THE EPA RADON MITIGATION TEST MATRIX: FRAMEWORK AND INITIAL PRIORITIZATION EFFORTS

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THE EPA RADON MITIGATION TEST MATRIX:

FRAMEWORK AND INITIAL PRIORITIZATION EFFORTS

Background

As part of the Agency effort to address the issue of indoor radon, the Office of Research and Development is conducting a program to develop and demonstrate cost-effective radon reduction measures for single-family houses (including existing houses, and new houses under construction). This program is national in scope, addressing the full range of residential substructure types, radon levels and geological/meteorological conditions representative of the entire country.

In order to assure effective coverage of the wide range of variables needed for a nationally-representataive program, a test matrix is being developed. This matrix will define the number of existing and new houses of each substructure type that would have to be tested with each radon mitigation technique to achieve a given degree of statistical confidence, considering the other variables of importance in the design and performance of the mitigation system. This matrix will serve, not only as a guide to avoid duplication and omissions in ORD's own testing, but as a mechanism by which installations made by others--such as installations resulting from ORP's House Evaluation Program--might contribute to satisfying segments of the overall data requirements.

This document is a description of the initial efforts to develop this matrix. Specifically, this document outlines the framework within which the matrix will be developed; and it describes some initial efforts to prioritize the elements in the matrix. As discussed later, such prioritization is important because the number of houses that would have to be tested in order to address all of the variables of concern, is too large for all variables to be addressed in a short time.

Efforts to develop the matrix, within the framework described here, are underway. But even after the matrix is initially defined, it is expected that it will be modified and updated regularly as further information becomes available during the course of the Radon Mitigation Demonstration Program.

Objectives

The overall objective of the test matrix is to define a radon mitigation field testing program which will:

1. be technically defensible
2. most efficiently and quickly put the Agency in a position to suggest cost-effective radon mitigation alternatives.
3. provide known confidence in the performance of these mitigation alternatives, to reduce the risk that techniques might not perform as expected in an application for which the Agency suggested them.
4. initially focus on the house types and the other particular conditions (e.g., house design details, geological conditions) which are responsible for a) the greatest cumulative population exposure nationwide, and b) the most acute individual exposure.
5. ultimately provide mitigation alternatives for any homeowner in the U.S. under any conditions.

The priority concern with acute exposures, in 4 above, naturally results from the dramatically increased lung cancer risks that occupants of worst-case houses face. The concern with cumulative exposure results from the possibility that very large numbers of people exposed to relatively low radon levels might have a greater combined dosage than the smaller numbers of people who live in "hot spots."

The ultimate objective of assuring the availability of alternative technologies applicable for any homeowner under any conditions, is ambitious. Not all conditions can be investigated immediately, due to limitations in available expertise and resources. It is for that reason that the initial prioritization of the matrix--to determine conditions responsible for the greatest acute and cumulative exposures--is so important, to direct near-term testing.

As a corollary objective, the test matrix is intended to provide a technical basis for selecting test sites from among those which become available. It will probably not be feasible to conduct EPA-sponsored mitigation testing in every state where an indoor radon problem is discovered. The matrix will assist EPA in making rational selection of those candidate sites which would produce the most required priority data.

Key Features

The major function of the test matrix is to define the number of houses, of each substructure type, in which each individual mitigation measure should be tested under each set of conditions. A "set of conditions", as considered here, refers to a set of selected values for the different independent variables (discussed in following section) which might influence the design and performance of the mitigation systems. In developing these numbers under the matrix, a combination of engineering judgement and statistics will be utilized in an effort to address, as efficiently as possible, those independent variables recognized now as possibly being of practical importance. The basic intent of the matrix approach is to define the performance (and the necessary design features) of the various techniques under each applicable set of conditions, to a pre-selected degree of statistical confidence, through testing in the minimum number of houses. Prioritization of the matrix will be attempted in an effort to assure where feasible that the most important sets of conditions are addressed first.

There will, in fact, be two matrices: one addressing testing on existing houses, and a separate one addressing mitigation features incorporated into new houses under construction.

The basic approach of the matrix is to initially include a limited amount of testing at each set of conditions which is of interest. At the present time, "limited" is defined as five houses. The data from these first five houses would be analyzed to define the data variability (the confidence intervals) at that set of conditions. Based upon these initial results, the number of houses could then be increased (or the testing redirected to address other variables which might be responsible for the observed variability) if necessary to narrow the confidence interval to the desired degree.

An underlying philosophy of the matrix approach is to minimize the amount of testing that will be required to achieve the goals. Efforts to minimize this testing include:

1. conduct of the testing in an incremental, step-by-step manner. As described in the previous paragraph, limited tests are conducted first, and decisions then made prior to further testing at a given set of conditions. In this manner, if testing needs to be redirected, such redirection can be accomplished before extensive testing is done; and once the confidence interval is narrowed to the goal level, testing at that set of conditions can be stopped.

