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STATE-SPECIFIC RADON RISK ASSESSMENT

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As evidence grows indicating a greater prevalence of elevated indoor radon than at first suspected, it becomes increasingly important to have an accurate assessment of the health risks associated with such exposures. As part of the New Jersey Statewide Scientific Study of Radon a refined health risk analysis was developed to provide more realistic evaluations of expected risks. The BEIR IV lifetime risk estimates were applied to location specific exposure estimates to compute estimated health risks for all the counties and selected municipalities in New Jersey.

Over 5,700 residential screening measurements were obtained during the statewide study, with one-third of the results exceeding the 4 pCi/l USEPA guideline. Performance of a health risk assessment based on a single screening measurement involves making assumptions concerning inter-floor radon ratios, equilibrium coefficients, inter-season radon ratios, occupancy rates, and smoking habits. Typically, assumed values are assigned to these "intervening factors" based on available literature data. For this study, a more refined assessment was made possible through supplemental on-site collection of radon/progeny and household data which provided a more scientific site-specific basis for designating these factors. The methodology used to infer the necessary "intervening factors" and infer population health risks is described in this paper.

INTRODUCTION

RESULTS OF PREVIOUS HEALTH STUDIES

There exists much epidemiologic evidence, provided principally by cohort studies of underground miners, linking radon progeny exposure to human lung cancer. Laboratory animal studies have also shown the appearance of lung cancer at similar rates per exposure. However, the available occupational data is based on the exposures to much higher levels of radon progeny than exist in homes (or even in today's workplace). Extrapolation from these past, relatively high exposures to modern, and on the average, lower conditions presents numerous uncertainties.

A number of preliminary studies addressing the effect of radon progeny exposure in non-occupational environments have been conducted. A recent review of past studies on household radon exposure and lung cancer summarized the results of 16 different studies (Neuberger, 1988). These studies tend to be ecologic studies examining lung cancer mortality in areas known or suspected to have elevated indoor radon concentrations. Other, more sophisticated epidemiologic studies, both retrospective and prospective are on-going. Overall, there is suggestive evidence of a positive association between residential exposure to radon and lung cancer. However, the methods used in most of the studies were crude and can generally only be considered qualitative. The ongoing epidemiologic studies are larger, more expensive and generally more sophisticated, however no substantial quantitative results are available from these studies at present. At present, then, it appears prudent to take the conservative approach and extrapolate from the miner studies.

QUANTITATIVE RISK ESTIMATES OF RADON PROGENY EXPOSURE

Because of the uncertainties associated with extrapolation from higher occupational exposures to modern residential exposures, the various published estimates of lifetime risk of lung cancer due to radon progeny vary by about one order of magnitude (from less than $1x10^{-4}$ to $10x10^{-4}$ per working level month (WLM) of exposure).

The National Research Council's Committees on the Biological Effects of Ionizing Radiations (BEIR) has recently completed a study reviewing the current knowledge of the somatic and genetic effects of internally-deposited alpha-emitters. Health effects of exposure to radon and its short lived decay products were a primary focus of that study. The findings report from this study, commonly called the BEIR IV report, was the primary document used for the risk assessment conducted for the Statewide Scientific Study of Radon.

The BEIR IV committee developed risk estimates of radon progeny exposure based on analysis of the four major epidemiologic data sets related to lung cancer in underground miners. Using statistical methods applied to the data from the four cohorts, they developed a relative risk, time-since-exposure (TSE) model, which they believe could be extrapolated to the indoor residential environment using the following assumptions:

- o The findings in the miners (with a maximum of 50 years of exposure) can be extended across the entire non-occupational life span (assumed to be 70 years).
- o An exposure to 1 WLM yields an equivalent dose to the respiratory tract in both occupational and environmental settings.
- o Cigarette smoking and radon progeny exposure interact multiplicatively.
- o The sex-specific baseline risk of lung cancer is increased multiplicatively by radon progeny for males and females.

It is these tables provided in the BEIR IV document, primarily Table 2-4, that were used in this risk assessment to estimate the risk to New Jersey citizens presented by exposure to radon progeny.

