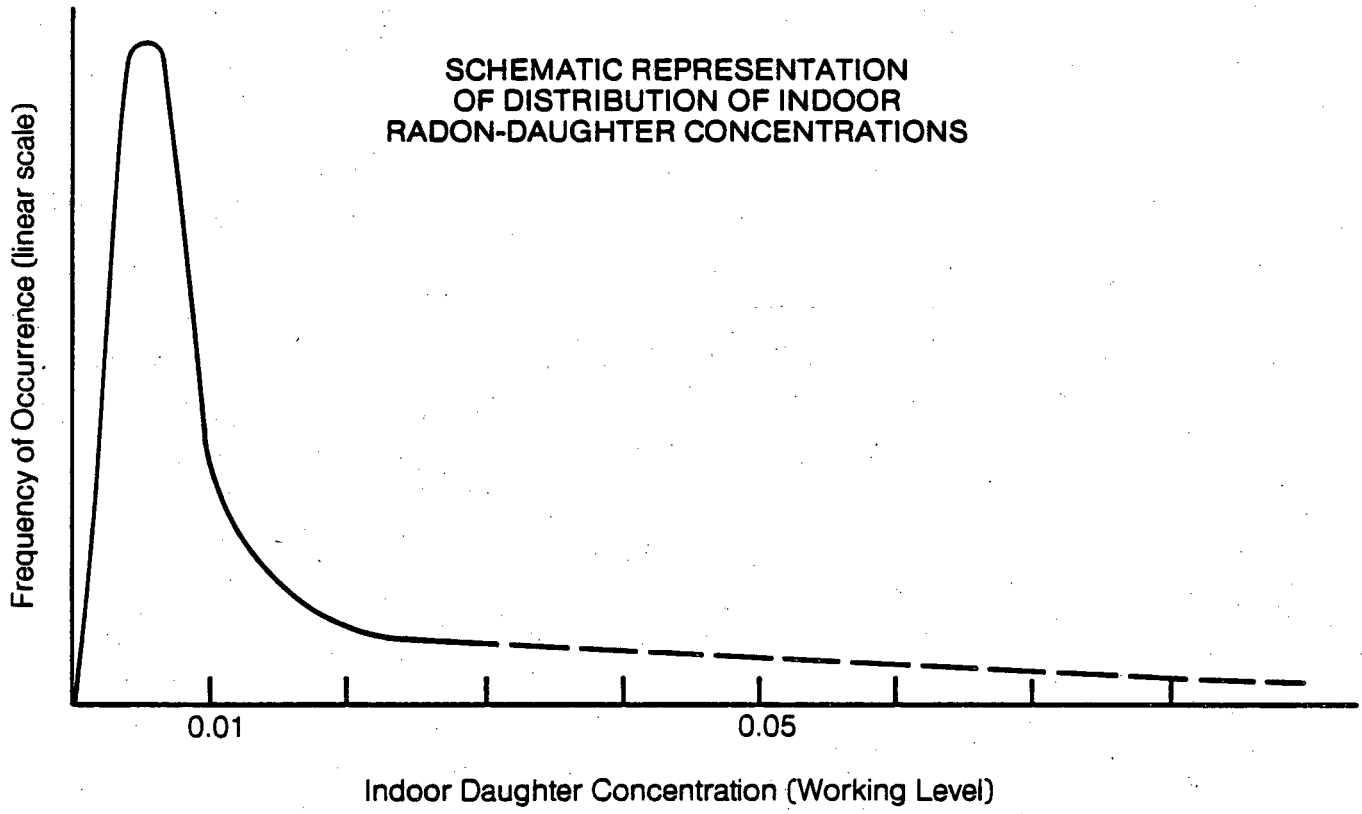
- NEED CONCENTRATIONS AND USE PATTERNS
- AVERAGE NOT KNOWN TO BETTER THAN FACTOR OF 2
- DISTRIBUTION NOT KNOWN AT ALL
- CAN'T YET CHARACTERIZE ON BASIS OF SOURCE STRENGTHS AND BUILDINGS CHARACTERISTICS

DOSE - RESPONSE:

- BASED ON MINERS
- RANGE OF UNCERTAINTY IS LARGE: FACTOR OF 10

ESTIMATING EFFECTS:

- POPULATION RISKS: E.G. AS BASIS FOR BUILDING STRATEGIES
- INDIVIDUAL RISK: E.G. AS BASIS FOR CONCENTRATION LIMITS



Average daughter concentration (U.S. housing): $\simeq$0.003 WL (x 1/3 to x 3)

Some incidence of much higher concentrations: $\simeq$0.05 + WL

Average daughter exposure: $\simeq$0.15 WLM/yr (x 1/3 to x 3)

Exposure of those in high concentrations: $\simeq$1.5 + WLM/yr

Dose-response factor: $\simeq$300 lung cancers/10^6 person-WLM (x 1/3 to x 3)

Estimated U.S. lung cancer incidence from
radon daughter exposures: $\simeq$45 cases per million population per year (9 to 225, considering uncertainty of x 1/5 to x 5)

Selected Radon and radon daughter measurements in U.S. residences
(residences are single family except where noted)

Location	Reference	^{222}Rn (nCi/m^3)[a]	Daughter PAEC (WL)[a]	Number of Residences	Type of Measurement	Comments
ORDINARY AREAS:						
Tennessee	Lowder 1980		0.008(0.0008-0.03)	15	Grab	Shale area; mostly concrete construction
Boston	Yeates 1972	0.07(0.005-0.2)	(up to 0.002)	7	Grab and ventilation	Single family; air exchange rate; 1-6/h
		0.09(0.01-0.2)	(up to 0.002)	3	Grab and ventilation	Multiple family, air exchange rate: 5-9/h
NY/NJ	George 1978	0.8[b](0.3-3.1)	0.004[b](0.002-0.013)	21	Several integrated measurements over year	17 single family; 3 multiple family; 1 apartment bldg.
Illinois	Rundo 1979	(0.3-33)	[0.003 - 0.08]*	22	Grab	Wood-frame construction, unpaved crawl spaces (windows closed)
San Francisco area	Berk 1980	(0.4-0.8)	[0.00] - 0.002]*	26	Grab and ventilation	Air change rate: 0.02-1.0/h (windows closed)
U.S./Canada	Hollowell 1980	(0.6-22)	[0.002 - 0.05]*	17	Grab and ventilation	Energy-efficient houses; air change rate: 0.04-1.0/h (windows closed)
SPECIAL AREAS:						
Grand Junction Colorado	Barnes 1975		0.006[b]	29	Integrated year round	Controls for remedial action program (which has included houses in range 0.02-1 WL)
Florida	Florida 1978		0.004	28	Integrated year round	Controls on unmineralized soils
	Guimond 1979		0.004(0.0007-0.014)	26	Integrated year round	Controls on unmineralized soils
	Guimond 1979		0.014	133	Integrated year round	Houses on reclaimed phosphate lands
Montana: Butte	EPA 1980		0.02	56	Integrated year round	Intensive mining area
Anaconda	EPA 1980		0.013	16	Integrated year round	Intensive mining area

[a]Individual values are averages; values given in parentheses are ranges. All measurements are in living space; values in basements are typically higher.

[b]Geometric mean.

*Calculated from measured radon concentration assuming 0.5 equilibrium factor.

9/80 as

Table 2 (RP80)

Estimated Life Time Risks of Fatal Lung Cancer from Radon Progeny

Estimator	Cases per 10^6 Person WLM	
UNSCEAR	200-450	30-yr. exposure to adults
NRC	360	all ages, 1967 U.S. population
EPA - absolute risk	350	cohort (stationary population)
EPA - relative risk	860	" "
BEIR III	850	" "
Victor Archer - absolute risk	1050	" "
NCRP - absolute risk	130	all ages, 1975 U.S. population

Source: U.S. Radiation Policy Council, Report of the Task Force on Radon in Structures, RPC-80-002, August 15, 1980.

ASSESSING CHANGES IN NET RISK

CAUSES:

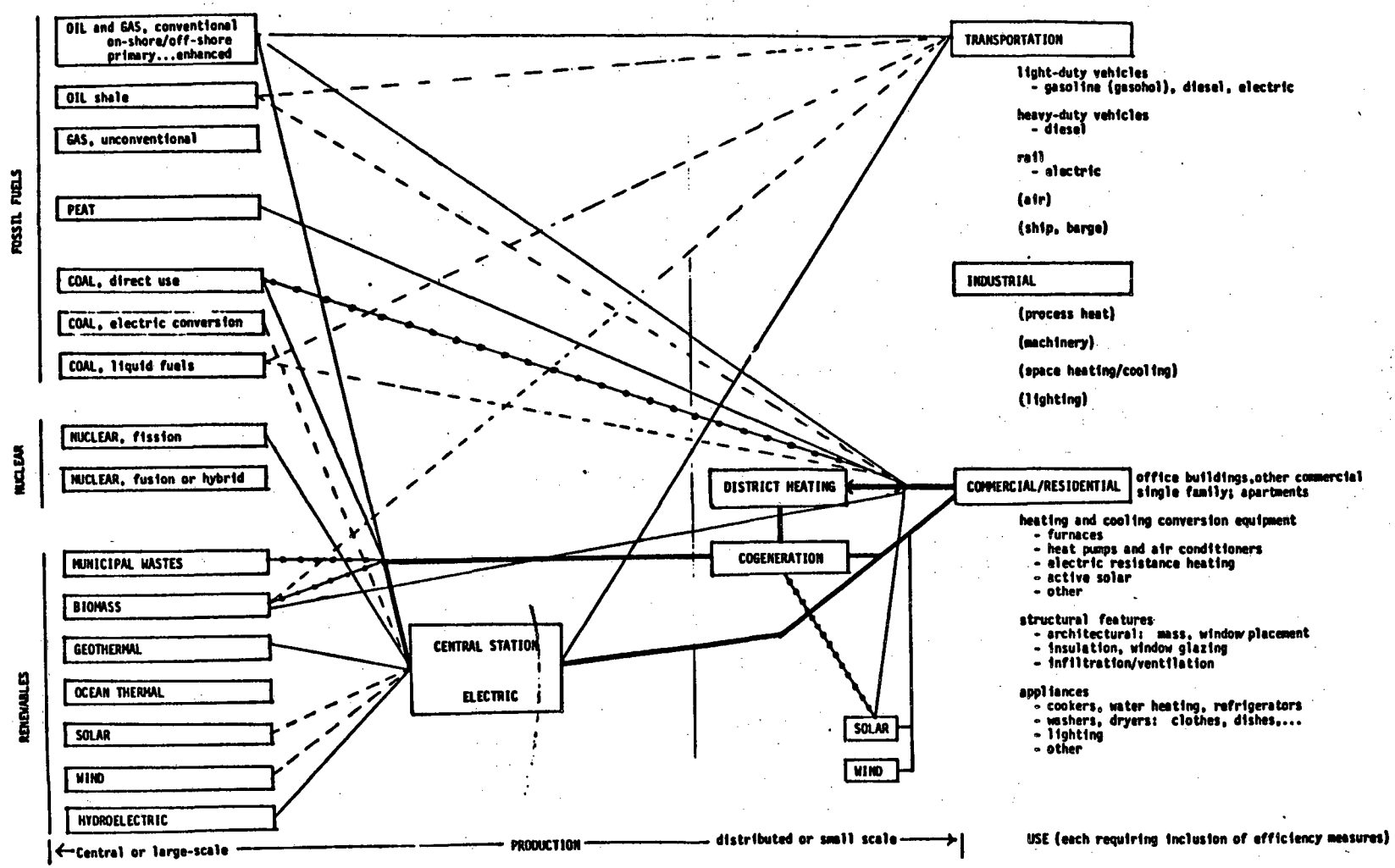
- CHANGES IN SOURCE STRENGTH (E.G., DUE TO CHANGES IN BUILDING TECHNOLOGY)
- CHANGES IN INFILTRATION OR VENTILATION RATE (DUE TO ENERGY CONSERVATION OR IAQ MEASURES)
- ACTIVE AIR CLEANING

MAJOR CONSIDERATIONS:

- MANY POLLUTANTS
- NEED EXPOSURES AND DOSE-RESPONSE FOR EACH
- CHANGES BOTH INDOOR AND OUTDOOR EXPOSURES
- HAVE TO EVALUATE BOTH POPULATION-AVERAGE AND INDIVIDUAL RISKS

A COMMON DIFFICULTY IN ANY SUCH EVALUATION IS TO PAY MOST ATTENTION TO THE RISKS THAT CAN BE QUANTIFIED AND TO IGNORE THE REST.