2. use of a fractional factorial experimental design, rather than a full factorial. The fractional method reduces the number of houses that must be tested to one-half or one-quarter the number that would be required by a full factorial, in some cases. This reduction is accomplished by testing only one-half to one-quarter of the possible sets of conditions, then using statistics to separate out the individual effects of each variable.

3. utilization of data from other investigators. Data from other sources will be used to complete portions of the matrix wherever the data quality from the outside sources is known and is adequate.

The number of houses included for testing in the matrix will be subdivided according to whether or not detailed diagnostic testing will be performed. All of the houses tested will include some diagnostic testing to help understand radon entry routes and why an installed system is or is not performing well; such diagnostic testing could include, e.g., spot radon measurements at specific locations within the house, pressure and flow measurements in the piping associated with the mitigation system, etc. But the houses involving detailed diagostics--perhaps 15% of the total houses--will have more comprehensive pre- and post-mitigation testing, involving a greater array of diagnostic techniques (and a higher cost per house), with the intention of gaining a more fundamental understanding of the house dynamics and of mitigation system performance. It is felt that the most cost-effective program will have a suitable balance between houses involving detailed diagnostics (to improve fundamental understanding, and to thus help guide the remainder of the program), and houses involving less detailed diagnostics (to develop, at reasonable cost, a data base sufficiently large to permit adequate statistical analysis). One other product of the detailed diagnostic testing will be protocols for house diagnosis and diagnostic testing. Such protocols can be utilized by others, so that other radon diagnosticians can do the job in a complete and consistent manner, and so that the data of others can most effectively be employed by EPA to satisfy segments of the data requirements under the matrix.

The matrix addresses only that part of the radon mitigation development/demonstration program involving field testing in houses. The field testing, of course, is the major element of the mitigation program. Other elements include: laboratory studies of specific mitigation approaches preparatory to, or in support of, field work (e.g., laboratory testing of air cleaner performance or of sealant performance/durability); and technology transfer activities (such as preparation of the mitigation brochure and manual).

Independent Variables

Six categories of independent variables are currently being considered in the design of the test matrix:

1. House substructure type (e.g., basement versus slab on grade versus crawl space).
2. Mitigation technique
3. House construction details within a given substructure type (e.g., whether or not a fireplace is present)
4. Initial radon concentration
5. Geological and meteorological conditions, insofar as they might influence mitigation performance
6. Mitigation technique design and operating conditions, within a given type of mitigation technique (e.g., whether a given active soil ventilation technique is operated to draw suction or to pressurize).

The definition of the specific variables of importance within each of these categories is still on-going. Between three and fourteen variables have been identified to date within the different categories; generally, there are at least two levels (possible values) for a specific variable.

The specific variables within each category for the matrix addressing existing houses are listed in Table 1, insofar as the variables have been defined to date.

Not all combinations of these variables shown in Table 1 need to be considered. For example, under the category of "House Design Details", the number of levels in the house (one story versus two story) could be very important if the mitigation technique being considered were a heat recovery ventilator, but the number of levels would not be expected to be important if the mitigation technique were sub-slab ventilation. As another example, under the category of "Initial Radon Concentrations", only the low and intermediate initial concentrations would be considered for heat recovery ventilators, since the degrees of reduction normally achievable with that mitigation technique are not sufficiently high for those devices to be applicable, by themselves, to high initial concentrations.

Table 2 lists the specific variables within each applicable category for the matrix addressing new houses in the design/construction stage. The number of variables (and categories) for the new house matrix are currently more limited than for the existing house matrix. Basically, this occurs because the mitigation approaches can be generally limited to closing off soil gas entry routes during construction (perhaps in combination with installation of passive or active ventilation systems). These construction

TABLE 1

RADON MITIGATION TEST MATRIX

RANGES OF VARIABLES (EXISTING HOUSES) (BEING CONSIDERED INITIALLY)

HOUSE SUBSTRUCTURE TYPE

1. BASEMENT - HOLLOW BLOCK FOUNDATION WALLS
2. BASEMENT - POURED CONCRETE FOUNDATION WALLS
3. BASEMENT - FIELDSTONE FOUNDATION WALLS
4. SLAB ON GRADE
5. CRAWL SPACE

COMBINATIONS OF THE ABOVE ARE ALSO POSSIBLE, BUT ARE NOT IDENTIFIED ON THE MATRIX.