OVERVIEW

This risk assessment utilizes municipality-specific radon exposure measurements, inferred from house specific radon, progeny and household data collected during task 3 of the New Jersey study, applied to the BEIR IV risk coefficients in order to estimate the current risk of contracting lung cancer due to residential exposure to indoor radon. Average risks were estimated for each New Jersey county and selected municipalities. Consideration was limited to municipalities for which at least 30 valid radon samples were obtained to help ensure that the data set would be representative of exposure conditions in that municipality.

The risk assessment methodology, then, consisted of two stages: (1) estimation of an average exposure for each municipality and county; and (2) inference of the average population risk based on the estimated exposure. For the case of indoor radon, it is exposure to radon progeny rather than radon itself that offers the most significant health risk; so that hereafter exposure will refer to working level (radon progeny concentration) exposure.

Expected exposures will vary depending on the spatial location of the house within the state of New Jersey, the season of the year, house structural and mechanical characteristics, and other environmental features. In addition, the BEIR IV report indicates that both sex and smoking status can significantly affect risk rates for a given exposure. Each of these factors were considered in the performance of this analysis.

EXPOSURE ESTIMATIONS

The first objective of the analysis was to delineate a method for estimating population exposures. To characterize these exposures it was necessary to both: (1) estimate the annual average working level concentrations for the selected population areas (counties, municipalities); and (2) estimate relevant population characteristics (fraction of male and female smokers and non-smokers) for these populations. The average exposure of a population area was estimated as the average of the exposures for sampled houses located in that population area. House exposure was computed from estimated working level (WL) concentrations on the first floor and basement (if applicable), and the amount of time the resident spends on each of these house levels. Exposure was measured in working level months per year (WLM/yr).

WLM/yr = WL x exposure hours/day x 365.25 days/yr ÷ 170 "hours"/month

Needed occupancy data was provided on data input forms completed by participants. The determination of annual WL per floor, however, necessitated the development of a scheme for inferring annual average working levels for the basement (where applicable) and first floors of the 5727 sampled houses from their lowest level radon concentrations measured in the Level I mass sampling which had been performed earlier in this study.

To project an annual average working level concentration from a single measurement requires estimates of equilibrium coefficients (the ratio of radon progeny (WL) to radon gas (pCi/l), 100 x WL ÷ pCi/l), inter-season radon ratios, and, for basement houses, inter-floor radon ratios. It was for the purpose of estimating these conversion parameters that the Level II sampling was conducted during task 3 of this study. In Level II, four-day integrated radon and radon progeny measurements were made on the lowest two levels of approximately 200 homes. To obtain seasonally differentiated data, this sampling effort was carried out in two successive rounds conducted over nine months.

Conversion parameters (equilibrium coefficients, inter-season ratios, and inter-floor ratios) were developed from the Level II data base, and then applied to the larger 5727 home data base to estimate first floor and basement annual average working level concentrations for each home in the larger data set. As suggested earlier in this section, indoor radon and working level concentrations will tend to systematically vary depending on season and house characteristics. The suitability of conversion parameters, then, should be improved by taking account of these dependencies to develop more house- and season-specific conversion parameters. To this end, a house typology was constructed, categorizing houses by substructure and heat distribution system, reflecting the sensitivity of indoor radon to these house features. Also two seasons were identified, which could be loosely designated a heating and a non_heating season. A set of conversion parameters was then developed separately for each house type and season (see figure 2), and applied to the 5727 home data set, from which annual WL, by floor, could be estimated.

To estimate the appropriate characteristics of each population group, data from both the 1980 Census and the data provided on the optional resident questionnaire ("yellow form") were used. A sample resident questionnaire is shown in figure 2. The 1980 Census data was used to approximate percentages of males and females in each population group. The resident forms were used to estimate percentages of smokers by sex and also to indicate the average occupancy time (in hours) for each floor of the houses sampled.

To summarize, the methodological approach developed for this study to assess the health risk associated with indoor radon exposure for selected populations consists of the following elements:

- For each of the 5727 houses for which radon screening measurements were available:
  (1) Estimate first floor and basement annual average working level concentrations using Level I radon data and appropriate conversion parameters developed from the Level II data base.

  (2) Compute exposure estimates from calculated annual working levels and information on average resident house occupancy schedule.

- For each selected population area:
  (1) Compute an average annual exposure as the mean of exposures for sampled houses in that area

  (2) Compute sub-population proportions (male and female smokers and non-smoker fractions) in that population area.