FIGURE 4: ENERGY SYSTEM



Source: A.V. Nero

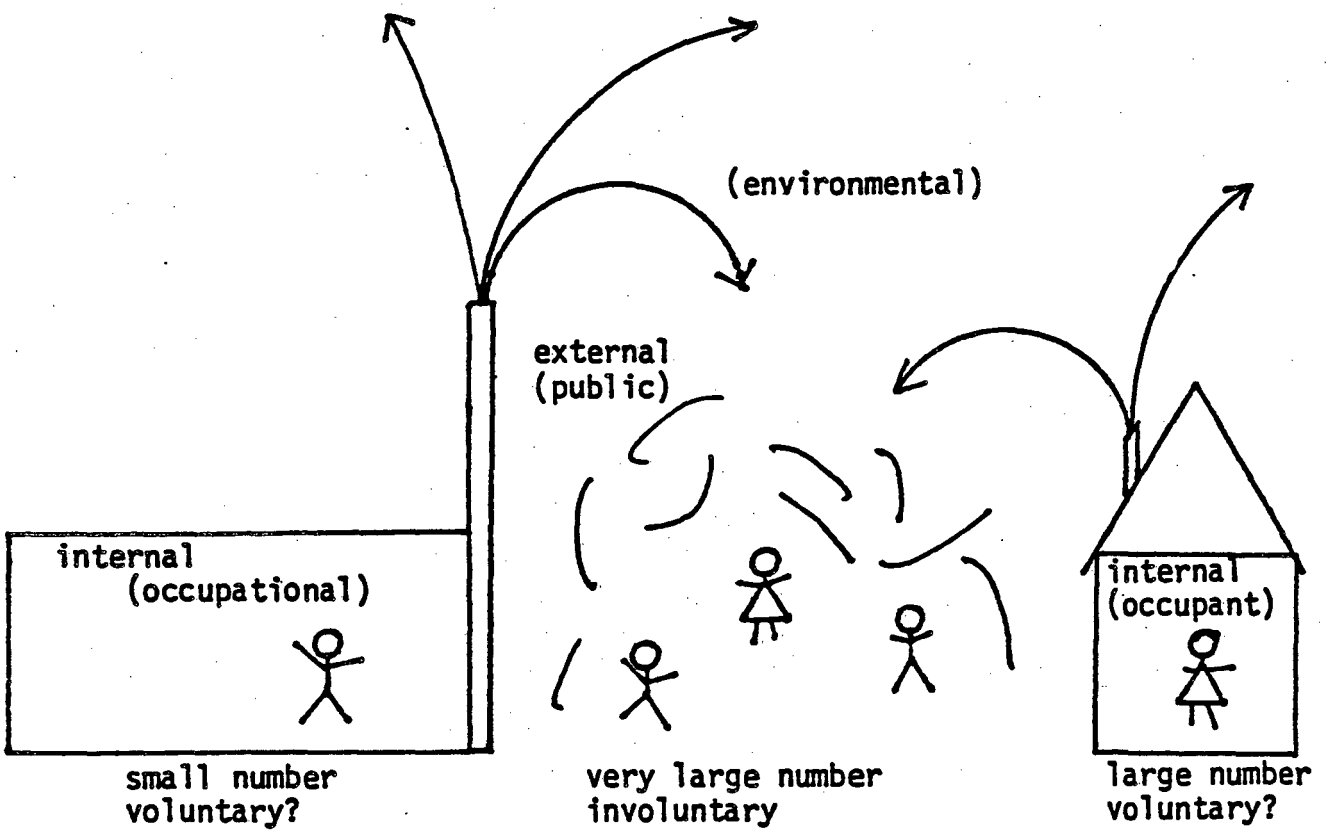


FIGURE 3: CLASSES OF ENVIRONMENTAL EFFECTS

EXAMPLE

EFFECTS OF CHANGE IN INFILTRATION RATE?