MITIGATION TECHNIQUE

HOUSE VENTILATION

1. HEAT RECOVERY VENTILATORS (AIR-TO-AIR HEAT EXCHANGERS)
2. NATURAL VENTILATION
3. FORCED VENTILATION

SEALING

4. COMPREHENSIVE SEALING

ACTIVE SOIL VENTILATION

5. HOLLOW BLOCK WALL VENTILATION
6. SUB-SLAB VENTILATION
7. WALL VENTILATION + SUB-SLAB VENTILATION
8. DRAIN TILE SUCTION

HOUSE PRESSURIZATION

9. AVOIDANCE OF DEPRESSURIZATION
10. PRESSURIZATION

AIR CLEANERS

11. PARTICULATE REMOVAL DEVICES
12. RADON GAS REMOVAL DEVICES

PASSIVE SOIL VENTILATION

13. SUB-SLAB VENTILATION

WELL WATER TREATMENT

14. ACTIVATED CARBON SORPTION, OTHER

HOUSE DESIGN DETAILS

1. ONE STORY VS. TWO STORY
2. BRICK VENEER VS. FRAME
3. FIREPLACE STRUCTURE VS. NO FIREPLACE
4. HALF-BASEMENT OR SLAB-ON-GRADE ADJOINING A FULL BASEMENT, VS. SUBSTRUCTURE ALL ONE LEVEL
5. BLOCK VS. POURED CONCRETE FOUNDATION FOR SLAB ON GRADE AND CRAWL SPACE HOUSES
6. WALL/SLAB OPENINGS ACCESSIBLE FOR SEALING VS. NOT ACCESSIBLE
7. INTERIOR BLOCK WALLS IN BASEMENT VS. NO INTERIOR BLOCK WALLS
8. EXTENT OF DRAIN TILE SYSTEM (COMPLETE VS. PARTIAL)
9. DRAIN TILE SYSTEM DESIGN (DRAIN TO ABOVE-GRADE DISCHARGE, VS. DRAIN TO INTERNAL SUMP)
10. FINISHED VS. UNFINISHED BASEMENT

NOTE: NOT ALL OF THESE ALTERNATIVES WOULD BE CONSIDERED FOR ANY ONE MITIGATION/SUBSTRUCTURE COMBINATION; AT MOST, THREE ARE CONSIDERED FOR A GIVEN COMBINATION, DEPENDING UPON THEIR POTENTIAL IMPORTANCE ON MITIGATION DESIGN AND PERFORMANCE.

INITIAL RADON CONCENTRATIONS

1. "LOW" - LESS THAN 0.1 WL
2. INTERMEDIATE - 0.1 - 1.0 WL
3. HIGH - ABOVE 1.0 WL

USUALLY NO MORE THAN TWO LEVELS OF RADON CONCENTRATION CONSIDERED FOR ANY ONE MITIGATION/SUBSTRUCTURE COMBINATION.

GEOLOGICAL/METEOROLOGICAL CONDITIONS

1. CONDITIONS RESULTING IN HIGH SOIL PERMEABILITY
2. CONDITIONS RESULTING IN LOW SOIL PERMEABILITY
3. POSSIBLY OTHER FACTORS

TECHNIQUE DESIGN/OPERATING CONDITIONS

1. REDUCED SEALING IN CONJUNCTION WITH SOIL VENTILATION TECHNIQUES, VS. INCREASED SEALING
2. INDIVIDUAL POINT BLOCK WALL VENTILATION VS. BASEBOARD APPROACH
3. SUB-SLAB SUCTION BY INDIVIDUAL POINTS VS. SUCTION ON SUMP
4. ACTIVE SOIL VENTILATION OPERATED IN SUCTION VS. PRESSURIZATION

TABLE 2

RADON MITIGATION TEST MATRIX

RANGES OF VARIABLES (NEW CONSTRUCTION) (BEING CONSIDERED INITIALLY)

House Substructure Type

1. Basement - hollow block foundation walls
2. Basement - poured concrete foundation walls
3. Slab-on-grade
4. Crawl space
5. Basement - poured concrete foundation walls, with adjoining half-basement or slab-on-grade

Mitigation Technique

1. For poured concrete foundations: thick plastic lining between aggregate and concrete slab; slab and footings monolithic pour; utility penetrations carefully sealed; any fireplace structure built to avoid leakage, thermal bypassing.

2. For hollow block foundations: as above for poured concrete foundations; solid cap block at top of foundation wall; block below grade covered with plastic barrier on outside face, coated to reduce porosity on inside face; gap between block and brick veneer mortared shut.

3. Other steps as appropriate.

House Design Detail

1. Fireplace structure vs. no fireplace.
2. Energy efficient construction vs. normal

Geological/Meteorological Conditions

1. Conditions resulting in high soil permeability.
2. Conditions resulting in low soil permeability.

changes also significantly reduce the number of "House Design Details" which can affect soil gas entry and mitigation design/performance.

In reviewing Tables 1 and 2, it is clear that a lot of variables can be important. It is apparent a priori that any attempt to address these variables, even in a reduced manner, is likely to add up to a lot of houses to be tested.

Matrix Format

The basic format of the matrix is presented in Table 3. Two of the six categories of independent variables are shown explicitly in Table 3: House Substructure Type defines the columns, and Mitigation Technique defines the rows. (The number of variables used in this table for these two categories reflect those identified in Table 1 for existing houses--5 substructure types, 14 mitigation techniques.) For each cell within the matrix--i.e., for each combination of substructure type and mitigation technique--a number of houses to be tested is identified (N_{ij}, the number of houses of substructure type j to be tested using mitigation technique i). The whole purpose of the matrix exercise, of course, is to derive reasonable values of each N_{ij}.