- Estimate population area risk as a weighted composite of sub-population risks using risk factors provided in the BEIR IV

Figure 3 presents the Risk Assessment Flow Diagram used for this task. It outlines the data sources used and presents the manner in which the methodology was structured to combine the data sources and perform the risk assessment.

ESTIMATION OF POPULATION EXCESS LIFETIME RISKS

The BEIR IV document provides estimates of excess lifetime risk of lung cancer due to radon as a function of working level months/yr (WLM/yr) exposure, including separate risk estimates for each sex and smoking category. (see Table 2-4 in the BEIR IV report). Risks for intermediate WLM/yr concentrations were computed by linear interpolation, as regression showed the excess risk to WLM/yr relationship to be highly linear ($r^2>0.90$).

To implement the risk estimation scheme for a particular population (municipality or county), first the average occupancy hours per floor were calculated for each residence who responded on the "yellow" forms. Next, the annual average first floor and basement (where applicable) working level concentrations for each sampled house were multiplied by the average of resident hours per day spent on the basement and first floor and levels of each house. For houses with no occupancy data, the municipality average was used. The resulting total annual working level months for each house were then averaged for each population area. This served as the basis for the estimation of population average exposure. Analyses were performed for all counties and for municipalities where there were 30 or more valid samples.

To produce an average excess risk for each sub-group within that population area, the appropriate sub-population risk coefficients from the BEIR IV report were applied to each population average working level exposure. Finally, the average lifetime risk for that population was determined as the weighted sum of the risks for the different sub-groups, with the weight being equal to the fractional size of each subgroup relative to the whole population for that municipality or county.

DISCUSSION

While the results of this risk assessment are not yet available, some preliminary remarks concerning risk assessment estimation computation can be made. Some qualitative observations concerning the approach adopted and the importance of particular inputs are presented below.

One feature of particular significance is the importance of obtaining good population behavioral characteristics, in particular occupancy and smoking behavior. Risks for smokers are about an order of magnitude larger than for non-smokers, so average risks are quite sensitive to the proportion of smokers in a population. Because of this sensitivity care must also be taken in designating the the smoker population. Preliminary results from this study that simple criteria of smoker status can produce estimates that differ substantially from published values, which can significantly influence risk estimates.

Occupancy schedules can also exert an important influence on risk calculations, particularly for basement homes which are the prevalent house type in New Jersey. Because of the significantly lower average radon concentrations on upper floors as compared to the basement (typical inter-floor ratios are 0.5-0.3 depending on heat distribution and other house features), overall risk can vary significantly depending on the relative amount of time spent in the basement vs. upstairs.

The occupancy rates obtained during this study are extremely interesting as they tend to vary enormously throughout the state. It was originally hypothesized that due to the voluntary nature of the mass sampling and the fact that samplers tended to sample in the daytime hours, the occupancy rates obtained would be biased high reflecting the fact that residents had to be home in order to be sampled. However, the average occupancy rates were not very high. On the average, residents in New Jersey spend about 1 hour in the basement, 11 hours on the first floor and 5 hours on the second floor for a total of 17 hours per day in the home, or an occupancy factor of 71%. This factor is 5% lower than the typically used 75% occupancy factor. It also should be pointed out that the 5 hour upstairs estimate (compared to the expected 8 hour average) is the result of averaging one-level homes with multi-level homes to produce municipality-wide averages.

A large uncertainty in the estimation of exposures appears to be the proper characterization of inter-seasonal variations in radon concentrations. If there is indeed a large and systematic inter-seasonal difference, this needs to be better delineated, so a more established basis for estimating annual averages can be determined. Our data suggests that inter-floor ratios and equilibrium coefficients are relatively more easily characterized, and more consistent, if a proper house typology is included to group the data.

Finally, it should be recognized that average risk calculations represent the mean of widely varying conditions, both in terms of exposure and occupancy and should be interpreted in that light.