RADON DAUGHTER EXPOSURES

- COMPLICATED IN ANY CASE
- DEPENDS ON MANNER OF IMPLEMENTATION

OTHER INDOOR POLLUTANTS

- NOT ALL IDENTIFIED
- RISKS USUALLY NOT QUANTIFIED

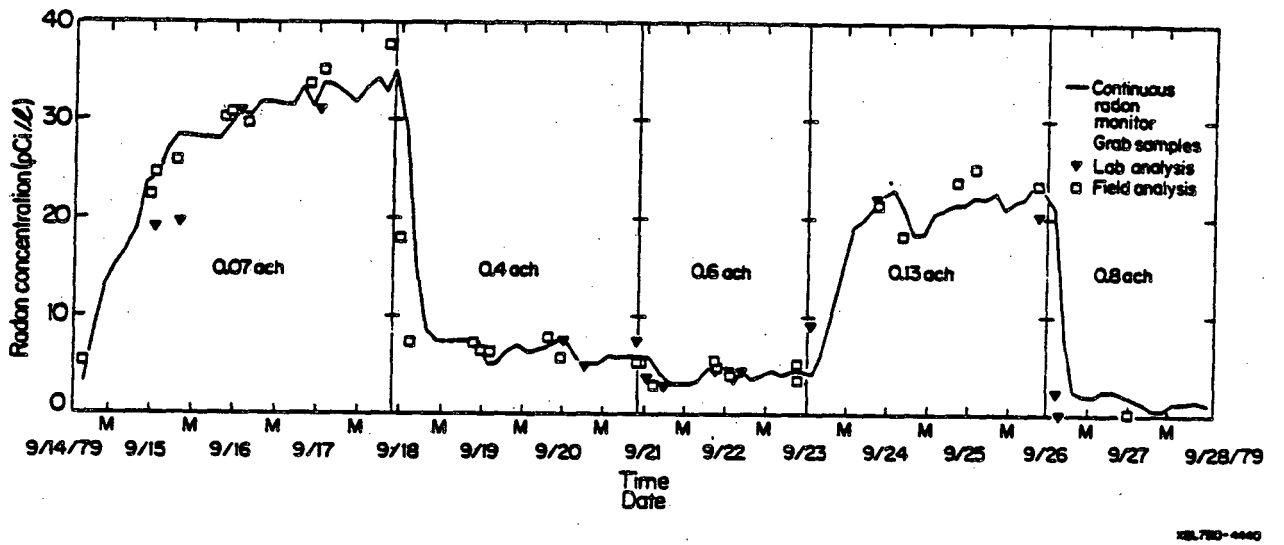
ASSOCIATED CHANGES IN OUTDOOR POLLUTION

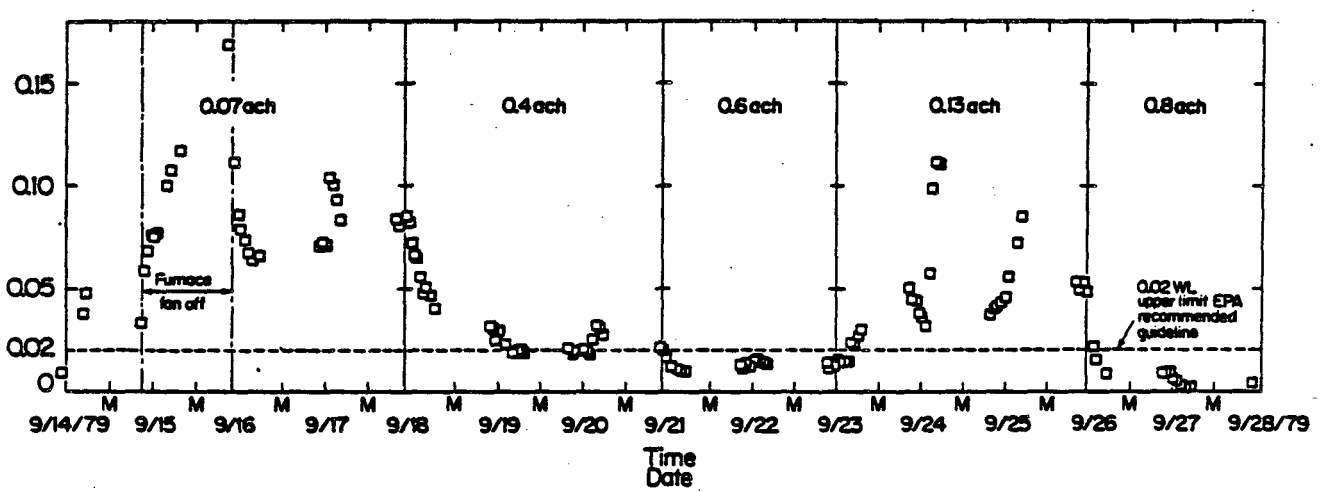
- EFFECTS FROM CENTRAL STATIONS
- EFFECTS FROM LOCALLY GENERATED POLLUTANTS?

INDIRECT HEALTH EFFECTS

- OIL WAR?
- CO_2?