The value of N_{ij} for a given cell will depend upon the extent to which the other four categories of independent variables are addressed for that particular substructure/mitigation technique combination. As discussed previously, not all values of the other variables would be pertinent to a given cell. For example, in no case would all 10 House Design Detail variables for existing houses in Table 1 be applicable to a single substructure/mitigation combination; in the estimates to date, a maximum number of 3 House Design Detail variables have applied to any single cell.

TABLE 3

RADON MITIGATION TEST MATRIX

MATRIX FORMAT

MITIGATION TECHNIQUE	HOUSE SUBSTRUCTURE TYPE: TYPE 1	TYPE 2	...	TYPE 5	COMMENTS
TECHNIQUE 1	N_{11}	N_{12}		N_{15}	
TECHNIQUE 2	N_{21}	N_{22}			
•					
•					
•					
TECHNIQUE 14	N_{14-1}			N_{14-5}	

N_{IJ} IS THE NUMBER OF HOUSES OF TYPE J TO BE TESTED USING TECHNIQUE I

COMMENTS COLUMN WOULD PRESENT THE LEVELS OF THE DIFFERENT INDEPENDENT VARIABLES USED IN DERIVING N_{IJ}.

EACH N_{IJ} WOULD INCLUDE SOME HOUSES WITH NORMAL DIAGNOSTIC TESTING AND SOME WITH DETAILED DIAGNOSTICS.

MAXIMUM NUMBER OF INDEPENDENT VARIABLES USED IN CALCULATING EACH N_{IJ}:

HOUSE DESIGN DETAIL - 10 VARIABLES, 2 LEVELS EACH
INITIAL RADON CONCENTRATION - 3 LEVELS
GEOLOGICAL/METEOROLOGICAL CONDITIONS - 2 LEVELS
MITIGATION DESIGN/OPERATING CONDITIONS - 4 VARIABLES, 2 LEVELS EACH

Each value of Nij would include some number of houses--perhaps 10 to 20 percent of the total--which would entail detailed diagnostic testing.

Example of Nij Calculation

Perhaps the most effective method for illustrating the approach to be used in developing the matrix, is to show a sample derivation of one of the values of Nij. Such a sample derivation is presented in Table 4.

For this example, the selected house substructure type is a basement house with concrete block foundation walls (Type 1 from Table 1 for existing houses). The selected mitigation technique is drain tile suction (Technique 8 from Table 1). Thus, for this example, Nij = N81

The first step in the derivation as shown in Table 4, is to determine hich variables within the other four categories are potentially important for this particular cell. Under the category of House Design Detail, three variables of potential interest have been identified for this cell to date. The completeness of the existing drain tile loop can clearly be important, since an incomplete loop might leave part of the foundation less well treated by the suction. The design of the drain tile system is important; if it drains to an above-grade discharge away from the house, the design of the mitigation system will be different from the case where the tiles drain to a sump inside the house. The presence of an interior block wall (which pentrates the slab and rests on footings) can be important; such interior footings normally do not have drain tiles laid beside them, and the interior wall (which can be an important soil gas entry route) might not be adequately treated unless the suction on the perimeter tiles extends effectively under-eath the entire slab.

TABLE 4

RADON MITIGATION TEST MATRIX

APPROACH (EXAMPLE OF N_{IJ} CALCULATION)

SELECTED ELEMENT FROM MATRIX

MITIGATION TECHNIQUE: 8 (DRAIN TILE SUCTION)

HOUSE SUBSTRUCTURE TYPE: 1 (CONCRETE BLOCK BASEMENT)

($N_{IJ} = N_{81}$)

STEP 1: IDENTIFY LEVELS OF EACH INDEPENDENT VARIABLE TO BE CONSIDERED

HOUSE DESIGN DETAIL:

COMPLETENESS OF DRAIN TILE LOOP: 2 LEVELS (COMPLETE, NOT COMPLETE)
DESIGN OF DRAIN TILE SYSTEM: 2 LEVELS (DRAIN TO SOAK-AWAY, DRAIN TO SUMP)
INTERIOR BLOCK WALL IN BASEMENT: 2 LEVELS (WALL, NO WALL)

INITIAL RADON CONCENTRATION: 2 LEVELS (LOW, HIGH)

GEOLOGICAL/METEOROLOGICAL: 2 LEVELS (LOW, HIGH SOIL PERMEABILITY)

MITIGATION TECHNIQUE DESIGN: 2 LEVELS (EXTENSIVE SEALING, LESS EXTENSIVE)

STEP 2: DERIVE FRACTIONAL FACTORIAL EXPERIMENT

FULL FACTORIAL EXPERIMENT WOULD BE 2X2X2X2X2X2=64 SETS OF CONDITIONS

1/4 FRACTIONAL FACTORIAL = 1/4 X 64 = 16 SETS OF CONDITIONS

A LARGER FRACTION (1/2) WOULD HAVE BEEN USED IF THERE HAD BEEN ONLY 5 VARIABLES INSTEAD OF 6.