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REFERENCES

1. Neuberger, John. 1988. Current and past Studies on Household radon Exposure and Lung Cancer. Presentation at the 81st Annual Meeting of APCA, Dallas, Texas, 1988. 88-105.8

FIGURE 1
LEVEL II COEFFICIENTS FOR BASIC HOUSE TYPOLOGY [a b]

HOUSE TYPE		NON-WINTER			WINTER			NON-WINTER:WINTER RADON	
SUBSTRUCTURE	HEATING SYSTEM	1ST FL:BASE RADON	BASEMENT EQUILIBRIUM[d]	1ST FLOOR EQUILIBRIUM[d]	1ST FL:BASE RADON	BASEMENT EQUILIBRIUM[d]	1ST FLOOR EQUILIBRIUM[d]	BASEMENT	1ST FLOOR
Basement	Forced air	0.45 ± 0.28 (31)	0.46 ± 0.24 (27)	0.48 ± 0.27 (20)	0.51 ± 0.27 (69)	0.34 ± 0.12 (57)	0.41 ± 0.18 (57)	0.97 ± 0.82 (30)	0.80 ± 0.98 (31)
	Hot water/ electric	0.27 ± 0.22 (55)	0.40 ± 0.15 (51)	0.50 ± 0.20 (48)	0.33 ± 0.24 (102)	0.37 ± 0.23 (87)	0.38 ± 0.17 (87)	0.89 ± 0.43 (48)	0.75 ± 0.54 (48)
	Other	0.11 (1)	0.32 (1)	0.71 (1)	0.45 ± 0.34 (4)	0.39 ± 0.14 (4)	0.42 ± 0.08 (4)	0.82 (1)	0.63 (1)
Slab-on grade/ crawlspace/ semi-basement	Forced air	—	—	0.32 (c)[c]	—	—	0.23 (1)	—	0.54 (c)[c]
	Hot water/ electric	—	—	0.42 (c)[c]	—	—	0.30 ± 0.12 (5)	—	0.49 (1)
	Other	—	—	0.36 (c)[c]	—	—	0.44 ± 0.34 (2)	—	0.45 (c)[c]

Notes: [a] Errors given are plus or minus one standard deviation
[b] Numbers in parenthesis indicate sample size
[c] (c) indicates number calculated from other ratios (see appendix B)
[d] Equilibrium = 100 x WL / Radon

TO THE RESIDENT:

On ____________ please cover your canister and fill-in the box below, noting date and time.

Place the tape around the canister and place the canister AND THIS FORM in the shipping envelope provided.

Seal and mail the package to the laboratory as soon as possible after closing the canister. Postage has already been paid. Your results will be mailed to you within six to eight weeks.

It is very important to return your canister for analysis as soon as the 4 day exposure period is up. Delay in returning the canister after it has been closed will invalidate your results.

OPTIONAL QUESTIONNAIRE

If possible, please fill out questions listed below:

1. Length of time you have lived at this address: ______ years
2. Occupancy Study:
   Please record the number of hours spent per day at EACH location listed below for each resident. If more than four residents live at this address, please list the occupancy hours for the residents who are at home the most.

	Resident # 1	Resident # 2	Resident # 3	Resident # 4
Age:	____ years	____ years	____ years	____ years
Sex:	M F	M F	M F	M F
Basement	____ hours/day	____ hours/day	____ hours/day	____ hours/day
First floor	____ hours/day	____ hours/day	____ hours/day	____ hours/day
Upstairs	____ hours/day	____ hours/day	____ hours/day	____ hours/day

3. Smoking History:
   Please record the number of packs of cigarettes smoked per day for EACH age category for each smoker in this household. If there are more than four smokers, please list the number of packs for those who smoke the most.

	Resident # 1	Resident # 2	Resident # 3	Resident # 4
Age:	____ years	____ years	____ years	____ years
Sex:	M F	M F	M F	M F
Age started:	____ years	____ years	____ years	____ years
Age stopped:	____ years	____ years	____ years	____ years
0 to 15 years	____ packs/day	____ packs/day	____ packs/day	____ packs/day
15 to 30 years	____ packs/day	____ packs/day	____ packs/day	____ packs/day
30 to 45 years	____ packs/day	____ packs/day	____ packs/day	____ packs/day
45 to 60 years	____ packs/day	____ packs/day	____ packs/day	____ packs/day
60 and over	____ packs/day	____ packs/day	____ packs/day	____ packs/day

FILL-IN BOX BELOW:

NEW JERSEY RADON STUDY

Laboratory Reference #	Canister Number	Location in House	Canister Opened: Date	Canister Opened: Time	Canister Covered: Date	Canister Covered: Time
________	________	Lowest level	______	______ AM PM	______	______ AM PM

CDM
environmental engineers, scientists, planners & management consultants

Figure 2

Sample Yellow Form

Statewide Scientific Study of Radon

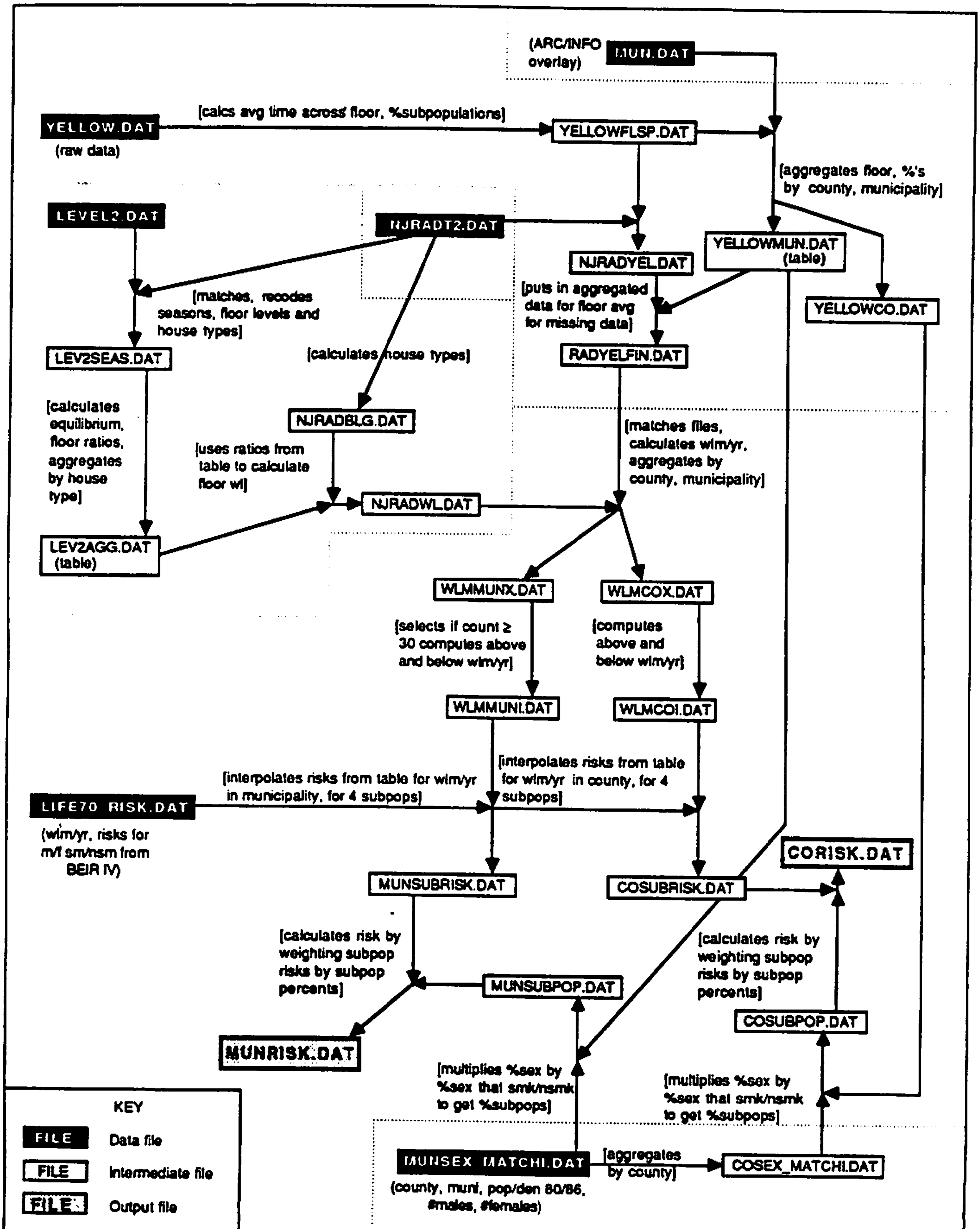

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Figure 3

Risk Assessment Flow Diagram

Statewide Scientific Study of Radon