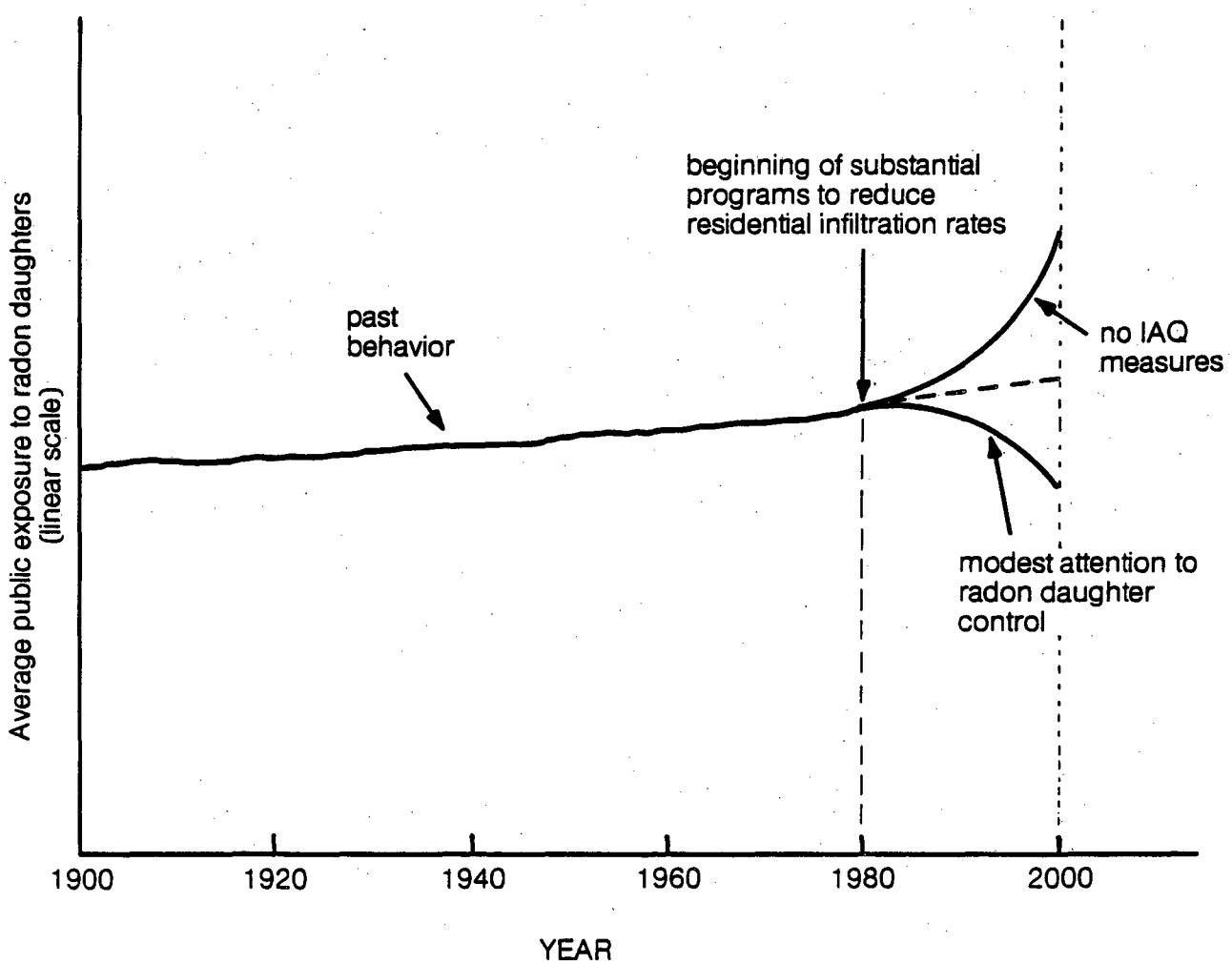
(MORE GENERAL ENVIRONMENTAL EFFECTS)





Radon concentration (pCi/l) and daughter concentration (Working Level) as a function of time in an energy research house. Measurements were performed over a 2-week period during which the ventilation rate was varied from 0.07 to 0.8 ach using a mechanical ventilator with an air-to-air heat exchanger.

ILLUSTRATION
OF POSSIBLE TRENDS
FOR PUBLIC RADON
DAUGHTER EXPOSURES



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