STEP 3: TEST 5 HOUSES (I.E., 5 REPLICATES) AT EACH SET OF CONDITIONS

16 SETS OF CONDITIONS X 5 HOUSES/SET = 80 HOUSES

$N_{81} = 80$

FIVE REPLICATES WILL INDICATE THE VARIABILITY IN THE DATA.

(A FEW OF THESE HOUSES WOULD INCLUDE DETAILED DIAGNOSTIC TESTING.)

STEP 4: EVALUATE THE DATA, DETERMINE FURTHER ACTION

IS THE CONFIDENCE INTERVAL NARROW ENOUGH SUCH THAT THE AGENCY WOULD FEEL COMFORTABLE SUGGESTING THE TECHNIQUE TO OTHER HOMEOWNERS HAVING SIMILAR CONSTRUCTION DETAIL/ RADON LEVEL/GEOLOGICAL CONDITIONS?

- IF YES, NO FURTHER TESTING AT THE GIVEN SET OF CONDITIONS IS NECESSARY

- IF NO, DETERMINE WHAT FURTHER TESTING IS WARRANTED TO NARROW THE INTERVAL:

  -- FURTHER REPLICATION AT THE GIVEN SET OF CONDITIONS, TO BETTER DEFINE THE DISTRIBUTION

  -- IDENTIFICATION OF OTHER VARIABLES WHICH MIGHT BE RESPONSIBLE FOR THE DATA VARIABILITY, INCORPORATION OF THOSE VARIABLES INTO THE MATRIX.

Two levels of initial radon concentration will be considered, low and high. The low level is considered because drain tile suction is inexpensive and aesthetic enough that it can reasonably be considered even when the radon levels in the house are not significantly elevated. On the other hand, the high level is considered because this technique is also effective enough that it can be considered even for worst-case houses (if they have drain tile systems in place). Since both high and low levels are being considered, it is not felt necessary to address the intermediate level. In being applicable to both high and low levels, drain tile suction is unique; most techniques capable of the high reductions needed for worst-case houses may be too expensive to be considered by homeowners facing a low degree of mitigation urgency. Thus, most techniques would be tested only at low and intermediate, or only at intermediate and high, initial concentrations.

In the category of Geological/Meteorological Conditions, soil permeability is considered to be the variable of importance, with two levels (high and low) considered. The success of drain tile suction depends upon its ability to draw soil gas away from potential entry routes into the house, and the permeability of the soil could potentially affect this ability.

In the category of mitigation technique design, one variable is considered (the degree of sealing of openings between the house and the soil). Such sealing is a mitigation technique in itself which can often be important in conjunction with other techniques. The naturally reduced pressures that typically exist within houses serve as a "pump" sucking radon-containing soil gas into the house, tending to work against the drain tile suction system. To the extent that house/soil connections are sealed, this tendency work against the drain tile suction system is reduced.

Reviewing the above paragraphs, it is seen that, at this time, six variables of interest have been identified among the four other categories of independent variables, for this case of drain tile suction in concrete block basement houses. Two levels are being considered for each of the variables.

The second step in the calculation of N81 is the derivation of the fractional factorial experimental matrix for these variables. If a full factorial experiment were to be conducted--considering every possible combination of both levels of all six variables--then the number of sets of conditions that would have to be tested would be 2 to the sixth power, or 64. (One "set of conditions" would be, for example, a complete drain tile loop draining to an external soak-away in a house having an interior all and a high initial radon level, on soil of low permeability, where extensive sealing was used in conjunction with the suction system.) In order to reduce the number of sets of conditions to be tested, statistics would be utilized to design a fractional factorial matrix. The objective of the fractional design is to enable separation of the effects of each variable without having to perform the full factorial. The specific sets of conditions which are selected for the fractional factorial are not arbitrary, but must be picked with careful statistical consideration. The compromise that one accepts when using a fractional design is that, as a result of interactions between the variables, the separation of the individual effects might not be possible with the same level of confidence as a full factorial would provide.

For the purposes of estimating N81--with two levels of each of six variables--is currently assumed that a one-quarter fractional factorial can be utilized.

Thus, the number of sets of conditions to be tested would be

1/4 x 64 = 16 sets of conditions.

With some of the other Nij cells, the number of variables of interest will be fewer than 6, and a 1/4 fractional factorial might therefore be too small to provide sufficient power to separate effects. In the current planning effort, it is assumed that if there are 3 variables (2 levels each), a one-half fractional factorial will be needed; if there are only two variables, a full factorial would be performed.

After the number of sets of conditions is identified, the initial value of N81 can be calculated by considering the number of houses to be tested at each set of conditions. This number per set of conditions must be large enough to give some reasonable measure of the data variability at that set of conditions, since the underlying intent is to narrow the confidence interval to some goal value. However, this number should not be too large, because we wish to reach the goals with a minimum number of tests. For the purposes of this planning, an initial number of 5 houses per set of conditions has been selected. These 5 will provide an initial indication of variability/confidence interval, so that a decision can then be made regarding what further testing, if any, is warranted at that set of conditions. Thus, the initial value of N81 is:

$$N81 = 5 \times 16 = 80.$$

This number has been referred to here as the initial value of N81. The ultimate value would be derived during the course of testing, as described below.

When the testing on five houses at a given set of conditions is completed, the data would be evaluated statistically. These results might be pictured as a plot of the fraction of houses tested versus the final radon concentration (or the percent radon reduction), defining some type of distribution. If the selected confidence interval for this distribution, apparent from these 5 houses, is sufficiently narrow that it falls within our goal value, then no further testing at that set of conditions is necessary. That is, the results from those first 5 houses were consistent enough such that we feel confident that we understand how that mitigation technique will perform in that house substructure type at that set of conditions. It is expected that, in fact, some of the sets of conditions will be satisfactorily addressed by the first 5 hosues.

With some other sets of conditions, however, the confidence interval resulting from the first 5 houses will undoubtedly be too wide. In those cases, it must be decided why it is too wide before deciding on the future course of action. In some cases, the interval will be too wide simply because the 5 data points do not adequately define the distribution; the statistical formulae calculate a large confidence interval (a low degree of certainty) due to the uncertainty in what the distribution really is. In such cases, it will sometimes be appropriate simply to test some additional houses at the same set of conditions, to better define the distribution. With the better-defined distribution, the confidence interval might narrow to the extent desired.

In other cases, the breadth of the interval might be due to inherent variability (which means, due to the presence of other variables which are not explicitly addressed in the matrix but which have an important influence on the observed results). In such cases, simply testing additional houses at that set of conditions will do no good; even if an infinite number of houses were tested, and the distribution perfectly defined, the confidence interval would still be too large. In those cases, the "hidden" variables must be identified (by rigorous inspection of the first 5 houses, if necessary), and that cell of the matrix redesigned as necessary to incorporate the new variables.

From the above discussion, it is apparent that, if anything, the initial value for N81 will increase as the testing proceeds.

Status

The framework for the matrix has been defined, as described previously. Detailed discussions between the engineering and statistical staff are underway to more completely define the matrix, and to derive the values for each Nij. In addition, a preliminary effort has been conducted to prioritize the matrix--i.e., to suggest which cells, and which sets of conditions within each cell, should be addressed first. This preliminary prioritization effort is described in a later section.

Very preliminary estimates have been made of the total numbers of houses that might be needed to fill out the existing house and new house matrices (i.e., the sum of all of the initial Nij's). Assuming 1/4 to 1/2 fractional factorials and 5 replicates per set of conditions, as discussed in the previous section, this preliminary total for initial coverage came out to be about 600 existing houses and about 100 new houses. About 15% of the houses would involve detailed diagnostics. These numbers sound large, but considering the number of variables involved, this size is not unreasonable from a technical standpoint.

As further understanding is gained, it might be possible to intelligently cut out certain variables or otherwise direct the program in a manner that will reduce the number of houses required. In addition, in some cases, one house can serve to address two or more data points on the matrix, at a reduction in cost compared to two different houses; for example, referring to the earlier example with drain tile suction, the conditions of extensive sealing and less extensive sealing can be tested in a single house, with only the incremental cost of additional sealing between conditions. However, on the other hand, the likelihood is significant that additional replications will be needed in order to narrow confidence intervals in many cases, or that additional variables will be identified. Thus, it seems reasonable to assume at this point that any net change in the estimates of the number of houses will more likely be in the direction of more houses.

Preliminary Effort to Prioritize Matrix Cells

A very preliminary effort is underway to obtain some prioritization of house substructure types for the purposes of the matrix. The effort consists of overlaying what we know about geographical substructure distribution, on top of gross estimates of the distribution of radon-prone lands. The intent is to identify whether particular substructure types appear to be more prevalent in areas where the risk of elevated radon levels is relatively greater. Such substructure types could then warrant higher priority in the testing effort. Other information which can be obtained from this assessment includes the geographical distribution of high-risk houses of a given substructure type (suggesting possible sites that might be considered for conducting the testing).

It is emphasized that this preliminary prioritization effort is intended to give very rough estimates, doing the best we can with what information is available.

The approach being employed in this effort is described below.

First, an estimate is developed of the geographical distribution of substructure types. The total number of housing units by state was obtained from the 1980 census; this will be updated to 1985 by considering building permits issued after 1980. The breakdown of substructure types within each state is being estimated using data obtained annually by the National Association of Home Builders (NAHB), which gives this breakdown for the houses built in each state after 1974. Multiplying the NAHB percentages times the census housing unit totals yields an estimate of how many units of each substructure type exist in a given state. There are a number of uncertainties built into this estimation approach, among the key ones of which are: a) the uncertainty regarding whether the NAHB data for a given year, which might be obtained from only perhaps 20% of the houses built in a given state, in fact represents the distribution among all houses built in the state during that year; and b) the uncertainty regarding whether the NAHB distribution for 1974-1985 in fact represents the distribution among housing units built prior to 1974.

The second step in the approach is to estimate the geographical distribution of high-risk lands. For the purpose of this effort, "high-risk lands" are assumed to be those with both: a) an elevated level of uranium near the surface of the ground; and b) a medium to high soil permeability, enabling radon transport to the house. Data from the National Uranium Resource Evaluation (NURE) were used to estimate what percentage of the land area in each state contained elevated near-surface soil uranium levels. A national map of surface geology type was used to estimate soil permeability, by assigning a high, medium or low permeability to the various geology types; the percentage of the land area in each state having high, medium and low permeability was calculated. The percentage of each state having elevated potential was then obtained by multiplying the NURE elevated uranium percentage times the high permeability percentage (or the high plus medium permeability percentage). The uncertainties in this approach for estimating radon risk are legion: high-radon areas may exist where there is not elevated uranium within one foot of the surface; the NURE data actually cover only a small percentage of the nation's land area; high-uranium and high-permeability areas may not randomly overlap, so that simple multiplication of those two percentages might not give an accurate picture; and others. However, this approach is used as a first approximation.

The last step in the approach is to calculate how many high-risk houses of each substructure type are in each state. This calculation is made by multiplying the percentage of high-risk land in each state times the total number of houses of each substructure in that state. This approximation assumes that the houses of all substructure types are uniformly distributed over all of the land area in the state.

This analysis is not yet complete. However, some initial results are presented in Table 5. As an example of how to read this table, the top entry indicates that Alabama has about 10% of its land area containing elevated near-surface uranium deposits, and about 25% having geologies considered highly permeable. Thus, the percentage of Alabama land assumed to have the potential for elevated radon is 10% x 25% = 2.5%. Since Alabama had 1,073,053 housing units in the 1980 census--of which 10.5% were basement,

TABLE 5

Gross estimate of houses, by substructure type, in areas with risk of elevated radon levels

COTERM-INOUS STATES	PERCENT OF LAND W/ URANIUM DEPOSITS (NURE MAP)	PERMEABILITY LOW	MED	HIGH	(PERM)* (NURE)	POTENTIAL ELEVATED RADON LEVEL HOMES (NURE MAP)	POTENTIAL ELEVATED RADON LEVEL BASEMENT HOMES (NURE MAP)	POTENTIAL ELEVATED RADON LEVEL CRAWL SPACE HOMES (NURE MAP)	POTENTIAL ELEVATED RADON LEVEL SLAB HOMES (NURE MAP)
AL	10%	15%	60%	25%	2.5%	26,826	2,817	8,182	15,828
AZ	6%	0%	45%	55%	3.3%	21,133	211	317	20,605
AR	7%	20%	60%	20%	1.4%	9,601	912	3,937	4,753
CA	4%	15%	45%	40%	1.6%	84,122	9,674	16,404	58,044
CO	10%	0%	45%	55%	5.5%	39,951	31,961	7,591	400
CT	20%	0%	100%	0%	0.0%	0	0	0	0
DE	5%	0%	100%	0%	0.0%	0	0	0	0
FL	33%	0%	35%	65%	21.5%	505,832	0	25,292	480,541
GA	11%	40%	40%	20%	2.2%	30,005	12,002	6,751	11,252
ID	5%	0%	35%	65%	3.3%	8,177	4,743	3,312	123
IL	0%	0%	80%	20%	0.0%	0	0	0	0
IN	10%	10%	80%	10%	1.0%	15,069	6,404	3,466	5,199
IA	0%	0%	90%	10%	0.0%	0	0	0	0
KS	15%	10%	70%	20%	3.0%	21,351	20,497	641	214
KY	8%	40%	30%	30%	2.4%	23,533	16,944	4,354	2,236
LA	4%	0%	80%	20%	0.8%	8,427	295	42	8,090
ME	5%	0%	90%	10%	0.5%	1,379	1,282	28	69
MD	10%	40%	40%	20%	2.0%	15,370	14,140	384	845
MA	8%	0%	100%	0%	0.0%	0	0	0	0
MI	3%	0%	90%	10%	0.3%	7,397	7,138	222	37
MN	0%	0%	70%	30%	0.0%	0	0	0	0
MS	0%	5%	95%	0%	0.0%	0	0	0	0
MO	10%	36%	47%	17%	1.7%	23,647	22,110	473	1,064
MT	10%	0%	77%	23%	2.3%	4,693	4,622	70	0
NE	10%	0%	70%	30%	3.0%	13,758	12,864	688	206
NV	5%	0%	35%	65%	3.3%	5,507	28	2,533	2,946
NH	3%	0%	100%	0%	0.0%	0	0	0	0
NJ	20%	10%	60%	30%	6.0%	85,865	44,650	35,204	6,011
NM	5%	5%	35%	60%	3.0%	9,586	144	288	9,155
NY	5%	0%	85%	15%	0.8%	19,501	15,894	780	2,828
NC	10%	40%	20%	40%	4.0%	64,691	10,674	36,227	17,790
ND	5%	20%	60%	20%	1.0%	1,617	1,537	40	40
OH	0%	0%	60%	40%	0.0%	0	0	0	0
OK	20%	40%	30%	30%	6.0%	56,572	1,697	566	54,310
OR	2%	10%	50%	40%	0.8%	5,695	1,310	4,129	256
PA	8%	20%	30%	50%	4.0%	96,296	88,592	3,852	3,852
RI	20%	0%	100%	0%	0.0%	0	0	0	0
SC	20%	30%	20%	50%	10.0%	81,465	6,517	50,508	24,439
SD	15%	5%	90%	5%	0.8%	1,437	1,286	50	101
TN	35%	25%	40%	35%	12.3%	153,650	43,790	67,606	42,254
TX	7%	15%	47%	38%	2.7%	98,764	1,481	0	97,282
UT	15%	0%	40%	60%	9.0%	29,625	28,143	889	592
VT	10%	0%	100%	0%	0.0%	0	0	0	0
VA	10%	50%	10%	40%	4.0%	52,368	24,613	13,092	14,663
WA	10%	15%	65%	20%	2.0%	22,251	13,907	7,788	556
WV	0%	0%	0%	100%	0.0%	0	0	0	0
WI	5%	0%	70%	30%	1.5%	17,837	16,143	178	1,516
WY	30%	0%	35%	65%	19.5%	21,293	19,270	1,916	106
TOTAL						1,684,293	488,291	307,799	888,203
% OF TOTAL						3.2%	29.0%	18.3%	52.7%

30.5% were crawl space and 59% were slab--multiplying 2.5% times the number of units with each of these substructures yields the estimated numbers of houses of each type having the potential for elevated levels under the assumptions used here (e.g., 2,817 basement houses).

It is noted in Table 5 that--from the national totals--this analysis suggests that slab-on-grade houses and basement houses have the greatest number of units in potentially radon-prone areas. The high representation by slab houses results from the large contribution from Florida, which has a relatively large percentage of high-radon-potential land area and involves slab construction almost exclusively. The lower number of radon-prone crawl space units is not surprising, since the total number of crawl space units nationwide is limited (15% of the total). It is emphasized that this analysis is attempting to develop gross estimates of the number of each house type built in areas with elevated risks for indoor radon; it cannot at this time predict what the distribution of radon levels inside the houses might be. For example, it cannot account for the impact of substructure type of actual indoor levels; due to the different degrees of house/soil contact, a basement house might often be expected to experience higher indoor levels in a given location than would a crawl space house.

The results of this analysis generally support EPA's current emphasis on basement and split-level (basement plus slab) houses, and suggest that further attention to slab houses might be in order. However, this result is one which might have been expected a priori, since the greatest number of houses nationwide are basement (50% of all units) and slab (35%). For this analysis to be more useful in directing the future program, the next steps in completing the analysis will address a finer breakdown of substructure types (e.g., block foundation wall basements and poured concrete foundation wall basements), and possibly combinations of substructure types (e.g., basement plus slab-on-grade or split levels). In the longer term, it would be desirable to attempt to estimate the distribution of actual indoor radon levels as a function of substructure type, if a meaningful method for making this estimation could be identified.

Efforts are continuing now to complete this preliminary study. In addition to expanding the number of substructure types addressed, as discussed above, the on-going work includes: refined estimation of the current number of units nationwide for each of the substructure types (by updating the census figures and more completely drawing upon the NAHB data base); and overlaying of the substructure type and the elevated-radon-potential land information on geographical unit finer than the state level (e.g., by county or zip code), in an effort to more accurately match the two.

Technical Issues Needing Review

There are a number of technical issues which need to be reviewed by the Mitigation Subcommittee of the Radiation Advisory Committee of the Science Advisory Board. Some of these are listed in this section. The Subcommittee will undoubtedly have additional questions they will want to raise (and answer). The matrix is evolving and is still under intensive review by the Air and Energy Engineering Research Laboratory. Suggestions by the Subcommittee will be incorporated in the next iteration to be prepared as soon as the Subcommittee recommendations are received.

1. Does the basic approach for the development of the matrix appear reasonable (fractional factorial design, 5 initial replicates per condition, further testing determined from the initial 5 tests)?

2. Do the selected independent variables (Tables 1 and 2) appear reasonable?

3. How narrow should the confidence interval be before testing is stopped? What confidence interval should be used (e.g., 68%, 95%)?

4. Regarding efforts to prioritize the matrix:

   a. Should initial focus be on conditions resulting in most acute exposure, or greatest cumulative exposure, or both?

   b. What other approaches for prioritization, in addition to the initial effort described in the previous section, might be considered?

   c. How might estimates be derived indicating the distribution of indoor radon concentrations for each substructure type?